The Effect of Fast Eccentric Squats on Measures of Strength, Power and Speed

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Abstract:

The aim of this study is to investigate the effect of increased eccentric movement velocity during a submaximal back squat on measures of strength, power and speed as well as examine the effect of recovery following eccentric training had on the performance. Eleven participants were randomly placed into a fast-eccentric group (FE; n = 6) or control group (CG; n = 5). Participants completed a four-week intervention training three times per week. The FE group completed the eccentric phase as fast as possible (average = 0.59s) and the CG completed the eccentric phase over two seconds with a metronome for tempo. Testing measures included box squat one repetition maximum (1RM), 20m sprint, 6s peak power output (PPO) Wattbike test and 0.4m drop jump (DJ). Testing was completed seven days prior to the start of the intervention and then seven, 14 and 28 days following the intervention. There were no significant ($p > 0.05$) between-group differences in performance; however, the FE group reported on average a significantly higher ($p < 0.05$) rate of perceived exertion (RPE) following RT sessions. Significant ($p < 0.05$) within-group differences were found with the CG demonstrating a significant increase ($p < 0.05$) in 1RM from BL to T3 (+11.2%). The CG also significantly increased ($p < 0.05$) 5m sprint time and decreased DJ flight time (FT) from BL to T1, T2 and T3. The findings from this study suggest that training with an increased eccentric movement velocity during isoinertial barbell back squats, leads to no added benefit to strength, power or speed compared to traditional training.

Acknowledgements:

This thesis is dedicated to Jarryd “Davo” Davidson, 1994 – 2019. The life of the party, sometimes for all the wrong reasons, but always with a massive grin and an infectious laugh, miss you mate.

To my family, Ann, Salvi, Gina and Louie, I would like to take this opportunity to let you guys know how much you mean to me. Thank you for your on-going support throughout the last twenty four years, I wouldn’t be here without you guys! To Meila, thank you for helping keep me sane over the last couple of years and listening to my many problems even though you had no idea what I was talking about 99% of the time.

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Abbreviations

1RM = one repetition maximum

AEL = accentuated eccentric loading

CG = control group

CMJ = counter movement jump

CSA = cross sectional area

CT = contact time

DJ = drop jump

DOMS = delayed onset muscle soreness

EIMD = exercise induced muscle damage

eMVC = eccentric maximal voluntary contraction

FE = fast eccentric

FT = flight time

HTMU = high threshold motor units

LFF = low frequency fatigue

MTU = musculotendinous unit

MVC = maximal voluntary contraction (concentric)

PPO = peak power output

RFD = rate of force development

RFE = residual force enhancement

RPM = revolutions per minute

RT = resistance training

SSC = stretch shortening cycle

Thesis Organisation

This thesis contains a traditional manuscript including an Introduction (Chapter One), Literature Review (Chapter Two), Methods section, (Chapter Three), Results section (Chapter Four), Discussion (Chapter Five), References (Chapter Six) and Appendices. As well as these traditional chapters, the appendices includes a manuscript which is ready for publication. This article will be sent for reviewing to the *Journal of Strength and Conditioning Research* (JSCR). This thesis is therefore formatted based upon the guidelines of the JSCR.

Chapter 1: Introduction

In power-based sports, defined as sprinting, throwing, basketball, volleyball and judo (47), the ability to generate maximal force in a short time frame (power) is considered critical for performance (25,73,74). Power is equal to the force produced divided by the velocity at which it was produced (73). Therefore, resistance training (RT) undertaken to try and influence power output should either look at increasing force output or decreasing the time over which force can be applied. To increase an individual's power, RT methodologies have included: low-load high-velocity training (10), high-load low-velocity training (9), plyometrics (137) and, more recently, eccentric focused training (28,99,126).

Muscles act in three distinct manners: concentrically, eccentrically and isometrically. Concentric muscle action involves the shortening of a muscle e.g., the quadriceps during leg extension (113). Eccentric muscle actions involve the active lengthening of a muscle e.g., the quadriceps during leg flexion (29). Isometric muscle actions occur when the muscle is active, but there is no apparent change in the length of the muscle (59).

The integration of an eccentric muscle action with a concentric muscle action is termed the stretch shortening cycle (SSC) (6). During SSC movement, elastic energy is created due to the stretching of the musculotendon unit (MTU) during an eccentric action. This stored elastic energy can be recovered during subsequent concentric contractions, leading to the potentiation of the concentric contraction. Other SSC factors that have been shown to enhance this potentiating effect are: an increased amount of time to produce force; potentiation of contractile elements; and the activation of stretch-reflexes (20). SSC occurs within everyday movements such as gait, where eccentric muscle actions help produce braking forces by absorbing the mechanical energy produced by concentric muscle actions (138). Within power-based sports, a fast and powerful eccentric pre-stretch leads to a greater level of contraction potentiation (21,146). A fast-eccentric pre-stretch completed with a near maximal or supramaximal (greater than concentric one repetition maximum) load has been demonstrated to increase countermovement jump (CMJ) performance, via increased power production and jump height (21,49,76,142).

Although part of everyday movements, SSC performance is thought to be an integral part of fast and cyclic movements such as sprinting and jumping (42). SSC performance can be quantified by deriving a reactive strength index (RSI), which is calculated by dividing flight time (FT) by contact time (CT) from a drop jump (16). Increases in RSI can occur either by increasing FT or decreasing CT; however, just increasing FT regardless of CT is not seen as a positive outcome, especially in power-based sports. In power-based sports (47), athletes have between ~50-250ms to create and apply force (74,130,131). Therefore, a positive performance increase in RSI is a decrease in CT while also increasing FT or keeping FT constant (ability to produce the same jump height/time in the air with a decreased CT). Eccentric training has been demonstrated to elicit a host of adaptations that lead to a rightward shift in the force-velocity curve (118), which is characterised by a greater amount of force production, produced at higher speeds (7). These adaptations include increased musculotendinous stiffness (86), increased fascicle length (44) and an increase in the percentage of type IIx muscle fibres (106). The time course for these adaptations differ depending on the mode of training and the loading used (86). As well as the adaptations above, eccentric training has also been shown to be a potent stimulus for increases in both strength and size (22,106). Eccentric strength has been demonstrated to increase after four to five weeks of RT (28,85,103), while changes in stiffness, fascicle length and IIx muscle fiber content occur over a longer time frame (28,75,95,106). Some evidence suggests that increased eccentric strength may influence RSI and indeed performance in power sports due to the muscles' ability to absorb and utilise greater amounts of elastic energy as well as the ability to control a short, powerful eccentric pre-load (12,92).

Currently, athletic training methods tend to emphasise concentric-based training, whereby the load lifted is dictated by one's concentric one repetition maximum (1RM; weight an individual can lift concentrically only once). It has been shown that individuals are on average 20% stronger during eccentric muscle actions, meaning that the eccentric portion of a lift is often under-stimulated in concentric based RT (99). Therefore, there has been a recent shift in research investigating the effects of overloading the eccentric phase (30,99,140,141) or increasing the movement velocity of the eccentric phase (28,38,126).

