The Effects of Accentuated Eccentric Loading during Drop Jumps on Strength, Power, Speed and Exercise-Induced Muscle Damage

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The Effects of Accentuated Eccentric Loading during Drop Jumps on Strength, Power, Speed and Exercise-Induced Muscle Damage

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Abstract

The overall aim of the thesis was to investigate the acute and chronic effects of accentuated eccentric load (AEL) drop jumps (DJ) on athletic performance andexercise-induced muscle damage (EIMD).

Study one assessed the test-retest reliability of a novel multi-joint isokinetic squat device (Exerbotics). The mean concentric peak force (PF) CV and ICC was 10% and 0.95 respectively. The mean eccentric PF CV and ICC was 7.2% and 0.90 respectively. Based on these findings it is suggested that the Exerbotics squat device shows good test-re-test reliability.

Study two investigated the relationships between concentric and eccentric PF during the Exerbotics squat and countermovement jump (CMJ) performance. Avery large relationship was found between absolute eccentric PF, absolute CMJ peak power (PP) and CMJ height. Based on these findings individuals wishing to enhance theirCMJ should include lower body eccentric strength training. Study three assessed the relationships between concentric and eccentric PF, DJs and athletic performance.A large negative relationship was observed between DJ height and sprint times. Based on these findings athletes may benefit from includingDJsin their training.

Study four investigated the acute effects of AEL DJs on CMJ performance. The 20% AEL condition resulted in greater CMJ height in comparison to all other conditions. The results of this study suggest fiveDJs with a 20% AEL followed by a two minute recovery period results in a significant enhancement in CMJ height and PP.

Study five investigated the effects of 30 and 50 AEL DJs on markers of exercise induced muscle damage including strength, jump performance, muscle soreness (SOR) and creatine kinase (CK) in resistance-trained athletes. In week one baseline CMJ, SJ, concentric and eccentric PF, CK and SOR were assessed. Subjects then completed 30 AEL DJs, and baseline measures were re-tested immediately post, 1, 24 and 48 hours later. Two weeks later the subjects completed the same protocol with an increase in AEL DJ volume (50 jumps). During CMJ testing in week one the subjects jump height was reduced compared to baseline immediately post intervention (ES = -0.38). During SJ testing in week one the subjects jump height was reduced compared to baseline immediately post intervention (ES = -0.24). During squat testing in week one concentric PF was reduced compared to baseline one-hour post intervention (ES = -0.22). During week three testing concentric PF was reduced compared to baseline immediately post intervention (ES = -0.30). During week one eccentric PF was reduced compared to baseline, immediately post intervention, 24 and 48hrs later (ES = -0.31, -0.22 and -0.22). Based on these findings it is proposed that AEL DJs result in minimal EIMD in resistance-trained athletes.

In conclusion, it would appear that AEL DJs enhance acute athletic performance with minimal EIMD.

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Attestation of Authorship

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

Lee Anthony Bridgeman

Co-Authored Works

The contribution of co-authors for publications (e.g. Bridgeman 85%) arising from these research studies and where they have been published is listed below.

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Ethics Approval

The Auckland University of Technology Ethics Committee (AUTEC) granted ethical approval for the thesis research on the 4th November 2014 for a period of three years:

- AUTEC: 14/322 The effects of accentuated eccentric loading during drop jumps on strength, power, speed and exercise-induced muscle damage.

Chapter 1

Introduction

1.1 Rationale

An eccentric muscle action results in the lengthening of a muscle or group of muscles as a result of the application of an external load [1-3]. Training eccentrically has previously been reported to result in; improvements in total strength, concentric and eccentric strength [3-6], increased hypertrophy compared to traditional concentric training [7-9], improvements in jumping power [10-12] and reduced risk of injury [13, 14]. These improvements have been attributed to a number of factors including; the mechanical nature of eccentric muscle actions resulting in greater force production [2, 3], an altered pattern of muscle recruitment which allows fast-twitch motor units to be recruited before slow-twitch motor units [15], an increased neural drive to agonists and an accompanying reduction in antagonist activation [16].

Despite the suggestion that eccentric muscle actions are different from concentric muscle actions, the majority of studies investigating the relationships between strength and athletic qualities (jumping, sprinting and change of direction) have not investigated eccentric strength in isolation[17, 18]. Although it is acknowledged that the correlation do not equal causation,if significant relationships between eccentric strength and athletic performance can be identified, this may help inform future programming or lead to further research into this area. Therefore this is an area of interest that this thesis sought to address.

One method which may result in high eccentric force production is reported to be the use of the drop jump (DJ) exercise [19] which is a common training method to improve lower extremity power and speed [20].Previously low volumes of DJs (1-2 sets of 5-10 repetitions) have been reported to result in acute enhancements in throwing performance [21], vertical jump performance [19, 22, 23] sprint performance [22] and strength [24]. Researchers have also reported the use of DJs as a training intervention led to improvements in; speed [25-27], jumping [25, 27-31], strength [25, 28] and agility [32]. To further enhance the DJ eccentric overload, Moore and Schilling [33] proposed using dumbbells or elastic bands to provide accentuated eccentric loading (AEL). Using this method as an athlete reaches the bottom position of the CMJ following the drop phase of the exercise they either release the dumbbells, or the elastic bands are released allowing them to perform the concentric portion of the exercise without any additional load [33]. At present, only one study has investigated the use of AEL with no additional load in the concentric phase during a DJ. In this study, AEL was applied using an elastic device [34]. The results of this study indicated that additional eccentric load enhanced eccentric impulse, the rate of force development (RFD) and resulted in small to moderate effect size (ES) increases in integrated electromyography(iEMG) across the eccentric phase.

However, there was no associated increase in jump height or concentric muscle activation reported [34]. Aboodarda et al. [34] only investigated the effects of AEL on the DJ exercise itself and did not assess the effect of AEL DJs on any subsequent acute performance or the ability of AEL DJs to improve performance when utilised as part of a training intervention. This is a gap in the current literature that needs to be addressed.

As a consequence of the DJ exercise resulting in high eccentric force production [19] there is the potential for athletes to suffer some degree of exercise-induced muscle damage (EIMD) [35]. The negative side effects of EIMD include acute reductionsin muscular strength and power [36], decreases in the range of movement (ROM), delayed onset muscle damage (DOMS), swelling [37, 38] and increases in markers of EIMD such as creatine kinase (CK) [39]. These negative side effects are reported to peak 24 – 72 hours after the initial bout of exercise and gradually disappear over the course of five to seven days [40]. Someof the mechanisms proposed as being responsible for performance decrements after a bout of eccentric exercise include the popping sarcomere theory [41], failure of the excitation coupling (E-C) process [42], DOMS [43] and increased membrane permeability [44].

Previously researchers have reported that DJs result in EIMD, but the extent of this damage is reduced after a subsequent bout of DJs[45, 46]. However, as yet, no studies have investigated the effects of AEL on the DJ exercise in resistance-trained subjects. Thus at present the magnitude of EIMD which may occur as a consequence of this additional eccentric load is unknown. This information will be of interest to S&C coaches, as they need to know that any new training modality will not prevent athletes from training or performing optimally. Therefore it is proposed that this is an area worthy of further investigation.

Because there are differences between maximal concentric and eccentric strength levels when investigating any changes in force production (as a result of EIMD) it would seemprudent to independently assess them. However, when assessing any changes in strength between trials tests must demonstrate a high level of reliability to be of value[47]. One method for assessing concentric and eccentric peak force independently is the use of an isokinetic squat device (Exerbotics).When utilising this device Stock and Luera [48] that this device had moderate to high reliability for peak concentric and eccentric force. In this study the authors classified their subjects as resistance-trained if they had six months previous training experience in the squat[48]. However, conducting research with resistance-trained athletes with an extensive training history is suggested to be important[49].Most S&C coaches in elite sport will work with athletes who have a long training history and therefore are interested in studies whose subjects have similar characteristics to their own athletes.Therefore reliability testing of the Exerbotics device with an experienced resistance-trained group of subjects was necessary.

1.2 Purpose of the Research

The overarching aims of this thesis were to investigate the relationships between eccentric strength and athletic performance and the acute and chronic effects of AEL DJs on strength, power and EIMD.

The objectives of this thesis were to:

1. Establish the test-retest reliability of a novel isokinetic squat device.This study was included as it was necessary to establish the reliability of this device prior to using it to measure any changes in concentric and eccentric force production in the final study.
2. Investigate the relationships between concentric and eccentric strength and jumping performance.
3. Investigate the relationships between concentric and eccentric strength, DJ, vertical jump performance, speed and change of direction (COD).
4. Investigate the effects of AEL during the DJ exercise and its acute effects on subsequent CMJ performance.
5. Assess the effects of an AEL DJ protocol on the EIMD response.

1.3 Significance of Research

Although it has been previously shown that DJs have the ability to enhance strength, power, speed and agility currently it is unknown what effect adding AEL during DJs will have. Initially, this research investigated the reliability of a novel isokinetic squat device to establish whether it could provide reliable data on concentric and eccentric peak force (PF).Based on the results of this study the same device was used to investigate the relationships between concentric and eccentric PF and jump performance. It was proposed that eccentric PFwould have a strong relationship with a stretch shortening cycle action such as the CMJ and thereforeS&C coaches may utilise methods to increase eccentric force production if their aim is to enhance jumping performance. The next study investigated the relationships between concentric and eccentric PF, jump performance, speed, and COD.Also this study investigated if DJ performance has any relationship with speed and COD performance.If relationships are found to exist between these variables this may also inform future training programme design.

The subsequent study in this thesis investigated whether AEL DJs can acutely enhance DJ and subsequent vertical jump performance. This led to practical recommendations for S&C coaches and athletes on the potential use of AEL DJs as part of a warm up or training session to enhance subsequent vertical jump performance.

Currently,it is known that exercises such as the DJ produce large amounts of eccentric force that results in EIMD. However, there is no research that has investigated the effect of adding AEL during the DJ on EIMD. Therefore the magnitude of damage that may occur as a result AEL during the DJs and the time course of recovery post intervention is currently unknown. This information will be of interest to both S&C coaches and athletes when considering the practical implications of including AEL DJs into training. Therefore this research aimed to address this.

1.4 Structure of the Thesis

This thesis is comprised of nine chapters (Figure 1-1) and the reference style utilised throughout is the numbered style. The first two chapters after the introduction contain the two literature reviews for this thesis(both of these chapters were published in the Journal of Australian Strength and Conditioning). The aim of the first literature review (Chapter two) was to provide a comprehensive review of theuse of different eccentric training modalities and the practical applications of these modalities. The subsequent literature review (Chapter three) investigated eccentric EIMD and the RBE.Chapter four (published in Journal of Strength and Conditioning Research) aimed to investigate the test-retest reliability of a novel isokinetic squat device to establish whether it could reliably measure concentric and eccentric PF. Chapter five (published in Journal of Strength and Conditioning Research) investigated the relationships between concentric and eccentric PF and jumping performance.Following on from thisChapter six investigated the relationships between concentric and eccentric PF, DJ, vertical jump performance, speed and COD.The aim of chapter seven (published in Journal of Strength and Conditioning Research) was to examine the effects of AEL on the DJ exercise and subsequent acute CMJ performance and provide coaches and athletes with practical recommendations on the acute use of AEL DJs.Chapter eightof the thesis investigated the EIMD response to AEL DJs. The final chapter (Chapter nine) is comprised of a general summary of the finding of this research, its limitations, and future research recommendations. Finally, practical recommendations from the research are proposed for S&C coaches and athletes.

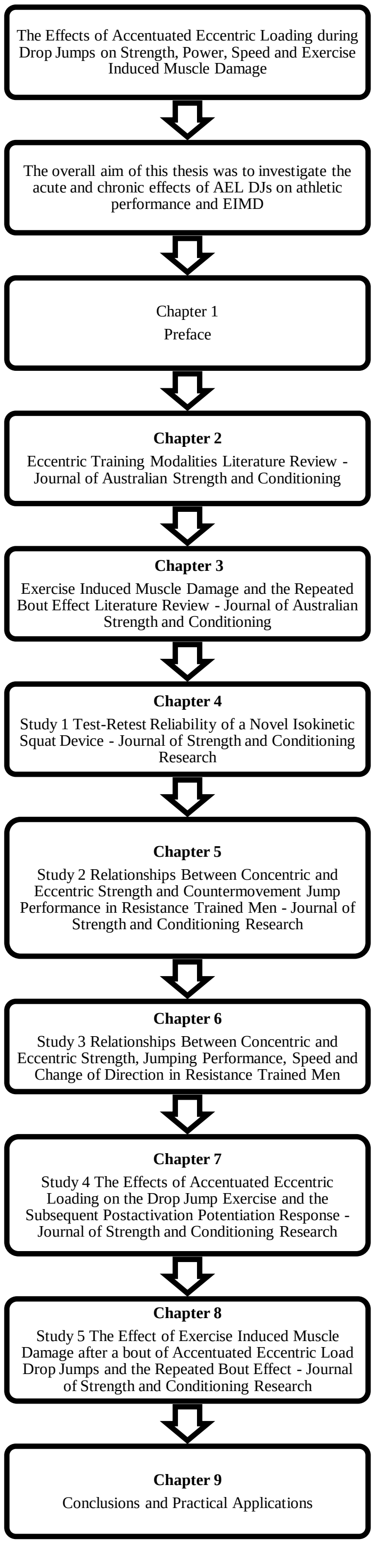

Figure 1-1. Thesis Structure

Chapter 2

Eccentric Exercise as a Training Modality: A Brief Review

Journal of Australian Strength and Conditioning

2.0 LEAD SUMMARY

As identified in the introduction chapter there is potential for eccentric exercise to result in enhanced performance. Therefore the aim of this chapter was to identify potential eccentric training modalities and provide practical recommendations on their use.

An eccentric muscle action involves the lengthening of a muscle due to an external load and occurs as a result of the mechanical disruption of action and myosin. The mechanical nature of the actin and myosin disruption during eccentric muscle actions is reported to allow for greater force production and requires a different neural activation pattern from a concentric action. As a consequence of these differences, it is suggested concentric focused resistance training may not overload the eccentric action sufficiently. Therefore the purpose of this review was to outline a variety of eccentric training modalities and provide the reader with practical recommendations on programming. A search of the literature was conducted for; eccentric; training; methods; cycling; isokinetics; drop jumps; flywheel; exercise-induced muscle damage; repeated bout effect. After this search, 106 papers were selected to form the basis of this review. When training isokinetically it was reported six to ten weeks of training at 180° s^{-1}, three times per week and with 24 – 30 maximal contractions per session resulted in improved hypertrophy and eccentric strength. When using dynamic exercises such as the squat and bench press a barbell load of 75 – 85% concentric 1RM with a releaser load of 40 – 55% (five – ten repetitions, 45 – 90 seconds between repetitions) may be appropriate. If the eccentric training is submaximal the barbell load has been recommended to be 50 – 65% concentric 1RM with a releaser load of 10 – 25% (15 – 20 repetitions, 15 – 30 seconds between repetitions). In conclusion, eccentric training may warrant inclusion as part of an athletes training program.

2.1 INTRODUCTION

A concentric muscle action occurs when muscles apply force, which results in those muscles shortening whereas an eccentric muscular action involves the lengthening of a muscle due to an external load [1-3]. The combination of these two actions is regularly seen in sport and is referred to as the stretch shortening cycle (SSC) [1, 50, 51]. During the SSC muscle is initially lengthened eccentrically, which then facilitates greater force production during the following concentric action [33]. This SSC has been suggested to result in a more efficient muscle action and can improve factors which are important in sporting performance such as running economy and jumping [51]. Although the combination of eccentric and concentric muscle actions during the SSC is suggested to be desirable, the process leading to each is reported to differ[52]. During a concentric muscle action actin and myosin, detachment is suggested to be ATP-dependent whilst during an eccentric muscle action the disruption of the action and myosin process is reported to be mechanical in nature [1, 33]. The mechanical nature of eccentric muscle actions has been suggested to allow for the production of greater force during eccentric actions than is observed in concentric actions [2, 3]. In addition to the mechanical differences between the two muscle actions neural activation during eccentric muscles actions appears to differ and these differences include; a reduction in muscle activation during maximal eccentric contractions [1], an altered pattern of muscle recruitment with fast-twitch motor units recruited prior to slow-twitch motor units [15], an increased neural drive to agonists and a reduction in antagonist activation [16] and a greater cross education effect [53]. Despite research reporting the ability of eccentric muscle actions to produce more force than concentric muscle actions and the unique neural activation associated with this, traditionally during resistance training, the intensity of exercises is set according to an athlete’s concentric strength. Thus although athletes may be working optimally during the concentric phase of an exercise they may not be working optimally eccentrically [5, 50, 54, 55]. This result is supported by the findings that athletes are stronger in the eccentric phase of a lift [56] compared to the concentric phase. Thus it is suggested that traditional training in isolation may not be adequate to maximally enhance eccentric strength which is required in many sporting actions and in particular those that wish to effectively utilise the SSC. Indeed training eccentrically has been reported to resulted in; improvements in total strength, concentric and eccentric strength [3-6], increased hypertrophy compared to traditional concentric training [7-9], improvements in jumping power [10-12] and reduced risk of injury [13, 14]. This brief review will outline different eccentric training methods, the use of these training methods to prevent injury or aid the rehabilitation process and provide practical recommendations on the use of eccentric training.

2.2 METHOD

A search of the literature was conducted for eccentric exercise modalities, exercise-induced muscle damage (EIMD) and the repeated bout effect (RBE). Databases PubMed, CINAHL, Web of Science and SPORTDiscus to February 2015 were searched for terms linked with Boolean operators ("AND", "OR"): eccentric; training; methods; cycling; isokinetics; drop jumps; flywheel; exercise-induced muscle damage; repeated bout effect. Papers were selected based on the title, then abstract, then text. Only papers, which specifically addressed eccentric training modalities, were included in this review. Once these criteria had been applied 106 papers were selected to form the basis of this review.

2.3 DISCUSSION

2.2.1 Eccentric Cycling

One method, which has been utilised to allow for eccentric overload, is eccentric cycling. Eccentric cycling involves the athlete resisting the action of the pedals which are being driven in reverse by an electric motor [57]. It has been shown to result in; increases in strength and power, increased muscle cross sectional area (CSA), increased leg spring stiffness and minimal demands for oxygen [57-63] (Table 2-1). Eccentric cycling therefore presents an attractive training method to a wide range of groups including athletes, the elderly, people with cardiovascular disease and those recovering from injury. Although at present most research has been conducted using untrained participants Gross et al. [57] divided trained junior alpine skiers into two groups (concentric and eccentric training groups). The concentric training group completed three lower body weights training sessions per week for six weeks which consisted of four exercises (five sets of leg-press and hamstring curls, four sets of squats and barbell lunges, all sets consisted of 30 repetitions). The participants in the eccentric training group completed the same exercises but only for three sets of 30 repetitions, participants then completed a 20-minute continuous session on the eccentric cycle ergometer. Initially, during these eccentric cycle training sessions, the workload was constant (200 – 250 watts at a pedalling cadence of 60-80 rpm) however, after week 2 variable wattage was introduced for these sessions. After six weeks of training Gross et al. [57] reported that only the eccentric cycling group had significant improvements in hypertrophy of the lower limb (2.1 ±1.6% and 1.5% ± 1.4% in the right and left legs respectively) and countermovement jump (CMJ) height (6.5%).

Table 2-1. Eccentric cycling studies

Study	Population	Intervention	Results
Elmer et al. [58]	Untrained subjects Eccentric group N = 6 (1 female) Mean age: 25±6 years	Eccentric cycling group trained 3 times per week for a total of 7 weeks. Intensity started at 54% max heart rate and at end of study was 66% of max heart rate	Significant increases in leg stiffness (10 ±3 %vs. -2 ± 3%) and jumping P_{max} (7 ±2 %vs. -2 ± 3%) compared to the concentric only training group
Gerber et al. [60]	Untrained subjects N = 32 Aged 18-50 years	3 weeks after ACL surgery participants completed a 12 week eccentric cycling program. Intensity was self selected and ranged from 20-40rpm	Quadriceps strength (124.2 Nm – 159.2 Nm) and hopping distance (80.3 – 112.9 cm) significantly increased in the eccentric cycling group compared to traditional training group. Activity level also decreased to lesser extent in the eccentric group.
Gerber et al. [59]	Untrained subjects N = 32 Aged 18-50 years	1 year follow up to the original Gerber et al. study discussed above	Significantly greater improvements in quadriceps (1430 ± 426 – 1763 ± 458 cm^3) and gluteus maximus muscle (596 ± 173 – 719 ± 169) volume in eccentric group compared to concentric group. Improvements in quadriceps strength (137 ± 34 – 182 ± 45 Nm) and hopping distance (71 ± 13 – 124 ± 38 cm) were also significantly greater in the eccentric group.
Gross et al. [57]	Trained alpine skiers N = 15 Mean age: 17.6±1.4 years	Eccentric cycling group performed three one hour weights sessions a week (3 sets of leg exercises) followed by 20mins on eccentric ergometer (various workloads) for 6 weeks	Significant increase in lean thigh mass, 6.5% improvement in squat jump height and no significant improvement in isometric force
LaStayo et al. [61]	Untrained subjects N = 14 Mean age: 23.9 years	Eccentric cycling group trained for 8 weeks, 2-5 times a week and for 15-30mins at an intensity of 54-65% HR_{peak}	Significant increases in isometric strength (36%) and CSA (52%). No significant changes in concentric training group
LaStayo et al. [62]	Untrained subjects N = 9 Mean age: 21.5 years	Eccentric cycling group trained for 6 weeks, 2-5 times per week, 10-30mins and at an intensity of 50-60rpm	Oxygen demand was less during eccentric cycling compared to concentric cycling despite higher workloads. There was a 33% increase in isometric leg strength in the eccentric group while no significant improvements were recorded in the concentric group.

Leong et al. [63]	Untrained subjects N = 8 (4 males and 4 females) Mean age: 22±2 years	Eccentric cycling 2 times per week, 5-10.5 minutes per session at an intensity of 20-55% P_{max}	Increased RF (24±4%) and VL (13±2%) thickness, increased RF (31±4%) and VL (13±1%) pennation angles. Increased P_{max} 1 week after training (5±1%) and 8 weeks after training (9±2%)

Rpm – Revolutions per minute
CSA – Cross sectional area
P_{max} – Power max
HR_{peak} – Peak heart rate
RF – Rectus femoris
VL – Vastus lateralis

Although no overall improvement was found in isometric strength it was reported strength increased at longer muscle lengths leading to the suggestion that eccentric cycling promoted the addition of sarcomeres in series [57]. The results of this study led the authors to conclude the ability of eccentric cycling to promote hypertrophy and its close dynamic correspondence to alpine skiing made it a beneficial training method. At present research would appear to indicate that eccentric cycle training might be a beneficial training method for untrained participants. However, currently there is not enough research to draw conclusions of its effectiveness on trained athletes and therefore more research is required.

2.2.2 Isokinetic and Computer Driven Eccentric Training

Another method of training eccentrically that is widely utilised is isokinetic training (Table 2-2). When training isokinetically, the load is moved at a constant velocity through the use of an isokinetic dynamometer [64]. When utilising, isokinetic eccentric training, studies have investigated the effects of different training velocities [65-67]. Paddon-Jones [66] reported that ten weeks of eccentric isokinetic training (three days a week, 24 maximal contractions per session) at 180° s^{-1} resulted in; reduced type I fibre percentage (53.8 – 39.1%), increased type IIb muscle fibre percentage (5.8 – 12.9%), increases in eccentric (29.6 ± 6.4%) and concentric torque (27.4 ± 7.3%) at 180° s^{-1}. These adaptations were not found to be present in the participants who trained eccentrically at 30° s^{-1}. Further studies by Farthing and Chilibek[65] and Shepstone [67] also reported faster speeds resulted in greater strength and hypertrophy. These findings were suggested to be as a result of fast contraction velocities leading to greater protein synthesis, which in turn promoted greater hypertrophy [67].

In addition to the findings on velocity Duncan et al. [68] reported that eccentric isokinetic training is mode specific with eccentric training resulting in the greatest increases in eccentric strength and concentric training resulting in the greatest improvements in concentric strength. In support of the idea of mode specificity Tomberlin et al. [69], Higbie et al. [7], Hortobagyi et al. [70], Seger, Arvidsson and Thorstensson[71] and Seger and Thorstensson[72] also reported that in untrained participants eccentric isokinetic training resulted in the greatest increases in eccentric strength whilst concentric training led to the greatest increases in concentric strength.

Table 2-2. Isokinetic devices and other machine driven eccentric training methods

Study	Population	Intervention	Results
Duncan et al. [68]	Untrained participants N = 48 Mean age: 23.9 years	Eccentric and concentric group trained for 6 weeks, 3 times per week, at 120° s^{-1}, 1 set of 10 maximal contractions of the quadriceps	Eccentric group had significantly improved eccentric force (25.1 ± 24.1%) but not concentric force. Concentric group improved concentric force but not eccentric force (7.8 ± 10.0%) Eccentric isokinetic training is mode specific.
Farthing et al. [65]	Untrained participants N = 36 (13 male and 23 female) Mean age: 21.9±1.5 years (fast group) and 19.6±0.7 years (slow group)	Eccentric and concentric training at two velocities fast 180° s^{-1} and slow 30° s^{-1}. Trained one arm eccentrically for 8 weeks then the other arm concentrically for 8 weeks	Eccentric 180° s^{-1} resulted in greater hypertrophy than all concentric velocities. Eccentric 30° s^{-1} resulted in greater hypertrophy than concentric 180° s^{-1}. Eccentric 180° s^{-1} resulted in greatest strength improvements.
Friedmann-Bette et al. [11]	Resistance trained participants N = 25 (11 eccentric) Mean age: 24.3±3.7 years	Knee Extension on a specially designed computer driven device, 6 weeks of training, 3 times a week, at an intensity of 5 sets at 8 repetition max (8RM). In ecc group maximum force applied on the lever arm during eccentric contractions resulted in a 1.9 fold higher eccentric load.	Increased max strength (11 – 15 kg) in both concentric and eccentric group, only the eccentric overload group had shift towards a faster muscle phenotype.
Friedmann-Bette et al. [73]	Untrained participants N = 18	Eccentric group trained on computer driven device, with loads equivalent to 30% 1RM concentric and 30% 1RM eccentric, for 4 weeks, 3 times a week and 3 sets of 25 repetitions per session	Results showed increase in peak torque (5%) and adaptation towards a stronger and faster muscle.
Godard et al. [74]	Untrained participants N= 28 (16 women and 12 men) Mean age eccentric group: 22±3.0 years	10 weeks of training, 2 times per week, one set of 8-12 unilateral knee extension with eccentric load 40% greater than the concentric load	Significant improvements in concentric knee extensor torque for both the eccentric (88.0 ± 20.9 – 170.4 ± 32.4 Nm) and concentric (85.8 ± 23.3 to 167.4 ± 35.5 Nm) training groups with no difference between the two.
Higbie et al. [7]	Untrained participants N = 60 Mean age: 20.1±1.1 years	Eccentric group trained for 10 weeks, 3 days per week, 3 sets of 10 repetitions (right leg knee extensions)	Eccentric group showed greatest increases in eccentric strength (36.2%) and concentric in concentric strength (18.4%). Supporting idea of mode specificity in isokinetic training.

Hortobagyi et al. [75]	Untrained women N = 30 Mean age: 20.9±1.2 years	Participants in the eccentric overload group completed unilateral knee extensions with an overload of 40-50% during the eccentric contraction for 7 consecutive days	The eccentric training group had on average a two-fold increase in strength compared to the standard training group.
Hortobagyi et al. [70]	Untrained participants N = 42 Mean age: 21.1±2.38 (eccentric group)	Training involved 824 eccentric quadriceps actions, over 6 weeks, 4 times a week, 4 sets of 6-10 repetitions at 60° s^{-1}	Eccentric training increased eccentric (42%) and isometric strength (30%) to a greater degree than concentric training. EMG adaptations were greater with eccentric training.
Komsis et al. [76]	Untrained participants N = 16 Mean age: 24±0.5 years	Eccentric training group trained on a custom built multi-joint isokinetic dynamometer, 2 times per week, 3-6 sets, 6-10 reps at an intensity of 70-90%	Significant increase in in eccentric and concentric force and improvement in drop jump height.
Paddon-Jones et al. [66]	Untrained participants N = 20 Mean age: 24.2±7.0 years	Two groups completed eccentric training at two different isokinetic velocities fast 180° $s^{-1}$and slow 30° s^{-1}. 10 weeks of training, 3 times a week, 24 maximal contractions (4 sets of six)	Fast group experienced significantly greater increase in eccentric (29.6 ± 6.4%) and concentric torque (27.4 ± 7.3%) at fast speed and isometric and eccentric torque at slower speed. % type I fibre decreased in fast group (53.8 – 39.1%) while type II increased (5.8 – 12.9%) No significant changes in slow group
Paschalis et al. [77]	Untrained participants N = 20 Mean age: 20±0.3 years	8 weeks, once per week, 5 sets of 15 eccentric or concentric MVC at 60° s^{-1}	Increased resting energy expenditure (+ 12.7%) and fat oxidation (+12.9%), improved blood lipid profile, reduced resting insulin resistance at week 8.
Seger et al. [72]	Untrained participants N = 10 Mean age: 25±1.8 years	Eccentric and concentric group trained for 10 weeks, 3 days per week, unilateral knee extension at 90° s^{-1}, 4 sets of 10 maximal efforts.	18% and 2% increase in mean eccentric and concentric force in eccentric group compared to 10% and 14% in concentric group. Changes in strength of trained legs revealed more specificity related to velocity and contraction type in eccentric compared to concentric actions

Seger et al. [71]	Untrained participants N = 10 Mean age: 25±2 years	Eccentric and concentric group trained for 10 weeks, 3 times per week, at 90° s^{-1}, 4 sets of 10 maximal efforts on left leg followed by same protocol on right leg	Effects of eccentric training on muscle strength were found to be more mode and speed specific than concentric training.
Shepstone et al. [67]	Untrained participants N = 12 Mean age: 23.8±3.4 years	Participants trained one arm at fast velocity 210 ° $s^{-1}$and one arm at slow velocity 20° s^{-1}, 8 weeks of training, 3 times a week	Type I muscle fibre size increased in both arms. Type II muscle fibre size increased to a greater extent in the fast arm. Maximum torque generating ability was also greater in the fast arm (11.3 ± 10.4 Nm improvement).
Theodosiou et al. [12]	Untrained participants N = 19 Mean age: 21.3±0.9 years	Eccentric group trained using a isokinetic hydraulic leg press, 8 weeks, 2 times per week, 3-6 set, 5-10 repetitions at an intensity of 70-90% max eccentric force	Significant increases in drop jump height (13.6 ± 3.2%) and maximally power (25.8 ± 1.2%), reduction in ground contact time (17.6 ± 2.6%), increased muscle stiffness and increased maximal eccentric and concentric leg press force.
Tomberlin[69]	Untrained participants N = 63 Mean age: 27.1 years	Eccentric group trained for 6 weeks, 3 times a week, at 100° s^{-1}, 3 sets of 10 repetitions (right quadriceps)	Eccentric group showed greatest increases in eccentric work and torque and concentric in concentric work and torque. Supporting idea of mode specificity in isokinetic training.

CSA – Cross sectional area
RM – Repetition max
Reps – Repetitions
EMG – Electromyography
PLP – Passive leg press

However, Goddard et al. [74] and Hortobagyi et al. [75] reported training with the additional load during the eccentric phase (40-50% concentric load) using an isokinetic dynamometer resulted in similar increases in concentric knee extensor torque and thigh hypertrophy for both concentric and eccentric training groups. When attempting to increase eccentric strength utilising isokinetic training the literature suggests three to four sets (three minutes between sets) of ten maximal eccentric contractions, three times a week for six – ten weeks utilising fast contraction velocities (~180° s^{-1}) results in optimal adaptations in untrained participants.

As well as the use of traditional unilateral isokinetic devices studies have also employed novel multijoint isokinetic devices to provide an eccentric overload in untrained participants [12, 76]. Studies by Komsis et al. [76] and Theodosiou et al [12] have reported that 8 weeks (two times per week, 70%+ max eccentric force) of seated leg press eccentric training utilising a multijoint isokinetic machine resulted in; greater concentric and eccentric force production and improvements in drop jump (DJ) height. Therefore the use of multijoint bilateral isokinetic devices is suggested to be an alternative to the unilateral devices currently popular in the literature.

Studies have also utilised specially designed computer driven apparatus to induce eccentric overload [11, 73]. In Friedmann-Bette et al. [73] study participants completed leg extensions on a computer driven device, which allowed them to overload the eccentric phase of the exercise 2.32-fold higher than in the concentric phase. Results of this study showed an increase in peak torque (5%). It was also suggested that the eccentric overload training resulted in a shift towards a more type II dominant muscle. In a further study trained participants (explosive strength athletes who had completed at least one – two strength training sessions per week for on average the last five years) performed leg extensions in the eccentric phase at a load 1.9-fold higher than the corresponding concentric load [11]. After six weeks of training, the eccentric overload group were reported to have increased maximal quadriceps strength (~18%), quadriceps CSA (~7%) and a significant increase in jump squat height. Friedmann-Bette et al. [11] suggested these results indicated that eccentric overload training led to a faster gene expression and a shift towards a faster muscle phenotype, resulting in a muscle that was better suited to explosive movements. Thus the results of these studies would be of particular interest to athletes involved in explosive and power based sports where a shift towards a faster muscle phenotype would be beneficial.

The results of the aforementioned studies agree that eccentric training improves eccentric strength to a greater extent than concentric training. However, the results of the effect of eccentric training on concentric strength are equivocal. In a meta-analysis investigating eccentric training Roig et al. [3] concluded that eccentric training leads to greater improvements in eccentric strength than concentric training. Concentric training was reported to show a non-significant trend towards having a greater impact on concentric strength than eccentric training, however, given the ability of eccentric training to improve concentric, eccentric and isometric strength Roig et al. [3] concluded that eccentric training was a superior method for increasing total strength.