Paddon-Jones, Leveritt, Lonergan and Abernethy (106) investigated the effects of increased movement velocity during eccentric-only training using dynamometry. Their findings showed that increased movement velocity (180 °/s compared to 60 °/s) during eccentric bicep curls (lengthening of the elbow flexors) led to greater eccentric strength gains at both the fast and slow speeds. Another finding from this investigation was a significant increase ($p < 0.05$) in the percentage of type IIx muscle fibres found in the biceps. Although Paddon-Jones et al. (19) demonstrated that eccentric focused training could significantly influence strength at various speeds as well as the percentage of type IIx fibres, there has been no attempt to replicate the speeds used by those investigators (180 °/s) with traditional RT. Instead, research progressed from RT completed using a dynamometer (37,38,98,106,134) to investigating the effect of overloaded eccentrics (65,99,120,139,141), rather than looking at the effects from increased eccentric movement velocity at submaximal loads.

Douglas, Pearson, Ross and McGuigan (30) examined the effect of accentuated eccentric loading (AEL) and traditional back squats during both fast and slow movement velocities on measures of strength, power and speed. The results from Douglas et al. (30)

demonstrated a plateau/decrease in performance following fast eccentrics (both traditional and AEL), which was contrary to previous findings (3,38,106). It was suggested that the overloaded and fast eccentrics completed by Douglas et al. (30) may have exceeded the fatigue – recovery relationship. Eccentric training leads to greater levels of exercise-induced muscle damage (EIMD), delayed onset muscle soreness (DOMS) and low frequency fatigue when compared to concentric training (64,66,78,98,124). It was suggested that a block of eccentric training will be followed by period of decreased performance due to fatigue/muscle damage (28). Therefore, it was hypothesised that after an initial period of decreased performance, performance will increase as fatigue and muscle damage diminish. However, there is no current literature which has investigated recovery from training fatigue/soreness following an eccentric training intervention and its effects on performance. The purpose of this research is to investigate:

1. The effect of fast-eccentric or controlled-eccentric squats using submaximal loads on measures of strength, power and speed.
2. The effect of recovery after a period of high intensity eccentrics and controlled eccentrics on measures of strength, power and speed.
3. The individual variations in performance following a period of high intensity eccentrics.

It is hypothesised that:

1. Participants who complete fast eccentric squats will significantly increase performance outcomes in both the 40cm drop jumps and Wattbike 6s PPO; however, there will be no significant difference in sprint times and an insignificant increase in squat 1RM.
2. Participants who complete the control squats will increase their squat 1RM; however, non-significant changes will be seen in the power or speed tests.

Chapter 2: Literature Review

The purpose of this review of the literature is to outline prior research that has been conducted in this field in order to demonstrate how the current study will add to the existing literature. The review starts broadly in defining muscular power and its constituents: force and velocity. The review then delves deeper into previous research involving eccentric contractions and why they are unique, as well as eccentric resistance training (RT) and the different ways to incorporate eccentric training into everyday RT. Throughout this review, the aim is to create links between previous work and the proposed study.

2.1 Muscular Performance and its Relationship to Athletic Performance

It is widely accepted, yet unproven that conditioning athletes to be bigger, stronger and/or faster will make them better at their chosen sport (13,14). It has also been reported that muscular power may be one of the main determinants of the outcome in athletic pursuits (14). Therefore, different ways to enhance an athlete's power output using a number of RT methods has been the primary focus of a number of investigations (3,4,30,65,83,88,122,135). However, there seems to be a disconnect between how power is tested within the research and how power may influence actual sporting performance (14). Buckner et al. (14) believed that many of the testing measures used are too far removed from the actual sport. An example of this is the use of the vertical jump as a measure of lower body power across a number of different cohorts. Although this may give insights into the lower body power capabilities of an individual, it should be clear that there is a big difference between a stationary counter movement jump (CMJ) performed within a lab, and a basketball player jumping for a rebound or a volleyball player going up for a spike. In a game situation, although athletes may complete jumps that look similar to the counter movement jump used during maximal vertical jumps, athletes may at times need to produce maximal force with minimal knee bend, in as short a time period as possible. This type of jump draws on the spring-like qualities of the musculotendinous unit (MTU) to produce maximal force rather than concentric force production (14,108). Since the CMJ does not tell us much about this quality, it is important that a range of testing measures are utilised to paint a better picture of athletes, to make sure that the RT interventions used are specific to them and their needs.

Associations between interventions and outcomes for athletic performance are more often than not based on assumptions that stronger, more powerful athletes who jump higher during laboratory-based testing will, therefore, be better at their sport (14). Consequently, there is a need to more clearly define what is meant by the different physical qualities discussed within this thesis and also create links between testing measures and 'the real world'.

2.1.1 Power

Knudson (70) argued that labelling individuals as power athletes or movements as power-based does not offer much, due to the fact that power can refer to any human movement. However, in an athletic pursuit, power can be seen to be one of the most important factors of muscular performance (73). Power (expressed as watts) is a function of the force applied multiplied by the velocity at which it is applied, or the rate at which work is performed (25,70,73,130,131,147).

$$\text{Power (P)} = \text{Force (F)} \times \text{Velocity (v)}$$

Power output can be manipulated by changing the force applied, the velocity at which it is applied, or both. For athletes who compete in power-based sports, the goal of training is to try and enhance power output via a rightward shift in the force-velocity curve. Such a shift is characterised by producing a greater amount of force at a higher velocity (48). This is important for power athletes due to the short period (~50-250ms) of time they have to exert maximal force into the ground to create movement (74,130,131).

Force is the maximum amount of energy which can be generated by skeletal muscle during a specified action (71).

$$\text{Force (F)} = \text{Mass (m)} \times \text{Acceleration (a)}$$

The amount of force which can be produced for any given movement is influenced by a number of factors. These include: morphological factors such as muscle cross sectional area (CSA), pennation angle and musculotendinous stiffness; as well as neurological factors such as motor unit recruitment, motor unit synchronisation, reflex contribution and neuromuscular inhibition (129).

$$\text{Velocity (v)} = \text{Distance (d)} / \text{Time (t)}$$

Velocity is the rate at which this force can be applied. Contraction velocity refers to the velocity at which contraction occurs and, much like the amount of force that can be exerted, is also influenced by a number of factors. Velocity is influenced by sarcomere length, fascicle length, cross-bridge cycling time, muscle viscosity, motor unit recruitment patterns, rate coding, muscle stiffness and muscle fibre type (2,73,84).

Typically, lower body power is trained through concentric muscle actions, for example a squat jump, where the eccentric phase is controlled and during the concentric phase the individual attempts to project their body vertically. Lower body power is also typically evaluated during concentric muscle actions, for example a maximal vertical jump. However, there is evidence to suggest that eccentric muscle actions play a critical role in increasing the force and power output of subsequent concentric contractions (28,42,73,99).

2.2 Muscular Contractions

Muscles act in three distinct manners: concentrically, eccentrically and isometrically. Concentric muscle action involves the shortening of a muscle e.g., the quadriceps muscle group during leg extension (113). Eccentric muscle actions involve the active lengthening of a muscle e.g., the quadriceps group during the lowering phase of the leg extensions (29). Finally, isometric muscle actions occur when the muscle is active, but where there is no apparent change in the length of the muscle (59). Although all three types of contractions are occurring all the time, there are clear differences between the different muscular contraction types in regards to both the neural activation and mechanisms of contraction, especially during eccentric actions (29,31,60).