Despite the findings that isokinetic training results in improvements in strength in a review Guilhem et al. [64] reported that isotonic eccentric training led to a greater increase in strength per session than isokinetic training (1.1 ± 1.0% per session vs. 0.6 ± 3.0%). In agreement with this Vogt and Hoppeler[51] also suggested that training eccentrically using isotonic exercise results in greater strength gains than training isokinetically. Also similarly to eccentric cycling, it is also suggested by the author that the majority of S&C coaches, athletes and the general population will not typically have easy access to isokinetic dynamometry. Therefore S&C coaches, athletes and clinicians may be required to come up with novel ways to train eccentrically with athletes.

2.2.3 Dynamic Eccentric Resistance Training

In addition to the use of isokinetic eccentric interventions and eccentric cycling, studies have investigated the effects of accentuated and supramaximal eccentric loading during dynamic movements more akin to those seen in sport (table 2-3). In the Sheppard et al. [10] study participants were placed into two groups, who then both completed normal resistance training three times per week for five weeks. The eccentric overload group, however, completed CMJs with additional load (males 20 kg and females 10 kg) in the eccentric phase before releasing the load and completing the concentric phase of the jump. Sheppard et al. [10] reported that this eccentric overload resulted in gains in peak power (20%), peak velocity (16%) and jump height (11%) characteristics in high performance volleyball players. In contrast Moore et al. [78] found that additional loading during the eccentric phase of a jump squat did not lead to any improvements in force, velocity and power. Moore et al. [78] proposed that this may be due to technical difficulties with the weight release devices or that the initial concentric load (30% 1RM) may not have exceeded the threshold needed for the additional eccentric load to lead to improved performance.

A study investigating the effects of lifting an additional eccentric load (additional 5% to concentric 1RM) during the bench press exercise through the use of weight releaser hooks reported an increase in subsequent concentric bench press 1RM (5 – 15 lbs) [54]. In a further study investigating dynamic eccentric overload in both the squat and bench press exercise Yarrow et al. [9] reported five weeks of eccentric overload training (three times a week, three sets of six reps at 40% concentric 1RM and 100% eccentric 1RM) resulted in increased bench press strength (~10%) and squat (~22%).

Table 2-3. Dynamic training

Study	Population	Exercise Modality	Intervention	Results
Brandenburg et al. [5]	Resistance trained university students N = 23	Preacher curls and supine elbow extension	Eccentric overload group trained for 9 weeks, 2-3 times a week, 3 sets of 10 repetitions with concentric load of 75% 1RM and eccentric load of ~120% concentric 1RM	No significant changes in CSA Eccentric training group produced significantly greater increases in concentric 1RM of elbow extensors (24%) than the concentric training group (15%)
Doan et al. [54]	Untrained athletes N = 10 Mean age: 23.9 years	Bench press	Eccentric overload group completed the eccentric phase of the barbell bench press with a load of 105% of concentric 1RM with weight releasers	The use of additional eccentric load significantly increased subsequent concentric 1RM in the bench press exercise (5 – 15 pounds)
Fernandez-Gonzalo et al. [79]	Untrained N = 32 (16 males and 16 females) Mean age men: 23±1 year Mean age women: 24±1 year	Bilateral flywheel supine squat	6 weeks of training, 2-3 times a week, four sets of 7 repetitions	Increases in strength (20 – 25%), power (3% - 6%) and muscle mass. Changes are comparable between men and women
Moore et al. [78]	Trained men N = 13 Mean age: 22.8±2.9 years	Augmented eccentric jump squat training	2 reps with 30% 1RM concentric load and additional eccentric load on weight releasers of 20,50 and 80% 1RM	No changes in acute force, velocity and power
Norrbrand et al. [8]	Untrained N = 15 Mean age: 39.1±8.1 years	Unilateral knee extensor flywheel training device	5 weeks of training, 2-3 times per week, 4 sets of 7 unilateral concentric-eccentric knee extensions	MVC increased at all angles, increased quadriceps CSA
Norrbrand et al. [80]	Untrained N = 17 Mean age: 38.81±5.0 years	Bilateral knee extensor flywheel training device	5 weeks of training 2-3 sessions per week, 4 sets of 7 repetitions of unilateral knee extensor training of left limb	MVC (8.1 %) and training specific strength increased. Higher EMG activity recorded in eccentric portion of action

Sheppard et al. [10]	Trained volleyball players N = 16 Mean age: 21.8±4.9 years	Accentuated eccentric load countermovement jumps	Eccentric training group trained for 5 weeks, 3 times per week. During eccentric phase of CMJ males held a 20 kg weight plate and females 10 kg	Significantly greater improvements in displacement, velocity and power in the eccentric group compared to body weight only group
Sheppard et al. [81]	Trained subjects N = 14 Mean age: 22.1±0.8 years	Bench throw	Participants performed the bench throw exercise with an extra eccentric load (20, 30 and 40 kg) in addition to the 40 kg concentric load	Superior concentric peak barbell displacement (0.27 v 0.24 m) were achieved in all eccentric overload conditions
Vikne et al. [55]	Resistance trained men N = 22 Mean age: 26.9±3.4 years	Specially designed elbow flexion apparatus	Eccentric training for 12 weeks, 2-3 times per week, 4-8RM	Eccentric training resulted in similar increase in concentric strength (14%) to concentric training but a greater increase in eccentric strength (26%) CSA of elbow flexors and type I and type II increased (11%) only after eccentric training
Yarrow et al. [82]	Untrained subjects N = 22 Mean age: 22.1±0.8 years	Bench press and squatting	Eccentric training for 5 weeks, 3 times per week, 3 sets of 6 repetitions at 40% concentric 1RM and 100% 1RM eccentric	Similar improvements in bench press and squat strength for both the eccentric and concentric training group Post exercise lactate clearance was greater in the eccentric group

1RM – 1 repetition max
CSA – Cross sectional area
MVC – Maximum voluntary contraction
EMG – Electromyography
CMJ – Countermovement jump

Although these results were similar to those of the traditional training group in the study it was reported that volume was reduced in the eccentric training group leading to the suggestion that eccentric training may be more efficient. It was also reported that post exercise lactate clearance was improved in the eccentric training group leading to the suggestion that eccentric training promotes a faster post activity recovery. In a further study investigating the effects of additional eccentric loading (20, 30 or 40 kg) using weight releasers whilst completing bench throws Sheppard and Young [81] reported superior peak concentric barbell displacement with all loads compared to an equal eccentric and concentric bar load. This led the authors to conclude that additional eccentric load can lead to improvements in the bench throw exercise. When using weight releasers it has been suggested that for maximal eccentric isotonic actions a barbell load of 75 – 85% concentric 1RM with a releaser load of 40 – 55% (five – ten repetitions, 45 – 90 seconds between reps) may be appropriate. If eccentric training is submaximal the barbell load has been recommended to be 50 – 65% concentric 1RM with a releaser load of 10 - 25% (15 – 20 repetitions, 15 – 30 seconds between repetitions) [33]. One potential drawback of this type of training may be the use of weight releasers as there use it is suggested by the author is labour intensive and requires spotters to reattach the additional load each time a repetition is complete. This type of training also requires a degree of skill on behalf of the lifter to ensure the bar path is smooth and the additional load is released simultaneously on both sides. The use of only single repetitions rather than a series of repetitions may potentially make this a time consuming training modality, especially in a team sport environment.

Studies have also utilised accentuated or supramaximal eccentric loads to train the elbow flexors and extensors. In Brandenburg and Docherty [5] study participants performed preacher curls to eccentrically train the elbow flexors and supine elbow extension to train the elbow extensors. The participants in the eccentric training group trained for nine weeks at 120% of their concentric one repetition max (1RM). After nine weeks the eccentric training group was reported to have greater increases in concentric strength (24 vs. 15%) of the elbow flexors than the concentric group in the elbow extensors. This led the authors to conclude that eccentric overload training may be more effective in improving strength than traditional resistance training alone. In a similar study Vikne et al. [55] reported that an eccentric training group had significant increases in concentric strength (14%), which were very closely matched to the concentric training groups concentric strength results. However, eccentric training resulted in a greater increase in eccentric strength (26%) accompanied by increases in cross sectional area (CSA) of the elbow flexors and type I and type IIa fibres (11%).

Studies have utilised commercially available flywheel devices (YoYo[tm] Technology Inc, Stockholm, Sweden) to induce eccentric overload [8, 79, 80]. When using these flywheel devices the participant completes the concentric phase of the exercise the strap that is attached to the flywheel unwinds and force and energy is transferred to the flywheel [8]. Once the concentric phase of the exercise is completed the strap rewinds and it is during this stage that participants resist the action of the strap being pulled in by the flywheel and thus complete the eccentric action [8]. In Norrbrand et al. [8] initial study participants performed five weeks of unilateral knee extension (two – three times per week). Upon completion of training maximum, voluntary contraction (MVC) was significantly increased in the flywheel-training group compared to the weight stack device-training group. A twofold greater increase in hypertrophy was reported in the eccentric flywheel group in comparison to the weight stack group. A potential explanation for the increase in hypertrophy was reported in Norrbrand et al. [80] study where it was proposed that flywheel training led to greater muscular activation due to increased eccentric loading which in turn resulted in superior protein synthesis and as a consequence a greater hypertrophic response. In a further study, participants completed six weeks of supine squat flywheel training with similar improvements in strength, power and muscle hypertrophy between men and women [79]. As a result of these studies, it is suggested that flywheel training may be an appropriate method to induce eccentric overload. However, it should be noted that due to the nature of the devices monitoring and thus programming might prove difficult.

The findings of these studies into the effects of additional eccentric load on increases in strength and power have been attributed to several possibilities [33]. The first of these is the suggestion that the increase in eccentric loading promotes greater numbers of motor units to be recruited [10, 33] secondly, the elastic properties of muscle allow for a more forceful concentric contraction after the stretch associated with the eccentric contraction [10, 54]. Another potential explanation is that during eccentric loading the agonist muscle can achieve an active state and force as a result of some cross bridges being attached prior the subsequent concentric portion of an exercise [54, 81]. Finally, it is suggested that the eccentric loading allows for greater agonist activation and a reduction in antagonist activation results in greater force production [5, 16]. Although the exact mechanisms that result in the AEL leading to performance improvements are not yet clear, the methods discussed previously may be of interest to S&C coaches and athlete alike.

2.2.4 Eccentric Training and Injuries

In addition to eccentric training having the ability to increase strength and hypertrophy several studies have reported that the use of eccentric training can; reduce instances of hamstring injuries [13, 83-87], strengthen the ankle during rehabilitation to a greater extent than concentric training [88], result in reduced knee pain [89], aid recovery from achilles tendinosis [90] and improve strength in the rotator cuff reducing the chances of injury [91, 92]. Of particular interest to anS&C coach or athlete may be the findings in relation to hamstring injuries as these are common in a range of sports and also have a high risk or reoccurring [84]. It is reported that athletes whose peak tension occurs at shorter lengths are more likely to suffer from muscular strains, which will result in absence both training or matches [50]. In a study investigating hamstring strains Brockett et al. [14] reported that optimum length of peak tension was an indicator of hamstring injury risk with shorter lengths more likely to result in injury. Therefore it has been suggested that shifting the optimum length to longer lengths is desirable if the aim is to reduce injury [13, 14, 50]. In a study investigating hamstring eccentric exercise Brockett et al. [13] reported that hamstring lowers (Nordics) (Figure 2-1) resulted in a shift in the optimum angle for torque generation to longer lengths (7.7° ± 2.1°**)** with this suggested to result in protection against subsequent strains.

Figure 2-1. Nordic hamstring exercise

A further study by Potier et al. [93] reported eight weeks of eccentric hamstring training resulted in increased; hamstring muscle strength and increased fascicle length. It is this increase in fascicle length that confers a protective effect and has been reported to be the result of eccentric exercise leading to the addition of sarcomeres in series that reduce strain during further eccentric contractions [41, 94]. Thus these finding in conjunction with other studies which have reported eccentric training of the hamstrings results in a reduction in hamstring injuries [83, 85-87] appear to make eccentric training an interesting proposition for S&C coaches who either wish to prevent injury or aid return to sport after injury. When programming the Nordic hamstring exercise it is suggested that in preseason athletes should initially complete two sets of five repetitions once a week progressing to three sets of 12, 10 and 8 repetitions three times a week in weeks 5 – 10 [95]. In season it is suggested that athletes should complete one – two sessions per week of three sets (12,10,8 repetitions) [95].

2.2.5 Drop Jumps

A further method, which has been suggested to overload the eccentric portion of a muscle action, is the use of a DJ. A DJ is a widely utilised plyometric training method [96, 97] and involves an athlete stepping off of a box and then upon making contact with the ground immediately performing an explosive CMJ [98]. This exercise has been suggested as a method that results in improved utilisation of the SSC [20, 26, 98, 99]. Therefore improving the ability of an athlete to utilise the SSC may be beneficial, indeed previously studies have reported that DJ training results in; improvements in sprint performance [25, 26, 100], improvements in jumping performance [19, 29-31, 101], strength [25, 28] and agility [100]. As a result of the findings of these studies, it appears that DJ may represent a useful exercise for a wide range of athletes across a host of sports.

When programming the DJ it has been suggested that S&C coaches use drop height as a determinate of intensity [20]. As drop height increases, it is reported that ground reaction force also increases upon impact thus resulting in an increase in intensity [102-104]. It is widely accepted that initially as drop height increases so does jump height performance, however, there comes a point where an increase in DJ will lead to a decrease in performance [97, 105, 106]. The initial increase in performance as drop height increases has been reported to be due to a number of factors including; increased neural activation resulting in greater motor unit activity and reuse of stored elastic energy as result of the initial eccentric muscle action [10, 97, 99, 104, 105, 107, 108]. Due to the findings on the effect of drop height when utilising DJ training, programmes need to be individualised due to athletes having differing neuromuscular capacities [107]. Thus if drop height is too low for an athlete, it may not sufficiently overload the athlete or if drop height is too high the athlete may not adequately be able to control the eccentric and transition phases [107]. Several methods have been proposed as measures of optimal DJ performance with two suggested as being the most popular. The first termed the maximal jump height (MJH) method involves looking at the jump height achieved upon completion of DJs from a range of different heights to assess which one results in the best jump height irrespective of ground contact time [107, 109]. Utilising this method the plyometric box height that corresponds to the greatest MJH for each athlete would then be the height that the athlete drops from when completing DJ during a training session. The other most popular method to determine optimal drop height involves taking jump height and dividing it by ground contact with this termed the reactive strength index (RSI) [99, 107, 109]. Using these method athletes complete DJs from a variety of increasing heights. When the RSI is maintained or shows an improvement with increased drop height and ground contact time is considered to result in a fast SSC (see below) it is suggested that athlete can attempt a greater drop height [99]. However, there will come a point, where the drop height becomes too great, and at this point, there will be a reduction in the RSI or the ground contact time will indicate that it is no longer a fast SSC action [99]. Thus using RSI the S&C coach will be able to establish the best individual drop heights for each athlete. Typically this may require the use of a contact mat or force platform however it is suggested that if these are not available simply observing the athletes landing may be sufficient [99]. Using this method an S&C coach should look at the landing as longer ground contact times are reported to result in the heels hitting the ground [99].

Another factor which an athlete or S&C coach may wish to consider is ground contact time as this has a bearing on the classification of the SSC action [99]. Previously it has been suggested that a ground contact time of <0.25 seconds would represent a fast SSC whilst anything over this threshold would be considered a slow SSC [110]. Thus athletes who wish to concentrate on simply improving jump height are suggested to benefit from longer contact times [99]. Whilst athletes such as sprinters whose contact times during running can be as little as 80-95 milliseconds and whose goal it is to improve speed whilst relying on fast SSC utilisation would benefit from shorter contact times [26]. Another consideration may be the knee angle of landing with the suggestion that different sports may require different angles at impact [33]. In a study by McNitt-Gray[102] it was reported that gymnasts and recreational athletes had different strategies at the hip, ankle and knee when landing following a DJ whilst Moore and Schilling[33] suggested that an American football lineman would require a smaller knee flexion angle upon impact than a volleyball player due to the demands of the sport. In summary the drop height, ground contact time and control strategies upon landing should be taken into account when considering prescribing DJs to an athlete.

As previously mentioned DJ intensity is usually dictated by drop height, however, it is also possible to manipulate the mass of an individual to alter DJ intensity [20, 103]. However, the increase in body mass through the addition of a weighted vest during DJ has been reported to result in no significant improvements in performance [103]. During this study, however, body mass remained constant for both the eccentric and concentric portion of the exercise. An alternative to this constant additional load approach is the suggestion that dumbbells or elastic bands provide additional load during the eccentric phase of a DJ [33]. Thus as an athlete reaches the bottom position of the CMJ following the drop phase of the exercise they either release the dumbbells or the elastic bands are released allowing them to perform the concentric portion of the exercise without any additional load [33]. At present, only one study has investigated the use of accentuated eccentric loading (AEL) during a DJ. In this study, AEL was applied through the eccentric phase by using an elastic device which increased the downward force by 20% or 30% of body mass [34]. The results of this study, indicated that additional eccentric load enhanced eccentric impulse ($p = 0.042$), rate of force development ($p < 0.001$) and resulted in small to moderate ES increases in iEMG across the eccentric phase (ES = 0.23 - 0.51) however, there was no associated increase in jump height or concentric muscle activation reported [34]. These findings led Aboodarda et al. [34] to suggest that the additional eccentric loading could be used as a method to increase DJ intensity without the need to increase drop height. It should be noted however that in the same manner as the weight releasers the use of the elastic bands in the Aboodarda et al. [34] study is currently labour intensive as it requires additional spotters. This method is also reliant on the spotter releasing the bands simultaneously, so there is a margin for human error. Based on these findings it is suggested more research is required on the using of AEL during the DJ exercise.

In terms of frequency and volume of DJ training it has been previously reported that moderate training frequency and volume of jumps (two days a week, 840 jumps over seven weeks) produced similar enhancements in jumping performance but greater efficiency compared with high frequency and volume DJ (fourdays per week, 1680 jumps over seven weeks) [25]. The results of this study also supported the notion that DJ training can significantly increase sprint performance and maximal strength in moderately trained athletes [25] Another consideration when programming DJ training for athletes is the influence of rest intervals on performance [108]. In a study which investigated this participants completed three sets of 10 DJ with rest intervals of 15, 30 and 60 seconds, the results demonstrated that a 15 second rest period was sufficient for recovery during the performance of DJ [108]. In summary, it is suggested that three sets of eight to ten jumps, two times per week, for seven to eight weeks with rest periods of 15 seconds between jumps and three minutes between sets may produce optimal results.

2.4 Exercise-Induced Muscle Damage

Despite the positive adaptations associated with eccentric training, the possible negative effect of this type of training is exercised induced muscle damage (EIMD). EIMD is reported to occur as a result of eccentric training being both high in intensity and an activity which athletes are unaccustomed to [111, 112]. EIMD as a result of eccentric training has been reported to result in acute reductions in muscular strength and power [36], decreases in the range of motion, delayed onset muscle soreness (DOMS) and swelling and the leakage of blood proteins including creatine kinase (CK) into the blood [113]. Some mechanisms have been proposed as being responsible for declines in performance following eccentric exercise, and these include the popping sarcomere theory [41], failure of the excitation coupling (E-C) process [42], DOMS [43] and increased membrane permeability [44].

2.4.1 The Repeated Bout Effect

Although eccentric exercise has been shown to result in EIMD, its effects may be reduced after a bout of similar exercise with this phenomenon termed the repeated bout effect (RBE) [2, 114, 115]. This RBE has been reported to result in; a reduction in ROM deficits, faster recovery of muscular strength and power, reduced swelling and

DOMS and smaller increases in blood protein markers [114]. As yet the mechanisms responsible for the RBE are unclear but are suggested to be neural [115, 116], mechanical [117] or cellular in nature [118]. Research has found that a preconditioning bout of maximal [119-121] and submaximal eccentric exercise [122, 123] as well as isometric contractions at long lengths [124, 125] can confer a protective effect against EIMD. These effects have been reported to last as long as six months after an initial bout of maximal eccentric exercise [121] or as little as three weeks after submaximal eccentric exercise [124]. Thus despite the fears of some about the effect of EIMD after a bout of eccentric exercise, it is suggested that proper planning can alleviate the effects of EIMD and indeed provide a protective effect against further eccentric induced damage.

2.5 CONCLUSIONS AND PRACTICAL APPLICATIONS

In conclusion, it would appear that training eccentrically may be beneficial to a wide ranging population including; athletes who wish to improve performance, recover from injury, patients suffering from cardiovascular disease and the general public. The results of studies, which have investigated eccentric training, suggest that it results in; improvements in strength, power and hypertrophy, a reduction in injury risk, improved rehabilitation from injury and additionally has general health benefits. Based on the finding of studies investigating eccentric cycling it is suggested that training for six weeks, three to five times per week, at an intensity of between 55%-65% heart rate max or 20-55% power max will result in improvements in strength and hypertrophy.

When utilising isokinetic, eccentric training results have shown that this can lead to greater improvements in eccentric strength and overall strength. It has also been reported that faster contraction speeds result in greater adaptations with less EIMD suffered by participants. Thus the inclusion of six to ten weeks of isokinetic training at

180° s^{-1}, three times per week and with 24 – 30 maximal contractions per session may result in improved hypertrophy and eccentric strength.

Despite the findings on the effectiveness of isokinetic eccentric training, it has been reported that isotonic eccentric training is a more effective eccentric training method. Thus the use of accentuated or supramaximal (greater than concentric 1RM) loads during the eccentric phase of an isotonic movement may enhance the subsequent performance of the concentric phase of a movement. When using weight releasers it has been suggested that when training maximally a barbell load of 75% - 85% concentric 1RM with a releaser load of 40 – 55% (five – ten repetitions, 45 – 90 seconds between reps) may be appropriate. If eccentric training is submaximal, the barbell load has been recommended to be 50 – 65% concentric 1RM with a releaser load of 10 - 25% (15 – 20 repetitions, 15 – 30 seconds between repetitions).

When using DJs to provide an eccentric overload, it is suggested if the goal is to increase jump height athletes would benefit from longer contact times (>250ms) [99]. Whereassprinters who rely on fast SSC utilisation should try to limit ground contact time[26]. Based on these findings and as a consequence of athletes having differing neuromuscular capabilities there is a need for optimal drop height to be assessed prior to starting DJ training and subsequently individualised. This can be assessed using either the MJH or RSI method. The use of three sets of eight to ten jumps (15 seconds between jumps and three minutes between sets), two times per week, for seven to eight weeks is suggested to produce optimal results.

Finally, eccentric training has been shown to be a useful tool in both the prevention of injury and rehabilitation[13]. Of particular interest is the idea that the inclusion of exercises such as hamstring lowers (Nordics) can result in a shift in optimum length and therefore a reduction in the risk of hamstring injuries. Thus it is suggested that the exercises be included in preseason training when athletes should initially complete two sets of five repetitions once a week progressing to three sets of 12, 10 and 8 repetitions three times a week in weeks five – ten. Whilst once the season has started it is suggested that athletes should complete one – two sessions per week of three sets (12,10,8 repetitions) In summary eccentric training has been shown to be beneficial in numerous studies and therefore it is suggested may warrant inclusion in a periodised training plan.

Chapter 3

Eccentric Exercise, Exercise-Induced Muscle Damage and the Repeated Bout Effect: A Brief Review

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3.0 LEAD SUMMARY

As identified in the previous chapter eccentric training can improve strength and power as well as being a stimulus for hypertrophy gains. However, a possible negative side effect is EIMD, which can have a detrimental effect on performance. The symptoms and causes of EIMD and the ability of the repeated bout effect to protect against muscle damage are discussed in this review. A search of the literature was conducted for; eccentric; training; methods; exercise-induced muscle damage; repeated bout effect. After this search, 82 papers were selected to form the basis of this review. The findings of this review suggest if isometric contractions are used as a preconditioning exercise these should be completed at long muscle lengths with ten isometric contractions reported to result in the greatest protective effect. Results of previous studies indicate that 30 repetitions of eccentric contractions at 10 - 40% maximal isometric strength (low intensity and volume) and ~4 seconds in duration have resulted in a RBE with little initial damage. Studies that have investigated low volume maximal eccentric contractions (6 – 24 reps, ~ four seconds in duration) have reported increased initial EIMD followed by a protective effect against further damage. When utilising maximal eccentric contractions, the protective effect is reported to last up to six months in comparison to a low intensity bout that may only offer protection for three weeks. In summary, athletes should initially complete low intensity low volume eccentric training. Athletes should then progress to low load maximal or supramaximal eccentric training before completing higher volume sessions to allow the repeated bout effect to offer protection against muscle damage.

3.1 INTRODUCTION

Resistance training has previously been reported to lead to improvements in both strength and power resulting in improved athletic performance [112, 126, 127]. When developing a programme to improve strength and power applying the principle of overload should be a key consideration as without this stimulus an athlete's potential to make improvements is greatly reduced. It has been reported that the eccentric portion of exercises may not be optimally loaded even if an athlete is working to their maximum concentrically [5, 50, 55]. Previous research has consistently demonstrated that subjects are stronger eccentrically that concentrically [56], thus it is suggested that the principle of overload is not always applied to the eccentric portion of movements.

The potential benefits of eccentric training are well documented and include; improvements in total strength, concentric and eccentric strength [3-6, 128], increases in hypertrophy [7, 8, 82], improvements in jumping power [10, 11] and a reduced risk of injury [13, 14]. However exercising eccentrically also has the potential to result in exercise-induced muscle damage (EIMD), as a result of athletes completing exercise which they are not accustomed to, which is high in intensity or long in duration [111, 112] and therefore may result in an acute reduction in performance. This brief review aims to outline the symptoms and causes of EIMD and explain how a bout of preconditioning eccentric exercise can provide a protective effect against subsequent eccentric training.

3.2METHOD

A search of the literature was conducted for eccentric exercise, EIMD and the repeated bout effect. Databases PubMed, CINAHL, Web of Science and SPORTDiscus to August 2014 were searched for terms linked with Boolean operators (“AND”, “OR”): eccentric; training; methods; exercise-induced muscle damage; repeated bout effect. Papers were selected based on the title, then abstract, then text. Only papers, which specifically addressed the effect of eccentric EIMD in humans and the repeated bout effect, were included in this review. Once these criteria had been applied 82 papers were selected to form the basis of this review.

3.3DISCUSSION

3.3.1 Exercise-Induced Muscle Damage

The symptoms of EIMD include; decreased muscular strength and power [36], delayed onset muscle soreness (DOMS), decreased range of motion (ROM) and the leakage of substances such as creatine kinase (CK) into the blood [113]. Acute strength loss after unaccustomed eccentric exercise has been reported to be as high as 50-65% [2, 114]. This loss of strength is reported to last 12-72 hours before returning to normal within 5-7 days [114, 129]. One theory proposed by Morgan [41] to explain this strength loss is the “popping” sarcomere theory. This theory suggests that muscle damage is the result of sarcomeres lengthening in a non-uniform fashion when the muscle is stretched beyond its optimal length. When this happens, the longest sarcomeres will be the weakest and thus stretched more rapidly becoming even weaker still. Because the weakest sarcomeres are spread out across the myofibril, this non-uniform lengthening is suggested to result in shearing of myofibrils and lead to damage of the t-tubules. The consequence of this is that there is a disruption in calcium ion homoeostasis and thus damage as a result of tearing of membranes or opening of stretch activated channels [44, 130]. Although this initial strength loss may not be desirable, some degree of EIMD may be necessary due to the suggestion that “popping” of the sarcomeres leads to the addition of sarcomeres in series [130]. This is reported to result in less EIMD after future bouts of eccentric exercise [130] and a reduced risk of injury in particular to the hamstring due to an increase in optimal muscle length [50].

Another potential mechanism for EIMD is the failure of the excitation coupling (E-C) process. It has been suggested that calcium release is impaired following myofibrillar damage and this results in loss of force [131]. Indeed Warren et al. [132] suggested that impairment in E-C coupling was estimated to result in a 50-75% strength loss in the first five days following an eccentric exercise bout. Although currently there is no consensus as to whether sarcomere damage or E-C coupling is the main cause of strength loss following eccentric exercise, both are likely to be responsible [44]. This was acknowledged by Morgan and Proske [130] who suggested non-uniform sarcomere lengthening leads to greater force being applied to the t-tubules which in turn results in greater disruption of the E-C process.

A further consequence of eccentric exercise is DOMS. In a review of DOMS Cheung et al. [43] suggested a model to explain the mechanisms of DOMS based on previous theories [133-135]. In summary, this model suggests that the high forces that are achieved with eccentric exercise initially result in damage to the muscle tissue and in particular the z-lines as well as damage being sustained by connective tissue. These initial events are then quickly followed by an inflammatory response. It is this environment, which is suggested to result in type III and type IV nerve endings becoming sensitised which produces the feeling of DOMS.

Unaccustomed eccentric exercise is also reported to result in increased muscle membrane permeability and as a consequence increases in muscle-specific proteins in the circulation. These include; CK, myoglobin, troponin and myosin heavy chain with CK suggested to be the most commonly measured [44]. The mechanisms associated with this increase in membrane permeability are currently unclear however it has been suggested that these changes may be linked to mechanical-induced membrane damage [136] or as a result of the activation of stretch-activated Na^{+} and Ca^{2+} channels [137].

It has been suggested in a review by Schoenfeld [138] that a degree EIMD may be necessary to increase skeletal muscle hypertrophy. In this review Schoenfeld [138] suggests increases in hypertrophy associated with EIMD may be due to increases in satellite cell activity, an increased inflammatory response, increases in insulin-like growth factor-1 signalling and an increase in intracellular water content. Although this would seem a promising proposition for eccentric exercise given that it results in the most EIMD and also greater skeletal muscle hypertrophy than other forms of training [7, 9] the evidence to support this causal relationship is equivocal at best. Furthermore, it has been suggested that muscular hypertrophy can be achieved in the absence of EIMD and the negative consequences associated with it [139]. At present, the optimal amount of muscle damage required to induce a hypertrophic response is not clear [138]. What is clear from the research, however, is that severe EIMD results in acute reductions in strength and power [36]. As a consequence of this in the short term, an athlete may have to reduce the intensity and volume of their training, which would result in a decreased training efficiency. Therefore if the aim of a particular block of training is to increase hypertrophy by utilising eccentric overload it is suggested that moderate rather than severe EIMD may provide the optimal stimulus [138].

3.3.2 Repeated Bout Effect

Although training eccentrically has been shown to be beneficial, athletes and coaches may be concerned with the negative effects associated with severe bouts of EIMD. It is possible that the effects of EIMD may be reduced after a bout of similar previous exercise with this termed the repeated bout effect (RBE) [2, 114, 131, 140, 141]. Utilised and planned for correctly the RBE is suggested to result in; a faster recovery of muscular function, a reduction in range of movement deficits, reduced swelling and soreness and smaller increases in muscle blood protein markers of EIMD such as CK [7, 114] and has been reported to last as long as six months [142]. Some protocols have been used to investigate the RBE these include submaximal and maximal eccentric isokinetic contractions of the elbow flexors [119, 123] and knee extensors [143, 144], DJs[45], downhill running [145] and maximal voluntary isometric contractions at long muscle lengths [146].

The exact mechanisms which allow the RBE to occur are as yet not fully understood although a number of theories have been proposed [118]. One such theory is neural theory, which suggests; increased motor unit activity, increased slow twitch muscle fibre recruitment and increased motor unit synchronisation are responsible for the RBE [116, 131, 147]. Evidence for neural adaptations is suggested to come from studies where decreased electromyographic (EMG) median frequency was found in the repeated bout which has been attributed to an increased recruitment of slow twitch motor units with a decrease in fast twitch motor unit recruitment [120, 132, 148] or increased motor unit synchronisation [116]. In contrast to these findings, a study investigating EMG analysis of repeated bouts of eccentric exercise reported that there was no evidence of neural adaptation [115]. Nosaka et al. [149] also reported that electrically stimulated forced lengthening did not support neural adaptation as a reason for the RBE. These authors suggested that the adaptations occur within the muscle itself. Further support for this was provided by Kamandulis et al. [144] who reported voluntary activation was similar between two bouts of eccentric exercise with neural adaptations not playing a significant part in the protective effect. This finding instead was attributed to peripheral adaptations. Thus as yet there is no clear consensus on the neural contribution to the RBE.

Another potential mechanism for the RBE is the cellular theory which proposes that the RBE is the result of; the strengthening of cell membranes, removal of weak fibres and the adding of sarcomeres in series [118]. In studies investigating the extent of eccentric muscle damage in humans it has been reported that the length of the eccentric contraction is the critical factor with longer muscle lengths resulting in the most damage [148, 150]. Thus Morgan [41] and Proske and Morgan [94] suggested one possible adaptation to eccentric EIMD which may promote an RBE is the addition of sarcomeres in series which reduces the strain during further eccentric contractions and therefore provide a protective effect. However in studies investigating the effects of carrying out a second eccentric exercise bout a couple of days after the initial bout and before full recovery the results indicate that this does not cause further EIMD or cause the recovery process to slow down [148, 151-153]. This McHugh et al. [131] suggested casts doubt on Morgan [41] theory as sarcomeres would have insufficient time to recover.

Disruption to the E-C process has been suggested to result in strength loss after an initial bout of eccentric exercise [131]. However, it is suggested that this initial bout also results in the strengthening of the sarcoplasmic reticulum preventing further damage to E-C process during a repeated bout [119]. It should be noted, however, that Warren et al. [132] findings about the large degree of strength loss as result of disruption to E-C process were based on electrically stimulated contraction in animal models and as yet there is no direct evidence to support this theory as a mechanism for the RBE [116].

Another reason for the RBE is the suggestion that muscle damage is reduced due to an altered inflammatory response after the initial eccentric bout [154, 155]. This adaptation in the inflammatory response is reported to explain the lack of further damage when the second bout of exercise is completed prior to full recovery [131].However, McHugh [116] points out that this reduction in inflammatory response may be simply the result of less mechanical disruption in the repeated bout and thus less of a stimulus.

Other suggestions as to what is responsible for the RBE focus on mechanical aspects and include increases in passive and dynamic muscle stiffness [154], adaptations being made to the cytoskeletal proteins desmin and titin to strengthen the structure of the sarcomere [117] and an increase in intramuscular connective tissue strength which protects against further damage [156].

As detailed above, the evidence for the mechanisms for the RBE is at present equivocal. Ultimately it would appear that one theory is unable to explain the RBE and therefore it is considered likely that each may play its part in conferring a protective effect [116, 131].

3.3.3Maximal Eccentric Contractions

Several studies (Table 3-1) have found evidence that utilising maximal eccentric contractions of the elbow flexors can lead to a RBE. Clarkson and Tremblay [119] found 24 maximal eccentric contractions in untrained participants resulted in a protective effect against 70 maximal contractions performed two weeks later with significant reductions in muscle soreness, pain and strength loss. Further research by Nosaka et al. [121] found that 2, 6 and 24 maximal eccentric contractions (three seconds eccentric action) were able to offer a protective effect against a further 24 maximal eccentric contractions performed two weeks later in untrained participants. Reductions in strength were found to be linked to the number of initial contractions and thus was proposed as evidence that the greater the number of eccentric contractions the greater the EIMD. Therefore this led Nosaka et al. [121] to conclude that a few maximal eccentric contractions may be preferable as they cause less initial muscle damage. In support of this Howatson et al. [120] found that both ten contractions and 45 contractions (three seconds eccentric action) conferred a protective effect against a further maximal eccentric session in participants who were resistance trained but not familiar with eccentrically biased exercise. This resulted in reductions in loss of strength, range of movement and soreness. Thus in agreement with Nosaka et al. [121] this study found low volume maximal eccentric contractions conferred a protective effect against further EIMD. Of particular interest potentially to athletes and coaches may be the findings of Nosaka et al. [142] who found that 24 maximal contractions of the elbow flexors were able to result in a RBE. When completing another bout of 24 maximal eccentric contractions six months and nine months after the initial bout Nosakaetal. [142] found a faster recovery in maximal isometric force.

Table 3-1. Repeated bout effect studies that have used a maximal eccentric conditioning load

Study	Muscle Group	Population	Exercise Modality	Intervention	Results
Brown et al. [143]	Knee extensors	Untrained subjects N = 24 Mean age: 21 years	Isokinetic dynamometer	3 groups performed initial bout of 10, 30 or 50 max ecc contractions of the knee extensors. Followed by 50 max ecc contractions 3 weeks later	Soreness reduced after 2nd session No increase in serum CK after 2nd bout in any group
Chen [148]	Elbow flexors	Untrained subjects N = 26 Mean age: 20 years	Isokinetic dynamometer	30 maximal ecc contractions followed 3 days later by either 70 or 30 max ecc contractions	All markers of EIMD changed following session 1 but no additional EIMD was found after the 2nd bout of either 70 or 30 max ecc contractions
Clarkson et al. [119]	Elbow flexors	Untrained subjects N = 8 Mean age: 24 years	Modified arm curl machine	One arm did 70 maximal eccentric contractions, and the other arm performed 24 maximal contractions, followed two weeks later by 70 maximal contractions	Significant changes in CK, muscle soreness, isometric strength and muscle shortening were found in the group that did the initial 70 max session. The 24 max group showed only minimal changes. Changes in the criterion measures were significantly smaller when the 24 max group performed 70 max contractions two weeks later compared to the group who initially performed 70 max contractions.

Study	Muscle Group	Population	Exercise Modality	Intervention	Results
Howatson et al. [120]	Elbow flexors	Untrained subjects N = 16 Mean age: 27 years	Isokinetic dynamometer	45 or 10 maximal ecc contractions followed 2 weeks later by another 45 max ecc contractions	Greater reductions in MVC, ROM and increased soreness and CK after initial ecc45. After 2^{nd} bout of ecc exercise RBE present. No sig diff between 10 ecc group and 45ecc in markers of EIMD
Nosaka et al. [142]	Elbow Flexors	Untrained subjects N = 35 Mean age: 19 years	Modified elbow flexor exercise	2 bouts of 24 max ecc contractions of elbow flexors separated by either 6, 9 or 12 months	Faster recovery of maximal isometric force after 6 and 9 months. Smaller increases in CIR, CK and T2 relaxation time after 6 months. 12 months did not show RBE
Nosaka et al. [121]	Elbow flexors	Untrained subjects N = 34 Mean age: 20 years	Modified arm curl machine	Initial bout of either 2, 6 or 24 max ecc contractions followed 2 weeks later by 24 max ecc contractions	All groups showed EIMD after initial bout. 6 and 24 max ecc contraction groups showed significantly smaller changes in EIMD in the repeated bout

Ecc – Eccentric
EIMD – Exercise-induced muscle damage
CIR – Circumference
Max – maximum
MVC – Maximal voluntary contraction
ROM – Range of movement

Also after six months but not nine they also reported smaller increases in upper arm circumference, plasma creatine kinase activity and T2 relaxation time. In the other group who repeated the initial bout 12 months later, no RBE was found. This led Nosaka et al. [142] to conclude that the RBE lasts at least six months after maximal eccentric contractions of the elbow flexors but is lost between nine and twelve months.

In summary, if athletes are required to complete maximal eccentric contractions completing low volume maximal eccentric contractions two weeks prior may confer a protective effect against EIMD which may last as long as six months. A practical example of this would be athletes squatting supramaximal eccentric loads (~110 – 130% concentric 1RM) with the aid of weight releasers or spotters only performing five – ten repetitions in the initial training session. This low volume session it is suggested would confer a protective effect against EIMD during further maximal eccentric sessions of increased volume. A further example of this is athletes utilising supramaximal eccentric bench press training to increase strength and hypertrophy. Using this method the athlete would typically lift 110 – 130% of their concentric 1RM for the eccentric phase only before spotters return the bar to the starting position. In the first session, athletes should only complete three – five repetitions to reduce the amount of initial EIMD before increasing the volume in subsequent sessions. This reduced volume in the first session may be particularly important when implementing this training method due to the suggestion that eccentric EIMD is greater in the upper body compared to the lower body [157, 158]. Thus starting with a lower volume would provide a protective effect against severe EIMD during future sessions. This low volume session would reduce the initial amount of eccentric EIMD sustained and therefore allow the athlete to train efficiently in the days that follow.

3.3.4Submaximal Eccentric Contractions

While maximal intensity eccentric contractions have been reported to result in a RBE studies have also found that low intensity eccentric contractions can confer a protective effect (Table 3-2) [122-125]. Lavender and Nosaka [123] reported that in untrained participants eccentric contractions (three – four seconds in duration) of the elbow flexors at 10% maximal isometric strength provided protection (significantly smaller decreases in MVC, ROM and muscle soreness) against a greater intensity eccentric contraction (40% MVIC eccentric) two days later. Also while investigating low intensity 10% maximal isometric strength (MVIC) eccentric contractions of the elbow flexors (three seconds in duration) Chen et al. [124] reported that this initial bout resulted in no EIMD but offered protection against 30 maximal eccentric contractions in untrained participants. However, the RBE effect was found to last two weeks, but three weeks later this protective effect was no longer present.

Another study by Chen et al. [122] with untrained participants found that four bouts of eccentric elbow flexion at 40% MVIC completed every two weeks and four times resulted in the same protective effect (reductions in ROM deficits, isometric concentric strength, and plasma CK) against 30 maximal eccentric contractions as two bouts of maximal eccentric exercise. It was also reported that the initial 40% eccentric bout resulted in much less EIMD than the initial maximal eccentric bout. A further study by Chen et al. [125] investigated the effects of different intensity eccentric and isometric preconditioning exercises on the RBE in untrained participants.

Table 3-2. Repeated bout effect studies which have used a submaximal conditioning load

Study	Muscle Group	Population	Exercise Modality	Intervention	Results
Chen et al. [124]	Elbow flexors	Untrained subjects N = 65 Mean age: 21	Elbow flexor activity with dumbbells	4 repeated bout groups performed 30 10% ecc contractions of elbow flexors either 2, 7, 14 or 21 days before 30 max ecc contractions Control group performed max ecc contractions only	10% ecc did not result in any EIMD Changes in EIMD markers were significantly smaller for 2, 7 and 14 day group than control after 30 max ecc contractions Effect attenuated between 1 and 2 weeks
Chen et al. [122]	Elbow flexors	Untrained subjects N = 30 Mean age: 22 years	Modified preacher curl	40% ECC completed 30 contractions 4 times (bouts separated by two weeks) then 100% ecc bout Control group performed two max ecc bouts separated by two weeks	No sig differences between either the 40% ecc group and 100% ecc group after the 2nd bout. Changes in ROM, iso con strength and plasma CK were reduced after the 2nd to 4th bout in 40% ecc group
Chen et al. [125]	Elbow flexors	Untrained subjects N = 65 Mean age: 20 years	Elbow flexor activity with dumbbells	Five groups; max ecc, 10% ecc, 20% ecc 90 degree ISO and 20 degree ISO. Ecc groups performed 30 DB contractions of elbow flexors at respective loads. ISO groups performed 30 ISO contractions 3 weeks later all performed 30 max ecc contractions	After 2nd bout (30 Max ecc contractions) changes in markers of EIMD (MVIC, con strength, ROM, upper arm circumference, plasma CK and soreness) were smaller for the 20% ecc and 20 degree ISO group. But this effect was smaller than protective effect of initial max ecc group
Lavender et al. [123]	Elbow flexors	Untrained subjects N = 18 Mean age: 21	Elbow flexor activity with dumbbells	Subjects in two groups 10-40% ecc or 40% ecc only 10-40% group completed 6 sets of 5 reps with DB at 10% MVIC followed 2 days later by ecc 40%	Sig smaller decreases in MVC, ROM and muscle soreness in 10-40% group compared to 40% only group

Ecc – Eccentric
EIMD – Exercise-induced muscle damage
CK – Creatine Kinase
CIR – Circumference
MVC – Maximal voluntary contraction
MVIC – Maximal voluntary isometric contraction
ROM – Range of movement

The results of this study showed that 20% MVIC eccentric contractions of the elbow flexors provided a protective effect (reductions in MVIC and concentric strength losses, upper arm circumference, plasma CK and ROM deficits) lasting three weeks but 10% MVIC eccentric contractions did not. These findings led the authors to conclude that an intensity threshold exists for the initial eccentric exercise bout to confer a protective effect.

The results of the studies investigating the ability of reduced intensity and volume eccentric contractions to protect against further damage are promising. In summary, these preconditioning sessions result in less initial EMID and still confer a RBE against future maximal eccentric bouts. However, the intensity threshold for this to occur is yet to be fully elucidated, and in comparison to an initial maximal eccentric bout, the RBE may not last as long. As a consequence of this, it is proposed that athletes who are about to start maximal and supramaximal eccentric training or those who have not done so for a period of time may initially consider utilising sub-maximal loads. The aim of this submaximal training is to familiarise the athlete with the movement patterns and timings required during eccentric focused training while also initiating the RBE. It is then suggested that the athlete would complete low volume maximal/supramaximal eccentric training before increasing to greater working volumes as required. By following this sequence it is suggested an athlete would be able to take advantage of the RBE to protect them from severe EIMD and the negative consequences associated with it.

3.3.5Muscle Length

A study by Pettitt et al. [159] investigated the effects of eccentric exercise on the RBE at both short and long lengths. Initially both the short and long length groups performed 3 x 25 maximal eccentric contractions of the elbow extensors through a range of movement of 0° to 80° (short length) or between 50° to 130° (long length). After one week both groups performed eccentric elbow extensions over the full range of movement (0° to 130°). The results of this study indicated that an initial bout of eccentric exercise at short muscle lengths caused decrements in average extensor torque production and did not result in a RBE whereas exercise at long lengths did. This was reported to be due to exercise at long lengths leading to a change in angle torque due to the addition of serialised sarcomeres. These findings led Pettitt et al. [159] to conclude that exercise at the full range of movement would be beneficial to protective against the effects of eccentric EIMD. Therefore using the previous example of the athlete completing the maximal eccentric squatting session it is suggested that getting them to squat to depth would result in a greater RBE than if they only completed a quarter squat.

3.3.6Contraction Velocity

To assess the impact of velocity of eccentric contractions on the RBE Barroso et al. [160] split participants into two groups; slow contraction velocity ($60°\cdot s^{-1}$) or fast velocity contraction ($180°\cdot s^{-1}$). The participants then completed exercise bouts every two weeks (three sessions in total) consisting of 30 maximal eccentric contractions of the elbow flexors on an isokinetic dynamometer. The results of this study indicated no significant differences in MVIC strength, ROM, muscle soreness or CK activity. However, Barroso et al. [160] reported significantly smaller changes in these markers after the second and third bouts in both groups compared to the first group indicating a

RBE. As a consequence of these results Barroso et al. [160] suggested that contraction velocity does not influence the RBE.

3.3.7 Musculature Investigated

Although the majority of the literature concerning eccentric muscle actions and the RBE focuses on the elbow flexors, there is some evidence that it may apply to other musculature of the body and other eccentric modalities. When performing eccentric maximal eccentric actions of the knee extensors Brown et al. [143] reported that 10, 30 and 50 contractions resulted in reduced force loss after 50 eccentric contractions performed three weeks later. Kamandulis et al. [144] had participants perform ten sets of 12 maximal voluntary contractions of the knee extensors then after two weeks they performed the same exercise bout. After the 2nd bout, EIMD was reduced and thus the initial session was reported to result in a protective effect. In a further study investigating the effect of stride length on the RBE, Rowlands et al. [145] found that a group who ran downhill utilising an understride, overstride and preferred running pattern were able to reduce strength loss during a 2nd downhill running bout. Whilethe overstride and preferred running stride group perceived less muscle soreness than in bout one. Thus it was suggested that a previous bout of downhill running might offer a protective effect against subsequent downhill eccentric contractions.

3.3.8Plyometrics

When investigating the effects of EIMD and the RBE utilising DJs Miyama and Nosaka [46] reported that performing five sets of 20 DJ from 0.6m provided a protective effect when completing the same DJ protocol eight weeks later. Miyama and Nosaka [46] found that after the second session there were significantly smaller changes in; maximal isometric force, muscle soreness, plasma CK activity and vertical jump height. In a further study utilising DJ Miyama and Nosaka [45] reported that 50 DJ resulted in a larger reduction in loss of muscular function, increased muscle soreness and increases in plasma CK activity than ten DJ. However, when these sessions were repeated 2 weeks later it was found that the ten DJ provided a similar level of protection as the 50 DJ. This supports previous research, which has found a small number of eccentric contractions can result in a protective effect. This led Miyama and Nosaka [45] to conclude that a when starting training with DJ a low number should be used initially as this will prevent severe muscle damage and result in a protective effect. Thus for athletes who are new to plyometric training, it is proposed that the initial sessions are low in volume as this may result in a protective effect against future high volume sessions.

3.3.9Isometrics

Another potential mechanism for protection against the effects of EIMD as a result of eccentric contractions is the use of isometric contractions as preconditioning exercises [125, 146]. In Chen et al. [146] initial study participants performed either 2 or 10 maximal voluntary isometric contractions (MVC-ISO) of the elbow flexors at long muscle length (20° flexion) with no evidence of EIMD post MVC-ISO. Two days later participants completed 30 maximal eccentric isokinetic contractions, with both two and ten MVC-ISO providing protection against EIMD. The ten MVC-ISO was found to have the greater protective effect than the two MVC-ISO conditions. In a follow up study Chen et al. [125] also found 30 MVC-ISO of the elbow flexors at long muscle lengths (20° flexion) provided a protective effect three weeks later against 30 maximal eccentric contractions. These results led to the suggestion that ISO-MVC at long muscle lengths should be included as preconditioning exercises when introducing athletes to eccentric training to minimise the effect of EIMD.

3.3.10Set Configuration

To investigate the effects of the configuration of eccentric training sets and reps Chan et al. [161] carried out a study in which participants initially completed either 3 x 10 or 10 x 3 maximal eccentric contractions of the elbow flexors. Four weeks later the same participants completed 20 x 3 maximal eccentric contractions to assess changes in EIMD from the initial session. The results of this study provided further evidence of the RBE with significant changes in MVC strength, range of motion, bicep brachii cross-sectional area and muscle soreness from bout one to two. However, there were no differences found between the different set configurations. This led Chan et al. [161] to conclude that the changing of the set configuration has little effect on muscle damage.

3.3.11Repeated Bout and Contralateral Effect

Cross education is a term that refers to an increase in strength in the contralateral (untrained) limb following training of the ipsilateral (trained) limb [10, 141]. This cross education effect has been proposed to be the result of neural adaptations [53] and therefore may support neural theory as a mechanism resulting in the RBE. Several studies have investigated the RBE (Table 3-3). Connolly et al. [162] first investigated whether this phenomenon was able to transfer the protective effect of a prior eccentric training session to the contralateral limb. In this study participants stepped up on a box with one leg (concentric) and then back down using the other leg (eccentric). During the initial trial, EIMD was found in the eccentrically trained leg. After two weeks the leg that was previously used to step up (concentric) now became the step down leg (eccentric). Analysis revealed that there was no difference in strength loss or tenderness between both sessions in the eccentrically trained limb. This led Connolly et al. [162] to conclude that there was no evidence of a crossover effect in this study.

Table 3-3. Results of studies investigating the contralateral effect

Study	**Muscle Group**	**Population**	**Exercise Modality**	**Intervention**	Results
Connolly et al. [162]	Lower Limb	Untrained subjects N = 12 Mean age: 22 years	Stepping on and off of a 46cm box	One leg used to go up (con) and one leg to step down (eccentric) for 20mins. 2 weeks later this was switched	No evidence of contralateral effect found in this study
Howatson et al. [163]	Elbow Flexors	Untrained subjects N = 16 Mean age: 26 years	Eccentric contraction – Isokinetic dynamometer	Contralateral group completed 3 sets of 15 maximal eccentric contractions with one arm then 2 weeks later completed the same exercise with the other arm	Contralateral group showed sig reductions during the repeated bout of MVC, CK and muscle soreness
Starbuck et al. [164]	Elbow Flexors	Untrained subjects N = 15 Mean age: 22 years	Eccentric contraction – Isokinetic dynamometer	60 maximal ecc contractions of ipsilateral arm followed 2 weeks later by 60 maximal ecc contractions of contralateral arm	Contralateral arm had reduced strength loss, muscle soreness and change in resting arm angle

Ecc – Eccentric
Con – Concentric
CK – Creatine Kinase

However, further studies investigating cross education in the elbow flexors have found evidence of cross education with a previous bout of eccentric exercise in the ipsilateral limb providing a protective effect in the contralateral limb [162-164]. The explanation for this cross education effect in the contralateral limb was provided by Starbuck and Eston [164] who found a reduction in median frequency (MF) in the elbow flexors after the initial session in both the ipsilateral and contralateral limb. This it was suggested is a consequence of more slow twitch muscle fibres being recruited initially during a second bout of eccentric exercise with this central adaptation occurring in the untrained limb resulting in a protective effect [164].

Although the evidence for the cross education effect and the reasons for its existence are currently equivocal, the positive findings may be of interest to athletes recovering from injury. If an injured limb has to be immobilised training eccentrically with the uninjured limb may alleviate the effects of EIMD when an athlete returns to training. This, therefore, may result in the athlete being able to complete their rehabilitation programme more efficiently and ultimately return to competition in a timely fashion [50, 163].

3.3.12Trained Athletes

In studies investigating the RBE on trained athletes the results have been less promising [165, 166]. Falvo et al. [166] and Falvo et al. [165] investigated the effects of high intensity and volume eccentric bench press on trained athletes. The subjects in these studies were considered trained if they were able to bench press concentrically at least their body weight, had been completing resistance training for at least six months and took part in at least one session a week targeting the pectorals, deltoids and triceps. In both studies, the results indicated that no RBE was present and it was not able to attenuate any decrements in exercise performance [166]. This was attributed to the fact that any adaptations from RBE were already present in resistance trained individuals [165].

In support of these conclusions Newton et al. [38] and Gibala et al. [167] reported that trained participants suffered less initial EIMD and recovered more quickly from a maximal elbow flexor eccentric bout than untrained participants. It should be noted however that despite the lack of improvement in performance measures Falvo et al. [166] did report a reduction in soreness, fatigue and RPE following an initial bout of eccentric exercise. Thus although no performance measures were improved in trained athletes the potential for a reduction in soreness and tiredness is potentially interesting.

The results of these studies investigating the RBE in trained athletes would appear to indicate that they have developed a resistance to eccentric EIMD as a consequence of their previous training history [167]. However, some degree of muscle damage does still occur even in trained athletes [167]. Thus it is suggested that trained athletes who are about to implement maximal/supramaximal eccentric training would still benefit from an initial low volume, low intensity session before progressing to maximal loads and greater volumes.

3.4CONCLUSIONS AND PRACTICAL APPLICATIONS

In summary, eccentric muscle actions may lead to EIMD, which can result in impaired performance. However, a bout of eccentric or isometric exercise utilised as a preconditioning exercise can confer a protective effect against further EIMD due to the RBE (Table 3-4).

Table 3-4. Recommendations for preconditioning bout to avoid eccentric EIMD

Maximal Bout	Sub Maximal Bout	Isometric Bout
10 - 24 maximal eccentric contractions 3-4 seconds in duration 15 seconds rest between contractions	30 eccentric contractions 3-4 seconds in duration 40% maximal voluntary isometric contraction strength Repeat session every 2 weeks for a total of 8 weeks	Contractions at long muscle lengths 10 maximal isometric contractions lasting 3 seconds each in duration 45 seconds rest between contractions

If isometric contractions are used as a preconditioning exercise these should be completed at long muscle lengths with ten isometric contractions reported to result in the greatest protective effect. Therefore an S&C coach may wish to include long length low volume isometrics as a stand-alone activity or in conjunction with an eccentric preconditioning bout.

When using an eccentric bout as a preconditioning exercise low volume, low intensity exercise can confer a protective effect. Results of previous studies have demonstrated that 30 repetitions of eccentric contractions at 10 - 40% maximal isometric strength and ~4 seconds in duration have resulted in a RBE with little initial damage.

When utilising, low volume maximal eccentric contractions (6 – 24 reps, ~ four seconds in duration) results have shown increased initial EIMD followed by a protective effect against further damage due to eccentric exercise. When utilising maximal eccentric contractions it has been suggested this may lead to a protective effect lasting as long as six months in comparison to a low intensity initial bout which may only confer protection for as little as three weeks.

In conclusion, it would seem prudent if introducing an athlete to eccentric training to start with low intensity low volume loads and gradually increase these beforecompleting any maximal or supramaximal eccentric training to protect against them against EIMD.

Chapter 4

Test-Retest Reliability of a Novel Isokinetic Squat Device with Strength Trained Athletes

Journal of Strength and Conditioning Research

4.0 LEAD SUMMARY

As previously identified in the literature reviews there is a significant difference between concentric and eccentric strength. Therefore, it is necessary to investigate methods that allow for the measurement of both concentric and eccentric strength in isolation. For these to be of practical value the measurements recorded need to be reliable.Therefore the aim of this study was to investigate the test-retest reliability of a novel multi-joint isokinetic squat device. The subjects in this study were ten strength-trained athletes. Each subject completed three maximal testing sessions to assess peak concentric and eccentric force (N) over a three-week period utilising the Exerbotics squat device. Mean differences between eccentric and concentric force across the trials were calculated. Intraclass correlation coefficients (ICC) and coefficients of variation (CV) for the variables of interest were calculated using an Excel reliability spread sheet. Between trials 1-2 an11.0% and 2.3% increase in mean concentric and eccentric force respectively was reported. Between trials 2-3 a 1.4% increase in the mean concentric force production and a 1.4% increase in eccentric force production was reported. The mean concentric peak PF CV and ICC across the three trials was 10% (7.6 – 15.4) and 0.95 (0.87 – 0.98) respectively. While the mean eccentric PF CV and ICC across the trials was 7.2% (5.5 – 11.1) and 0.90 (0.76 – 0.97) respectively. Based on these findings it is suggested that the Exerbotics squat device shows good test-re-test reliability. Therefore practitioners and investigators may consider its use to monitor changes in concentric and eccentric PF.

4.1 INTRODUCTION

Strength and Conditioning (S&C) coaches and investigators are typically required to monitor maximal strength using dynamic exercises where the load remains constant [48]. However, during these maximal dynamic tests, it has previously been reported that an athlete's maximal eccentric strength may not be adequately considered [33]. This is due to athletes being stronger during eccentric muscle actions as they are mechanical in nature whereas the concentric muscle actions typically seen during strength testing are ATP dependent [56, 168]. In addition,maximal eccentric muscle actions have also been reported to result in an acute reduction in strength [2, 114]. Therefore it is suggested it would be useful to be able to test an athlete's maximal eccentric strength in addition to their maximal concentric strength. One method that could be utilised to find a true eccentric 1RM is the use of weight releasers to add additional load during the eccentric phase of the exercises such as the back squat or bench press [33]. However, the use of weight releasers has previously been reported to be problematic as they require several spotters and also require the lifter to ensure the bar path is smooth so the additional load is released simultaneously on both sides [52]. Therefore, this may not be the most appropriate method for assessing maximal eccentric strength.

Another method for testing maximal strength is the use of an isokinetic dynamometer which allows a load to be moved at a constant velocity [64]. However, there are some criticisms of thistesting method. Previously it has been proposed that humans rarely maintain a constant velocity during movements and therefore isokinetic testing does not replicate the speed of movements seen in sporting performance [169]. Thus concerns have been raised about the external and face validity of isokinetic testing [48]. Although generally isokinetic testing is single-joint in nature, the use of multiple-joint isokinetic devices for maximal strength assessments has been proposed[48]. However, for these tests to allow for the tracking of athletic performance between trials they must demonstrate a high level of reliability [47]. One method used to investigate retest reliability is the use of the typical error of measurement (TEM), which has been described as the standard deviation in scores between tests after any shifts in the mean have been taken into account [170]. While, the coefficient of variation (CV) is the typical error expressed as a percentage of the subjects mean scores and is reported to be useful when investigating the reliability between athletic events or performance tests [170]. In addition, as the CV is expressed as a percentage, it has also been suggested that any changes in subjects mean scores between tests should also be reported as percentage changes [170].

In an initial study investigating the reliability of a multiple-joint isokinetic squat device, Wilson, Walshe [171] reported ICCs of 0.89 – 0.96 and CVs of 3.1 – 7.8% which they reported indicated that the device was highly reliable. A further study investigating the test-retest reliability of an isokinetic squat device (eSQ; Exerbotics, LLC, Tulsa, OK, US) was completed by Stock and Luera [48]. This commercially available device utilises a load cell to measure an individual's force output throughout their range of movement when squatting and is capable of producing 634 kgs of force. During both the concentric and eccentric phase of the exercise the load cells records 514 force measurements resulting in 1028 data points per repetition. When utilising this device Stock and Luera [48] reportedintraclass correlation coefficients (ICC) and standard error of measurement (SEM) for concentric peak force (PF) = 0.783 (8.8%) and eccentric PF = 0.696 (10.6%). The authors concluded that this indicated moderate to high reliability for peak concentric and eccentric force. It should be noted, however, that in this study subjects were classified as resistance trained if they had six months previous training experience in the squat exercise and only performed two maximal strength-testing sessions with the Exerbotics squat device. Conducting research with resistance-trained athletes with an extensive training history is important, as S&C coaches often work with these types of athletes. Thus studies that investigate untrained or novice athletes may not be as relevant to the strength and conditioning community. Therefore, the aim of this current study was to assess the test-rest reliability of the Exerbotics squat device using strength-trained athletes with at least two years prior resistance training experience and who could squat at least 1.5 times body weight over three separate trials.

4.2 METHODS

4.2.1 Experimental Approach to the Problem

During this study,subjects attended the laboratory on three separate occasions to assess concentric and eccentric PF utilising an isokinetic squat device (eSQ; Exerbotics, LLC, Tulsa, OK, US). During week one each subject's range of movement (ROM) was established for the subsequent trials. Maximal concentric and eccentric force testing consisted of one repetition at 50% of the subject's perceived maximal effort followed by two maximal efforts. Upon completion of this testing, test-retest reliability was then calculated using ICC's and CV's for the variables of interest (peak concentric and eccentric force).

4.2.2 Subjects

Ten strength trained (powerlifters and weightlifters) men (mean ± SD age = 25.2 ± 4.1 years, height = 180.0 ± 6.6 cm, mass = 85.7 ± 7.5 kg, 1RM squat = 148.9 ± 28.1 kg, 1RM squat relative to BW = 1.76 ± 0.28 and training experience 7.1 ± 2.1 years) participated in this study. All subjects had at least two years strength training experience, regularly squatted and were able to squat at least 1.5 times BW. Before commencing testing, all subjects were fully informed about the procedures, possible risks and purpose of the study. All subjects also provided informed written consent. The Auckland University of Technology Ethics Committee approved this study.

4.2.3 Procedures

This study required the subjects to attend the laboratory for testing on three separate occasions. Initially, upon arrival in the laboratory, the subjects completed a five min cardiovascular warm up (level 10 at 70rpm) on an exercise ergometer (95C Lifecycle, Life Fitness, Hamilton, New Zealand). Following the warm up testing with the squat device (eSQ; Exerbotics, LLC, Tulsa, OK, US)(Figure 4-1) commenced. Prior to maximal strength testing during session one each subjects range of motion (ROM) was established. The ROM was based on the knee joint and was set at 90 degrees flexion at the bottom of the squat and 170 degrees between the thigh and leg at the top position [172].

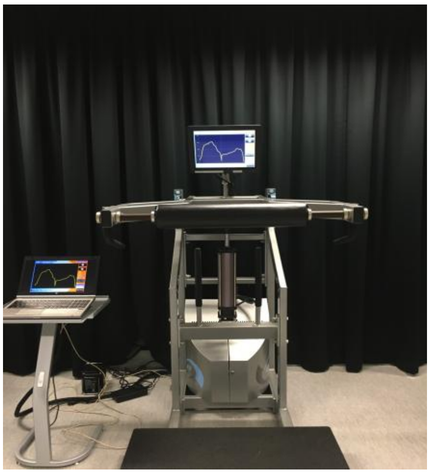

Figure 4-1. Exerbotics squat device

After the establishment of ROM during session one and after the aerobic warm up in the subsequent sessions, subjects completed ten-body weight (BW) squats. During maximal testing, each subject used the handles, had the back pad on the top of their trapezius, feet shoulder width apart and toes turned slightly outwards. Maximal strength testing involved the completion of three continuous repetitions with concentric and eccentric actions lasting four seconds separated by a half second pause. During the first repetition, subjects were instructed to apply force at what they considered to be 50% of their maximum effort. During the next two repetitions, the subjects were instructed to apply maximal force (test speed = 20° s^{-1}). The tester provided verbal encouragement to the subjects throughout encouraging them to resist during the eccentric phase and push during the concentric phase of the squat. The best PF score (Newtons) during the separate concentric and eccentric phases of the squat was used for further analysis. The data collections were separated by a week (subjects were tested at the same time of day ± 1 hour across all three trials), and subjects were advised to avoid any lower body exercise 48 hours before testing.

4.2.4 Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all the dependent variables mentioned previously. The percentage change in mean concentric and eccentric force production was also calculated between trials 1-2 and 2-3. Test-retest reliability was calculated by testing the subjects on three separate occasions over a three-week period. ICCs and CVs for the variables of interest were calculated using an Excel reliability spread sheet found at www.sportsci.org[173].

Previously it has been suggested that an ICC of 1.00 represents a perfect agreement and a small variation in the inter-day variables of interest while, an ICC of less than 0.67 is reported to be representative of a less than perfect agreement and higher variability

[174]. Additionally, Hopkins [175] suggests that the use of ICCs is appropriate for small samples sizes such as in this study and reports that an ICC of greater than 0.9 represents a nearly perfect retest reliability. When examining the CV it has previously been reported that a score of less than 10% is considered small [176]. Combining these two measures (ICC and CV),Bradshaw, Hume [177] suggest variability as small with an ICC > 0.67 and CV < 10%, moderate when ICC < 0.67 or CV > 10% and large when ICC < 0.67 and CV > 10%.

4.3 RESULTS

There was an 11% increase in mean concentric force output and 2.31% increase in mean eccentric output between trials 2-1. Between trials 3-2 a 1.4% and 1.4% increase in the mean concentric and eccentric force production was found (Table 4-1).Based on Bradshaw et al. [177] classifications of variability the overall mean CV and ICC for both concentric and eccentric PF across the three weeks would be considered small (ICC > 0.67 and CV < 10%) (Table4-2).

Table 4-1. Mean (±SD) concentric and eccentric force (Newtons)

	Week 1	Week 2	Week 3
Peak Concentric Force (N)	2339.07 ± 582.29	2601.24 ± 783.73	2635.97 ± 899.41
Peak Eccentric Force (N)	2326.31.31 ± 457.87	2380.21 ± 783.73	2415.46 ± 529.21

When analysed separately the variability of peak concentric force between weeks one and two (trial 2-1) was considered moderate [177] (CV > 10%). However, the concentric PF variation between weeks two and three (trial 3-2) based on Bradshaw et al. [177] classification would be classified as small. When examining the eccentric PF between individual trials (trial 2-1 and trial 3-2) the variance between trials was found to be small [177] (Table 4-2).