2.2.1 Concentric and isometric muscle actions

In 1954, Andrew Huxley proposed the sliding filament theory that underpinned and attempted to explain muscular contractions (89). The theory was based on the interaction of two protein filaments which make up a contractile unit, also known as a sarcomere (34,67). Huxley suggested that changes in muscle length were caused by the sliding of a thin myosin filament relative to the thick actin filament (34). Myosin filaments are comprised of a long tail and two myosin heads (23). During muscle contractions, the myosin head binds to actin, creating a cross bridge between the two filaments. When the cross bridge is initially formed, it is in a weakly-bound, low-force state (41). Cross bridges then transition into a strongly-bound, high-force state via the hydrolysis of adenosine triphosphate (ATP) and the phosphorylation of the myosin head (41). Once attached to actin, the myosin head performs a power stroke, moving the myosin filament in relation to the actin filament, and thus creating shortening, a concentric contraction. During isometric contractions, it is thought that cross bridges are predominantly in a strongly-bound, high-force state, creating force with no apparent change in length (41).

The amount of force that is able to be generated during any single concentric contraction is dependent on the number of cross bridges formed at any one time. That is, the more cross bridges formed, the greater the ability of the muscle to produce force (110). The number of cross bridges that form for any given concentric contraction is dependent on two main variables: the length of the muscle and the velocity of contraction. These are also known as the length-tension relationship and the force-velocity relationship of muscular contraction (110).

Doheny, Lowery, Fitzpatrick and O'Malley (27) investigated the effect of changes in elbow joint angle on force production and electromyography (EMG) amplitude. Their results showed that altering the joint angle had a significant ($p < 0.05$) impact on the amount of force which could be produced by the muscle, with no significant ($p > 0.05$) difference found on EMG amplitude at different joint angles. Their findings showed that the elbow flexor and extensor muscles produced the greatest force at an angle of 90°, which is in agreement with similar studies (51,79,110), whereas flexion or extension that occurs above/below 90° leads to a decrease in force production. This decrease in force production due to changes in joint position is suggested to be because of a decrease in the number of cross bridges formed between actin and myosin at an either a shortened or lengthened position (110).

During maximal concentric contractions, it has been shown that increased contraction velocity has a negative effect on the amount of force which can be produced; this is termed the force-velocity relationship. As the velocity of contraction increases, the amount of force that can be produced by skeletal muscle acting concentrically decreases exponentially (38). Farthing and Chilibeck (38) looked at the differences in strength and hypertrophy gains between fast and slow eccentric and concentric training. During their pre-testing they found that the amount of force produced concentrically decreased as the contraction velocity increased. It has been hypothesised that at higher contraction velocities, the time which actin and myosin have to form cross bridges decreases significantly. This leads to a decrease in the number of cross bridges formed, and therefore also decreasing the force production capabilities of the muscle (40).

Although there is evidence to suggest that the force-velocity and length-tension relationships occur during concentric and isometric contractions, there is also evidence to suggest that eccentric actions do not abide by the same relationships (29). It is, therefore, believed that the sliding filament theory does not govern eccentric contractions the same way as it does for concentric and isometric contractions.

2.2.2 Eccentric muscle actions

There is a clear discrepancy between our understanding of eccentric contractions compared with concentric and isometric contractions (29,31,61). "When active muscles are stretched, our understanding of muscle function is stretched as well" (61). However, the gap is slowly closing as more research investigates eccentric contractions and their benefits to not only everyday life but also sporting performance and rehabilitation.

The main evidence that eccentric contractions are not governed by the sliding filament theory is the fact that eccentric contractions do not appear to abide by either of the length-tension or force-velocity relationships that concentric and isometric contractions abide by (29,31,35,60,110). A review article by Douglas, Pearson, Ross and McGuigan (29) looked at the physiological characteristics and acute responses that occur with eccentric contractions and attempted to explain the mechanisms behind them. The authors described both the molecular and neuromuscular differences that lead to increased force production in eccentric actions above that of isometric and concentric actions and at a lower metabolic cost. Douglas et al. (29) suggested that the increased force production capabilities during eccentric contractions is due to the activation of a secondary (partner) myosin head; however, this theory is still unproven. The secondary myosin head is thought to also bind to actin during lengthening contractions, increasing the amount of cross bridges formed two-fold, and thus increasing the ability of the muscle to produce force (110). The activation of the secondary myosin head is believed to be due to the mechanical strain placed on the single myosin head during active lengthening (29). Increased strain on the myosin head during active lengthening also leads to it being forcefully detached from actin (29). This means that formed cross bridges do not complete a full cycle, decreasing the amount of ATP used during active lengthening. Decreased ATP usage during eccentric actions has been shown via decreased metabolic cost of eccentric movements at any given intensity compared to concentric and isometric contractions (29,80).

It has been shown that the neural activation of eccentric contractions differs from that of concentric and isometric contractions (29,31,35). The size principle of motor unit (MU) recruitment for concentric and isometric contractions suggests that MUs are recruited from smallest to largest as the velocity of contraction increases. However, there is evidence to suggest that during eccentric contractions the size principle is reversed, with the preferential recruitment of high threshold motor units (HTMU) (58,68). HTMUs can be described as motor units which innervate a large number of muscle fibers, and therefore are recruited when a large amount of force is required (81,100,148). HTMUs have been demonstrated to innervate type II muscle fibres predominantly, while low-threshold MUs innervate predominantly type I fibres (77,101). The practical implications of this finding are that the preferential recruitment of HTMUs may lead to a change in phenotype towards a faster contraction velocity. An increase in contraction velocity influences power output by decreasing the time it takes to produce maximal force.

Another difference seen is a decrease in electromyogram (EMG) amplitude during maximal voluntary eccentric contractions (eMVC) compared with maximal voluntary concentric contractions (MVC) at the same intensity and velocity (1,31,35). This decrease in EMG amplitude during eMVC is still observed even when force production during eMVC is greater than that of MVC (31). It has been suggested that during eMVC there is less spinal and corticospinal excitability when compared to concentric and isometric MVC due to neuromuscular inhibition (1,31). Neuromuscular inhibition is a reduction in muscle activation during eMVC, which influences the ability of the muscle to generate force (129). This reduction in muscle activation could potentially be a safety mechanism to protect against injury when an active muscle lengthens. Westing, Seger and Thorstensson (144) found that during eMVC knee extensor muscles produced significantly less ($p<0.05$) torque compared to when the muscles were electrically stimulated (+11-15%). These results suggested that by bypassing the spinal and corticospinal regulation of eccentric contractions, the resultant contraction can produce more force than during voluntary contractions. However, this finding has also been shown during concentric contractions to a lesser extent (144). Thus, as eccentric contractions produce more force than concentric, there may be some benefit of being able to reduce this inhibition to be able to train at a much higher level above concentric 1RM.

Resistance training can help reduce the amount of neuromuscular inhibition that occurs during eMVC, increasing the total amount of torque that can be produced during voluntary eccentric muscle actions (6). Andersen and Aagaard (6) showed significantly greater ($p = 0.001$) neuromuscular activation of the quadriceps via EMG, during both maximal voluntary eccentric and concentric contractions, was achieved after a training period of 12 weeks. Amiridis, Martin, Martin and Hoecke (5) demonstrated that electrical stimulation significantly increased ($p < 0.05$) the eMVC of sedentary participants but not highly strength-trained individuals. These studies show that completing RT may lead to neural changes that reduce the amount of neuromuscular inhibition, leading to greater levels of force production during maximal contractions. However, the mechanisms behind this change are still unknown.

2.2.3 Titin

Not only has it been postulated that the interaction between actin and myosin is different during lengthening contractions, but recent findings suggest a third protein, titin, might play an important role in lengthening contractions (58). Titin was initially discovered in the mid-1970s, and it was termed a ‘spring like’ protein, which helped with passive force production during eccentric actions (58). Titin spans half of the sarcomere (I-Band), and attaches the thick myosin filament to the Z band as well as creating a permanent link between actin and myosin (29,58).

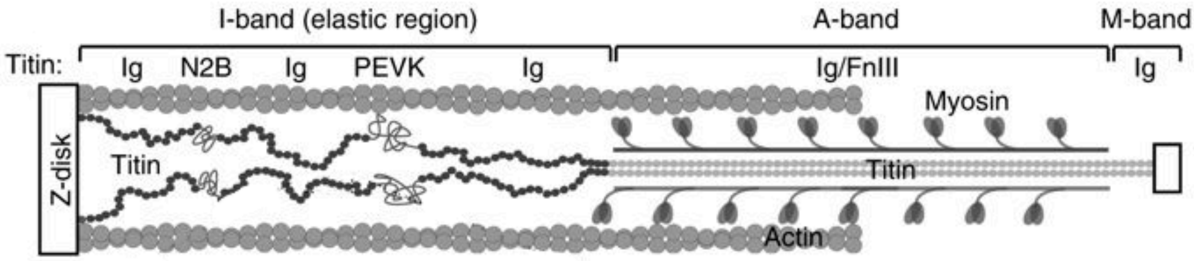

Figure 2.1: Schematic representation of the half-protein assembly, showing where titin is found in relation to actin and myosin.
Titin is shown to connect the Z-disk to the base of the thick myosin.
Image adapted from https://commons.wikimedia.org/wiki/File:Titin_IG_Domains.jpg

The latest school of thought, presented by Herzog (58), is that titin plays a role in passive force production, residual force enhancement (RFE) and the stabilisation of sarcomeres during active eccentric contractions. Passive force is defined (58) as any force that results from the structural elements of a contractile unit (sarcomere), occurs without metabolic energy consumption and is not a direct result of actin-myosin cross-bridge cycles. The amount of passive force that can be generated by titin is dictated by its stiffness (58,60). Titin's stiffness has been shown to be modulated by calcium binding to titin at the onset of muscle activation, the phosphorylation of titin, and the interactions between titin and other structural proteins found within a sarcomere e.g., actin and myosin (33,58).

Residual force enhancement refers to an increase in the isometric force production capabilities of a muscle immediately following an eccentric contraction. The increase in isometric force production is proportional to the force produced during the eccentric contraction that precedes it (60). This potentiation of isometric force production cannot be explained by the sliding filament theory of contractions, but is a phenomenon which has been accepted as one of the functions of skeletal muscle (60). Although it is not fully understood, RFE could play a role in the subsequent increase in concentric power after completing an eccentric pre-load (e.g., during a counter movement jump or drop jump).

2.3 Stretch Shortening Cycle (SSC) and Athletic Performance

The SSC is the complex integration of an eccentric contraction coupled with a concentric contraction. The SSC has three distinct phases: an initial pre-loading (eccentric) phase; the amortisation (transition) phase; and, finally, a propulsion (concentric) phase where the desired movement occurs (127). Movements that involve the SSC occur throughout everyday life, as muscle actions seldom occur in isolation. The ability to optimise SSC performance may have positive effects during athletic endeavours. It has been shown that completing an SSC movement prior to jumping can enhance performance (increased concentric power output and jump height), compared to a concentric-only movement (e.g., a squat jump with no countermovement vs a countermovement jump) (42,72,99,137). During an SSC movement, the rapid elongation (eccentric pre-stretch) of a muscle leads to the storage of elastic potential energy (28). This eccentric pre-stretch allows for increased time for the system to produce concentric force (17), increases neural excitability (42) and leads to augmentation of the stretch-reflex (72). The length of the amortisation phase determines the amount of elastic potential energy that is utilised during the concentric phase (127). The longer the amortisation phase, the less force can be produced due to elastic energy being dissipated as heat (28). Moreover, a decreased amortisation phase leads to increased elastic energy utilisation and, therefore, increased movement performance. The practical applications of this finding is that during fast SSC movements, especially with power sport athletes, the focus should be on decreasing contact time (and thus decreasing amortisation time) rather than purely increasing jump height.

Stretch shortening cycle movements can be classified as either fast or slow (56,138), with fast SSC movements characterised by brief contraction times (<0.25ms), coupled with small angular displacements at the hip, knee and ankle e.g., a drop jump (42). A slow SSC is characterised by longer contraction times (>0.25ms) and large angular displacements e.g., maximal vertical jumps (42). Performance in fast SSC movements relies more on power and reactive strength than pure strength qualities due to the decreased contact time (CT), and therefore a reduced time in which to produce force (123).

Part of the testing battery used in the present study is a fast SSC movement known as a drop jump (DJ), which was used to measure changes in reactive strength/power. DJs can be used as a performance measure for athletes who engage in fast SSC movements in game situations (e.g., sprinting, volleyball and basketball). The specific joint angles utilised and the fast-eccentric pre-load during a DJ can provide a better understanding of an athlete's reactive strength/power abilities compared to a counter movement jump (CMJ). The nature of the sports (basketball and volleyball) dictates that athletes will also complete slow SSC movements; therefore, it is suggested that testing batteries should include both fast and slow SSC movements (138). For the current study, changes to fast SSC movements are the primary focus and testing, therefore, includes only a fast SSC movement (DJ).

2.3.1 Reactive strength index and DJs

Reactive strength can be described as one's ability to overcome an initial eccentric load, and the amount of force that can be subsequently be produced from it (28,42). Reactive strength can be quantified by the calculation of an individual's reactive strength index (RSI), which is equal to their jump flight time (FT) divided by the landing contact time (CT) from a DJ (28,42,82). DJs have been shown to be have high inter- and intra-day reliability as a measure of reactive strength (16,28,50). It is important to consider the optimal height for DJs, with the general consensus showing that drops from between 20 and 60cm offer the optimal dropping intensity for peak power output in different individuals (16,28,50).