Table 4-2. Test-retest CV and ICC (90% confidence interval) for peak concentric and eccentric force

	CV Trial 2-1	ICC Trial 2-1	CV Trial 3-2	ICC Trial 3-2	Mean CV	Mean ICC
Peak Concentric Force	10.4% (7.5 – 17.7)	0.93 (0.81 – 0.98)	9.4% (6.7 – 16.7)	0.96 (0.87 – 0.99)	10% (7.6 – 15.4)	0.95 (0.87 -0.98)
Peak Eccentric Force	6.6% (4.8 – 11.2)	0.90 (0.70 – 0.97)	7.8% (5.5 – 13.7)	0.90 (0.70 – 0.97)	7.2% (5.5 – 11.1)	0.90 (0.76 – 0.97)

4.4DISCUSSION

The aim of this study was to investigate the test-retest reliability of a novel multiple-joint isokinetic squat device for peak concentric and eccentric force over three separate trials. The variance in peak concentric and eccentric force across all three trials based on previous research would be classified as small [177]. This would suggest that there is good test-retest reliability for peak concentric and eccentric force utilising the Exerbotics squat machine and is in agreement with a previous study by Stock and Luera [48]. In particular, the authors suggest that the findings about the retest reliability of eccentric PF are particularly encouraging (CV = 7.2% and ICC = 0.90). However, it is acknowledged that the overall variance in peak concentric force, when measured as a CV (10%) may be considered large. Additionally, the greatest variance as measured by CV was between trials 2-1 for concentric PF (CV = 10.4%). It should be noted, however, that when examining the CV for peak concentric force between trials 3-2 it was reduced to 9.4%.

Previously it has been reported that the low reliability of isokinetic tests may be due to the unnaturalness of the movements and therefore the CVs may be higher in isokinetic testing that other performance tests [47]. In support of this, the subjects in the current study reported that they struggled with the eccentric movements in particular,but felt more comfortable as the testing progressed. This may explain why the subjects produced greater concentric PF in comparison to eccentric PF. This disagrees with previous research that proposes eccentric PF should be greater [2, 3]. Therefore it may be necessary when utilising the Exerbotics squat device to spend more time familiarising subjects prior to any testing to ensure they are able to achieve their potential during the eccentric PF testing.

When using this device to assess peak concentric and eccentric multi-joint lower body force each test excluding the warm-up takes approximately five minutes to complete and requires only one tester to administer it. Thus the use of this device is both time and labour efficient and would allow for large groups of athletes to be tested in a timely fashion. This current study used strength trained athletes with at least two years strength training experience, and who were able to squat at least 1.5 times their body weight, therefore, it is suggested that the results of this study may apply to other strength trained athletes. Therefore it is proposed S&C coaches and investigators could monitor changes in lower body eccentric strength in strength-trained athletes following a period of eccentric training utilising this device.

Due to the finding that eccentric exercise results in exercise-induced muscle damage (EIMD) [111, 112] there may bereductions in force generating capabilities. The extent of EIMD has been classed as mild if there is a reduction inmaximal force of 20% or less with full recovery within 48 hours, moderate if there is a 20 – 50% reduction with full recovery between 48 hours and 7 days and severe if there is a greater than 50% reduction in force which lasts longer than a week [178]. The magnitude of this damage has been proposed to be the result of the prior exercise protocol [178]. Paulsen et al.[178] suggested that resistance training (equal concentric and eccentric loads), and running down stairs does not result in severe muscle damage whereas single joint, maximal eccentric exercise across a large ROM does. The findings of this study suggest that the Exerbotics squat device may be another useful tool to monitor these reductions in strength as a consequence of EIMD and the time course of recovery.

In conclusion, it is suggested that the Exerbotics squat device produced a small degree of variance in-between trials for peak eccentric force production and while the variance is larger for concentric PF this may still be considered acceptable based on previous findings on isokinetic reliability. However, a potential limitation of this current study is the small sample size. Conversely, despite the small subject numbers, this is the first study to have used strength-trained athletes to investigate the test-retest reliability of the Exerbotics squat device. Based on these findings it is suggested that the Exerbotics squat machine is a reliable device for measuring for peak concentric and in particular eccentric force in strength trained athletes. Therefore the Exerbotics squat device could be utilised to monitor changes in PF, which may be of interest to S&C coaches and investigators.

4.5PRACTICAL APPLICATIONS

As a consequence of the findings of this current study, it is suggested that the Exerbotics squat device provides reliable measures of concentric and eccentric PF. In particular, the reliable assessment of peak eccentric force achieved by this device allows for the monitoring of changes in eccentric strength due to resistance training and acute reductions in strength as a consequence of eccentric EIMD. In addition, this device allows eccentric strength to be assessed efficiently (three maximal repetitions (five minute test) in comparison to dynamic maximal eccentric testing protocols which are both time consuming and labour intensive. Before a maximal testing session, athletes should be fully familiarised with the Exerbotics device so that they are accustomed to the unfamiliar movements and can perform maximally.

Chapter 5

Relationships Between Concentric and Eccentric Strength and Countermovement Jump Performance in Resistance Trained Men

Journal of Strength and Conditioning Research

5.0 LEAD SUMMARY

In the previous chapter, the reliability of the Exerbotics squat device was established. Therefore its use in subsequent studies to assess concentric and eccentric strength would appear to be warranted. The purpose of this study was to use the Exerbotics squat device to investigate the relationships between concentric and eccentric PF and CMJ performance in resistance-trained men. Subjects were 12 men (mean ± SD; age: 25.4 ± 3.5 years; height: 177.2 ± 4.5 cm; mass: 84.0 ± 10.1 kg). The subjects were tested for concentric and eccentric PF using the Exerbotics squat device. Subjects then completed three CMJs to allow for the calculation of PP, peak ground reaction force (PGRF) and jump height (JH). Correlations between the variables of interest were calculated using Pearson product moment correlation coefficients. A large relationship was found between absolute concentric PF and absolute CMJ PP (r = 0.66, p< 0.05). Absolute eccentric PF had a very large relationship with absolute CMJ PP and CMJ JH (r = 0.74, p< 0.01 and r = 0.74, p< 0.001 respectively). In addition absolute eccentric PF was found to have a moderate relationship with relative CMJ PP (r = 0.58, p< 0.05). Relative eccentric PF had a very large relationship with relative CMJ PP and CMJ JH (r = 0.73, p < 0.001 and r = 0.79, p < 0.001 respectively). Based on these findings S&C coaches and athletes who wish to enhance CMJ performance may wish to include exercises, which enhance lower body eccentric strength within their training.

5.1 INTRODUCTION

Previous research has found significant relationships between strength and power and jumping performance using a variety of testing methods including isometric tests [179, 180], multijoint dynamic tests [179-182] and isokinetic dynamometry [183]. McGuigan et al. [180] found a very strong relationship between peak force (PF) in an isometric mid thigh pull (IMTP) and vertical jump (VJ) performance (r = 0.72, p < 0.05) and 1RM (one repetition maximum) squat and VJ performance (r = 0.69, p< 0.05) in recreationally trained men. Nuzzo et al. [179] reported significant correlations between relative 1RM squat and power clean (1RM/body mass) and relative countermovement jump (CMJ) peak power (PP), CMJ peak velocity (PV) and CMJ height in male college athletes. However, they reported no significant correlations between the CMJ and measures of absolute strength (1RM squat, power clean, isometric squat PF and isometric mid thigh pull (IMPT) PF) [179]. These findings led Nuzzo et al. [179] to suggest an increase in maximal strength relative to body mass may lead to improvements in explosive lower body movements.

Sheppard et al. [182] found moderate correlations (r = 0.53 – 0.65, p< 0.001) between relative performance in the power clean and squat and CMJ performance in elite volleyball athletes. In an investigation using dynamic testing, Comfort et al. [181] reported that absolute strength in well trained youth soccer players during a predicted maximal squat test showed the strongest correlation with CMJ height (r = 0.76, p< 0.001). When utilising isokinetic dynamometry Augustsson et al. [183] reported moderately strong correlations between isokinetic concentric knee extensions and VJ performance (r = 0.51, p< 0.05). Based on these findings it would appear that an increase in lower body strength would be beneficial to athletes who wish to increase their jumping performance. It should be noted, however, that the majority of these studies have utilised recreationally trained, youth athletes or college athletes[179-181] and therefore it is proposed that more research needs to be completed with resistance-trained subjects. The results obtained with these subjects may not be applicable to resistance-trained athletes with anextensive strength training history. Therefore for research to be of greater value to strength and conditioning (S&C) coaches working with elite athletes, the characteristics of the subjects utilised in studies should more accurately represent the athletes with whom they work.

During dynamic activities such as the CMJ, the utilisation of the stretch shortening cycle (SSC) results in enhanced performance in comparison to a squat jump (SJ) which has no SSC component (~2 – 4 cm in maximum JH) [184]. During the SSC the muscle is initially stretched eccentrically, which results in enhanced force production during the subsequent concentric phase [33, 52, 179, 185, 186]. Previously one of the reasons given for this improved force production is an increase in cross-bridges potentiating the subsequent concentric phase [10, 187]. Because eccentric strength is mechanical in nature and thus a consequence of the number of cross-bridges [1] formed it is proposed that greater lower body eccentric force may also result in greater cross-bridge potentiation and thus enhanced performance in SSC activities such as the CMJ. Despite this suggestion, very few studies have investigated the relationships between eccentric PF in isolation and jumping performance.

Recently an isokinetic device (Exerbotics squat) which utilises a load cell to measure an individual's PF has been used to measure both concentric and eccentric PF [188]. Therefore, the purpose of this investigation was to use the Exerbotics squat device to examine the relationships between concentric and eccentric PF (absolute and relative) and CMJ performance in resistance-trained men. Although it is recognised that correlation does not equal causality, if a significant relationship can be established between lower body eccentric force production and CMJ performance, this may lead to the inclusion of lower body eccentric strength training to enhance jumping ability. It was hypothesised that a large relationship would exist between eccentric force (absolute and relative) and CMJ performance.

5.2 METHODS

5.2.1 Experimental Approach to the Problem

This was a correlational study, to assess the relationship between concentric and eccentric PF as measured by a novel isokinetic squat device and CMJ variables (absolute and relative PP, PF and JH) in resistance-trained men. All testing took place at the same time of day, with CMJ's completed before maximal strength testing utilising the Exerbotics squat device. If a significant relationship was found S&C coaches may wish to consider the inclusion of specific lower body eccentric training to improve subsequent jump performance. The testing took less than one hour for each subject to complete. Before commencing testing, all subjects were fully informed about the procedures, possible risks and purpose of the study. All subjects also provided informed written consent. The Auckland University of Technology Ethics Committee approved this study.

5.2.2 Subjects

Twelve male strength trained athletes (weightlifters, powerlifters, cyclists and rugby players) who could squat at least 1.5 times their body mass and were over 18 years of age (mean ± SD; age: 25.4 ± 3.5 years; height: 177.2 ± 4.5 cm; mass: 84.0 ± 10.1 kg, 1RM squat: body mass = 1.89± 0.27) volunteered to participate in this study. All subjects had at least two years strength training experience and were engaged in regular strength training (3.9 ± 1.2 sessions per week), which included the squat exercise. Before participation all subjects provided written informed consent, consistent with the principles outlined in the Declaration of Helsinki. The Auckland University of Technology Ethics Committee approved this study.

5.2.3 Procedures

Subjects were asked to refrain from training in the 48 hours before any testing session. All subjects visited the laboratory twice over a two-week period. Before the main testing, session subjects attended a familiarisation session where their range of movement was established on the Exerbotics squat machine (eSQ, Exerbotics, LLC, Tulsa, OK)(Figure 1) and completed a maximal strength test. During this session, the subjects initially completed a five-minute cardiovascular warm up on a stationary exercise ergometer (95C Lifecycle, Life Fitness, Hamilton, New Zealand) followed by ten body weight (BW) squats. The range of movement (ROM) on the Exerbotics was then established, this was based on the knee joint being set at 90° degrees flexion at the bottom of the squat and 170° between the thigh and leg at the top position [172].

Once the ROM was established each subject then completed a maximal strength test. During maximal testing, each subject used the handles, had the back pad on the top of their trapezius, feet shoulder width apart and toes turned slightly outwards. Maximal strength testing involved the completion of three continuous repetitions with concentric and eccentric actions lasting four seconds(test speed = $20°.s^{-1}$) separated by a half second pause. During the first repetition, subjects were instructed to apply force at what they considered to be 50% of their maximum effort. During the next two repetitions, the subjects were instructed to apply maximal force. The tester provided verbal encouragement to the subjects throughout, encouraging them to resist during the eccentric phase and push during the concentric phase of the squat. The best PF score (Newtons) during the separate concentric and eccentric phases of the squat was used for further analysis. The reliability of this method of testing in our laboratory is high (concentric PF ICC = 0.95 and eccentric PF ICC = 0.90) [188].

In the testing session, the subjects initially completed a warm up as described. Upon completion of the warm-up subjects completed three maximal CMJ (15 seconds between jumps). During the CMJ subjects squatted to a self-selected depth and were permitted to use their arms.However, they were not permitted to perform a tuck jump. During the CMJs the tester provided verbal encouragement to each subject. The CMJ variables of interest were absolute and relative PP (watts) (CV = 2.0%, ICC = 0.98), PGRF (N) (CV = 7.8%, ICC = 0.71), and CMJ height (cm) (CV = 3.6% ICC = 0.90). All CMJ variables were measured using a force plate (400S, Fitness Technology, South Australia, Australia) sampling at 600Hz and were analysed using the Ballistic Measurement System Software (BMS) (Fitness Technology, South Australia, Australia). After a five-minute rest period peak eccentric and concentric squat force (N) was assessed utilising the Exerbotics squat device as described previously.

5.2.4 Statistical Analysis

During this study, all statistical analysis was completed using the SPSS software (Version 12.0, SPSS Inc, Chicago, IL, USA). Correlations between variables were calculated using a Pearson's product-moment (*r*). The strength of the relationship was considered small (0.1 to 0.3), moderate (0.3 to 0.5), large (0.5 to 0.7), very large (0.7 to 0.9) and nearly perfect (0.9 to 1.0) [175]. Correlations were considered significant and highly significant at values of $p < 0.05$ and $p < 0.001$, respectively. The intrasessionICCs and CVs for the CMJ variables of interest were calculated using an Excel spread sheet found at www.sportsci.org[173]. Previously it has been suggested that an ICC of 1.00 represents a perfect agreement and a small variation while, an ICC of less than 0.67 is reported to be representative of a less than perfect agreement and higher variability [174]. When examining the CV it has previously been reported that a score of less than 10% is considered small [176].

5.3 RESULTS

The means and SDs for the strength and power performance variables of the Exerbotics squat and CMJ are shown in Table 5.1. Pearson's correlation coefficients (Table 5.2) demonstrated a very large relationship between absolute concentric force and absolute eccentric PF (r = 0.74 p< 0.001). A large relationship was found between relative eccentric force and relative eccentric PF (r = 0.68 p< 0.05).

Table 5-1.Performance variables for strength and power measurements in the Exerbotics squat and CMJ

Variable	Value
Exerbotics concentric peak force (N)	2691.21 ± 537.76
Exerbotics eccentric peak force (N)	2487.65 ± 660.60
Exerbotics concentric relative peak force ($N.kg^{-1}$)	32.07 ± 5.69
Exerbotics eccentric relative peak force ($N.kg^{-1}$)	29.57 ± 6.85
CMJ peak power (W)	4516.60 ± 604.72
CMJ relative peak power ($W.kg^{-1}$)	53.68 ± 1.79
CMJ peak force (N)	2192.00 ± 443.48
CMJ relative peak force ($N.kg^{-1}$)	2.65 ± 0.29
CMJ height (cm)	47.21 ± 4.68

Table 5-2.Correlations matrix of strength, power and CMJ jump performance of resistance trained males (90% Confidence intervals)

	ConFAbs	EccFAbs	ConFRel	EccFRel	CMJAbsPP	CMJRelPP	CMJAbsPF	CMJRelPF	CMJH
ConFAbs	1.00								
EccFAbs	0.74** (0.57-0.91)	1.00							
ConFRel	0.77** (0.39-0.96)	0.53 (0.15-0.88)	1.00						
EccFRel	0.59* (0.25-0.90)	0.89** (0.72-0.97)	0.68* (0.46-0.86)	1.00					
CMJAbsPP	0.66* (0.34-0.86)	0.66* (0.46-0.91)	0.14 (-0.45-0.71)	0.40 (-0.11-0.77)	1.00				
CMJRelPP	0.27 (-0.19-0.77)	0.58* (0.27-0.82)	0.48 (0.11-0.74)	0.73** (0.54-0.91)	0.36 (-0.35-0.82)	1.00			
CMJAbsPF	0.59 (0.05-0.77)	0.21 (-0.20-0.72)	-0.29 (-0.57-0.60)	-0.16 (-0.55-0.36)	0.67* (0.20-0.95)	-0.28 (-0.72-0.39)	1.00		
CMJRelPF	0.24 (-0.47-0.62)	-0.12 (-0.56-0.33)	-0.16 (-0.56-0.40)	-0.32 (-0.67-0.02)	0.21 (-0.30-0.74)	-0.29 (-0.69-0.16)	0.82** (0.41-0.93)	1.00	
CMJH	0.41 (-0.39-0.86)	0.74** (0.44-0.89)	0.38 (0.06-0.68)	0.73** (0.54-0.91)	0.62* (-0.37-0.92)	0.93** (0.83-0.98)	-0.12 (-0.60-0.26)	-0.18 (-0.68-0.44)	1.00

ConFAbs = peak concentric force during Exerbotics squat; EccFAbs = peak eccentric force during Exerbotics squat; ConFRel = peak relative concentric force during Exerbotics squat; EccFRel = peak relative eccentric force during Exerbotics squat; CMJAbsPP = peak power during CMJ; CMJRelPP = relative peak power during CMJ; CMJAbsPF = peak ground reaction force during CMJ; CMJRelPF = relative peak ground reaction force during CMJ; CMJH = jump height during CMJ

*Significant at $p \leq 0.05$ and ** Significant at $p \leq 0.001$.

A large relationship was found between absolute concentric PF and absolute CMJ PP ($r = 0.66$, $p < 0.05$). Absolute eccentric PF was found to have a very large relationship with absolute CMJ PP and CMJ JH ($r = 0.74$, $p < 0.01$ and $r = 0.74$, $p < 0.001$ respectively). In addition absolute eccentric PF was found to have a moderate relationship with relative CMJ PP ($r = 0.58$, $p < 0.05$). Relative eccentric PF was found to have a very large relationship with relative CMJ PP and CMJ JH ($r = 0.73$, $p < 0.001$ and $r = 0.79$, $p < 0.001$ respectively). CMJ absolute PP had a large relationship with CMJ absolute PF and CMJ jump height ($r = 0.67$, $p < 0.05$ and $r = 0.62$, $p < 0.05$ respectively). CMJ relative PP had a nearly perfect relationship with CMJ JH ($r = 0.93$, $p < 0.001$).

5.4 DISCUSSION

In agreement with our hypothesis both absolute and relative eccentric PF strongly correlated with CMJ height in resistance-trained men. Large to very large relationships were also reported between absolute and relative eccentric PF and absolute and relative CMJ PP. Previous studies have reported strong relationships between maximal squat strength and CMJ performance [181, 182, 189]. However, to the author's knowledge, this was the first study to separately investigate the relationships between concentric and eccentric PF during the squat exercise and CMJ performance.

When examining the relationships between eccentric PF and CMJ height, relative PF was found to have a stronger relationship than absolute PF ($r = 0.79$ vs. $r = 0.74$). Previously it has been suggested that relative strength is more strongly correlated with CMJ height as a consequence of relative measures taking into account body mass which is accelerated during any jumping action [179]. Therefore, in line with previous research, it is suggested that an increase in eccentric lower body PF whilst maintaining the same body mass or a decrease in body mass with the same PF may result in an improvement in CMJ performance [179]. This, however, should be balanced by the demands of the sport. Whilst it may be desirable for a field athlete such as a long jumper or high jumper to reduce body mass, the same may not be said of a contact sport athlete such as a rugby or American football player. Thus an individualised approach to programming eccentric strength training should be considered.

In the current study absolute concentric PF was only correlated with CMJ absolute PP. This suggests that during the CMJ exercise the ability to produce force eccentrically may be the key determinate of jump performance. This is unsurprising given that the CMJ is an SSC exercise in which the initial eccentric muscle lengthening results in an enhanced force production in the subsequent concentric contraction [190]. Cormie et al. [187] proposed that higher force production during the eccentric phase of the SSC suggests greater active stiffness regulation. This results in a reduced displacement of muscles fibres during the initial stretch allowing them to operate nearer their optimal length and thus produce greater concentric force and enhance JH [187].

Eccentric force production is also reported to be mechanical and dependent on the number of active actin-myosin cross bridges [1, 33]. Previously it has been proposed an increase in active actin-myosin cross bridges results in a greater potential for contractile potentiation during SSC movements [187]. Sheppard et al. [10] reported that five weeks of accentuated eccentric load CMJ training resulted in improved lower body jumping and power characteristics. This improved jumping performance was attributed to a greater number of cross-bridges resulting in greater joint movements at the start of the concentric phase of the jump [10]. During this study, it is proposed the levels of eccentric strength recorded during the Exerbotics squat were the result of subjects being able to maintain cross-bridges throughout the movement. Therefore the ability to produce eccentric force when squatting may indicate that during a CMJ, which is a biomechanically similar exercise, more cross-bridges exist resulting in greater potentiation at the start of the concentric phase and thus improved CMJ performance. As a result increasing lower body eccentric force production may be of interest to S&C coaches and athletes who wish to enhance jump performance.

Eccentric muscle actions have been reported to produce greater PF [2, 3] than concentric muscle actions. Thus although athletes may be working optimally concentrically they may not be overloading the eccentric portion of an exercise [50, 52]. Therefore the inclusion of eccentric focused training exercise may be desirable. Exercises which have previously been suggested to improve lower body eccentric strength include depth jump training [182], eccentric cycling [57], isokinetic training [11, 65, 68] and dynamic, eccentric training [10, 79]. It should be noted however in the current study the subjects hadlower PF readings in the eccentric phase of the squat compared to the concentric phase. This is in contrast to previous studies that have reported that eccentric force production is higher than concentric force production [2, 3]. This may have been the result of subjects not being accustomed to having to produce maximal eccentric force during a squatting pattern. They would however be used to producing maximal force during the concentric phase of a squat as this would occur as part of their regular strength training.

Although eccentric force variables were found to have a stronger relationship with CMJ variables relationships were also found to exist between concentric (absolute and relative) PF and eccentric PF (absolute and relative). This suggests that an increase in concentric strength may still also result in an enhancement in eccentric strength and as a consequence CMJ performance [187]. In conclusion, significant correlations were found between both absolute and relative eccentric force and CMJ height. In particular, relative eccentric PF was found to have a very large relationship with CMJ height.

5.5 PRACTICAL APPLICATIONS

The results of this study indicate that there is a strong relationship between lower body eccentric strength and CMJ performance. Thus the inclusion of lower body eccentric strength training in addition to traditional strength training may lead to an improvement in jump performance. This may be particularly important in sports that would benefit from an increase in jump performance such as basketball, volleyball and track and field. Eccentric training methods that S&C coaches may utilise to enhance lower body eccentric strength include supramaximal eccentric loading during exercises such as the squat (Sets of 1 rep (3 -10 sets), 110 – 130% concentric 1RM, 8 – 10 seconds if load = 110 – 120% and 4 – 6 seconds if load = 120 – 130%) [191], DJs[182] (3 sets of 8 – 12 reps, twice a week) and accentuated eccentric load (40kg males and 20kgs females) CMJ's (sets of 2 x 5 reps, twice a week for five weeks)[10]. For a comprehensive review of different eccentric training methods and modalities refer to the reviews by Bridgeman et al. [52] and Mike et al. [191].

Chapter 6

Relationships Between Concentric and Eccentric Strength, Jumping Performance, Speed and Change of Direction in Resistance Trained Men

6.0 LEAD SUMMARY

In the previous chapter, the relationships between concentric and eccentric PFand CMJ performance were investigated. However, CMJ performance may not be applicable to all athletes so the aim of this current chapterwas to investigate the relationships between concentric and eccentric PF and athletic performance. In addition, the relationships between DJ variables, speed and COD were investigated. Subjects were fifteen male rugby union athletes (mean ± SD; age: 19.7 ± 1.0 years; height: 182.3± 9.8 cm; mass: 92.1 ± 5.9 kg). The subjects in this study completed speed (10, 30 and 40m splits), COD (5-0-5 test), CMJ, SJ, DJ and concentric and eccentric squat PF testing. Correlations between the variables of interest were calculated using Spearman's correlation coefficients. Small and moderate relationships were found between absolute and relative concentric and eccentric PF and CMJ and SJ variables. Concentric absolute PF had a large positive relationship with 10, 30 and 40m sprint times, whilst eccentric absolute PF had a moderate positive relationship with sprint times. Small negative relationships were found between all concentric and eccentric PF measures and COD times. There was a large negative relationship between DJ height and all sprint distances and a very large negative relationship with COD times. RSI had a moderate negative relationship with sprint performance and a large negative relationship with COD performance. The results of this study indicated a relationship between DJ performance, maximal velocity sprinting and COD performance in male rugby union players. It is proposed that if an athlete wishes to enhance sprint and COD performance utilising the DJ they should focus on enhancing their DJ height.

6.1 INTRODUCTION

Previously it has been reported that eccentric muscle actions result in greater force production than concentric muscle actions [56]. It has been proposed that this is due to eccentric muscle actions being mechanical in nature whereas concentric muscle actions are ATP-dependent[52]. There are also neural differences between the two muscle actions[52]. Eccentric muscle actions are reported to result in a reduced muscle activation compared to concentric actions [1], the recruitment of fast twitch muscle fibres before slow twitch muscle fibres [15] and an increased neural drive to agonists coupled with a reduction in antagonist activation [16]. As a consequence of athletes being stronger eccentrically than concentrically traditional strength testing may not adequately assess eccentric strength [78]. Therefore studies thathave utilised concentrically biased strength assessments when exploring relationships with athletic performancemay not adequately take into consideration the unique nature of eccentric muscle actions.

A review by Suchomel et al. [17] reported that strength is strongly correlated with jump performance. However, the majority of the studies in this review utilised concentric focused strength testing to examine the relationship between strength and jump performance. Therefore it appears there is a lack of information currently on the relationship between eccentric strength and jump performance. In a study which investigated the relationships between concentric and eccentric peak force (PF) in an isokinetic squat and countermovement jump (CMJ) performance in strength trained men, Bridgeman et al. [192] reported a large relationship between absolute concentric PF and absolute CMJ peak power (PP). Absolute eccentric PF was reported to have a large relationship with absolute CMJ PP and CMJ height whilst relative eccentric PF was also reported to have a large relationship with the same CMJ variables. This led to the conclusion that improvements in lower body eccentric strength may result in improved vertical jump performance [192]. Based on these findings it is proposed that more research is required on the contribution of eccentric PF to vertical jump performance in a range of athletes and sports.

Previously it has been reported that the majority of evidence supports a moderate to very large relationship between maximal strength and change of direction (COD) times[17]. However, the majority of studies have also focused on concentric strength testing whilst not assessing eccentric strength in isolation. One exception was a study by Spiteri et al. [193] which investigated the relationships between concentric and eccentric strength and COD times during a 5-0-5 test with elite female basketball players. They reported strong relationships between relative eccentric strength and COD times[193]. This led the authors to propose that the ability to tolerate a greater eccentric load may be crucial for a successful COD.

When examining the relationships between squat strength and sprint times, a meta-analysis reported a very large relationship [18]. This suggests that enhanced lower body strength positively transfers to sprinting performance [18]. Suchomel et al. [17] also reported a positive relationship between strength and sprint times. In a study investigating the effects of eccentric training on sprint times, Cook et al. [194] reported that eccentric training alone did not result in an improvement in maximal running performance over 40m despite an increase in overall strength. Therefore at present the relationship between eccentric strength and sprint performance is unclear.

In addition to examining the relationships between maximal force production (concentric and eccentric) at slow speeds or where no change in muscle length occurs it is proposed that investigating the relationship between stretch shortening cycle (SSC) activities and athletic performance is warranted. During SSC actions a muscle is initially lengthened eccentrically which then facilitates increased force production in the subsequent concentric phase [52]. The drop jump (DJ) has been identified as fast stretch shortening SSC exercise (contact time <250 milliseconds) [52]. Previously it has been proposed that the DJ exercise is related to sprint performance when both distance and velocity increase due to a greater fast SSC contribution to locomotion [195]. Barr and Nolte [109] reported a strong negative correlation between DJ height and sprint performance. Thus, the inclusion of the DJ exercise may be warranted if athletes wish to enhance their sprint performance.

At present, the majority of the research has focused on concentric strength testing to investigate the relationship between strength and athletic performance. There is also a limited amount of data available on the relationships between DJ, sprint and COD performance. Therefore the purpose of this study was to investigate the relationships between lower body concentric and eccentric PF and athletic performance and secondly the relationships between DJ variables and athletic performance.

6.2 METHODS

6.2.1 Experimental Approach to the Problem

This study used a cross-sectional design, to assess the relationships between concentric and eccentric PFas measured by a novel isokinetic squat device, jumping performance (CMJ, squat jump (SJ) and DJ), speed (10, 30 and 40m splits) and COD (5-0-5 agility test) in resistance-trained rugby union athletes. Subjects were required to attend the laboratory on three occasions over a two-week period. During the initial session, the subjects were familiarised with the Exerbotics squat device and the DJ exercise. The following week each subject completed the jump and Exerbotic testing and the sprint and COD testing (all testing sessions were separated by a 48 hour rest period). Before commencing testing, all subjects were fully informed about the procedures, possible risks and purpose of the study.

6.2.2 Subjects

Fifteen strength trained male rugby players union who were over 18 years of age (mean ± SD; age: 19.7 ± 1.0 years; height: 182.3 ± 9.8 cm; mass: 92.1 ± 5.9 kg; 1RM squat relative to BW = 1.69 ± 0.17) volunteered to participate in this study. All subjects had at least one year of strength training experience and were engaged in regular strength training (at least three times per week), which included the squat exercise. Before participating all subjects provided written informed consent. The Auckland University of Technology Ethics Committee approved this study.

6.2.3 Procedures

Subjects were asked to refrain from training 48 hours before the initial testing session and also in between all testing sessions. All subjects visited the laboratory three times over a two-week period. Prior to the main testing, session subjects attended a session where they were familiarised with the DJ exercise and the Exerbotic squat testing. During the squat familiarisation subjects, range of movement (ROM) was established on the Exerbotics squat machine (eSQ, Exerbotics, LLC, Tulsa, OK) prior to the completion a maximal strength test. During this session, the subjects initially completed a cardiovascular warm up (skipping) and the ROM on the Exerbotics was established, this was based on the knee joint being set at 90° degrees flexion at the bottom of the squat and 170° between the thigh and leg at the top position [172].

Once the ROM was established each subject then completed a maximal strength test. Prior to testing the subjects completed ten body weight (BW) squats. During maximal testing, each subject used the handles, had the back pad on the top of their trapezius, feet shoulder width apart and toes turned slightly outwards. Maximal strength testing involved the completion of three continuous repetitions with concentric and eccentric actions lasting four seconds separated by a half second pause. During the first repetition, subjects were instructed to apply force at what they considered to be 50% of their maximum effort. During the next two repetitions, the subjects were instructed to apply maximal force. The tester provided verbal encouragement to the subjects throughout, encouraging them to resist during the eccentric phase and push during the concentric phase of the squat. Relative PF was calculated by dividing the absolute PF scores by the subject's body mass ($N.kg^{-1}$). The reliability of this method of testing in our laboratory is high (concentric PF CV = 10% and eccentric PF CV = 7.2%) [188].

Speed and Change of Direction Testing

Prior to testing the subjects completed a thorough twenty-five minute dynamic warm-up on an indoor track. Each subject then completed three maximal 40m sprints (five minutes recovery between trials). SWIFT dual beam Speedlight gates (Speed Light V2 gate, Swift, Wacoi, QLD, Australia) were set up at the start line and at 10 (CV = 5.6%), 30 (CV = 0.7%) and 40m (CV = 0.7%) to capture timing splits. Subjects started 50cm behind the first timing light and adopted a split stance position with their preference of lead leg before being given the command to go. The mean times for the 10, 30 and 40m splits were calculated from the three trials and used in further analysis.

Upon completion of the sprint testing and after a further five minute recovery period, the subjects completed four 5-0-5 runs. During this testing, two timing gates (SWIFT Speedlight) were placed five metres from the turning point. Subjects began their run from a start position 10m from the timing gates (15m from the turning point). The subjects were told to accelerate as quickly as possible towards the COD point and then return as quickly as possible through the timing lights [196]. Subjects completed four trials in a randomised order; two changing directions with a left foot plant and two with a right foot plant. The average times for each leg were calculated, and the fastest COD leg was used for further analysis.