DJs are not to be confused with depth jumps, which are the slow SSC variation of the DJ. The two terms have often been used synonymously, which has caused confusion within the strength and conditioning world (107). DJs are a fast SSC movement where individuals step off an elevated box and, as soon as they contact the ground, rebound into a maximal vertical jump (107). The aim of a DJ is to decrease the time that the feet are in contact with the ground (CT), while maintaining jump height (or FT). That strategy will increase an individual's RSI. Douglas (28) found that, compared to untrained individuals, trained sprinters had a higher RSI (effect size [ES]: 3.11 ± 0.86), which was attributed to a reduction in CT (ES: -1.49 ± 0.53). The author concluded that the increase in RSI seen in sprint-trained individuals compared to untrained may be due to a shorter, but more forceful eccentric pre-load phase (28). This difference in RSI, and indeed CT, could be due to differences in musculotendinous unit (MTU) stiffness. Stiffness can be described as the relationship between the force applied to a system (in this case the MTU) and the amount of deformation that occurs (95). It has been shown that athletes who are sprint trained have significantly greater ($p < 0.05$) levels of lower limb MTU stiffness than endurance-trained athletes (62). Increased lower limb stiffness has been shown by Butler, Crowell and Davis (15) to positively influence sprinting through increased running velocity, decreased stride length (during acceleration phase) and increased running economy. During DJs, increased MTU stiffness is associated with decreased contact times and increased vertical ground reaction forces during DJs when performed between 20 and 60cm (95).

Changes in MTU stiffness through strength, power and plyometric training are normally only evident after interventions of more than eight weeks (30,75,95). Therefore, the current study which involves a four-week training intervention was unlikely to influence MTU stiffness. However, increasing eccentric strength may play a role in one's ability to overcome eccentric pre-stretch during SSC movement and subsequent concentric performance.

Miyaguchi and Demura (97) found a positive correlation (r = 0.70) between peak power output achieved during an upper body SSC movement.

2.4 The Case for Eccentric Training

Not only is there a clear difference in how muscles contract when acting eccentrically, but eccentric-focused RT has also been shown to be a potent stimulus for both strength and muscle hypertrophy (78,96,111,129,132,133,140). In their review article Franchi, Reeves and Narici (45) investigated the differences in morphological, molecular and metabolic adaptations that occur after eccentric-only and concentric-only loading. The review highlighted that when the total volume of training was equated, eccentric-only training produced very similar increases in muscle CSA when compared with concentric-only training. However, an interesting finding was the fact that eccentric-only training (106) and eccentric-overloaded training (47) both led to significant increases ($p < 0.05$) in type II fibre CSA, whereas concentric-only and traditional concentric/eccentric training did not. Hautier et al., (54) investigated the relationship between the velocity of peak power during cycling (revolutions per minute; RPM) and fibre type composition. Their findings showed that a higher percent of type II muscle fibres was positively correlated (r = 0.88, p = 0.001) to a higher optimal velocity, which is the RPM at which peak power output (PPO) is reached. Therefore, the testing battery for the current study includes a 6s PPO test on a Watt Bike to examine the effect that eccentric training had on both concentric lower body power and peak RPM. Hypothesis number one (Chapter One) suggests that fast-eccentric training would lead to an increase in concentric PPO which would be achieved at a higher RPM. Although this could be indicative of changes to the composition of type I and II muscle fibres, as muscle biopsies were not completed, this was not tested but rather inferred based off of the findings from Hautier et al. (54). One of the proposed mechanisms behind this is the motor recruitment pattern seen during eccentric contractions. The reversal of size principal which governs concentric and isometric contractions means that during eccentric contractions, HTMUs are preferentially recruited during eccentric contractions (58,68). High threshold motor units have been shown to innervate predominantly type II fibres (77,101) and therefore, repeated activation of HTMU may lead to the preferential hypertrophy of these fibres. An individual with an increase in the percent or CSA of type II fibres should be able to apply maximal force at a faster rate due to an increased contraction velocity (106). This potentially could lead to a higher RPM for any given PPO. Future research should aim to re-test the findings from Hautier et al. (54) with a larger sample population of trained athletes from a range of sports to confirm the finding that increased type II fibres is correlated to the optimal velocity of PPO.

Another adaptation from eccentric training that may also influence contraction velocity is an increase in fascicle length (109). Abe, Kumagi and Brechue (2) found that elite level sprinters (100m; 10.0-10.9s) had significantly longer ($p < 0.05$) fascicle lengths in the vastus lateralis, gastrocnemius medialis and gastrocnemius lateralis than distance runners (5000m; 13.5-14.5 minutes). The authors suggest that increased fascicle length helps facilitate higher sprinting speeds due to increased shortening velocity during contractions. Hence, there may be an advantage to using eccentric training when the goal is to try and influence contraction velocity via changes to fibre type composition and increased fascicle length.

2.4.1 Eccentric-only loading

Early studies that investigated the differences between concentric-only and eccentric-only training utilised isokinetic dynamometry (39). Movement utilising an isokinetic dynamometer is unique due to the fact that the velocity of movement can be set over a pre-determined range of motion. This means researchers can quantify the exact movement velocity and measure how much torque an individual applies during the movement (39). This was seen as the gold standard for early research as different movement speeds and movement velocities could be measured with a high level of accuracy.

Tomberlin et al., (134) looked at the effect of concentric- and eccentric-focused training during bilateral leg extensions using an isokinetic dynamometer set at a movement speed of 100 °/second. Both the eccentric and concentric groups had significant increases ($p < 0.05$) in strength gains only when tested with the contraction type that they trained with; thus, gains from eccentric and concentric training appeared to be specific to the muscle action utilised during training. Since then, research has demonstrated that eccentric-focused training increases concentric strength as well as eccentric strength (113). Roig et al., (113) reviewed the literature surrounding eccentric-only and concentric-only training. They determined that eccentric training at the same intensity as concentric training led to significantly greater increases ($p < 0.05$) in muscle mass, reported as muscle girth. They also showed that eccentric-only training led to a significantly greater increase ($p < 0.05$) in both concentric-only and eccentric-only strength. Another finding from their review was that strength gains from eccentric-only RT seemed to be velocity-specific; that is, increases in eccentric strength were more prominent at the velocity at which the training occurred. Specificity of training is thought to be one of the main principles when programming RT for athletes (128), as RT should be specific to the desired performance outcome. Therefore, for athletes who perform in sports where velocity of movement is important (power sports), training with fast movement velocities (both eccentric and concentric) may help increase eccentric and concentric force production at higher velocities (rightward shift in force-velocity curve).

2.4.2 Velocity of movement

Research has shown that training with fast movement velocities using both eccentric (106) and concentric (22) muscle actions can influence the percentage and/or CSA of type IIx muscle fibers. Coyle et al. (22) utilised concentric bilateral leg extensions at different movement velocities; 60 °/s (slow), 60 °/s and 300 °/s (mixed) or 300 °/s (fast). The volume (the time at which the muscle was active and under tension) of training was equated between groups by manipulating sets and reps. The results showed that all three training groups had significantly increased ($p < 0.05$) their peak torque at 60 °/s and 180 °/s; however, only the two groups who trained at 300 °/s (fast and mixed) had a significant increase ($p < 0.05$) at that speed. On top of this, the fast group was the only group that had a significant increase ($p < 0.05$) in the CSA of their type IIx fibres (+12%). The change in CSA of type IIx fibres during this study occurred after just six weeks of fast concentric training. This shows that training is velocity-specific and, although training at high speeds increases torque at the same speed, it also increases torque production at the slower speeds as well.

Paddon-Jones et al. (106) looked at the effects of eccentric bicep curls using an isokinetic dynamometer at either 60 °/s (slow) or 180 °/s (fast), three times/week for 10 weeks. Within each session, participants completed 24 maximal eccentric contractions at their intervention speed (4 x 6 reps). The results from this study showed that the participants who were in the fast group had a significant increase ($p < 0.05$) in the amount of torque they could produce at both the fast and slow speeds, while the slow group only had a significant ($p < 0.05$) increase at the slow speed. The group that completed fast-eccentric training also had a significant increase ($p < 0.05$) in the percent of type IIx fibres found in the biceps (+7.12%), and a significant decrease ($p < 0.05$) in the percentage of type I fibres (-14.7%). These findings could be explained by the neural changes thought to occur with eccentric training and the supposition that fast-eccentric contractions leads to the preferential recruitment of HTMU (67). The specific recruitment of HTMU may lead to an increase in the number of IIx fibres and/or an increase in the CSA of the IIx fibres due to the higher levels of activation (29,31,105).

However, the investigation by Paddon-Jones et al. (106) only included participants that were untrained. This means that the results may not be generalisable to individuals who have a high training age. Moreover, movement which is isokinetic in nature follows a pre-determined path and velocity is controlled by the dynamometer (movement is at a constant velocity and the only thing that changes is the amount of force applied by the individual). Hence, there is need for research examining the practical implications of fast contraction velocities within a normal training environment, for example the gym rather than the laboratory and utilising trained individuals.

A study that almost met this criteria was undertaken by Stasinaki, Zaras, Methinitis, Bogdanis and Terzis (126) who investigated the effects of fast and slow eccentric-only squats on the rate of force development (RFD) and muscle architecture. The fast group completed nine sets of nine reps at 70% of their concentric 1RM as fast as possible, while the slow group completed five sets of six reps at 90% of their concentric 1RM with a four-second eccentric phase. Both groups completed six weeks of eccentric-only half squats two times per week. In this study, eccentric-only squats were performed by the participants lowering the bar at either their specified fast or slow speed. When the bottom of the squat (thighs parallel) was reached, the bar was brought back to the start position via an electric motor. Both the fast and slow training groups demonstrated significant increases ($p < 0.05$) in box squat 1RM, with the fast group's 1RM also improving significantly ($p < 0.05$) more than the slow group's. Fast training stimulated significant increases in both the RFD and quadriceps fascicle length, with significant between group differences. Although this study utilised fast submaximal eccentric squats, the squats did not incorporate a concentric phase and, therefore, cannot be classified as SSC movements. This may be one of the reasons that even though the fast group showed significant increases in strength and RFD, there were no significant changes to CMJ performance in either group. Inclusion of the concentric phase in this study could have positively influenced CMJ performance as training would have involved being able to overcome large amounts of eccentric force and the utilisation of stored elastic energy. The squats used by Stasinaki et al. (126) involved the rapid deceleration of the bar once individuals reached the desired squat depth, leading to the storage of elastic energy in the MTU. However, since there was no concentric phase this energy would have been dissipated as heat (28). It is suggested that the inclusion of an SSC movement would have enabled participants to be able to use this stored elastic energy from a rapid deceleration during the subsequent concentric phase, leading to a potentiation of concentric performance (99).

Much like Paddon-Jones et al. (106), this study recruited untrained individuals. This factor coupled with the high volume of training (9 x 9 @ 70% 1RM) meant that four participants in the fast group had to be replaced before the study began due to intense muscle soreness. Hence, the current study uses a progressive loading pattern to ensure this intense and severe muscle soreness does not occur, as this would not only deter participants from participating but also lead to large performance decreases within their own sport trainings.

Stasinaki et al. (126) conclude that submaximal fast eccentrics should be progressed throughout a programme, with the load starting as low as 30-40% concentric 1RM. The current study starts at a load of 50% of concetric 1RM and progresses 5% each week.

2.4.3 Accentuated eccentric loading (AEL)

Accentuated eccentric loading is RT in which the eccentric portion of the lift is overloaded compared to the concentric portion (140). The theory behind this method of training is that an individual's eccentric 1RM is around 20% greater than the concentric 1RM for the same movement (99). Thus, traditional concentric/eccentric training, where the load lifted is dictated by concentric strength only, provides a less than optimal stimulus during the eccentric portion. Increasing the load used during the eccentric portion increases the total amount of load that is lifted, which could positively affect strength and size adaptations from RT (45). It has been shown that supramaximal AEL training, where the eccentric overload is greater than the individuals concentric 1RM, leads to the preferential recruitment of high threshold motor units (140). Although research has been published on different variations of AEL training, there is no consensus on the optimal loading parameters of AEL training i.e., how much overload is optimal.

Accentuated eccentric loading, when completed with a short amortisation phase and fast movement velocities, incorporates the SSC, making it a more sport-specific training method compared to eccentric-only actions provided by an isokinetic dynamometer. AEL can be achieved using elastic bands (140), counterbalance weight systems (140), weight releasers (139), computer driven adjustments (28) and manual adjustments applied by an individual (140). AEL has been investigated during plyometric work (3,122) and also during RT (30,99,139). During plyometrics, AEL is achieved by adding weight during the eccentric pre-load phase of movement and then releasing the weight prior to the propulsion phase (3,122). Aboodarda, Yusuf, Osman, Thompson and Mokhtar (3) had participants complete three different CMJ trials, with two of the trials using resistance bands to create AEL. The first trial was body weight only jumps, the second was body weight +20% and the third was body weight +30%. The results showed that completing countermovement jumps with body weight +30% led to a significant increase ($p < 0.05$) in peak power and peak concentric force compared to both body weight and body weight +20%. However, this increase in power and concentric force came at a cost; a significant increase ($p < 0.05$) in contact time. It is important to remember that this increase in CT occurred due to an increase in the eccentric braking forces required to overcome the eccentric preload (increased amortization phase). As this was not a training intervention, the study does not show the long-term effects of AEL during CMJs. Therefore, it was not clear whether completing CMJs with AEL (increased CT) translated into a decreased CT when using body weight jumps only.

Sheppard et al., (122) investigated the effects of AEL CMJs on strength and power characteristics in high performance volleyball players, training over five weeks. To achieve eccentric overload, participants completed the eccentric loading phase with a 20 kg (male) or a 10kg (female) plate in each hand, dropping them before the propulsion phase. This study showed that training with AEL led to a significant increase ($p = 0.001$) in jump height of 5.3cm (+11%). The AEL group also had significant increases ($p < 0.05$) in peak velocity (+6%) and peak power (+20%) respectively during the concentric propulsion phase. These results suggested that five weeks of training utilising AEL during CMJs leads to an increase in power and force production of the concentric phase during bodyweight CMJs (122).