Jump and Strength Assessment

The subjects initially completed the warm up as described previously followed by ten BW squats, five CMJ's and five SJ's. Upon completion of the warm-up and after a three minute rest period subjects then completed three maximal CMJ (15 seconds between jumps). During the CMJ subjects squatted to a self-selected depth and were permitted to use their arms [192] while the tester provided verbal encouragement. After a three minute rest period subjects then completed three SJ's. During the SJ subjects squatted to parallel and held this position before completing the SJ. The variables of interest during these jumps were PP (watts) (CMJ CV = 2.6% and SJ CV = 2.2%) and jump height (cm) (CMJ CV = 4.8% and SJ CV = 3.8%). Relative PP was calculated by dividing the absolute peak power scores by the subject's body mass ($W.kg^{-1}$). All jumps were completed utilising the SwiftSpeedMat (Swift, Wacoi, QLD, Australia) with the mean of the three trials for each jump used in further analysis. After a three minute rest period, the subjects then completed three DJs from a height of 52cm onto the SwiftSpeedMat (30 seconds between jumps). This drop height was selected as in previous pilot testing it resulted in the greatest maximal jump height. During the DJs, the subjects were instructed to step off of the box and then upon making contact with the ground immediately performing an explosive CMJ. When performing the DJs the subjects were not permitted to perform a tuck jump or pike jump. The variables of interest during these DJs were jump height (JH) (CV = 6.2%), contact time (CT) (CV = 16.8%), flight time (FT) (CV = 3%) and the reactive strength index (RSI) = JH ÷ CT[99]) (CV = 15.1%). The means of the three jumps were used in further analysis. After a five-minute rest period, subjects peak eccentric and concentric squat force (N) was assessed utilising the Exerbotics squat device as described previously.

6.2.4 Statistical Analysis

During this study, the statistical analysis was completed using the SPSS software (Version 12.0, SPSS Inc, Chicago, IL, USA) and Microsoft Excel. A Spearman's correlation coefficient (r_s) was utilised to investigate the relationships between the variables of interest due to the non-parametric nature of the data. The strength of the relationship was considered small (0.1 to 0.3), moderate (0.3 to 0.5), large (0.5 to 0.7), very large (0.7 to 0.9) and nearly perfect (0.9 to 1.0) [175].

A Wilcoxon matched pairs signed rank test was used to establish any differences between concentric and eccentric PF (absolute and relative). An Excel spread sheet was used to assess the effects between concentric and eccentric PF [197]. Coefficients of variation (CVs) for the intra-day variables of interest were calculated using an Excel reliability spread sheet [173].

6.3 RESULTS

The means and SDs for the Exerbotics squat, jump, speed and COD assessments are shown in Table 6-1. Absolute eccentric PF was found to be greater than absolute concentric PF ($p < 0.05$, ES = 0.67) and relative eccentric PF was found to be greater than relative concentric PF ($p < 0.05$, ES = 0.79).

The strength of the relationships between both absolute and relative concentric and eccentric PF and the CMJ and SJ variables (jump height, absolute PP and relative PP) were small and moderate in magnitude (r_s = -0.01 – 0.64) (Table 6-2). The relationships between both absolute and relative concentric and eccentric PF and the DJ variables (jump height, CT, FT and RSI) were small in magnitude (r_s = -0.001 – 0.14) (Table 6-3).

Concentric absolute PF had a large positive relationship with 10, 30 and 40m sprint performance (r_s =0.53 – 0.58*)*, whilst eccentric absolute PF had a moderate positive relationship with the same variables (r_s = 0.36 – 0.47)(Table 6-4). Small negative relationships were found between all concentric and eccentric PF measures and COD performance (r_s = -0.30 – 0.20) (Table 6-4).

There was a large negative relationship between DJ height and all sprint distances (r_s = -0.59 – -0.69) and a very large negative relationship with COD performance (r_s = -0.70) (Table 6-5). Flight time was also found to have a large negative relationship with 10 and 30m sprint and COD performance (r_s= -0.60 – -0.67) and a very large negative relationship with 40m sprint performance (r_s = -0.70). In addition RSI had a moderate negative relationship (r_s = -0.40 – -0.43) with sprint performance and a large negative relationship with COD performance (r_s = -0.65).

Table 6-1. Mean ± SD jump performance, speed and COD variables (n = 15)

Variable	Mean ± SD
Concentric peak force (N)	2738.00± 639.65
Eccentric peak force (N)	3194.79 ± 536.85
Relative concentric peak force ($N.kg^{-1}$)	29.71 ± 6.13
Relative eccentric peak force ($N.kg^{-1}$)	34.81 ± 5.40
CMJ height (cm)	43.64 ± 6.65
CMJ peak power (W)	4880.85 ± 464.19
Relative CMJ peak power ($W.kg^{-1}$)	52.94 ± 5.13
SJ height (cm)	40.43 ± 5.74
SJ peak power (W)	4720.56 ± 418.39
Relative SJ peak power ($W.kg^{-1}$)	51.18 ± 4.32
Drop jump height (cm)	39.82 ± 5.01
Contact time (secs)	0.39 ± 0.06
Flight time (secs)	0.57 ± 0.04
Reactive strength index (RSI)	105.47 ± 19.58
10m sprint split (secs)	1.76 ± 0.11
30m sprint split (secs)	4.25 ± 0.25
40m sprint split (secs)	5.42 ± 0.25
Best COD (secs)	2.41 ± 0.10

N – Newtons
$N.kg^{-1}$ – Newtons per kilogram body weight
cm – Centimetres
W – Watts
$W.kg^{-1}$ – Watts per kilogram body weight
Secs – Seconds
COD – Change of direction

Table 6-2. Spearman's correlation coefficients (r_s) matrix of strength, power, CMJ and SJ performance

	Con PF	Ecc PF	Rel Con PF	Rel Ecc PF	CMJ H	SJ H	CMJ PP	SJ PP	Rel CMJ PP	Rel SJ PP
Con PF (N)	1.00									
Ecc PF (N)	0.73	1.00								
Rel Con PF ($N.kg^{-1}$)	0.78	0.58	1.00							
Rel Ecc PF ($N.kg^{-1}$)	0.34	0.74	0.62	1.00						
CMJ H (cm)	-0.07	-0.27	0.19	-0.04	1.00					
SJ H (cm)	-0.20	-0.35	0.09	-0.06	0.96	1.00				
CMJ PP (watts)	0.64	0.16	0.34	-0.24	0.27	0.21	1.00			
SJ PP (watts)	0.54	0.20	0.13	-0.30	0.12	0.13	0.93	1.00		
Rel CMJ PP ($W.kg^{-1}$)	-0.11	-0.28	0.18	-0.01	1.00	0.95	0.23	0.08	1.00	
Rel SJ PP ($W.kg^{-1}$)	-0.24	-0.35	0.11	0.00	0.95	0.98	0.13	0.02	0.96	1.00

PF – Peak force
CMJ H – Countermovement jump height
SJ H – Squat jump height
CMJ PP – countermovement jump peak power
SJ PP – Squat jump peak power
Con – Concentric
Ecc – Eccentric
Rel – Relative
N – Newtons

Table 6-3. Spearman's correlation coefficients (r_s) matrix of strength, drop jump height (DJH), contact time (CT), flight time (FT) and reactive strength index (RSI)

	Con Pf	Ecc PF	Rel Con PF	Rel Ecc PF
Con PF (N)	1.00			
Ecc PF (N)	0.73	1.00		
Rel Con PF ($N.kg^{-1}$)	0.78	0.58	1.00	
Rel Ecc PF ($N.kg^{-1}$)	0.34	0.78	0.62	1.00
DJH (cm)	-0.19	-0.19	0.02	0.14
Contact time (secs)	0.14	-0.001	-0.09	-0.18
Flight Time (secs)	-0.14	-0.18	0.08	0.16
RSI	-0.11	-0.08	-0.03	0.12

PF – Peak Force
DJH – Drop jump height
RSI – Reactive strength index
Con – Concentric
Ecc – Eccentric
Rel – Relative
N – Newtons

Table 6-4. Spearman's correlation coefficients (r_s) matrix of strength, speed and COD performance

	Con PF	Ecc PF	Rel Con PF	Rel Ecc PF	10M	30M	40M	COD
Con PF (N)	1.00							
Ecc PF (N)	0.73	1.00						
Rel Con PF ($N.kg^{-1}$)	0.78	0.58	1.00					
Rel Ecc PF ($N.kg^{-1}$)	0.34	0.74	0.62	1.00				
10m (secs)	0.55	0.47	0.33	0.02	1.00			
30m (secs)	0.53	0.36	0.19	-0.13	0.90	1.00		
40m (secs)	0.58	0.39	0.22	-0.12	0.87	0.98	1.00	
COD (secs)	0.20	0.01	-0.08	-0.30	0.35	0.59	0.61	1.00

Con – Concentric
Ecc – Eccentric
PF – Peak force
N – Newtons
Rel – Relative
COD – Change of direction (5-0-5 agility test)

Table 6-5. Spearman's correlation coefficients (r_s) between drop jump height (DJH), contact time (CT), flight time (FT), reactive strength index (RSI), sprint split times and change of direction (COD) times

	DJH	CT	FT	RSI	10M	30M	40M	COD
DJH (cm)	1.00							
CT (secs)	0.02	1.00						
FT (secs)	0.98	0.02	1.00					
RSI	0.68	-0.28	0.66	1.00				
10M (secs)	-0.59	-0.02	-0.60	-0.40	1.00			
30M (secs)	-0.64	0.08	-0.65	-0.41	0.90	1.00		
40M (secs)	-0.69	0.10	-0.70	-0.43	0.87	0.98	1.00	
COD (secs)	-0.70	0.27	-0.67	-0.65	0.35	0.59	0.61	1.00

DJH – Drop jump height
CT – Contact time
FT – Flight time
RSI – Reactive strength index
COD – Change of direction (5-0-5 agility test)

6.4 DISCUSSION

This study aimed to address the gap in current research on the relationship between eccentric strength and athletic performance. It also examined the relationships between DJ performance, speed and COD, as at present there is limited information available to coaches and athletes. The results of this study support the findings of previous research that eccentric strength is significantly greater than concentric strength [2, 3]. Therefore it is proposed that these two contrasting muscle actions should be assessed on an individual basis when assessing an athlete's ability to produce PF.

In this study, there was a small negative relationship between eccentric PF and CMJ height (Table 6-2). This is in contrast with previous research utilising the same methods where Bridgeman et al. [192] reported a large positive relationship between eccentric PF and CMJ height. In the previous study, the subjects were strength trained athletes rather than team sports athletes and thus it is proposed that the strength of the relationships may be specific to the population tested.

Absolute concentric PF was found to have a large positive relationship and absolute eccentric PF a moderate positive relationship with sprint times at 10, 30 and 40m (Table 6-4). This is in contrast with previous research which has reported large negative relationships between strength and sprint times[198, 199]. However, it should be noted that the studies utilised dynamic strength assessment rather than isokinetic assessments. Therefore one potential reason for the positive relationships between PF and sprinting in this current study may be due to the slow speed of the eccentric assessment utilised during the Exerbotics squat. In support of this Cronin et al. [195] suggested that isokinetic assessments have little resemblance to the limb actions that occur during sprinting whilst the absence of SSC actions during isokinetic testing also reduce the validity of this method of assessment. Therefore when investigating relationships between strength and sprint performance, it would seem prudent to avoid the use of isokinetic testing methods. Another possible explanation is the characteristics of the subjects utilised in this current study. In rugby union the stronger players are typically forwards who are also generally slower than the faster but weaker backs[200]. This may have influenced the results in the current study as the majority of the subjects were forwards (9 forwards, 6 backs) and therefore although they were able to produce greater PF, their sprint times were slower.

Previously Spiteri et al. [193] reported that eccentric strength was a predictor of COD performance. In contrast, this current study found only small relationships between COD times and eccentric PF. In Spiteri et al. [193] study the subjects performed a dynamic eccentric squat as opposed to an isokinetic assessment and had a faster eccentric movement velocity (three second eccentric cadence vs. four seconds in this current study). In addition as discussed previously the characteristics of this current study may have influenced the strength of any relationships. Therefore it is suggested that not only is testing athlete specific but also highly mode and speed specific. More research is required to establish the nature of the relationship between eccentric strength utilising different testing methods, sports and COD performance.

In contrast to the strength testing, the DJ, which utilises the SSC, was found to have large negative relationships with sprint performance (Table 6-5). Previously Barr and Nolte [109] reported significant correlations between DJ height and sprinting performance in female rugby athletes. In agreement with those findings, the current study also found large negative correlations between 10, 30 and 40m sprint times and DJ height. Flight time also had a large and very large negative relationship with 10, 30 and 40m sprint times respectively. In agreement with previous research, the strength of the relationships between the DJ variables (height, FT and RSI) in this current study increased as the distance of the sprint did. It is proposed that this is the result of the DJ simulating the joint angles, contraction velocities and SSC function associated with maximal velocity sprinting [109].

In addition to DJ height and FT, RSI was also found to have moderate negative relationships with 10, 30 and 40m sprint times. This is in contrast to previous research, which reported weak relationships between RSI and sprint performance [109, 195]. It should be noted however that comparisons between studies is hard because of the range of drop heights utilised by different studies and also the potential for different tester instructions during the DJ which can influence DJ performance [201].

Drop jump height was also found to have a very large negative relationship with COD times. It is proposed that an increase in DJ height may indicate a subjects ability to tolerate the high eccentric forces associated with the DJ exercise [52]. This enhanced tolerance may then transfer into COD of direction performance where the athletes are also reported to have to tolerate high eccentric forces during deceleration [193]. In addition FT and RSI were found to have a large negative relationship with COD performance. Based on these findings it is recommended that if athletes are utilising the DJ exercise during training, they should focus on improving DJ height as this may result in improvements in speed and COD performance.

One factor in this current study that needs to be taken into account when interpreting the DJ results is the large CVs associated with both CT (16.8%) and the RSI scores (15.1%). When examining CVs it has previously been reported that a score of less than

10% is considered small [176]. Therefore, a CV over 10% may indicate a larger degree of variability, which may have affected the strength of the relationships between CT, RSI and the other variables of interest.

6.5 PRACTICAL APPLICATIONS

The results of this current study indicated that there is a relationship between DJ performance, maximal velocity sprinting and COD times in male rugby union players. Although it is acknowledged that the correlations seen in this current study do not equal causation it is proposed that if an athlete wishes to enhance their sprint and COD performance utilising the DJ they should focus on enhancing their DJ height. In addition whilst utilising isokinetic testing may be useful to investigate concentric and eccentric strength capabilities in isolation. It is proposed that due to the slow speed of the testing, it may not be appropriate to utilise this method to examine relationships between PF and athletic performance.

Chapter 7

The Effects of Accentuated Eccentric Loading on the Drop Jump Exercise and the Subsequent Postactivation Potentiation Response

Journal of Strength and Conditioning Research

7.0 LEAD SUMMARY

Although previous studies have reported that the DJ exercise may result in acute performance enhancements, at present no research has investigated the ability of AEL DJsto enhance subsequent performance. Therefore the aims of this study were to investigate (i)the acute effects of different DJ AEL protocols and (ii) the effect of these AEL DJ protocols on subsequent CMJ performance. The subjects were 12 strength-trained athletes. Baseline CMJ performance was assessed, and individual optimal DJ drop height identified. In subsequent weeks subjects completed one set of fiveDJs with no additional load or an AEL of 10, 20 or 30% of their individual body mass (BM) utilising dumbbells to provide the extra load. After the AEL DJ protocols three CMJ's were completed after 2, 6 and 12 minutes rest. A generalised linear mixed model was used to investigate the effects of AEL load and time post DJs on CMJ height, peak power and GRF. The 20% AEL condition resulted in greater CMJ height in comparison to all other conditions ($p < 0.001$). CMJ height was significantly greater after two and six minutes rest compared to 12 minutes ($p < 0.001$ and $p < 0.05$ respectively). Greater PP was also found during the CMJ's after the 20% AEL condition compared to baseline, BM and 10% AEL ($p < 0.05$). In conclusion fiveDJs with 20%, AEL followed by a two minute recovery period resulted in significant enhancement in CMJ height and PP.

7.1 INTRODUCTION

The drop jump (DJ) is a plyometric exercise which is widely utilised by strength and conditioning (S&C) coaches[202]. It involves an athlete stepping off of a box and then upon making contact with the ground immediately performing an explosive vertical jump [98]. The DJ exercise has been suggested to result in improved utilisation of the SSC [20, 26, 98] and results in high eccentric force production [19]. Previously training using the DJ exercise has been reported to lead to; improvements in sprint performance [26, 203], improvements in jumping performance [29, 31, 101], enhanced strength [25] and greater agility [100] and therefore may be an attractive option to S&C coaches. It has also been proposed that the inclusion of a low volume of DJs may lead to subsequent enhancements in performance as the result of a postactivation potentiation (PAP) response [22, 23].

Plyometric activities such as the DJ have previously been reported to result in a PAP response[22]. This refers to the phenomenon by which muscular performance characteristics are improved due to their contractile history [204]. As yet the mechanisms responsible for the PAP response are unclear, however, when using plyometric activities such as the DJ it has been proposed that the preferential recruitment of type II motor units may be responsible for the subsequent improvement in lower-body performance (see Maloney et al. [205] and Seitz et al. [206] for a full review of the mechanisms associated with PAP during plyometric exercise).

Previously studies have investigated the effects of plyometric activities on PAP and its influence on acute performance [19, 21-24, 207]. Lima et al. [22] reported that two sets of five DJ (from a height of 0.75 m) with professional strength trained athletes resulted in increased vertical jump performance (6% 15 minutes post stimulus) and improved 50 m sprint performance (2.4% and 2.7% 10 and 15 minutes post stimulus respectively). In a study investigating the acute effects of different DJ volumes and recovery times on subsequent CMJ performance in plyometric trained male volleyball athletes Chen et al. [23] reported both one set of five repetitions and two sets of five repetitions resulted in improved CMJ height two minutes post stimulus. In a further study with professional male rugby players, Tobin and Delahunt [207] suggest that the use of plyometric exercises as a preload stimulus may be preferable to the use of heavy load stimulus as a result of the required rest periods to elicit a PAP being shorter. Although some studies have reported plyometric exercises resulted in a PAP response others have not[208, 209]. It is therefore suggested the evidence supporting the use of the plyometric exercises, as a PAP stimulus is controversial.

Although the intensity of the DJ exercise is usually dictated by drop height previous research has suggested that another method for altering intensity is by manipulating the mass of an individual [20, 103]. An alternative to this constant additional load approach is the suggestion that dumbbells or bands provide accentuated eccentric loading (AEL) during the eccentric phase of the DJ exercise [33]. Thus as an athlete reaches the bottom position of the CMJ, they release the dumbbells or bands and perform the concentric phase without any additional load [33].

Currently, only one study has investigated the use of AEL during DJs. In this study, AEL was applied through the use of elastic bands which increased the downward force by either 20% or 30% of BM [34]. The results of this study using highly resistance trained subjects indicated that additional eccentric load significantly enhanced eccentric impulse ($p < 0.05$), rate of force development ($p < 0.001$) and resulted in small to moderate ES increases in iEMG across the eccentric phase (ES = 0.23 - 0.51) however, no increases in jump height or concentric muscle activation were reported [34]. Due to the finding that the AEL resulted in improved quadriceps iEMG it is proposed by the authors that the AEL may result in greater recruitment of type II motor units and thus may result in a greater PAP stimulus than that provided by unloaded DJs alone.

At present, there is no research, which has investigated the effects of using dumbbells to provide an AEL during the DJ exercise and its ability to improve subsequent lower body performance as a result of the PAP phenomenon. Therefore the aims of this study were to (1) investigate the effects of AEL DJ on DJ performance (jump height, flight time, contact time and ground reaction force [GRF]) and (2) to investigate the acute effects of completing AEL DJs on subsequent CMJ performance (jump height, peak power and GRF). It was hypothesised that the addition of the eccentric load (10, 20 and 30% of participants BM) during the DJs would result in a significant increase in jump height and peak power in the subsequent CMJ's in comparison to DJs completed without any additional load.

7.2 METHODS

7.2.1 Experimental Approach to the Problem

A repeated measures design was used to investigate the acute effects of AEL DJ on DJ performance and subsequent CMJ performance in strength trained athletes. Initially subject's baseline CMJ performance and optimum drop height were established. In the following two weeks subjects DJ and CMJ performance were assessed during and after four protocols: (1) a DJ protocol with BM only, (2) a DJ protocol with an additional dumbbell load of 10% during the eccentric phase, (3) a DJ protocol with 20% additional load and (4) a DJ protocol with 30% additional load. The additional loads utilised during the AEL DJs were calculated as a percentage of each subjects individual BM.

These loads were selected based on the previous findings by Aboodarda et al. [34] that both a 20% and 30% additional AEL load resulted in enhanced eccentric impulse and rate of force development. During each protocol the subjects completed one set of five repetitions before completing three CMJ's at each of the following recovery times: (a) 2 minutes, (b) 6 minutes and (c) 12 minutes post.

7.2.2 Subjects

Twelve male strength trained athletes (mean age: 25.4 ± 3.5 years; mean height: 177.2 ± 4.5 cm; mass: 84.0 ± 10.1 kg and 1RM squat relative to BW: 1.89± 0.27) with previous experience of plyometric training volunteered to participate in this study. All subjects had at least two years strength training experience and were able to squat at least 1.5 times BW. The sample size in this study was based on previous studies which have utilised a similar study design and number of subjects [22, 23]. Before commencing testing, all subjects were fully informed about the procedures, possible risks and purpose of the study. All subjects also provided informed written consent. The Auckland University of Technology Ethics Committee approved this study.

7.2.3 Procedures

Subjects were asked to refrain from training in the 48 hours before any testing session (Figure 7-1). In testing session one the subjects completed a five-minute warm up on a stationary exercise bike (95C Lifecycle, Life Fitness, Hamilton, New Zealand) followed by 10 BW squats. Upon completion of the warm-up subjects completed three maximal CMJ (15 seconds between jumps). During the CMJ all subjects squatted to a self-selected depth and were permitted to use their arms while the tester provided verbal encouragement. During baseline testing the within session reliability of the CMJs was assessed via Intraclass correlation coefficients (ICC's) and coefficients of variation (CV) using an Excel reliability spread sheet found at www.sportsci.org[173]. The results of this analysis based on Bradshaw et al. classification [177] indicated a small variability between the 3 trials (jump height, CV = 3.6% and ICC = 0.90, peak power CV = 2.7% and ICC = 0.98 and GRF (normalised for BM) CV = 7.8% and ICC = 0.71).

Upon completion of the CMJ testing subjects then did five warm up DJ from plyometric boxes (38 and 62 cm, 15 seconds between jumps and three minutes between drop heights). Subjects then attempted three maximal DJ with no additional load from the following plyometric box drop heights 28, 38, 52, 62 and 70 cm (15 seconds between each jump and three minutes rest between different heights). These heights were selected to provide a range of drop heights from low to high in line with previous research investigating the use of the DJ exercise [23, 109]. During these DJ the subjects were instructed to step off of the box and immediately upon contact with the ground complete a CMJ (use of arms permitted).

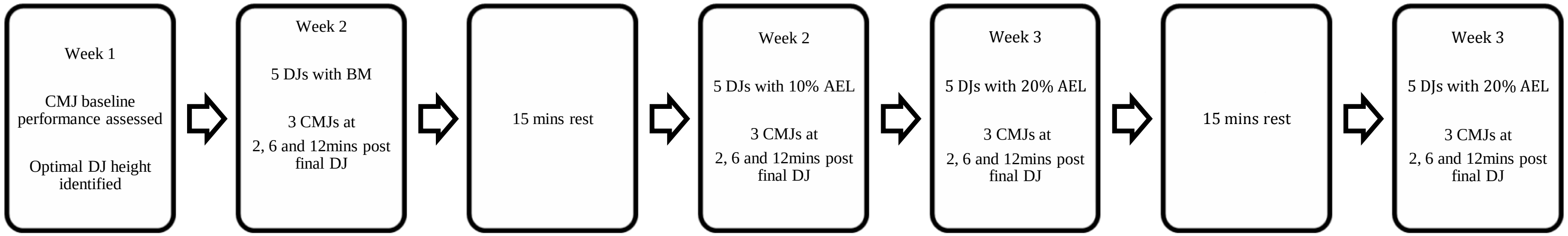

Figure 7-1. Structure of the study

From these trials, each subjects individual optimal drop height was determined as the drop height that elicited the best maximal jump height (MJH) [109]. Finally at the end of this testing session subjects were familiarised with AEL DJ protocol using dumbbells (Hammer Strength, Life Fitness, Hamilton, New Zealand) to provide the additional load. During this familiarisation each subject completed five DJs with each of the AEL from a height of 38cm.

One week after the initial testing session the subjects returned to the lab and completed the same warm up as described previously. Subjects then completed fiveDJs from their individual optimal drop height. These DJ were completed as normal but when each subject hit the bottom position of the CMJ (thighs parallel to the ground) the dumbbells were released allowing the subjects to complete the concentric phase of without any additional load. Two minutes after the completion of these jumps the subjects completed three CMJ’s (30 seconds between each jump). This process was repeated 6 and 12 minutes after the five initial DJ. These recovery times were selected based on the finding by Chen et al. [23] that CMJ height was greater two minutes after completing a low volume DJ protocol than during the pre-test, 6 minutes and 12 minutes. In addition, six minutes recovery was also found to result in greater CMJ height than 12 minutes post [23]. A review by Maloney et al. [205] also reported that when using ballistic exercises as a PAP stimulus rest periods of one – six minutes have been successfully prescribed.

During the 1st week of DJ testing the subjects initially, completed the DJs with no additional load and then after a 15 minute rest (post the final CMJ) subjects completed fiveDJs with an additional dumbbell load of 10% BM. After a further week’s recovery,the subjects returned to the lab for the final time. The subjects initially warmed up as before completing five DJ with an additional dumbbell load of 20% BM followed by the CMJ testing previously described. Finally, after a further 15 minutes rest the subjects completed five DJ with an additional dumbbell load of 30% BM before completing the CMJ testing.

During the DJs, the variables of interest were jump height (cm), contact time (s), flight time (s) and peak ground reaction force (GRF [N]). During CMJ testing jump height, peak power and GRF (normalised for BM) were the variables of interest. All variables were measured using a force plate (400S, Fitness Technology, South Australia, Australia) sampling at 600Hz. The mean values of each the variables of interest during the DJs in each AEL condition and the subsequent CMJ's were used during further statistical analysis.

7.2.4 Statistical Analysis

During this study, all statistical analysis was completed using the SPSS software (Version 12.0, SPSS Inc., Chicago, IL, USA). Freidmann ANOVA was used to compare the DJ variables across the four different loads with significance set at $p< 0.05$. Where differences were found post hoc testing utilised the Wilcoxon signed ranked-test to investigate where these differences occurred. Adjusting for multiple comparisons the alpha level was set at $p = 0.008$ during post hoc testing (0.05 divided by the number of conditions). A generalised linear mixed model was used to investigate the effects of load and time on jump height, peak GRF and peak power after completion of the DJ conditions with subjects as the random effect. This generalised mixed model was chosen to analyse the data as it was found to be non-parametric.

Where statistical differences were identified ES (90% confidence interval) were calculated using an Excel spread sheet (*Post-only crossover*) found at Sportsci.org [197]. For assessing the magnitude of standardised effects, threshold values of <0.2, 0.2, 0.6, 1.2 represent trivial, small, moderate, and large differences, respectively [210].

7.3 RESULTS

Drop Jump Analysis

Although significant main effects were found for DJ variables, post hoc testing taking into account multiple comparisons did not find any significant differences (p> 0.008) between the conditions. However, ES analysis identified trivial and small differences between the different conditions. DJ jump height was found to be greater in the BW condition compared to the 10% and 30% AEL conditions (p = 0.012 ES = 0.39 (0.17 – 0.60) and p = 0.023, ES = 0.34 (0.11 – 0.56) respectively). It was also found that DJ jump height was greater in the 20% condition compared to the 10% and 30% AEL conditions (p = 0.012, ES = 0.37 (0.20 – 0.55) and p = 0.019, ES = 0.32 (0.12 – 0.52)). Significant main effects were also found for DJ flight time (p< 0.05). Post hoc analysis revealed greater DJ flight time in the BW condition compared to the 10% and 30% AEL conditions (p = 0.019, ES = 0.38 (0.16 – 0.59) and p = 0.018, ES = 0.34 (0.11 – 0.56). In addition greater flight time was found in the 20% AEL DJ condition compared to the 10% and 30% AEL DJ conditions (p = 0.019, ES = 0.36 (0.20 – 0.52) and p = 0.010, ES = 0.32 (0.12 – 0.52)).

Post Drop Jump Analysis

A generalised linear mixed model found significant main effects of load and time on CMJ height (p < 0.001), no significant load and time interaction was demonstrated. Post hoc testing indicated that the 20% AEL DJ condition resulted in significantly greater

CMJ height in comparison to baseline (ES = 0.47 (0.24 – 0.71), the BW (ES = 0.48 (0.30 – 0.66) and the 10% (ES = 0.37 (0.17 – 0.57) and 30% (ES = 0.34 (0.17 – 0.51) AEL DJ conditions ($p < 0.001$) (Figure 7-2).

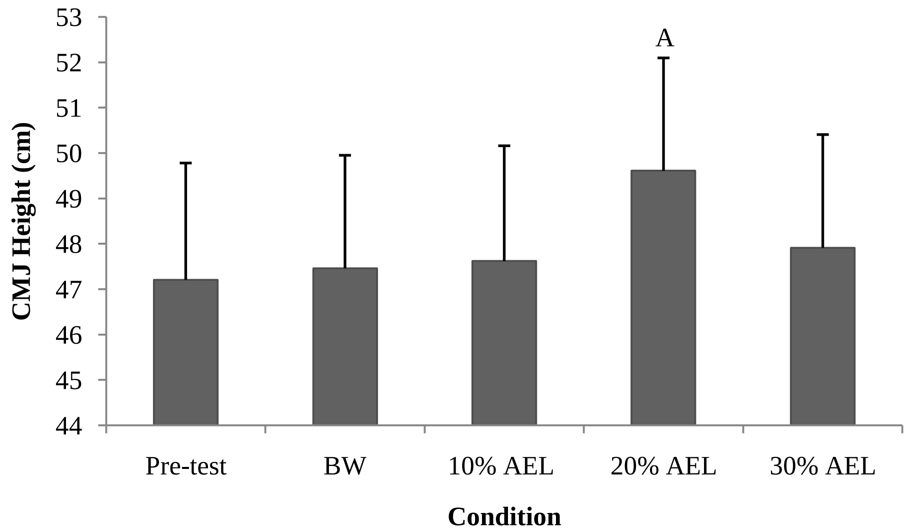

Figure 7-2.CMJ height (mean ± SD) at baseline and after completing each DJ condition. A) Indicates significant differences between CMJ height in the 20% AEL condition compared to all other conditions (*p*< 0.001).

Post hoc testing indicated significantly greater CMJ height two minutes and six minutes post DJs compared to 12 minutes post DJ ($p < 0.001$, ES = 0.64 (0.48 – 0.80) and $p < 0.05$, ES = 0.17 (0.09 – 0.25) respectively) (Figure 7-3). A main effect was found for load on ground reaction force relative to BW ($p < 0.05$). Post hoc testing indicated a significantly greater GRF during CMJ at baseline compared to post the 10% AEL DJ condition ($p < 0.05$, ES = 0.29 (0.02 – 0.56) (Figure 7-4).

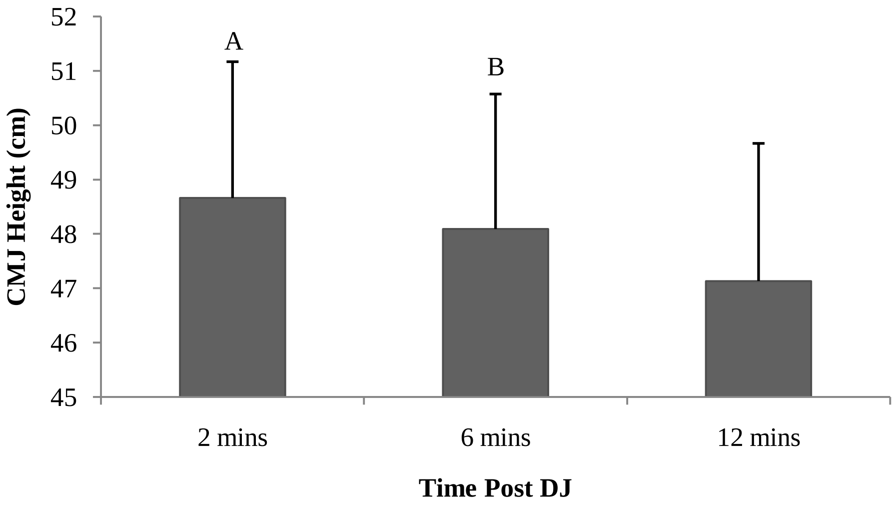

Figure 7-3. CMJ height (mean ± SD) each time point upon completion of DJ. A) Indicates significant differences between CMJ height 2 mins post DJ and 12 mins (*p*< 0.001). B) Indicates significant differences between CMJ height 6 mins post DJ and 12 mins (*p*< 0.05)

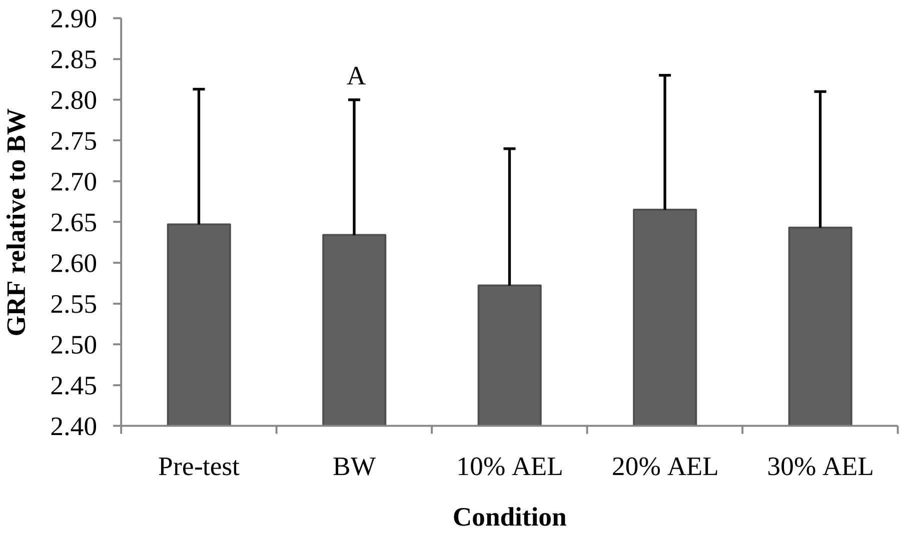

Figure 7-4.GRF relative to BW (mean ± SD) during CMJ at baseline and after completing each DJ condition. A) Indicates significant differences between CMJ GRF between the BW and 10% AEL conditions (*p*< 0.001).

A main effect was also found for load on peak power ($p < 0.05$). Post hoc testing indicated significantly greater peak power ($p < 0.05$) in the CMJ's after completion of the 20% AEL DJ condition in comparison to baseline (ES = 0.17 (0.09 – 0.26), BW (ES = 0.17 (0.09 – 0.26) and 10% AEL DJ (ES = 0.14 (0.06 – 0.22) (Figure 7-5).

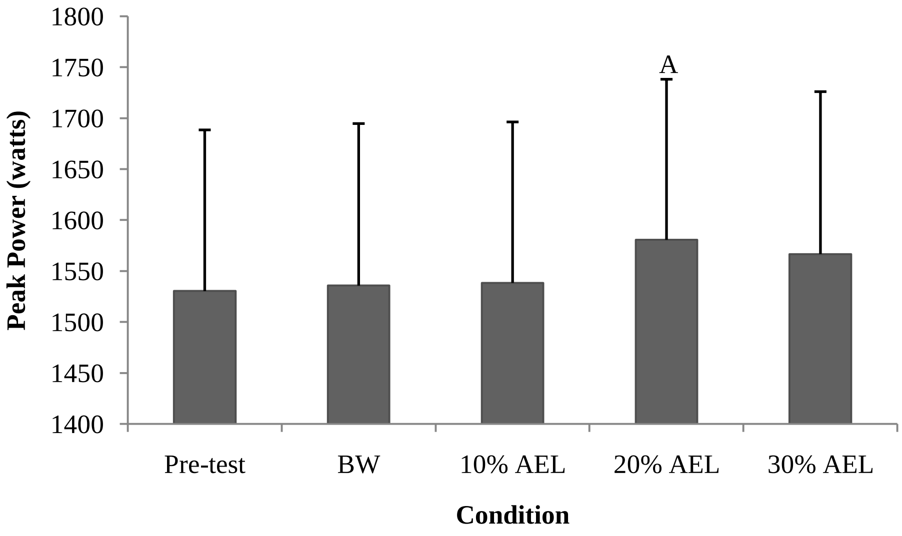

Figure 7-5.Peak power (mean ± SD) during CMJ at baseline and after completing each DJ condition. A) Indicates significant differences in CMJ peak power between the 20% AEL condition, baseline, BW and 10% AEL conditions (p< 0.05).

7.4 DISCUSSION

The main findings of this study were that one set of five DJs utilising an AEL of 20% BM resulted in significantly greater CMJ height in comparison to baseline and all other DJ conditions. The 20% AEL condition also produced greater peak power outputs during the subsequent CMJ's in comparison to baseline and the BW DJs and the 10% AEL DJs. In addition, it was found that CMJ height was significantly greater after two minutes recovery compared to 12 minutes and after six minutes compared to 12 minutes. The results of this study are in agreement with other studies that have found low volume DJs can enhance lower body performance [19, 22-24].

Plyometric activities such as the DJ have been reported to carry a greater potential to induce a PAP response than traditional resistance exercises (back squat) due to their high intensity [205, 206]. This increase in PAP potential may be the consequence of plyometric exercises leading to preferential recruitment of type II motor units which is one of the premises that underpin PAP [206, 211] and may lead to improvements in CMJ performance [23]. In addition eccentric contractions that occur during DJs have been reported to result in increased muscle temperature leading to high muscular activation, increased storage and recoil of elastic energy and enhanced phosphorylation of the myosin light chain (MLC) all of which may contribute to increased subsequent CMJ performance [23]. Thus in this current study, it is suggested that the 20% AEL DJ condition was the optimal additional eccentric load required by the subjects to take advantage of the PAP response.

Repeated contractions can lead to fatigue and impaired performance but also may result in potentiation and improved performance [212, 213]. Initially upon completion of exercise fatigue effects are proposed to dominate, however, potentiation has been reported to last longer [214]. Thus getting the balance right between recovery to allow the effects of fatigue to recede and potentiation to be in the ascendancy is crucial for performance enhancements [204]. A review by Maloney et al. [205] into the use of ballistic exercises such as the DJ reported that currently there is no agreement on the required recovery times to produce an optimal PAP response. However, plyometric activities have also been proposed to result in less fatigue in comparison to traditional resistance exercises despite their high intensity and thus result in a greater subsequent state of potentiation [206].

In relation to vertical jump performance Lima et al. [22] reported vertical jump performance was potentiated 15 minutes after a bout of DJ. However, in contrast, Chen et al. [23] reported greatest increases in vertical jump performance two minutes after a bout of DJ in comparison to six and 12 minutes recovery. Tobin and Delahunt [207] also reported improvements in vertical jump performance at one, three and five minutes after a bout of ballistic jumping exercise. Based on these findings and the results of other studies investigating ballistic exercise to induce PAP Maloney et al. [205] concluded that the recovery duration needed to induce a PAP response may be reduced compared to heavy resistance exercise (such as the squat) due to reductions in system mass.

In this current study, a rest period of two (moderate ES) and six minutes (trivial ES) resulted in greater CMJ performance than 12 minutes. Thus in agreement with the findings of Chen et al. [23] by 12 minutes it is speculated that the PAP response from completing the DJs was starting to diminish and as a consequence CMJ performance declined. Although there were no significant differences in CMJ performance between two and six minutes, two minutes recovery resulted in the greatest CMJ performance. Based on the findings of this current study and in agreement with previous research by Chen et al. [23] it would appear that two minutes would be the most effective rest period to enhance CMJ performance following a bout of DJs.

One potential limitation of this study was that the optimal drop height for each subject was identified with no additional load. Thus although the drop height identified initially may have resulted in MJH with no extra load the addition of the AEL may have resulted in a different optimal drop height. Therefore future research may be required to investigate the effect of AEL on optimal drop height during the DJ and how this influences the subsequent PAP response. Additionally, the subjects in this study initially completed five DJs without any load followed 15 minutes after the last CMJ (30 minutes post the initial bout of DJs) by a further set of DJs with 10% additional load.

The following week the subject initially completed the DJs with 20% followed by 30% additional load. It may, therefore, be argued that the initial bout of DJs may have had a negative effect on the subsequent bout of DJs ability to produce a PAP response and therefore enhance CMJ performance and this may be a limitation to this current study. The authors, however, suggest that the 30 minutes between bouts of DJs is adequate to allow recovery in agreement with the research of Maloney et al. [205] on recovery times following ballistic exercise. Also baseline, CMJ performance was assessed during week one and thus there may have been a change in subject's baseline performance across the two week testing period. However, a recent review suggests that in strength trained individuals such as those in the current study the degree to which alterations in strength influences performance may be reduced [17]. Therefore it is suggested that the initial baseline performance is still valid when used as a comparison upon completion of the DJs.

In conclusion one set of five DJs utilising dumbbells to provide an AEL of 20% BM resulted in the greatest subsequent CMJ performance. A 2 minute recovery period after the DJs appears to result in optimal subsequent CMJ performance.

7.5 PRACTICAL APPLICATIONS

This study was the first to show that AEL during the DJ exercise can potentiate subsequent CMJ performance. Five DJs utilising dumbbells to provide an additional eccentric load equal to 20% of each subjects BM resulted in the greatest acute improvements in CMJ height. In addition two minutes recovery was found to be the optimal rest period necessary to enhance CMJ performance. Therefore it is suggested that athletes wishing to enhance their vertical jump performance may benefit from utilising an AEL DJ protocol. Based on the findings of this current study S&C coaches should initially identify the optimal drop height for each athlete based on the MJH method. Athletes would then (approximately two minutes prior to competing) complete five AEL DJs during their warm up (from the drop height previously identified) with an additional load of 20% BM in order to potentiation subsequent vertical jump performance.

Chapter 8

The Effects of Accentuated Eccentric Load Drop Jumps in Resistance Trained Male Athletes

8.0 LEAD SUMMARY

In the previous chapter, it was established that the use of AEL DJscould enhance acute CMJ performance. Although previous studies have investigated EIMD after a bout of unloaded DJs, none have investigated the effects of AELDJs on EIMD. The purpose of this study was to investigate the effects of 30 and 50 AEL DJs on strength, jump performance, muscle soreness (SOR) and blood markers in resistance-trained athletes. Eight subjects participated in this study. In week one baseline CMJ, SJ, concentric and eccentric PF, CK and SOR were assessed. Subjects then completed 30 AEL DJs, and baseline measures were re-tested immediately post, 1, 24 and 48 hours later. Two weeks later the subjects completed the same protocol with an increase in AEL DJ volume (50 jumps). During CMJ testing in week one the subjects jump height was reduced compared to baseline immediately post intervention (ES = -0.38). During SJ testing in week one the subjects jump height was reduced compared to baseline immediately post intervention (ES = -0.24). During squat testing in week one concentric PF was reduced compared to baseline one-hour post intervention (ES = -0.22). During week three testing concentric PF was reduced compared to baseline immediately post intervention (ES = -0.30). During week one eccentric PF was reduced compared to baseline, immediately post intervention, 24 and 48hrs later (ES = -0.31, -0.22 and -0.22). Based on these findings it is proposed that AEL DJs result in minimal EIMD in resistance-trained athletes.

8.1 INTRODUCTION

The drop jump (DJ) is a plyometric training method [96] that produces high eccentric force [19]. It involves an athlete stepping off of a raised platform and upon landing performing an explosive countermovement jump (CMJ) [98]. Research has reported that DJs result in acute enhancements in vertical jump performance [19, 22] and sprint performance [22]. In addition, the use of DJs in training has led to improvements in; speed [25, 27], jump height [25, 27], strength [25] and agility [32]. Therefore based on the acute and chronic enhancements and low time cost [25] associated with DJs, athletes may consider their inclusion during a warm up or as part of a training programme.

A potential adaptation to the traditional DJ proposed by Moore and Schilling [33] involves the use of accentuated eccentric load (AEL). During AEL DJs an athlete overloads the eccentric portion of the exercise through the use of either elastics bands or dumbbells prior to completing the concentric phase with no additional load [33]. Previously a study utilised AEL through the use of elastic bands to increase the downward force by 20% and 30% of body mass (BM) [34]. The results indicated that AEL significantly enhanced eccentric impulse and rate of force development. A further DJ study reported an AEL of 20% BM provided by dumbbells resulted in enhanced CMJ performance [215]. Thus the use of AEL DJs may be of interest to athletes.

Although there are performance enhancements associated with the use of DJs, there is also potential for exercise-induced muscle damage (EIMD) [216]. This is a consequence of the eccentric muscle actions seen in the initial landing phase of the DJ being high in intensity [112]. Miyama and Nosaka [217] had subjects perform five sets of 20 DJs from a box height of 60 cm. Upon completion of these jumps it was reported there was a significant reduction in maximal isometric force, CMJ height and squat jump (SJ) height[217]. Whilst a significant increase in creatine kinase (CK) and muscle soreness (SOR) was reported [217] In a further Study Miyama and Nosaka [45] reported that an initial bout of 10 or 50 DJs resulted in significant reductions in maximal isometric torque of the knee extensors, significant reductions in CMJ and SJ height and significant increases in CK and SOR.

Although studies have identified that DJs can result in EIMD, it should be noted that during both these studies the subjects had little to no previous resistance training experience[45, 217].There is limited research on how resistance-trained individuals respond to unfamiliar eccentric exercise [49]. In a study investigating the effects of eccentric exercise of the elbow flexors,Newton et al.[38] reported thatthe resistance-trained group showed significantly smaller changes (maximal voluntary isometric and isokinetic torque, range of motion, arm circumference and CK activity) post intervention compared to untrained group.The authors suggested smaller changes may be the result of removal of stress susceptible fibres, structural reinforcement of the fibres and/or connective tissue, adaptations to the heat shock system and neural adaptations in the trained group [38].

Despite the fact that previous research has identified the benefits of AEL DJs [34, 215], there is no research that has investigated the magnitude of EIMD when utilising AEL DJs. Therefore any negative effects associated with AEL DJs or the recovery time required to alleviate these effects is currently unknown. It is suggested that this information is necessary to plan an athletes training week and to ensure they have enough time after a bout of AEL DJs to sufficiently recover before competition. In addition the previous research investigating EIMD as a result of DJs was carried out with non-resistance trained subjects[45, 217] thus these findings may not be applicable to resistance-trained athletes. Therefore, the aim of this study was to investigate the effect of completing AEL DJs on markers of EIMD and performance in resistance-trained men.

8.2 METHODS

8.2.1 Experimental Approach to the Problem

A cross-sectional repeated measures design was used to investigate the magnitude of EIMD upon completion of an AEL DJ protocol. Initially subject's baseline CMJ and SJ performance, concentric and eccentric PF, CK and SOR values were assessed. Subjects then completed an AEL DJ protocol (five sets of six repetitions from a 52 cm box, 15 seconds between repetitions and three minutes between sets) with a dumbbell load equal to 20% of their own BM. Immediately upon completion of the DJ protocol blood was taken for analysis of CK, subjects were asked to rate their SOR at rest and during a squatting pattern, completed CMJ and SJ testing and finally completed concentric and eccentric strength testing. This process was then repeated one, 24 and 48 hours later. Two weeks after this initial protocol the subjects returned to the laboratory and completed the same testing procedure but with an increase in AEL DJ volume (five sets of ten repetitions). This design was utilised as it allowed the assessment of the magnitude of EIMD, any performance decrements and the time course of the recovery following a bout of AEL DJs in both weeks one and three.

8.2.2 Subjects

Eight male strength trained athletes (mean ± SD; age: 26.3 ± 5.1 years; height: 176.8± 4.9 cm; mass: 83.0 ± 12.4 kg) who could all squat at least 1.5 x their body weight volunteered to participate in this study. All subjects had at least two years strength training experience. Prior to commencing testing, all subjects were fully informed about the procedures, possible risks and purpose of the study. All subjects also provided informed written consent. The Auckland University of Technology Ethics Committee approved this study.

8.2.3 Procedures

Peak Concentric and Eccentric Force Assessment

Beforeweek one testing, all subjects attended a session to familiarise them with the Exerbotics squat machine (eSQ, Exerbotics, LLC, Tulsa, OK) (Figure 8-1). During this session, the subject's range of movement (ROM) was established and they completed a maximal strength test. The ROM was based on the knee joint and was set at 90 degrees flexion at the bottom of the squat and 170 degrees between the thigh and leg at the top position.

During maximal testing each subject had the back pad on the top of their trapezius, feet shoulder width apart and toes turned slightly outwards. Maximal strength testing involved the completion of three continuous repetitions with concentric and eccentric actions lasting four seconds separated by a half second pause. During the first repetition, subjects were instructed to apply force at what they considered to be 50% of their maximum effort. During the next two repetitions, the subjects were instructed to apply maximal force. The tester provided verbal encouragement to the subjects throughout encouraging them to resist during the eccentric phase and push during the concentric phase of the squat. The best score (peak concentric and eccentric force (N)) during the final two repetitions was used in future analysis. This testing procedure has previously been shown to be reliable in our laboratory (Concentric PF CV = 10% and ICC = 0.95 and eccentric PF CV = 7.2% and ICC = 0.90) [188].

Creatine Kinase Assessment

To measure CK activity venous blood was sampled (8.5 mL)from a forearm vein. Blood was then centrifuged at 1500 G and 4°C for 10 min, and the separated plasma was removed and stored at – 80°C. Plasma CK (U/L) activity was measured using an automatic biochemical analyser (Roche, Indianapolis, USA). In men, the normal reference range for CK activity is 39 – 308 U/L according to the manual provided with theanalyser.

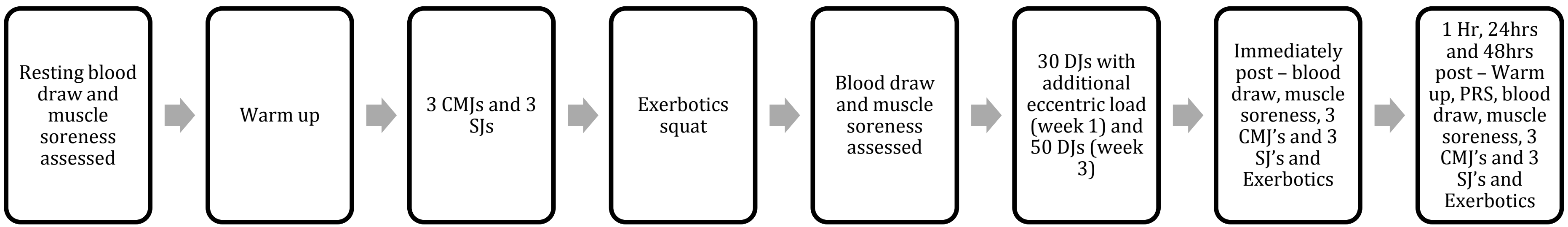

Figure 8-1. Structure of the study

Muscle Soreness Assessment

To investigate SOR an investigator used the palm of their hand to apply firm pressure to the belly of the knee extensors and flexors using previously described methods [45]. The subjects self-reportedSOR using a 10-point numeric pain scale (0 = no pain – 10 = worst possible pain). Knee extensor SOR was also self-reported by the subject as they completed a half squat from a standing position.

Countermovement Jump and Squat Jump Testing

To assess CMJ and SJ performance subjects completed three maximal CMJ and three maximal SJ (15 seconds between jumps and three minutes between CMJ and SJ) on a force plate (400S, Fitness Technology, South Australia, Australia) sampling at 600Hz. The variable of interest during these jumps was jump height (JH) as this has previously been used to assess performance in other DJ EIMD studies [45, 217]. During the CMJ subjects squatted to a self-selected depth and were permitted to use their arms whilst the tester provided verbal encouragement. During the SJ subjects squatted to parallel and held this position (two seconds) until instructed to jump. The mean value of the three jumps (CMJ and SJ) was used for further analysis (BaselineCMJ; ICC = 0.97 and CV = 2.5% and SJ ICC = 0.97 and CV = 3.4%).

Accentuated Eccentric Load Drop Jumps

During the AEL protocol the subjects performed five sets of six AEL DJs (15 seconds between reps and three minutes between sets) from a drop height of 52 centimetres with dumbbells providing an AEL equal to 20% of their BM. These DJs were completed as normal, but upon hitting the bottom position of the CMJ (thighs parallel to the ground), the dumbbells were released allowing for the completion of the concentric phase without any additional load. At the end of every set the subjects self-reported their rating of perceived exertion (RPE) using the ten point Borg scale [218].

In week three the subjects returned to the laboratory and completed the same protocol as outlined above. However, the volume was increased to 50 jumps (five sets of ten DJs). Between testing sessions subjects avoided all lower body plyometric training.

8.2.4 Statistical Analysis

Magnitude-based inferences (MBI's) were utilised in this study to describe the results rather than statistical significance. An Excel spread sheet was used to assess the effects between baseline scores and scores post intervention and between weeks one and three[197]. The magnitude of the difference was assessed by standardisation; that is, the difference between the means was divided by the standard deviation of the reference criteria.

For assessing the magnitude of standardised effects, threshold values of <0.2, 0.2, 0.6, 1.2 and >2 represent trivial, small, moderate, large and very large differences, respectively. Uncertainty in the estimates of effects was expressed at 90% confidence limits. Qualitative probabilistic inferences regarding the true effect were then made, as described in detail elsewhere [219]. In summary, if the probabilities of the true effect being substantially positive and negative were both >5%, the effect was expressed as unclear; otherwise, the effect was clear and expressed as the magnitude of its observed value. The scale for interpreting the probabilities was 25-74%, possibly, 75-94%, likely and >95% very likely.

8.3RESULTS

There were no clear effects when comparing the subjects RPE scores post intervention between week one and week three.

During CMJ testing in week one (Table 8-1) the subjects jump height was reduced compared to baseline immediately post intervention (ES = -0.38). After 48 hours the subjects jump height was found to have increased in comparison to baseline (ES = 0.26). During week three testing CMJ height increased 24 and 48 hours post intervention (ES = 0.47 and 0.29). Subjects CMJ height was reduced in week one compared to week three, post intervention, 1 and 24 hours later (ES = -0.37, -0.29 and -0.39).

Table 8-1.Countermovement jump height and squat jump height in weeks 1 and 3 and inferences for change in the means

Countermovement Jump Height (cm)

		Baseline	Post	1 Hour	24 Hours	48 Hours
Week 1	**Mean ± SD**	47.52 ± 5.49	45.15 ± 4.77	46.49 ± 5.12	47.42 ± 4.75	49.10 ± 4.18
	ES ± CI		-0.38 ± 0.28	-0.17 ± 0.18	-0.02 ± 0.30	0.26 ± 0.31
	Inference		Small**	Trivial*	Unclear	Small*
Week 3	**Mean ± SD**	47.40 ± 4.67	47.46 ± 3.85	48.28 ± 3.90	49.85 ± 4.48	48.91 ± 3.35
	ES ± CI		0.01 ± 0.28	0.17 ± 0.24	0.47 ± 0.29	0.29 ± 0.40
	Inference		Unclear	Trivial*	Small***	Small*
Comparison Week 1 to Week 3	**ES ± CI**	0.02 ± 0.27	-0.37 ± 0.25	-0.29 ± 0.26	-0.39 ± 0.18	-0.15 ± 0.45
	Inference	Unclear	Small**	Small*	Small***	Unclear

Squat Jump Height (cm)

		Baseline	Post	1 Hour	24 Hours	48 Hours
Week 1	**Mean ± SD**	43.67 ± 6.39	41.92 ± 4.76	42.92 ± 5.36	44.22 ± 4.72	45.68 ± 4.21
	ES ± CI		-0.24 ± 0.35	-0.10 ± 0.26	0.08 ± 0.28	0.28 ± 0.24
	Inference		Small*	Trivial*	Unclear	Small*
Week 3	**Mean ± SD**	44.26 ± 5.21	44.38 ± 3.92	46.06 ± 4.05	46.95 ± 3.56	48.91 ± 3.35
	ES ± CI		0.02 ± 0.24	0.31 ± 0.31	0.46 ± 0.30	0.73 ± 0.32
	Inference		Unclear	Small*	Small**	Moderate***
Comparison Week 1 to Week 3	**ES ± CI**	-0.08 ± 0.46	-0.34 ± 0.29	-0.44 ± 0.26	-0.38 ± 0.24	-0.40 ± 0.34
	Inference	Unclear	Small**	Small**	Small**	Small**

Note: Values are mean ± SD; ±90% confidence limits. Trivial and small inference: *possibly, 25 - 74%; ** likely, 75-94%; *** very likely >95%. Changes relative to baseline performance and to week 1 in week to week comparison

During SJ testing in week one the subjects jump height was reduced compared to baseline immediately post intervention (ES = -0.24). After 48 hours the subjects jump height was found to have increased in comparison to baseline (ES = 0.28). During week three testing SJ height increased 1, 24 and 48 hours post intervention (ES = 0.31; 0.46 and 0.73). Subjects SJ height was reduced in week one compared to week three, post intervention, 1, 24 and 48 hours later (ES = -0.34, -0.44, -0.38 and -0.40).

During squat testing in week one (Table 8-2) concentric PF was reduced compared to baselineone-hourpost intervention (ES = -0.22). During week three testing concentric PF was reduced compared to baseline immediately post intervention (ES = -0.30). After 48 hours the subjects concentric PF was found to have increased (ES = 0.32). Subject's concentric PF was reduced in week one compared to week three24 and 48 hours post intervention (ES = -0.23 and -0.32).

During week one eccentric PF was reduced compared to baseline, immediately post intervention, 24 and 48hrs later (ES = -0.31, -0.22 and -0.22). During week three eccentric PF increased after 24 and 48 hours (ES = 0.22 and 0.48). Subject's eccentric PF was reduced in week one compared to week three, post intervention and 48 hours later (ES = -0.24, and -0.50).

During week one CK (Table 8-3) increased from rest, pre intervention, 1 hour and 24 hours later (ES = 0.46, 0.55 and 0.93). During week three testing CK increased from rest post intervention, 1 hour and 24 hours later (ES = 0.30, 0.23 and 0.56). Subjects CK levels was smaller in week onecompared to week three at rest and post intervention (ES = -0.56 and -0.65).

Table 8-2. Concentric and eccentric peak force during the Exerbotics squat in week 1 and week 3 and inferences for change in the means

Concentric Peak Force (Newtons)

		Baseline	Post	1 Hour	24 Hours	48 Hours
Week 1	**Mean ± SD**	2176.59 ± 640.23	2084.00 ± 675.38	2017.18 ± 632.59	2214.26 ± 760.17	2209.70 ± 737.70
	ES ± CI		-0.13 ± 0.20	-0.22 ± 0.14	-0.01 ± 0.26	0.05 ± 0.21
	Inference		Trivial*	Small*	Unclear	Trivial**
Week 3	**Mean ± SD**	2217.06 + 618.04	2096.89 ± 626.65	2006.15 ± 520.63	2349.50 ± 585.06	2442.69 ± 581.01
	ES ± CI		-0.17 ± 0.20	-0.30 ± 0.33	0.19 ± 0.16	0.32 ± 0.18
	Inference		Trivial*	Small*	Trivial*	Small**
Comparison Week 1 to Week 3	**ES ± CI**	-0.06 ± 0.11	-0.02 ± 0.16	0.02 ± 0.30	-0.23 ± 0.35	-0.32 ± 0.36
	Inference	Trivial***	Trivial**	Unclear	Small*	Small*

Eccentric Peak Force (Newtons)

		Baseline	Post	1 Hour	24 Hours	48 Hours
Week 1	**Mean ± SD**	2524.85 ± 733.57	2266.11 ± 756.83	2413.26 ± 649.69	2409.06 ± 634.80	2343.36 ± 589.64
	ES ± CI		-0.31 ± 0.25	-0.14 ± 0.30	-0.22 ± 0.33	-0.22 ± 0.37
	Inference		Small**	Trivial*	Small*	Small*
Week 3	**Mean ± SD**	2403.45 ± 657.78	2462.31 ± 534.88	2399.77 ± 677.65	2568.99 ± 508.46	2759.06 ± 607.56
	ES ± CI		0.08 ± 0.22	0.00 ± 0.35	0.22 ± 0.30	0.48 ± 0.29
	Inference		Trivial**	Unclear	Small*	Small**
Comparison Week 1 to Week 3	**ES ± CI**	0.15 ± 0.28	-0.24 ± 0.22	0.02 ± 0.29	-0.16 ± 0.31	-0.50 ± 0.33
	Inference	Trivial*	Small*	Unclear	Trivial*	Small**

Note: Values are mean ± SD; ±90% confidence limits. Trivial and small inference: *possibly, 25 - 74%; ** likely, 75-94%. Changes relative to baseline performance and to week 1 in week to week comparison

Table 8-3.Creatine kinase values in week 1 and week 3 and inferences for change in the means

Creatine Kinase

		Rest	**Pre**	**Post**	**1 Hour**	**24 Hours**	**48 Hours**
Week 1 Comparisons to Rest	**Mean ± SD**	223.38 ± 77.42	276.29 ± 115.26	238.88 ± 88.71	271.25 ± 105.43	304.75 ± 83.78	246.63 ± 69.67
	ES ± CI		0.46 ± 0.47	0.18 ± 0.36	0.55 ± 0.32	0.93 ± 0.67	0.27 ± 0.53
	Inference		Small**	Trivial*	Small***	Moderate***	Unclear
Week 3 Comparisons to Rest	**Mean ± SD**	262.43 ± 116.25	285.00 ± 120.65	303.00 ± 132.26	288.50 ± 158.16	337.29 ± 136.34	302.17 ± 108.18
	ES ± CI		0.17 ± 0.15	0.30 ± 0.34	0.23 ± 0.24	0.56 ± 0.50	0.11 ± 0.82
	Inference		Trivial*	Small*	Small*	Small**	Unclear
Comparison Week 1 to Week 3	**ES ± CI**	-0.56 ± 0.62	-0.10 ± 0.95	-0.65 ± 0.83	-0.15 ± 1.29	-0.15 ± 1.29	-0.23 ± 0.92
	Inference	Small**	Unclear	Moderate**	Unclear	Unclear	Unclear

Note: Values are mean ± SD; ±90% confidence limits. Trivial, small and moderate, large and very large inference: *possibly, 25 - 74%; ** likely, 75-94%; *** very likely >95%. Changes relative to baseline performance and to week 1 in week to week comparison

In week one there was an increase in quadriceps SOR after 1, 24 and 48 hours (ES = 0.49, 1.70 and 1.09) (Table 8-4). In week three prior to the intervention there was a reduction in SOR (ES = -0.24). After 24 hours there was an increase in SOR (ES = 0.64). Subject's quadriceps SOR was greater in week one compared to week three, 1 hour and 48 hours post intervention (ES = 0.61 and 1.09).

In week three after 1 hour and 24 hours there was an increase in hamstring SOR (ES = 1.89 for both). Hamstring SOR was smaller in week one compared to week three,1 hour post intervention (ES = -0.47).

During squatting SOR scores increased during week one immediately post intervention, 24 and 48 hours later (ES = 0.63, 2.51 and1.57). In week three there was a reduction in SOR prior to the intervention (ES = -0.21) and an increase after 24 hours (ES = 1.72).

Table 8-4.Muscle Soreness (10 point VAS Scale) in Week 1 and Week 3 and Inferences for Changes in the Means

		Rest	Pre	Post	1 Hour	24 Hours	48 Hours
Quadriceps Soreness							
Week 1 Comparisons to Rest	**Mean ± SD**	0.63 ± 0.92	0.50 ± 0.76	0.63 ± 0.52	1.13 ± 0.64	2.38 ± 2.20	1.75 ± 1.83
	ES ± CI		-0.12 ± 0.23	0.00 ± 0.49	0.49 ± 0.49	1.70 ± 0.97	1.09 ± 0.73
	Inference		Trivial*	Unclear	Small**	Large***	Moderate***
Week 3 Comparisons to Rest	**Mean ± SD**	0.75 ± 1.39	0.38 ± 1.06	0.50 ± 1.07	0.75 ± 1.16	1.75 ± 1.75	0.63 ± 1.06
	ES ± CI		-0.24 ± 0.22	-0.16 ± 0.30	0.00 ± 0.32	0.64 ± 0.32	-0.08 ± 0.74
	Inference		Small*	Trivial*	Unclear	Moderate***	Unclear
Comparison Week 1 to Week 3	**ES ± CI**	0.24 ± 0.58	0.12 ± 0.73	0.12 ± 0.64	0.36 ± 0.48	0.61 ± 0.85	1.09 ± 1.12
	Inference	Unclear	Unclear	Unclear	Small*	Unclear	Moderate**
Hamstring Soreness							
		Rest	**Pre**	**Post**	**1 Hour**	**24 Hours**	**48 Hours**
Week 1 Comparisons to Rest	**Mean ± SD**	0.25 ± 0.71	0.13 ± 0.35	0.13 ± 0.35	0.50 ± 0.53	1.00 ± 1.41	0.25 ± 0.46
	ES ± CI		-0.16 ± 0.30	-0.16 ± 0.30	0.31 ± 0.60	0.94 ± 1.33	0.00 ± 0.45
	Inference		Trivial*	Trivial*	Unclear	Unclear	Unclear
Week 3 Comparisons to Rest	**Mean ± SD**	0.13 ± 0.35	0.25 ± 0.71	0.38 ± 1.06	0.88 ± 1.13	0.88 ± 1.33	0.63 ± 1.41
	ES ± CI		0.31 ± 0.60	0.63 ± 1.19	1.89 ± 1.49	1.89 ± 1.96	1.26 ± 2.55
	Inference		Unclear	Unclear	Large***	Large**	Unclear
Comparison Week 1 to Week 3	**ES ± CI**	0.00 ± 0.90	-0.16 ± 0.70	-0.31 ± 0.98	-0.47 ± 0.63	0.16 ± 1.14	-0.47 ± 1.35
	Inference	Unclear	Unclear	Unclear	Small**	Unclear	Unclear

Note: Values are mean ± SD; ±90% confidence limits. Trivial, small and moderate, large and very large inference: *possibly, 25 - 74%; ** likely, 75-94%; *** very likely >95%. Changes relative to baseline performance and to week 1 in week to week comparison

Quadriceps Soreness during Squatting

		Rest	Pre	Post	1 Hour	24 Hours	48 Hours
Week 1 Comparisons to Rest	**Mean ± SD**	0.13 ± 0.35	0.25 ± 0.46	0.38 ± 0.52	0.25 ± 0.71	1.13 ± 1.46	0.75 ± 1.04
	ES ± CI		0.31 ± 0.60	0.63 ± 0.78	0.31 ± 0.60	2.51 ± 2.01	1.57 ± 1.25
	Inference		Unclear	Moderate**	Unclear	Very Large***	Large***
Week 3 Comparisons to Rest	**Mean ± SD**	0.38 ± 0.52	0.25 ± 0.46	0.50 ± 0.93	0.38 ± 0.74	1.38 ± 1.51	1.13 ± 1.55
	ES ± CI		-0.21 ± 0.41	0.21 ± 0.74	0.00 ± 0.87	1.72 ± 1.51	1.29 ± 1.71
	Inference		Small*	Unclear	Unclear	Large***	Unclear
Comparison Week 1 to Week 3	**ES ± CI**	0.31 ± 0.60	0.00 ± 0.90	-0.31 ± 1.67	-0.31 ± 0.60	-0.63 ± 2.34	-0.94 ± 2.69
	Inference	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear

Note: Values are mean ± SD; ±90% confidence limits. Trivial, small and moderate, large and very large inference: *possibly, 25 - 74%; ** likely, 75-94%; *** very likely >95%. Changes relative to baseline performance and to week 1 in week to week comparison

8.4DISCUSSION

Before utilising a new training method, it is important that athletes and coaches be fully aware of any negative side effects that may occur. This appears to be the first study to assess the effects of a bout of AEL DJs on PF, jump performance, CK and SOR in resistance trained athletes. Despite the increase in DJ volume from week one to week three, there was no increase in subjects RPE scores. It should also be noted that there was no differences in the baseline values between week one and three in jump performance, SOR and only trivial differences between baseline PF measures between bouts.