AEL is also utilised during RT. Munger et al. (99) looked at the effect that supramaximal AEL front squats had on subsequent concentric performance (peak velocity, peak power output and rate of force development). During a testing session, participants completed two repetitions at different AEL loads using weight releasers. The eccentric loads used were 105%, 110% and 120% of individual's concentric 1RM, while the concentric portion remained constant at 90% of 1RM. There was a significant increase ($p < 0.05$) in both the peak velocity and power of the subsequent concentric portion when the AEL load was 120% of an individual's concentric 1RM. This demonstrated that AEL training can increase the power output of subsequent concentric muscle contractions and may be a good tool to use when athletes have reached a plateau training for power production. However, Wagle et al. (139) found no potentiation in concentric performance after completing AEL, where the eccentric phase was completed with 105% concentric 1RM and the concentric phase was completed with 80% of concentric 1RM. As the training loads utilised, volume of work (sets and reps) and the training age of the participants differ between studies, comparing results between studies is difficult.

Although AEL has been shown to improve the power production capabilities of subsequent concentric movements and improve jumping performance, it is difficult to employ within an everyday gym setting. The ability to overload the eccentric portion of a lift relies on either prior knowledge of accommodating resistance (e.g., bands or chains) or equipment such as a weight releaser. The easiest way to achieve AEL is through a partner applying an external force onto the bar/machine during the eccentric portion of a lift; however, it is very hard to quantify the extra load being applied to the eccentric phase. Within a training intervention, there is far too much variation in load during partner-assisted AEL to provide a reliable study design. Hence the rationale for the current study was to explore the effect of increased movement velocity during traditional submaximal RT rather than AEL.

The current study followed a similar design and intervention to that used by Douglas (28) who used fast-eccentric movement velocities with trained individuals using a back squat performed on a purpose-built pneumatic Smith machine. The Smith machine was computer–controlled, enabling the eccentric and concentric load to be altered within the same movement. Using this technology, Douglas (28) utilised accentuated eccentric loading (AEL) of the back squat with individuals loaded up for the eccentric portion of the squat by 18-25% above the concentric load. That meant that in in Week One, participants completed squats with the eccentric load at 101% of concentric 1RM and the concentric load at 77%. The Smith machine had a built-in linear positional transducer (LPT) to track bar speed and therefore movement velocity (28). Participants were pair-matched based on strength levels into either a control group, which completed traditional concentric/eccentric RT, or an intervention group that completed AEL. All participants completed two, four-week training blocks within the study intervention, separated by two weeks of rest. For the first block, all participants completed slow eccentric squats with a tempo 2/0/1/0 (first number is eccentric movement duration, second is pause between eccentric and concentric movement, third is concentric duration and fourth is the pause before the next repetition). During the second block, all participants completed fast eccentrics with a tempo of 1/0/1/0.

The aim of Douglas' (28) study was to compare AEL and traditional training at the same speed and to compare slow and fast-eccentric movement velocities during both AEL and traditional RT. Based on previous literature, the fast block was expected to produce greater gains in both speed and power testing, especially in the AEL intervention group (22,38,106,122). This was not the case with results showing that performance variables had likely small (ES ~0.50) improvements after both slow AEL training and traditional RT. However, during the fast AEL training and traditional RT, sprint performance decreased from baseline (BL) and there were no significant ($p < 0.05$) changes in any of the other performance measures. Douglas (28) hypothesised that the decrease or plateau in performance after fast-eccentric training was due to increased muscular fatigue from the intensity of fast-eccentric training. It should be questioned, however, whether a one-second eccentric is in fact a 'fast' eccentric movement. This movement speed, whereby an individual moved from standing to knees at parallel (90° of movement), equates to 90 °/s, and is a lot slower than the 180 °/s fast eccentrics employed by Paddon-Jones et al. (106). Therefore, future research should explore movement velocities closer to that utilised by Paddon-Jones et al. (106) before looking at the effects of AEL and movement velocity.

2.4.4 Fatigue, exercise-induced muscle damage and the repeated bout effect

Delayed onset muscle soreness (DOMS) is "the sensation of muscular discomfort and pain during active contractions that peaks 24-48 hours after strenuous exercise" (46). Symptoms of DOMS include a decrease in strength and power production (due to decrease in muscle function), reduced range of motion and increased plasma levels of creatine kinase (11,46). It has been shown that DOMS is related to the eccentric portion of exercise, rather than the concentric (46). A multitude of studies (e.g., 13,71) have shown that eccentric training at the same intensity as concentric training leads to higher levels of EIMD and levels of perceived muscle soreness. It is suggested that this is due to the breakdown of cross-bridge proteins that occurs as a result of forceful detachment during active lengthening (66).

However, it has also been shown that the repeated bout effect can influence the amount of DOMS that occurs after eccentric training (124). That is, DOMS are highest after an initial eccentric session, and the severity of DOMS decreases with successive eccentric sessions. Eccentrics should therefore be progressively introduced into the training programmes of any athletes/individuals. Ross and Douglas (118) outlined a potential periodisation template for the implementation of eccentrics in order to gradually build up to fast/ballistic eccentrics. Their periodised plan follows progressions from training to train (normal concentric/eccentric training after a period of rest), slow eccentrics, overloaded eccentrics (AEL), fast eccentrics and finally ballistic eccentrics. This plan attempts to decrease the amount of DOMS from eccentric training and also aims to limit the muscular impairment experienced with EIMD. Thus, athletes should be able to maintain their field/track/court training that they are doing outside of the gym without DOMS restricting that training.

2.4.5 Low frequency fatigue (LFF)

Douglas (28) hypothesised that fast AEL squats may have led to a decrease in performance due to the training load exceeding the fatigue-recovery relationship. That is, the amount of fatigue arising from the training block was too high to permit full recovery before the post-testing session ~ seven days after the final RT session. One form of fatigue that might have influenced muscular performance after fast AEL eccentrics is low frequency fatigue (LFF). LFF can be described as fatigue that occurs due to the impairment of one or more processes impacting the excitation-contraction coupling, which can last hours or days (32,66). It is hypothesised that one of the main mechanisms behind LFF is a fatigue induced decrease in calcium release from the sarcoplasmic reticulum and increased levels of oxidative stress (43,66,69). LFF has been shown to occur as a direct result of both concentric and eccentric training. However, LFF is seen at much higher levels after eccentric contractions compared to concentric actions (66) and movements involving the SSC (43).

These fatigue-related suggestions are the rationale for the present study where post-training testing is scheduled seven, 14 and 28 days after the four-week fast-eccentric training block. In this respect, the study seeks to examine the effect that rest/recovery has on performance outcomes in strength, power and speed tests after fast eccentrics.

2.5 Summary

It is clear from the literature that there are a host of benefits from RT that may help positively impact performance in power-based sports. Furthermore, it is suggested that eccentric-focused training may serve as a novel stimulus that, if part of a well-rounded RT programme, could enhance performance to a greater extent than traditional RT. However, there are still a lot of unknowns when it comes to eccentric training and the best way to implement it within a periodised programme. Prior research has investigated the effect of eccentric-only training using dynamometry, submaximal and supramaximal AEL, and AEL with higher movement speeds during the eccentric phase. It is clear that there is still no gold standard in terms of the utilisation of eccentric training for athletic performance in terms of the loading patterns or movement velocities. There is need for more research looking at the effects of a range of different movement velocities (especially faster) utilising a range of loading techniques. Therefore, the current study aims to investigate:

1. The effect of fast-eccentric or controlled-eccentric squats using submaximal loads on measures of strength, power and speed.