A loss of strength after eccentric exercise has been suggested as a valid indirect measure of EIMD [220]. Thus the finding that concentric PF was reduced until 24 hours post intervention in week one and three and eccentric PF still after 48 hours in week one suggests that the AEL DJs did result in some EIMD rather than fatigue alone [217]. It should be noted that the magnitudes of these differences from the pre-tests were only trivial to small. Previously Paulsen et al. [178] have proposed that a decline in force production of no more than 20% would be classified as mild EIMD. In this current study the maximum reduction in concentric force was 7% in week one and 9% in week three. When examining eccentric force the maximum reduction was 10% after the first bout with no reductions in PF reported after the second bout. Therefore based on the classification by Paulsen et al. [178],theAEL DJs resulted in only mild EIMD.

Immediately after the initial bout of AEL DJs, there was a decrease in CMJ performance.However 48 hours post intervention an increase in CMJ performance was reported. After the 2nd bout of AEL DJs CMJ performance was enhanced when compared to baseline 24 and 48 hours post intervention. In comparison to week one greater CMJ performance was reported in week three immediately post, 1 and 24 hours later. We have previously reported a strong relationship between eccentric PF and CMJ performance [192]. Therefore it is suggested the absence of reductions in eccentric PFafter the second bout resulted in the subjects being able to produce enhanced CMJ performances post intervention in comparison to week one.

After the initial bout of AEL DJs,SJ performance was initially decreased in agreement with previous studies [45, 217]. However, after the 2nd bout of AEL DJs there were no reductions in SJ performance reported at any time point post intervention. In addition, despite the increase in AEL DJ volume in the second bout SJ performance was also greater at all post intervention time points compared to the initial bout. Based on the results from both the CMJ and SJ, the use of AEL DJs resulted in small decrements in jumping performance in resistance-trained athletes, which returned to baseline levels within 24 hours.

Previously CK has been proposed to be a marker of EIMD [168]. This is due to eccentric exercise resulting in increased muscle membrane damage and therefore permeability [168]. After the 1st bout increases in CK were reported until 48 hours post intervention. In agreement with previous DJ research CK peaked after 24 hours [45, 217]. When examining CK after the second bout the values peaked 24 hours post intervention before starting to decline after 48 hours. Despite the increase in volume and a higher pre-test value after the second bout of AEL DJs, the only observed difference to week one was greater CK levels immediately post intervention. In comparison to previous studies that have used untrained subjects[45, 217], the resting values reported in this current study are higher. However, it is proposed that in the previous studies the subjects had not completed any training prior to testing. In this study despite the subjects resting for 48 hours prior to baseline testing they may still have had elevated CK levels due to prior training sessions.

When utilising untrained subjects,Miyama et al [217]reported the magnitude of SOR to be greatest in the quadriceps 48 hours after completing a DJ intervention. In contrast in this current study after both bouts of AEL DJs SOR was found to peak 24 hours post intervention in the quadriceps. However, upon examining these scores in relation to the VAS subjects reported very low levels of muscle soreness that do not appear to have affected either jump performance or PF production. Despite the increase in AEL DJ volume in the second boutthere were no differences in quadriceps SOR reported during a squatting pattern compared to the initial bout.

Previous research investigating the effects of eccentric exercise has reported that resistance-trained subjects are less susceptible to EIMD compared to non-resistance trained subjects[38]. In this current study despite the addition of an AEL the subjects did not suffer large degrees of EIMD and performance decreases in comparison to other DJ research utilising non-trained subjects[45, 217]. Newton et al. [38]proposed that resistance-trained subjects whom regularly experienced both concentric and eccentric contractions may have got a similar protective effect to subjects in studies reporting a repeated bout effect (RBE). A number of mechanisms for the RBE have been proposed which include, increased motor unit activity, increased slow twitch muscle fibre recruitment and increased motor unit synchronisation, the strengthening of cell membranes, removal of weak fibres, the adding of sarcomeres in series and strengthening the sarcoplasmic reticulum after an initial bout of exercise[131, 168]. Despite the suggestion that resistance-trained athletes may be less susceptible to

EIMDas a result of their training history[38],the exact mechanisms that lead to this is currently unknown and therefore further research is warranted.

In conclusion, this study investigated the effects of AEL DJs on markers of muscle damage after 30 and 50 jumps. It would appear that in resistance-trained athletes the use of an AEL DJ protocol results in only minor EIMD and decreases in performance which have recovered to baseline levels within 48 hours. At present the exact mechanisms that result in a protective effect in resistance-trained athletes is unknown and therefore further research is required to identify these.

8.5 PRACTICAL APPLICATIONS

Athletes who are engaged in regular resistance training do not appear to suffer large degrees of EIMD as a result of completing AEL DJs. When starting to utilise AEL DJswith resistance-trained athletes initially they should complete a small volume of jumps (~30) prior to increasing the volume in subsequent weeks. This appears to result in minimal EIMD with any decreases in performance returning to baseline after 48 hours. Thereforewhen first including this type of training the S&C coach should allow 48 hours between sessions to allow a full recovery prior to the next session or before any competition to avoid any negativeinfluence on performance.

Chapter 9

Summary, Practical Applications and Future Research Directions

9.1 General Summary

The overarching aims of this thesis were to investigate the relationships between eccentric strength and athletic performance and the acute and chronic effects of AEL DJs on strength, power and EIMD. Initially two literature reviews, which investigated different eccentric training modalities and eccentric EIMD, were conducted.

The initial experimental study in this thesis (chapter four) assessed the test-retest reliability of a novel squat device (Exerbotics) that was capable of independently assessing concentric and eccentric PF during a multijoint movement.Across the three weeks the mean concentric PF CV and ICC was 10% and 0.95 respectively and the mean eccentric PF CV and ICC was 7.2% and 0.90 respectively. The Exerbotics squat device shows good test-re-test reliability and therefore was used in the final study of this thesis to assess changes across time in PF after completing bouts of AEL DJs.

The relationships between concentric and eccentric PF during the Exerbotics squat and CMJ performance was investigated in Study two (chapter five). A very large relationship was found between absolute eccentric PF, absolute CMJ PP and CMJ height. The results of this study suggest that high levels of eccentric strength may lead to enhancements in force production during the concentric phase of the movement and increases in jump height. Therefore increases in lower body eccentric PF may enhance vertical jump performance. As a consequence of these findings investigating methods to enhance lower body eccentric PF will be of interest to S&C coaches.

Chapter six sought to build further on the findings from the previous chapter by investigating the relationships between concentric and eccentric strength and athletic performance as well as investigating the relationships between DJ performance, speed and COD. Concentric absolute PF had a large positive relationship with 10m, 30m and 40m sprint times, whilst eccentric absolute PF had a moderate positive relationship with sprint times. There was a large negative relationship between DJ height and all sprint distances and a very large negative relationship with COD performance. RSI had a moderate negative relationship with sprint times and a large negative relationship with COD times. These large negative relationships between DJ height, RSI and sprint times are proposed to be the result of the DJ exercises mimicking the joint angles, contraction velocities and SSC function which is associated with maximal velocity sprinting [109]. The results of this study suggest that if an athlete wishes to enhance sprint and COD times utilising the DJ they should focus on enhancing their DJ height.

As identified in chapter five an increase in lower body eccentric force production may be beneficialto enhancing vertical jump performance. Therefore research into methods that could enhance eccentric force production would be of interest.Previous research has investigated the effects of plyometric activities on PAP and its influence on acute performance [19, 21-24, 207]. Although research has investigated the effects of unloaded DJs on subsequent performance, very little research existed on the acute effects of AEL DJs. Therefore, the aim of chapter seven was to investigate the acute effect of AEL DJs on CMJ performance.In this study, the 20% AEL condition resulted in greater CMJ height in comparison to all the other conditions ($p< 0.001$). CMJ height was significantly greater after two and six minutes rest compared to 12 minutes ($p< 0.001$ and $p< 0.05$ respectively). It has previously been proposed that plyometric exercises lead to the preferential recruitment of type II motor units resulting in improvements in subsequent explosive movements such as the CMJ [23]. The AEL in this study may have resulted in increased type II motor unit recruitment during the initial DJs and therefore a greater subsequent PAP response. Other mechanisms which may explain the increased PAP response in the AEL conditions include an increase in muscle temperature as a consequence of the greater eccentric load resulting in higher muscular activation, increased storage and recoil of elastic energy and enhanced phosphorylation of the MLC[23]. In addition, the short recovery time required following the DJs compared to heavy resistance exercises such as the squat may be a result of reductions in system mass [205]. This reduced system mass results in less fatigue and therefore less recovery time post PAP stimulus is required.

Based on these findings, if an S&C coach or athlete wishes to utilise AEL DJs to enhance acute vertical jump performance, the inclusion of five DJs with an additional dumbbell load of 20% of an athlete's body mass during the eccentric phase only may be warranted. The athletes would then rest for two minutes prior to completing the vertical jump. This information may be of particular interest to athletes competing in jumping events such as the high jump.

Although the previous chapter found acute enhancements in CMJ performance with low volumes of AEL DJs (5 DJs) no research has investigated the effects of greater volumes of AEL DJs (30+ DJs) on EIMD and athletic performance. Previous research utilising unloaded DJs has found these jumps resulted in EIMDas a result of the high eccentric forces during the DJs [45, 217]. Therefore it is not unreasonable to expect that by increasing the load during the eccentric phase of a DJ would result in EIMD and performance reductions. Thus prior to coaches and athletes introducing AEL DJs into training programmes, it is necessary to establish to what extent this exercise could impair training or competition performance.

This study indicated that in resistance-trained athletes completing AEL DJs only minor EIMD and decreases in performance resulted, which recovered to baseline levels within 48 hours. This may be due to resistance-trained athletes being accustomed to completing both concentric and eccentric contractions as part of their normal training routines[38]. Newton et al. [38]suggested the reason for this protective effect in resistance-trained athletes is similar to the repeated bout effect (RBE) described in previous DJ research [45, 217]. This protective effect is proposed to be due prior training/exercise resulting in adaptations which are either neural [116], mechanical [117], cellular [118] or a combination of these factors [116, 131].

Theresults of thefinal study indicate that resistance-trained athletes completing AEL DJs do not suffer large degrees of EIMD or decreases in strength and power. Therefore based on these findings and on those in previous chapters the inclusion of AEL DJs as part of a training programme may be warranted.

9.2 Practical Applications

The results of this thesis have provided insights into the utilisation of a novel squat device to assess concentric and eccentric PF and the use of AEL DJs that S&C coaches may wish to consider when programming training for their athletes in the future. The practical applications from this thesis include:

1. The Exerbotics squat device provides reliable assessments of both concentric and eccentric PF. Therefore this device may be utilised by S&C coaches to monitor changes in PF production as a consequence of planned resistance training or due to EIMD. It should be noted here however, when using this

device athletes need to spend time familiarising themselves with the device to ensure that they can achieve their maximum force generating capability.

2. In strength trained athletes there was a strong relationship between lower body eccentric strength and CMJ performance. Therefore the inclusion by S&C coaches of lower body eccentric strength exercises for their athletes may lead to enhancement in vertical jump performance. Examples of exercises which may be considered include supramaximal squatting (single sets of 1repetition (three – ten sets), 110 – 130% concentric 1RM), DJs (three sets of 5 – 12 repetitions, twice a week) and AEL CMJs (2 x 5 repetitions, twice a week for five weeks).

3. Due to the findings of a relationship between DJ variables (DJ height, flight time and RSI) and 10, 30 and 40m sprint and CODtimes the inclusion of DJs as part of a periodised programme may be warranted to improve these important athletic qualities.

4. Coaches utilising the DJ to enhance sprint and COD performance in athletes should focus on enhancing their maximal DJ height.

5. Coaches wishing to enhance athlete'sacute vertical jump performance could employ an AEL DJ protocol. Athletes would (approximately two minutes prior to competing) complete five AEL DJs during their warm up (from the drop height previously identified) with an additional load of 20% (body mass) to potentiate subsequent vertical jump performance.

6. When incorporating AEL DJs into a training programme starting with a small number (week one – four sets of eight repetitions twice a week) before progressing to higher volumes as training progresses (week four – four sets of 12 repetitions twice a week) will result in minimal EIMD (chapter eight).

9.3 Limitations

The following limitations of this thesis are noted:

1. Although the Exerbotics squat device was reliable for assessing concentric and eccentric peak force, it should be noted that during the reliability study and subsequently in chapter five greater levels of concentric force compared to eccentric force were reported. These results are unexpected as it is generally accepted that eccentric PF is greater than concentric PF. However, it should be noted that in chapter six and chapter eight using the same device eccentric PF was higher than concentric PF.

2. Throughout the experimental chapters in the thesis explanations are proposed for the results of the studies. However, the underlying mechanisms could have been explored in more detail through the use of methods such as ultrasound, EMG and muscle biopsies and should be the focus of future research in this area

3. Despite the inclusion of a case study in the appendix investigating the inclusion of AEL DJs within a training programme, the limited number of subjects meant they have been considered individually rather than as a

group. This therefore reduces the power of the study and makes it harder to extrapolate the results to similar groups of athletes.

9.4 Future Research Directions

This thesis investigated the acute and chronic effects of AELDJs on athletic performance and EIMD. The practical applications derived from the thesis provide directions for future research including:

1. In chapter five a relationship between eccentric strength and CMJ performance was reported. However, this relationship was not found to exist when examining team sport athletes (rugby union players) in chapter six. Therefore further investigation into the influence of eccentric strength on jump performance across a variety of sports and athletes is warranted.

2. The use of AEL DJs with a horizontal jump upon landing as opposed to a vertical jump should also be investigated as this may result in greater subsequent enhancements in sprint and change of direction performance than the vertical AEL DJ alone.

3. During chapter seven the optimal DJ height for each subject was established during unloaded DJs. Further studies that investigate the relationship between AEL and drop height may be of interest.

4. Resistance-trained athletes suffered minimal EIMD as a result of completing AEL DJs (chapter eight). However, as yet the mechanisms that protect these athletes from EIMD have only been speculated upon. Therefore further research is required to identify the mechanisms responsible.

5. Although a case study investigating the use of AEL DJs as a training intervention has been included in Appendix 2, further research into its effectiveness with a larger number of subjects is required. Future research should investigate whether it results in a superior training effect to completing a DJ training intervention with no AEL.

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Appendices

Appendix 1: Individual Subjects Smallest Worthwhile Change from Chapter 7. The Effects of Accentuated Eccentric Loading on the Drop Jump Exercise and the Subsequent Postactivation Potentiation Response

Table 1. Smallest worthwhile change (SWC) for individual subjects at different time points post DJ in each condition (* indicates SWC achieved)

Subject number	BW			10% AEL			20% AEL			30% AEL		
	2mins	6mins	12mins	2mins	6mins	12mins	2mins	6mins	12mins	2mins	6mins	12mins
1	54.1	54.1	53.1	47.6	50.9	48.9	55.9	54.6	53.3	51.9	50.8	50.3
2	50.9*	48.6*	46.7	50.3*	49.7*	45.5	47.5*	48.2*	47.8*	51.4*	48.1*	48.1*
3	45.70	44.8	42.6	43.2	42.2	44.3	49.9*	48.4*	44.3	47.4	43	42.6
4	50.8*	49.1	49.2	51.5*	52.1*	52	50.3*	51.6*	51.7*	50.8*	52.5*	50.3*
5	52.6	51.6	52.6	57.5*	54.8*	53.4	57.7*	54.4	52.7	49.8	51.3	50.6
6	41.4	40.5	41.8	41.8*	39.8	40.9	43.8*	43.0*	41.3	41.8	41.9*	42.2*
7	49.6	49.3	48.4	49.5	50.2*	49.4	52.6*	51.9*	51.5*	51*	51.4*	51.9*
8	49.4	50.2	47.9	48.2	49.8	48.7	51.8*	52.3*	49.8	50.9	50.6	49.3
9	49.7*	45.7	44.4	45.2	44.5	42.9	50.5*	45.9	44.6	46.8	43.1	43.6
10	54.5*	51.8	51.9*	54.3*	53.9*	55.4*	56.5*	58.9*	56.9*	57.5*	57.8*	55.3*
11	46.1	44.8	43.0	44.9	42.9	41.8	46.4	46.6*	44.4	42.1	43.4	43.6
12	55.7	53.9	52.4	54.9	54.1	51.6	56.7	57.4	53.3	56.8	53.8	52.1

To establish the smallest worthwhile change (SWC) in CMJ height for each subject the between-subject standard deviation for the three baseline CMJs was calculated and this number multiplied by 0.2 [221].

Examining the individual subjects SWC in CMJ height following the different DJ it was found that 25% achieved their individual SWC in the BW condition, 42% in the 10% additional load condition, 83% in the 20% additional load condition and 42% in the 30% additional load condition.

When examined as a group the 20% AEL DJ condition and two minutes recovery time was found to result in the greatest improvement in subsequent CMJ performance. However, when investigating individual subjects SWC a small number achieved optimal performance improvements in the 10% and 30% AEL DJ conditions and after a six recovery. Therefore in agreement with previous research whenever possible loads and recovery times should be individualised to optimise the PAP response [110, 222].

Appendix 2: A Case Study Investigating the Effects of an Accentuated Eccentric Load Drop Jump Training Programme on Strength, Power, Speed and Change of Direction

LEAD SUMMARY

The aim of this study was to assess the chronic effects of AEL DJs and unloaded DJs on concentric and eccentric strength, jumping, speed and COD. Eight academy rugby union players (mean ± SD; age: 18.7 ± 1.0 years; height: 180.5 ± 5.9 cm; mass: 92.7 ± 10.7 kg) were assigned to either an AEL or unloaded DJ group. Subjects performed DJ training twice a week for four weeks as part of their normal training program. In this study changes in the CV were used to calculate meaningful changes in individual subjects performancesWhen examining the CMJ results four out of five subjects achieved their individual targets post intervention in the AEL DJ group. In the BW DJ group one out of the three subjects achieved their individual meaningful change score. When examining the SJ all of the subjects in both groups achieved their target scores post intervention. Three out of the five subjects achieved their target scores in the DJ exercise after completing the AEL DJ. While one out of the three BW DJ subjects achieved their DJ target post intervention. When examining the sprint performance results achieved post intervention two subjects in the AEL group achieved their target scores over 10m and one over 30m. During COD testing two subjects in the AEL DJ group and one subject in the BW group achieved their target scores. The results of this study suggest that the inclusion of four weeks of AEL DJ training can enhance athletic performance and in particular vertical jump ability.

INTRODUCTION

The drop jump (DJ) is a high intensity plyometric exercise [223] which can be utilised to overload the eccentric portion of a muscle action [52]. When performing a DJ, an athlete drops down from a raised platform and upon making contact with the ground completes an explosive vertical or horizontal jump [98]. Previously it has been suggested that the DJ is a fast stretch shortening cycle (SSC) exercise as it results in a short ground contact time (<250 milliseconds) [195]. Thus it has been proposed that DJs may be utilised to enhance athletic performance during fast SSC actions [52]. Studies which have investigated the use of the DJ have reported improvements in sprint performance [22, 27, 203], agility [32] time trial performance [27] jumping [19, 23, 27, 31, 101], strength [224] and throwing performance [21]. Therefore the use of the DJ may be beneficial for enhancing athletic performance.

When programming the DJ into a resistance training program it has been reported that a moderate training frequency and volume of jumps (2 days a week, 840 jumps over 7 weeks) produced similar enhancements in jump performance compared to a higher volume and frequency of DJs (4 days per week, 1680 jumps over 7 weeks) [25]. This led the authors to conclude that a moderate DJ training frequency and volume resulted in a greater training efficiency [25]. When investigating rest periods between DJs Read and Cisar[108] reported that 15 seconds rest between repetitions was a sufficient rest period between DJs to maintain performance. Based on these findings Bridgeman et al. [52] proposed that three sets of eight to ten DJs, two times a week with 15 seconds between repetitions and three minutes between sets may be optimal.

The intensity of a DJ can be manipulated by altering the height from which a subject drops [20]. As DJ height increases so does ground reaction forces upon landing which increases exercise intensity [102-104]. Alternatively changing the body mass of an athlete completing a DJ can alter the exercise intensity. However, when using a constant additional mass in the form of a weighted vest during both the eccentric and concentric phase of a DJ, it was reported that a change in drop height more effective way of manipulating intensity [103].

Another method which can be utilised to alter the intensity of a DJ is additional load added in the form of dumbbells or elastic bands during the eccentric portion of the exercise only, with this termed accentuated eccentric loading (AEL) [33]. Utilising this method Aboodarda et al. [34] used elastic bands to increase the force during the eccentric phase of a DJ by 20 and 30% of body mass (BM). The results indicated that the additional eccentric load resulted in enhanced eccentric impulse and rate of force development (RFD). However, there was no increase in jump height or concentric muscle activation [34]. In a subsequent study Bridgeman et al. [215] reported that 5 DJs with an AEL of 20% BM resulted in acute enhancements in subsequent countermovement jump (CMJ) jump height and peak power (PP). In addition Hughes et al. [225] reported that DJs completed with an AEL of 5% of each subjects body mass resulted in a significant improvement in subjects subsequent CMJ performance. Therefore the use of AEL during the DJ exercise appears promising. However, at present researchers have only studied the acute effects of AEL DJs and therefore the use of AEL DJs, as part of a training intervention requires investigation.

Although previous studies have investigated the effects of DJ training interventions and the acute effects of AEL DJs as yet, none have investigated the use of AEL DJs as a training intervention. Therefore the aim of this case study was to investigate the effects of an AEL DJ intervention on strength, jump performance, speed and COD in rugby union athletes.

METHODS

Experimental Approach to the Problem

This was a case study conducted with academy rugby union athletes. Subjects were divided into two training groups that performed either AEL DJs (*n* = 5) or unloaded DJs (*n* = 3) as part of their normal resistance training programs. The current study was performed during the player's representative playing season (July – September 2016). Overall the study lasted seven weeks and consisted of one week of familiarisation, one week of pre-testing, a four week training intervention and a week of post testing. To isolate, the effect of the different training protocols all additional resistance training between the two groups was matched. The tests to assess changes in performance utilised in this current study included CMJ, squat jump (SJ), DJ, 10 and 30m sprint and a 5-0-5 change of direction test (COD).

Subjects

Eight strength trained male rugby union athletes who were over 18 years of age (mean ± SD; age: 18.7 ± 1.0 years; height: 180.5 ± 5.9 cm; mass: 92.7 ± 10.7 kg; 1RM squat relative to BW = 1.65 ± 0.24) volunteered to participate in this study. All subjects had at least two years of strength training experience and were engaged in regular strength training (at least three times per week), prior to the start of the training intervention. All subjects provided written informed consent and the Auckland University of Technology Ethics Committee approved this study.

Procedures

Prior to the main testing, sessions subjects attended two laboratory sessions where they were familiarised with the Exerbotic squat testing and also the sprint warm-up and 5-0-5 COD test. During the squat familiarisation subjects, range of movement was established on the Exerbotics squat machine (eSQ, Exerbotics, LLC, Tulsa, OK) prior to the completion a maximal strength test. During this session, the subjects initially completed a three minute cardiovascular warm up (skipping) followed by ten body weight (BW) squats. The range of movement (ROM) on the Exerbotics was then established, this was based on the knee joint being set at 90° degrees flexion at the bottom of the squat and 170° between the thigh and leg at the top position [172].

Once the ROM was established each subject then completed a maximal strength test. During maximal testing, each subject used the handles, had the back pad on the top of their trapezius, feet shoulder width apart and toes turned slightly outwards. Maximal strength testing involved the completion of three continuous repetitions with concentric and eccentric actions lasting four seconds separated by a half second pause. During the first repetition, subjects were instructed to apply force at what they considered to be 50% of their maximum effort. During the next two repetitions, subjects were instructed to apply maximal force. The tester provided verbal encouragement to the subjects throughout, encouraging them to resist during the eccentric phase and push during the concentric phase of the squat. The reliability of this testing in our laboratory is high (concentric PF CV = 10% and eccentric PF CV = 7.2%) [188]. After 24 hours rest subjects then returned to the laboratory and were familiarised with the sprint warm up that would be used during testing and the 5-0-5 COD test.

Speed and Change of Direction Testing

Before testing the subjects completed a twenty-five minute dynamic warm-up on an indoor track. Each subject then completed three maximal 30m sprints (five minutes recovery between trials). SWIFT dual beam Speedlight gates (Speed Light V2 gate, Swift, Wacoi, QLD, Australia) were set up at the start line and at 10 and 30m to capture timing splits. During this testing subjects started 50cm behind the first timing light and adopted a split stance position with their preference of lead leg before being given the command to go. The mean times for the 10m (Baseline CV = 1.3%) and 30m (Baseline CV = 0.7%) splits were calculated from the three trials and used in further analysis.

Upon completion of the sprint testing and after a further five minute recovery period the subjects then completed four 5-0-5 runs. During this testing, two timing gates (SWIFT Speedlight) were placed five metres from the turning point. Subjects began their run from a start position 10m from the timing gates (15m from the turning point). The subjects were told to accelerate as quickly as possible towards the COD point and then return as quickly as possible through the timing lights [196]. Subjects completed four trials in a randomised order (Baseline CV = 1.4%); two changing directions with a left foot plant and two with a right foot plant. The average times for each leg were calculated, and the fastest COD leg was used for further analysis.

Jump and Strength Assessment

The subjects initially completed the warm up as described previously followed by ten BW squats, five CMJ’s and five SJ’s. Upon completion of the warm-up and after a three minute rest period they then completed three maximal CMJ (15 seconds between jumps). During the CMJ subjects squatted to a self-selected depth and were permitted to use their arms [192] whilst the tester provided verbal encouragement. After a further three minute rest period, subjects then completed three SJ's. During the SJ subjects squatted to parallel and held this position before completing the SJ. The variable of interest during both the CMJ (Baseline CV = 3.9%) and SJ (Baseline CV = 3.0%) was jump height (cm). All jumps were completed utilising the SwiftSpeedMat (Swift, Wacoi, QLD, Australia) with the mean of the three trials for each jump used in further analysis. After a three minute rest period, the subjects then completed three DJs from a height of 52cm onto the SwiftSpeedMat (30 seconds between jumps). During the DJs, the subjects were instructed to step off the box and then upon making contact with the ground immediately performing an explosive CMJ. The variable of interest during these DJs was jump height (JH) (Baseline CV = 4.5%). The means of the three jumps were used in further analysis. After a final five-minute rest period, subject's peak eccentric and concentric squat force (N) was assessed utilising the Exerbotics squat device as described previously.

At the end of the final pre intervention testing session, both group A and group B completed AEL DJs with a load of 20% of each subjects BM (Two sets of eight repetitions). This was done to ensure the subjects were familiar with the AEL DJ exercise prior to commencing training.

Training Intervention

During the training intervention, the subjects were randomly assigned to one of two groups. One group completed resistance training with unloaded DJs (n = 3) and the other completed AEL DJs (*n* = 5) (See Table 1 for an outline of the training program). All subjects attended ≥90% of the training sessions during the intervention period. The AEL DJs were completed as normal but when each subject hit the bottom position of the CMJ (thighs parallel to the ground) the dumbbells providing the AEL (20% of each subjects BM) were released allowing the subjects to complete the concentric phase of without any additional load. This 20% load was based on the previous finding by Bridgeman et al. [215] that this resulted in the greatest acute enhancement in CMJ performance. The 52cm drop height utilised during the intervention was based on the previous findings in our laboratory that this drop height resulted in minimal exercise-induced muscle damage with a 20% AEL[226] and when completing volumes similar to those utilised in this current study. During the training intervention all subjects completed supervised resistance training three times a week (Monday, Tuesday, and Thursday mornings), in addition, they also completed two field training sessions of approximately one hour in length (Monday and Wednesday evenings) and played one match per week (Saturday). The subjects performed AEL or unloaded DJs on Tuesday and Thursday each week. DJ volume was matched for the two groups over the four weeks with the only difference being that the DJs were either loaded or unloaded. After the four week training intervention the subjects returned to have their speed, COD, jump and concentric and eccentric PF reassessed utilising the same methodology as outlined previously.

Table 1. Outline of training intervention

Monday – Upper Body Focus				
	Week 1	Week 2	Week 3	Week 4
Exercise	Sets/Reps	Sets/Reps	Sets/Reps	Sets/Reps
1a.Bench Press	W/U 6,5,5,4,4	W/U 6,4,4,3,3	W/U 6,4,4,3,3	W/U 6,4,3,2 OR 1
1b. Row Option	6,6,5,5	5,5,5,5	5,5,4,4	6,4,3,2 or 1
2a. Military Press	W/U 6,5,5,4,4	W/U 6,4,4,3,3	W/U 6, 4,4,3,3	W/U 6,4,3,2 OR 1
2b. Heavy Shrug	6,6,6	6,6,6	5,5,5	4,4,4
3a. Underhand weighted chin	W/U 6,5,5,4,4	W/U 6,4,4,3,3	W/U 6,4,4,3,3	W/U 6,4,3,2 OR 1
3b. DB shoulder press	6,6,6	6,6,6	5,5,5	4,4,4
4. Nordic Hamstrings	5,5,5	5,5,5	5,5,5	5,5,5

W/U – warm up
Reps - repetitions
DB - dumbbell

Tuesday – Lower Body Focus				
[redacted] Exercise	Week 1 Sets/Reps	Week 2 Sets/Reps	Week 3 Sets/Reps	Week 4 Sets/Reps
1a.Back/Front Squat	W/U 6,5,5,5	W/U 6,5,5,5	W/U 6,5,4,4	W/U 6,4,3,2 OR 1
1b. DJ loaded or unloaded	8,8,8,8	8,8,8,8	10,10,10,10	12,12,12,12
2. Resisted 10m chain sprint	X3 – 5	X3 – 5	X3 – 5	X3 – 5
3a. Single leg option	6,6,5,5	5,5,4,4	5,5,4,4	4,4,3,3
3b. Bicep + Tricep option	10,10,10,10	8,8,8,8	8,8,8,8	6,6,6,6
4a. Hip Thrust	4,4,3,3	4,4,3,3	3,3,3,3	3,3,2,2
4b. Neck rotations	12,12,12,12	12,12,12,12	12,12,12,12	12,12,12,12
5. Core Circuit (plank, side plank (20-40secs), medicine ball supermans x 15	X3	X3	X3	X3

W/U – warm up
Reps – repetitions
DJ – drop jump

Thursday – Power Session				
[redacted] Exercise	Week 1 Sets/Reps	Week 2 Sets/Reps	Week 3 Sets/Reps	Week 4 Sets/Reps
1a. Olympic power snatch or clean	W/U 4,3,3,3	W/U 4,3,3,3	W/U 4,3,3	W/U 4,3,3,2 OR 1
1b. Explosive 5m prowler push	1,1,1	1,1,1	1,1,1	1,1,1
2a. 60kg band bench	W/U 4,3,3,3	W/U 4,3,3,3	W/U 4,3,3,3	W/U 4,3,3,3
2b. DJ loaded or unloaded	8,8,8,8	8,8,8,8	10,10,10,10	12,12,12,12
3. Banded kettle bell swing	5,5,4,4	5,5,4,4	4,4,3,3	4,3,3,3
4. 10m accelerations	X2 – 4	X2 – 4	X2 – 4	X2 – 4
5. Core Circuit (plank, side plank (20-40secs), medicine ball supermans x 15	X3	X3	X3	X3

W/U – warm up
Reps – repetitions
DJ – drop jump

Statistical Analysis

The coefficient of variation (CV) for the variables of interest during the baseline testing were calculated using an Excel reliability spread sheet [173]. Descriptive statistics (mean ± SD) was calculated for all the dependent variables (Tables2 and 3). Due to the small number of subjects in this study changes in the CV was used to calculate meaningful changes in individual subjects performances (Table 4) from pre to post intervention utilising the methods described by Turner et al. [221]. The following calculation was used to determine targets for each subject post intervention:

Individual subjects best performance – (best performance * ((group CV * 2) ÷ 100))

RESULTS

The results of the individual post intervention PF testing are displayed in table 3. With the exception of one subject in the AEL DJ group all of the subjects improved their concentric PF post intervention. Six of the eight subjects (one subject from each group did not) enhanced their eccentric PF production post intervention.

Individual subjects pre and post intervention jumping (CMJ, SJ and DJ), sprint and COD results are displayed in tables 2 and 3. Utilising the methods described by Turner [221] meaningful changes were calculated for each individual subject (Table 4).

When examining the CMJ results four out of five subjects achieved their individual targets post intervention in the AEL DJ group. In the BW DJ group one out of the three subjects achieved their individual meaningful change score. When examining the SJ all of the subjects in both groups achieved their target scores post intervention. Three out of the five subjects achieved their target scores in the DJ exercise after completing the AEL DJ. While one out of the three BW DJ subjects achieved their DJ target post intervention.

When examining the sprint performance results achieved post intervention two subjects in the AEL group achieved their target scores over 10m and one over 30m. No subjects in the BW DJ group achieved their target scores over either distance. During COD testing two subjects in the AEL DJ group and one subject in the BW group achieved their target scores.

Table 2. Individual subjects performance variables before and after the training interventions

Subject Number	Intervention Group	Mean CMJ Pre (cm)	Mean CMJ Post (cm)	Mean SJ Pre (cm)	Mean SJ Post (cm)	Mean DJ Height Pre (cm)	Mean DJ Height Post (cm)	Mean 10m Pre (secs)	Mean 10m Post (secs)	Mean 30m Pre (secs)	Mean 30m Post (secs)	Mean COD Pre (secs)	Mean COD Post (secs)
1	AEL	37.33 ± 0.58	38.67 ± 1.53	33.67 ± 1.53	39.00 ± 1.73	36.67 ± 2.52	39.33 ± 2.08	1.84 ± 0.01	1.67 ± 0.01	4.53 ± 0.01	4.00 ± 0.02	2.56 ± 0.00	2.44 ± 0.05
2	AEL	40.00 ± 1.80	49.00 ± 0.00	35.70 ± 1.31	41.67 ± 1.53	37.13 ± 2.84	51.00 ± 0.00	1.72 ± 0.01	1.76 ± 0.01	4.13 ± 0.01	4.13 ± 0.02	2.55 ± 0.00	2.26 ± 0.04
3	AEL	42.33 ± 0.58	50.67 ± 2.08	40.00 ± 1.00	46.67 ± 2.52	39.33 ± 1.53	43.33 ± 0.58	1.79 ± 0.05	1.76 ± 0.06	4.17 ± 0.06	4.20 ± 0.01	2.27 ± 0.04	2.18 ± 0.01
4	AEL	35.33 ± 0.58	40.00 ± 1.00	35.67 ± 0.58	39.67 ± 0.58	31.33 ± 0.58	35.67 ± 0.58	1.85 ± 0.02	1.85 ± 0.02	4.35 ± 0.02	4.43 ± 0.04	2.47 ± 0.03	2.4 ± 0.06
5	AEL	41.67 ± 1.53	44.00 ± 0.00	39.33 ± 1.53	44.67 ± 1.53	38.33 ± 1.53	42.00 ± 2.00	1.83 ± 0.01	1.83 ± 0.02	4.40 ± 0.02	4.39 ± 0.03	2.53 ± 0.13	2.41 ± 0.02
6	BW	45.33 ± 1.53	49.00 ± 0.00	40.33 ± 0.58	45.33 ± 0.00	38.33 ± 1.15	40.33 ± 1.15	1.74 ± 0.01	1.76 ± 0	4.15 ± 0.02	4.16 ± 0.03	2.29 ± 0.04	2.27 ± 0.03
7	BW	33.00 ± 2.00	37.33 ± 1.53	30.33 ± 1.15	36.33 ± 1.53	35.67 ± 1.53	37.67 ± 0.58	1.87 ± 0.04	1.86 ± 0.01	4.51 ± 0.06	4.51 ± 0.04	2.48 ± 0.08	2.46 ± 0.06
8	BW	55.67 ± 0.58	56.33 ± 1.53	49.00 ± 1.00	53.00 ± 1.53	50.33 ± 2.52	57.00 ± 1.00	1.71 ± 0.01	1.72 ± 0.02	4.09 ± 0.02	4.07 ± 0.03	2.30± 0.03	2.17 ± 0.09

AEL – Accentuated eccentric load
BW – Body weight
CMJ – countermovement jump
SJ – Squat jump
DJ – Drop jump
RSI – Reactive strength index
COD – 5-0-5 agility test

Table 3. Individual subjects concentric and eccentric force production (N)

Subject Number	Intervention Group	Concentric Peak Force Pre (N)	Concentric Peak Force Post (N)	Percentage change (%)	Eccentric Peak Force Post (N)	Eccentric Peak Force Post (N)	Percentage change (%)
1	AEL	2854.71	3158.82	10.65	3050.91	3570.84	17.04
2	AEL	1530.36	2364.21	54.48	2580.03	2913.57	12.92
3	AEL	2403.45	2795.85	16.32	3256.92	4149.63	27.40
4	AEL	2354.4	2285.73	-2.91	2795.85	2736.99	-2.10
5	AEL	3668.94	3904.38	6.40	3855.33	4316.40	11.95
6	BW	3198.06	3541.41	10.73	3453.12	3767.04	9.09
7	BW	2962.62	3119.58	5.29	3659.13	4120.20	12.6
8	BW	2697.75	3031.29	12.36	3109.77	3090.15	-0.63

AEL – Accentuated eccentric load
BW – Body weight
N – Newtons
Pre – pre-intervention
Post – post-intervention

Table 4. Targets for each subject based on initial pre-intervention testing and testing results achieved post intervention

Subject Number	Intervention Group	CMJ Target (cm)	Best CMJ (cm)	SJ Target (cm)	Best SJ (cm)	DJ Height Target (cm)	Best DJ Height (cm)	10m Target (secs)	Best 10m (secs)	30m Target (secs)	Best 30m (secs)	COD Target (secs)	Best COD (secs)
1	AEL	40	40	37	40	43	41	1.79	1.67	4.48	3.99	2.46	2.40
2	AEL	44	49	39	43	43	51	1.67	1.76	4.07	4.14	2.45	2.23
3	AEL	46	53	43	49	45	44	1.69	1.76	4.08	4.19	2.15	2.17
4	AEL	38	41	38	40	35	36	1.80	1.83	4.28	4.39	2.35	2.40
5	AEL	45	44	43	46	44	44	1.78	1.78	4.33	4.41	2.34	2.39
6	BW	50	49	43	46	43	41	1.70	1.76	4.08	4.14	2.17	2.18
7	BW	37	39	33	37	40	38	1.78	1.85	4.40	4.48	2.32	2.42
8	BW	59	58	53	53	58	58	1.67	1.70	4.03	4.04	2.19	2.10

Shaded box = target score achieved
AEL – Accentuated eccentric load
BW – Body weight
CMJ – Countermovement jump
SJ – Squat jump
DJ – Drop Jump
10m – 10-metre sprint time
30m – 30-metre sprint time
COD – 5-0-5 change of direction test

DISCUSSION

This case study investigated the chronic effects of an AEL DJ training intervention on athletic performance. Improvements in jump performance were found post intervention in both groups in agreement with studies which have utilised the DJ as part of a training intervention [227, 228]. Although this is the first study to utilise AEL DJs as part of a training intervention, previous studies have investigated acute effects of AEL DJs on subsequent vertical jump performance [215, 225]. In both these studies, an AEL DJ protocol resulted in subsequent enhancement in CMJ performance [215, 225].

When examining the meaningful changes in this current study although all subjects achieved their meaningful changes during the SJ this was not the case during the CMJ (Table 4). Four subjects in the AEL DJ group achieved their targets for CMJ compared to one in the BW DJ group. One explanation for the greater improvements in theAEL group is that during the four week training period they were exposed to greater eccentric loads, which resulted in greater enhanced neural excitability and selective recruitment of high threshold motor units (MU)[225]. This may have resulted in the subjects being able to utilise these high threshold MU to a greater degree post training and therefore perform better during explosive movements such as the CMJ. Another possible explanation is that enhanced eccentric control and coordination as a result of exposure to AEL training resulted in an enhanced performance in stretch shortening cycle (SSC) function by modulating the eccentric phase of the movement during the CMJ [229].

Previous studies have reported enhancements in DJ performance (DJ height and RSI) after a DJ training intervention [227, 230]. In agreement with these findings, the current study also found meaningful changes in DJ height post training for individuals in both groups (three subjects in the AEL group and one in the BW group). In a study investigating vertical and horizontal DJ training with elite handball players Antonio et al. [228] reported that vertical unilateral DJs showed greater improvements in vertical jump height compared to the horizontal unilateral DJ group. Whilst it was reported that the horizontal DJ group showed greater enhancements in sprint and COD performance [228]. The authors concluded that force orientation should be a key consideration when planning the inclusion of plyometric activities [228]. Although meaningful individual improvements in the AEL group (2 subjects over 10m and 1 over 30m) were seen in sprint times the magnitude of these improvements was small in comparison to the improvements seen in vertical jump performance. It is proposed that future research may wish to investigate the effects of AEL during horizontal-orientated DJs.

Previously Spiteri et al. [193] investigated relationships between concentric and eccentric strength and COD performance during a 5-0-5 test with elite female basketball players. They reported strong relationships between relative eccentric strength and COD performance [193]. The authors concluded that the ability to tolerate greater eccentric loads may result in improved COD performance [193]. When examining the results of this current study the two subjects in the AEL group whom achieved their meaningful change scores during the COD also had large increases in eccentric PF post intervention (17.04 and 12.92% respectively). However, it should be noted that the subject in the AEL group with the largest increase in eccentric PF (27.40%) did not achieve any meaningful change in his COD performance. In addition the subject in the BW group who achieved a meaningful change in their COD performance actually recorded a reduced eccentric PF (-0.63%) post intervention. Therefore it is proposed more research is required to examine the relationships between eccentric force production and COD performance.

The authors acknowledge that the sample size in this current study was small. A combination of factors such as injury and developmental players being called up to the first team contributed to this small sample size. However, this case study adds to the literature, as it is the first to investigate the chronic effects of an AEL DJ program. This study used the individual initial pre-intervention scores to identify meaningful changes in performance. This has previously been suggested to be of interest to S&C coaches as it allows them to establish when working with elite athletes whenever a training program is having the desired effect on performance [221].

PRACTICAL APPLICATIONS

Based on the study findings, it is proposed that the inclusion of AEL DJs warrants further investigation. If S&C coaches wish to incorporate AEL DJs into a training programme starting with a smaller volume (week 1 – four sets of eight repetitions twice a week) before progressing to higher volumes as training progresses (week 4 – four sets of 12 repetitions twice a week) is recommended (Table 1). Although improvements in sprint and COD performance were found in the AEL group, the greatest enhancements were reported in the vertically orientated measures such as the CMJ, SJ, and the DJ. Therefore it is suggested that the inclusion of four weeks of AEL DJ training during the in-season can enhance athletic performance and in particular vertical jump ability.

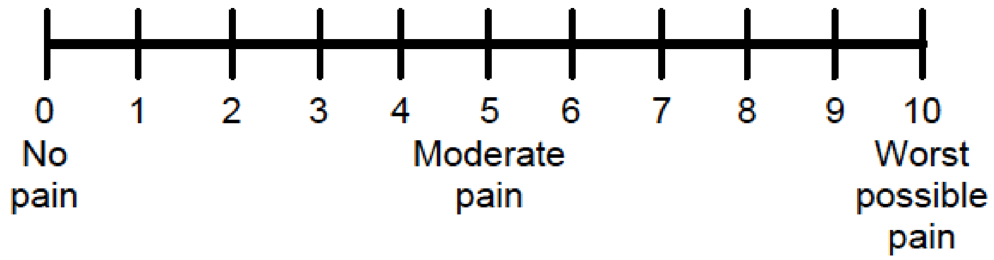
Appendix 3: 10 point RPE scale

RPE 10 Point Scale

0	Nothing at all
0.5	Very, very light
1	Very light
2	Fairly light
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Very, very hard (maximal)

Appendix 4: Pain scale for muscle soreness

0–10 Numeric Pain Rating Scale



Appendix 5: Ethics Approval

A U T E C
S E C R E T A R I A T

4 November 2014

Michael McGuigan
Faculty of Health and Environmental Sciences

Dear Michael

Re Ethics Application: **14/322 The effects of accentuated loading during drop jumps on strength, power, speed and exercise-induced muscle damage.**

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

Your ethics application has been approved for three years until 3 November 2017.

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

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 3 November 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 3 November 2017 or on completion of the project.

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

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

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

All the very best with your research,

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

Cc: Lee Bridgeman lee.bridgeman@aut.ac.nz

Appendix 6: Consent Forms

Appendix 6A: The Effect of Additional Load During the Eccentric Phase of Drop Jumps

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: **The Effect of Additional Load During the Eccentric Phase of Drop Jumps**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Lee Bridgeman***

○ I have read and understood the information provided about this research project in the Information Sheet dated 30/06/2014.

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

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

○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.

○ I agree to take part in this research.

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

Participant's signature: ....………………………………………………………

Participant's name: ....………………………………………………………

Participant's Contact Details (if appropriate):

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………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Appendix 6B: The Effect of Exercise-induced muscle damage after a Bout of Accentuated Load Drop Jumps and The Effects of a Repeated Bout of Accentuated Drop Jumps on Exercise-induced muscle damage

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: **The Effect of Exercise-induced muscle damage after a Bout of Accentuated Load Drop Jumps and The Effects of a Repeated Bout of Accentuated Drop Jumps on Exercise-induced muscle damage**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Lee Bridgeman***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 30/06/2014.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I consent to having venous blood drawn by a qualified phlebotomist
- ○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: ....……………………………………………………

Participant's name: ....……………………………………………………

Participant's Contact Details (if appropriate):
………………………………………………………………………………………..
………………………………………………………………………………………..
………………………………………………………………………………………..
………………………………………………………………………………………..
Date:

Appendix 6C: The Effects of a Four Week Accentuated Drop Jump Training Programme on Strength, Power and Speed

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: **The Effects of a Four Week Accentuated Drop Jump Training Programme on Strength, Power and Speed**

Project Supervisor: ***Mike McGuigan***

Researcher: ***Lee Bridgeman***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 30/06/2014.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Appendix 7: Study Information Sheets

Appendix 7A: The Effect of Additional Load During the Eccentric Phase of Drop Jumps

Participant Information Sheet

Date Information Sheet Produced:

30/06/2014

Project Title

The Effect of Additional Load During the Eccentric Phase of Drop Jumps

An Invitation

I, Lee Bridgeman, am a PhD student based at the Sports Performance Research Institute in New Zealand at the AUT-Millennium Campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that examines the use of additional dumbbell load during the landing phase of the drop jump exercise. Your participation in this study is voluntary and you are free to withdraw at any time you wish.

What is the purpose of this research?

The purpose of this research is to establish which drop heights and additional dumbbell loads result in improvements in drop jump performance. This study will form part of my proposed PhD.

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

You have been chosen as a potential participant as you have previous experience of resistance and plyometric training, are able to squat 1.5 times your own body weight and are aged between 18 – 35 years.

What will happen in this research?

This research will require you to attend three separate testing sessions. During the 1st session (W/C 16th February) you will initially complete countermovement jump and squat jump testing. Upon completion of this you will then have your squat strength assessed utilising the Exerbotics squat machine. After a 20 minute rest period you will then have the opportunity to complete three practice drop jumps from 38 and 62cm.

After these practice jumps you will then complete three maximal drop jumps with no additional load from the following drop heights; 28, 38, 52, 62 and 72cm (15 seconds between each jump and three minutes rest between different drop height) to identify your optimal drop height. Finally you will be familiarised with the use of dumbbells for additional load during the drop jump exercise.

The following week (W/C 23rd February) you will return to the lab to complete the 2nd session. After a thorough warm-up you will complete five drop jumps from the optimal height identified during session one initially with no additional load. Your countermovement jump performance will then be reassessed 2mins, 6mins and 12mins after you have completed the drop jumps. After a 20 minutes break you will again complete 5 drop jumps but this time with an additional load of 10% body weight provided by dumbbells. These drop jumps will be completed as normal but when you land you will release the dumbbells. Again upon completion of these drop jumps your countermovement jump performance will be reassessed as described above.

In the 3rd and final testing session (W/C 2nd March) you will complete the same procedure as described in session 2 but this time with additional loads of 20% and 30% bodyweight.

What are the discomforts and risks?

Due to the heavy eccentric load the Exerbotics machine is able to provide during maximal testing and the nature of the drop jump exercise you may feel fatigued upon completion of testing and suffer some muscular pain and discomfort in the days following the testing.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the testing procedure prior to maximal testing. You will also warm up thoroughly in preparation for these exercises. If at any points during the testing process you do not feel that you are able to proceed inform the tester and the test will cease immediately. Finally if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at the earliest possible opportunity.

What are the benefits?

The benefits to you are that you will gain knowledge of both your maximal concentric and eccentric strength in the squat exercise using a novel piece of equipment which you may incorporate into your own future training. You you will find out your unloaded optimal drop height for the drop jump exercise. In addition you will get information on the best additional dumbbell load and drop height to improve countermovement jump performance which you may then wish to include as part of your warm up.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain anonymous and will only be shared with my supervisors (Mike McGuigan and Nic Gill) and you as a participant upon completion of the study.

What are the costs of participating in this research?

The initial session will last approximately 45 minutes. Each testing session will last approximately 90 minutes and therefore with the initial session and two 2 testing sessions the maximum amount of time required is expect to be no more than three hours and 45 minutes over a two week period.

What opportunity do I have to consider this invitation?

It would be useful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Lee Bridgeman to arrange to complete an informed consent form and return it to myself prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results via email which you may then incorporate when planning your own future training.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, or mobile 021605179

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Lee Bridgeman – lee.bridgeman@aut.ac.nz

Mobile 021347001

Project Supervisor Contact Details:

Prof. Mike McGuigan – mike.mcguigan@aut.ac.nz

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Appendix 7B: The Effect of Exercise-induced muscle damage after a Bout of Accentuated Load Drop Jumps and The Effects of a Repeated Bout of Accentuated Drop Jumps on Exercise-induced muscle damage

Participant Information Sheet

Date Information Sheet Produced:

14/07/2015

Project Title

The Effect of Exercise-induced muscle damage after a Bout of Accentuated Load Drop Jumps and The Effects of a Repeated Bout of Accentuated Drop Jumps on Exercise-induced muscle damage

An Invitation

I, Lee Bridgeman, am a PhD student based at the Sports Performance Research Institute in New Zealand at the AUT-Millennium Campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that will look at the effect of drop jumps on muscle damage.

What is the purpose of this research?

The purpose of this research is to establish if drop jumps with additional dumbbell load during landing results in muscle damage. A secondary aim of this study is to investigate whether an initial drop jump drop session can protect against muscle damage when the same session is completed two weeks later. This study will form part of my proposed PhD thesis.

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

You have been chosen as a potential participant as you have previous experience of resistance and plyometric training are able to squat 1.5 times your own body weight and are aged between 18 – 35 years.

What will happen in this research?

Initially you will come to the laboratory and have your maximum squat strength assessed utilising the Exerbotics squat machine. After a rest period you will then do three maximal countermovement jumpsand three maximal squat jumps.

The next time you return to the laboratory a blood sample (venous blood from a forearm vein) will be taken to test markers of muscle damage (at rest) and muscle soreness from a selection of muscles will be recorded at rest, whilst the soreness of the knee extensors will also be recorded during a squatting pattern. You will then complete a drop jump protocol with an additional dumbbell load (20% of body weight) for landing portion of the exercise only.

Immediately after the drop jump protocol is completed another blood sample will be taken, squat strength, countermovement and squat jump performance, and muscle soreness will be re-tested and then these tests will be repeated one hour, 24 and 48 hours later. This will allow for the monitoring of exercise-induced muscle damage markers as a result of the drop jump protocol.

Two weeks after the completion of the initial testing you will be required to return to the laboratory and complete the same protocol as previously described above.
In total blood will be drawn by a qualified phlebotomist on 10 occasions during the course of this study (5 times during the 1st testing protocol and 5 times when you return 2 weeks later) at the time points detailed above. The purpose of taking these blood samples is to analyse them for creatine kinase, which is a marker of muscle damage. The samples will be stored for analysis in the Sports Immunology and Biochemistry laboratory at AUT Millennium. Once they have been analysed the samples will be destroyed unless you wish to have your blood samples returned you. If this is the case you can email the lead researcher to arrange this.

What are the discomforts and risks?

Due to the heavy eccentric load the Exerbotics machine is able to provide during maximal testing and the nature of the drop jump exercise you may feel fatigued upon completion of testing and suffer some muscular pain and discomfort in the days following the testing. Risks involved in the study are minimized, as you will already have filled out a 'Health Screen for Study Volunteers' questionnaire and a further health questionnaire before the exercise trials that will alert us of any health problems you may have. However, the tests are strenuous and you may feel some discomfort towards the end of the exercise periods due to the fatiguing nature of the tests.

There will also be a very small physical risk and mild soreness involved during testing through blood collection.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the testing procedure prior to maximal testing. You will also warm up thoroughly in preparation for these exercises. The completion of the first testing session should also provide some protection against muscle soreness and damage when completing the second testing session two weeks later.

If at any points during the testing process you do not feel that you are able to proceed inform the tester and the test will cease immediately. Finally if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at the earliest possible opportunity.

The blood samples will be taken by a qualified member of staff you is experience in taking blood samples and in supervising exercise tests of this nature.

At least two researchers will be present in the laboratory during the whole experiment period. Researchers are trained in resuscitation (MediTrain, Basic First Aid).

What are the benefits?

The benefits to you are that you will gain knowledge of both your maximal concentric and eccentric strength in the squat exercise using a novel piece of equipment which you may incorporate into your own future training. You will also experience a novel training method which you may also wish to include in any future training.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain anonymous and will only be shared with my supervisors (Prof. Mike McGuigan, Dr Nicholas Gill and Dr Deborah Dulson) and you as a participant upon completion of the study.

What are the costs of participating in this research?

The initial testing session will last approximately 90 minutes whilst the three following sessions will last approximately 1 hour. This will then be repeated two weeks later therefore the total amount of time needed to take part in this study will be approximately 9 hours.

What opportunity do I have to consider this invitation?

It would be useful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Lee Bridgeman to arrange to complete an informed consent form and return it to myself prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results emailed to you, which you may then incorporate when planning your own future training. You may also request your blood samples to be returned upon completion of analysis.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, or mobile 021605179

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Lee Bridgeman – lee.bridgeman@aut.ac.nz

Mobile 021347001

Project Supervisor Contact Details:

Prof. Mike McGuigan – mike.mcguigan@aut.ac.nz

Mobile 021605179

Appendix 7C: The Effects of a Four Week Accentuated Drop Jump Training Programme on Strength, Power and Speed

Participant Information Sheet

Date Information Sheet Produced:

30/06/2014

Project Title

The Effects of a Four Week Accentuated Drop Jump Training Programme on Strength, Power and Speed

An Invitation

I, Lee Bridgeman, am a PhD student based at the Sports Performance Research Institute in New Zealand at the AUT-Millennium Campus, School of Sport and Recreation, Faculty of Health and Environmental Sciences.

I would like to invite you to participate in a research study that examines the effects of a drop jump-training programme on strength, power and speed. Your participation in this study is voluntary and you are free to withdraw at any time you wish.

What is the purpose of this research?

The purpose of this research is to investigate the effects of a six week additional eccentric load drop on strength, power and speed in comparison to a traditional six week drop jump training programme. This study is the final part of my proposed PhD thesis.

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

You have been chosen as a potential participant as you have previous experience of resistance and plyometric training, are able to squat 1.5 times your own body weight and are aged between 18 – 35 years.

What will happen in this research?

This study will include three distinct stages a pre-test, training intervention and post intervention re-test.

Initially in this study strength, countermovement jump and squat jump ability will be tested and recorded. You will also complete an initial assessment of your drop jump ability followed 15 minutes later by three maximal 40-metre sprints and three 5-0-5 agility runs.

Upon completion of this testing you will be randomly assigned to one of two training groups. Group A will complete four weeks of drop jump training with no additional load whilst, Group B will complete drop jump training with additional dumbbell load for the four-week training period. You will complete this twice a week through the study irrespective of group with sessions separated by a 24-hour recovery period.
Upon completion of this four-week training period you will then complete the same tests as carried out prior to the training.

What are the discomforts and risks?

Due to the heavy eccentric load the Exerbotics machine is able to provide during maximal testing and the nature of the drop jump exercise you may feel fatigued upon completion of testing and suffer some muscular pain and discomfort in the days following the testing and training.

How will these discomforts and risks be alleviated?

You will have the opportunity to familiarise yourself with the testing procedure prior to maximal testing. You will also warm up thoroughly in preparation for these exercises. As you complete each training session you will become more accustomed to the drop jump protocol which will offer some protection against the discomfort which may occur initially.

If at any points during the testing process you do not feel that you are able to proceed inform the tester and the test will cease immediately. Finally if you suffer an injury during the testing process or in the weeks leading up to testing that is likely to affect your performance or result in further injury please notify the tester at the earliest possible opportunity.

What are the benefits?

The benefits to you are that you will gain knowledge of both your maximal concentric and eccentric strength in the squat exercise using a novel piece of equipment which you may incorporate into your own future training. In addition you will also have access to your power (countermovement jump and squat jump), speed (40m sprint including splits) and 505 test data (change of direction ability) which may inform your future training.

If you are allocated to group B you will also experience a novel training method which you may also wish to include in any future training.

What compensation is available for injury or negligence?

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

How will my privacy be protected?

Your results will remain anonymous and will only be shared with my supervisors (Prof. Mike McGuigan and Dr Nicholas Gill) and you as a participant upon completion of the study.

What are the costs of participating in this research?

The initial and follow up testing session upon completion of the training programme will last approximately 90 minutes. During the training programme the bouts of drop jumps should last approximately 30 minutes and this will be completed twice a week for a total of four weeks. Therefore the total amount of time required to take part in this study should be no more than 10 hours spread over a seven week period.

What opportunity do I have to consider this invitation?

It would be useful to the testers if you could indicate whether you wish to take part in this study within 2 weeks of receiving this information sheet.

How do I agree to participate in this research?

If you wish to take part in this study please contact Lee Bridgeman to arrange to complete an informed consent form and return it to myself prior to testing.

If at any time after completing the informed consent form you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any point without prejudice.

Will I receive feedback on the results of this research?

Once all testing is completed you will receive a copy of your own results via email, which you may then incorporate when planning your own future training.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, michael.mcguigan@aut.ac.nz, or mobile 021605179

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

Whom do I contact for further information about this research?

Researcher Contact Details:

Lee Bridgeman – lee.bridgeman@aut.ac.nz

Mobile 021347001

Project Supervisor Contact Details:

Prof. Mike McGuigan – mike.mcguigan@aut.ac.nz

Mobile 021605179

Appendix 8: Abstracts of Chapters as Published or in Review

Appendix 8A: Chapter 2 Journal of Australian Strength and Conditioning

Bridgeman, L., A., M. McGuigan, R., and N. Gill, D., *Eccentric exercise as a training modality*.Journal of Australian Strength and Conditioning, 2015.**23**(5): p. 52-66.

An eccentric muscle action involves the lengthening of a muscle due to an external load and occurs as a result of the mechanical disruption of action and myosin. The mechanical nature of the actin and myosin disruption during eccentric muscle actions is reported to allow for greater force production and requires a different neural activation pattern from a concentric action. As a consequence of these differences it is suggested concentric focused resistance training may not overload the eccentric action sufficiently. Therefore the purpose of this review was to outline a variety of eccentric training modalities and provide the reader with practical recommendations on programming. A search of the literature was conducted for; eccentric; training; methods; cycling; isokinetics; drop jumps; flywheel; exercise-induced muscle damage; repeated bout effect. After this search 106 papers were selected to form the basis of this review. When training isokinetically it was reported six to ten weeks of training at 180° s^{-1}, three times per week and with 24 – 30 maximal contractions per session resulted in improved hypertrophy and eccentric strength. When using dynamic exercises such as the squat and bench press a barbell load of 75 – 85% concentric 1RM with a releaser load of 40 – 55% (5 – 10 repetitions, 45 – 90 seconds between repetitions) may be appropriate. If the eccentric training is submaximal the barbell load has been recommended to be 50 – 65% concentric 1RM with a releaser load of 10 – 25% (15 – 20 repetitions, 15 – 30 seconds between repetitions). In conclusion eccentric training may warrant inclusion as part of an athletes training program.

Key Words: Eccentric, training, cycling, isokinetics

Appendix 8B: Chapter 3 Journal of Australian Strength and Conditioning

Bridgeman, L., A., M. McGuigan, R., and N. Gill, D., *Eccentric exercise, exercise-induced muscle damage and the repeated bout effect: A brief review.*Journal of Australian Strength and Conditioning, 2015.**23**(3): p. 74-84.

Eccentric training has the ability to improve strength and power as well as being a stimulus for hypertrophy gains. However a possible negative side effect is exercise-induced muscle damage, which can have a detrimental effect on performance. The symptoms and causes of exercise-induced muscle damage and the ability of the repeated bout effect to protect against muscle damage are discussed in this review. A search of the literature was conducted for; eccentric; training; methods; exercise-induced muscle damage; repeated bout effect. After this search 82 papers were selected to form the basis of this review. The finding of this review suggest if isometric contractions are used as a preconditioning exercise these should be completed at long muscle lengths with 10 isometric contractions reported to result in the greatest protective effect. Results of previous studies indicate that 30 repetitions of eccentric contractions at 10 - 40% maximal isometric strength (low intensity and volume) and ~4 seconds in duration have resulted in a RBE with little initial damage. Studies that have investigated low volume maximal eccentric contractions (6 – 24 reps, ~ 4 seconds in duration) have reported increased initial EIMD followed by a protective effect against further damage. When utilising maximal eccentric contractions the protective effect is reported to last up to 6 months in comparison to a low intensity bout that may only offer protection for 3 weeks. In summary it is suggested athletes should initially complete low intensity low volume eccentric training. Athletes should then progress to low load maximal or supramaximal eccentric training prior to completing higher volume sessions to allow the repeated bout effect to offer protection against muscle damage.

Key Words: Eccentric, exercise-induced muscle damage, repeated bout effect

Appendix 8C: Chapter 4 Journal of Strength and Conditioning Research

Bridgeman, L.A., et al., *Test-Retest Reliability of a Novel Isokinetic Squat Device.*Journal of Strength and Conditioning Research, 2016.

The aim of this study was to investigate the test-retest reliability of a novel multi-joint isokinetic squat device. The subjects in this study were 10 strength-trained athletes. Each subject completed three maximal testing sessions to assess peak concentric and eccentric force (N) over a three-week period utilising the Exerbotics squat device. Mean differences between eccentric and concentric force across the trials were calculated. Intraclass correlation coefficients (ICC) and coefficients of variation (CV) for the variables of interest were calculated using an excel reliability spread sheet. Between trials 1-2 an 11.0% and 2.3% increase in mean concentric and eccentric force respectively was reported. Between trials 2-3 a 1.35% increase in the mean concentric force production and a 1.4% increase in eccentric force production was reported. The mean concentric peak force CV and ICC across the three trials was 10% (7.6 – 15.4) and 0.95 (0.87 – 0.98) respectively. Whilst the mean eccentric peak force CV and ICC across the trials was 7.2% (5.5 – 11.1) and 0.90 (0.76 – 0.97) respectively. Based on these findings it is suggested that the Exerbotics squat device shows good test-re-test reliability. Therefore practitioners and investigators may consider its use to monitor changes in concentric and eccentric peak force.

KEY WORDS: Exerbotics, reliability, concentric, eccentric, force

Appendix 8D: Chapter 5 Journal of Strength and Conditioning Research

Bridgeman, L.A., et al., *Relationships Between Concentric and Eccentric Strength and Countermovement Jump Performance in Resistance Trained Men.*Journal of Strength and Conditioning Research, 2016.

The purpose of this study was to investigate the relationships between concentric and eccentric peak force (PF) and countermovement jump (CMJ) performance in resistance-trained men. Subjects were 12 men (mean ± SD; age: 25.4 ± 3.5 years; height: 177.2 ± 4.5 cm; mass: 84.0 ± 10.1 kg). The subjects were tested for concentric and eccentric PF using the Exerbotics squat device. Subjects then completed 3 CMJs to allow for the calculation of peak power (PP), peak ground reaction force (PGRF) and jump height (JH). Correlations between the variables of interest were calculated using Pearson product moment correlation coefficients. A large relationship was found between absolute concentric PF and absolute CMJ PP ($r = 0.66$, $p< 0.05$). Absolute eccentric PF had a very large relationship with absolute CMJ PP and CMJ JH ($r = 0.74$, $p< 0.01$ and $r = 0.74$, $p< 0.001$ respectively). In addition absolute eccentric PF was found to have a moderate relationship with relative CMJ PP ($r = 0.58$, $p< 0.05$). Relative eccentric PF was had a very large relationship with relative CMJ PP and CMJ JH ($r = 0.73$, p < 0.001 and $r = 0.79$, p < 0.001 respectively). Based on these findings strength and conditioning coaches and athletes who wish to enhance CMJ performance may wish to include exercises, which enhance lower body eccentric strength within their training.

KEY WORDS: Exerbotics; jumping; peak force; peak power

Appendix 8E: Chapter 7Journal of Strength and Conditioning Research

Bridgeman, L.A., et al., *The Effects of Accentuated Eccentric Loading on the Drop Jump Exercise and the Subsequent Postactivation Potentiation Response*.Journal of Strength and Conditioning Research, 2016.

The aims of this study were to (A) investigate the acute effects of different drop jump (DJ) accentuated eccentric loading (AEL) protocols and (B) to investigate the effect of these AEL DJ protocols on subsequent countermovement jump (CMJ) performance. The subjects were 12 strength-trained athletes, initially, baseline CMJ performance was assessed and individual optimal DJ drop height identified. In subsequent weeks subjects completed 1 set of 5 DJs with no additional load or an AEL of 10, 20 or 30% of their individual body mass (BM) utilising dumbbells to provide the extra load. After the AEL DJ protocols 3 CMJ's were completed after 2, 6 and 12 minutes rest. A generalised linear mixed model was used to investigate the effects of AEL load and time post DJs on CMJ height, peak power and GRF. The 20% AEL condition resulted in greater CMJ height in comparison to all other conditions ($p < 0.001$). CMJ height was significantly greater after 2 and 6 minutes rest compared to 12 minutes ($p < 0.001$ and $p < 0.05$ respectively). Greater peak power was also found during the CMJ's after the 20% AEL condition compared to baseline, BM and 10% AEL ($p < 0.05$). In conclusion 5 DJs with 20% AEL followed by a 2 minute recovery period resulted in significant enhancement in CMJ height and peak power.

KEY WORDS: countermovement jump, jump height, peak power