2. The effect of recovery after a period of high intensity eccentrics and controlled eccentrics on measures of strength, power and speed.

3. The individual variations in performance following a period of high intensity eccentrics.

Chapter 3: Methods

An experimental study design was employed, involving two training groups and an eight-week training block. Participants were pairwise matched based on their strength-to-weight ratio (1RM box squat/body mass). Once pairwise matched, they were then randomly assigned to one of two training groups: fast-eccentric (FE) or control (CG). Randomisation was achieved via a random number generator.

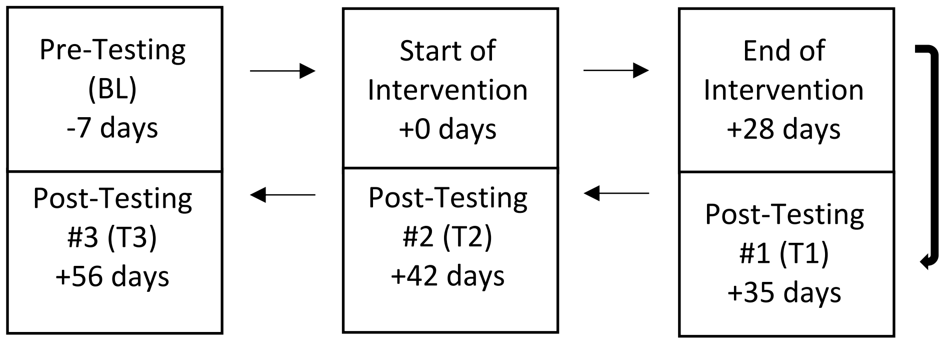

Figure 3.1: Study timeline

3.1 Participants

The research design was reviewed and approved by the Otago Polytechnic Research Ethics Committee in consultation with the Kaitohutohu Office (Appendix A). Participants were sought from the power-based sports of basketball, volleyball, sprinting and throwing (47). Recruitment was via a poster (Appendix B), which was sent to local administrators of eligible sports (Basketball Otago, Volleyball Otago and Athletics Otago). The notice was also placed at local gyms, recreation centers and posted on social media. Inclusion criteria included being injury-free for at least six months prior to the study, having a resistance training age greater than two years and competing at a regional or national level within their chosen sport. In accordance with ethical approval, participants were provided with an information sheet and signed a consent form before being assigned to a training group or participating in baseline testing. As participants were also training with their individual sports clubs/teams at the same time, training diaries were kept so that all training outside of the intervention were recorded.

3.2 Measures

Strength, power and speed were assessed seven days prior to intervention and at seven, 14 and 28 days after completion of the initial four-week training cycle. The testing order adhered to on each occasion was: standardised warm up, 20m sprint, 40cm drop jump, 6s Wattbike PPO test and box squat 1RM. Testing was conducted at a standardised time of day for each testing session.

3.2.1 Warm up

Participants completed a thorough supervised 15-minute warm up for each testing session, which included jogging, dynamic movements (136) and three acceleration stride outs over 10m at 70, 80 and 90% of self-selected intensity. Participants then completed a near maximal 20m sprint to conclude their warm up. Test-specific warm ups were conducted before each test and are detailed below.

3.2.2 Sprint splits

For the measurement of sprint speed, participants completed three 20m sprints, with timing gates placed at 5, 10 and 20m (Swift Speedlight Timing Gates, San Francisco). A rollout distance of 0.50 m was used to ensure the distance-time data was comparable with industry standard timings (28). Rest time between each 20m rep was 120s. Participants' 5, 10 and 20m split times (seconds) were recorded to the nearest 0.01s for each sprint and presented in the results as the average (± SD) of the three trials at each split during each testing session.

3.2.3 40cm drop jump (DJ)

For the measurement of reactive strength and the utilisation of the SSC (28), participants completed three bilateral DJs from a 40cm height. Participants were permitted three warm up jumps at the testing height, then three maximal effort drop jumps, with 30s rest in between jumps to ensure adequate recovery (28). Participants were instructed to keep their hands on their hips (akimbo) and to ensure that they stepped forward off the box (not stepping down or jumping up). Participants were instructed to simultaneously attempt to minimize their ground contact time while maximizing their jump height but to prioritise a brief ground contact time (30). Trials in which participants exhibited less than ideal technique (e.g. excessive knee valgus, loss of balance or prolonged ground contact) were excluded and replaced. DJs were recorded using a SWIFT ezeJump Contact Mat (Swift Performance, San Francisco). Peak power (W), contact time (s) and flight time (s) from each trial were extracted, recorded to the nearest watt for power and 0.01s for CT and FT using the ezeJump software (Swift Performance Equipment) which was used to calculate reactive strength index (RSI; FT divided by CT). The validity of the ezeJump contact mat has been previously established. Maulder and Cronin (90) found no significant differences (p = 0.01) for measures of both flight and contact time between the ezeJump contact mat and a force platform.

3.2.4 6s Wattbike peak power output (PPO) test

For the measurement of maximal lower body concentric power output, participants completed one six-second sprint on a Wattbike (Wattbike Ltd, Nottingham, UK). Participants completed a warm up on the Wattbike prior to the first trial, consisting of three minutes of cycling. Wattbike resistance was set based on participant's weight and gender as per the Wattbike website (143). Minute one was completed @ 80rpm, minute two @ 90rpm and minute three @ 100rpm. Participants then rested for 60s before completing the sprint. During the sprint, participants were instructed to stay seated on the bike and to drive their legs as hard as possible. Data recorded from the test sprint was peak power output (PPO) and peak cadence (PRPM). The use of a six-second all-out Wattbike sprint to measure lower body power was validated by Herbert et al (57), who found no significant ($p > 0.05$) difference between PPO after a 30s Wingate, a modified 10s Wingate or a 6s PPO test. Data presented in results is actual PPO and PRPM from a single trial.

3.2.5 Box squat 1RM

Lower body strength was measured by finding the participant's one repetition maximum (1RM - the weight an individual can only lift once) for the barbell box squat. Prior to testing, four warm up sets, adapted from Douglas et and McBride et al (29,91) were completed. At baseline, these consisted of 8-10 reps at 30% of the participants estimated 1RM (their best estimate of their 1RM), 4-6 reps at 50% of their estimated 1RM, 2-4 reps at 75% of their estimated 1RM and 1 rep at 90% of their estimated 1RM with the intention of reaching a maximal lift within 3-4 lifts. Warm up sets were rounded to the nearest 5kg. Rest in between sets/attempts was three minutes (91). During subsequent testing, warm up reps were based on the 1RM recorded at the most recent testing session.

Although lifts needed to be maximal, they also needed to be completed with the appropriate technique. To ensure this, participants were cued to make sure they maintained correct technique as follows: squat stance was a wide set up (feet wider than shoulder width), natural foot position, unrestricted movement of the knees (with heels remaining in contact with the ground throughout the movement) and a lordotic curve of the spine maintained throughout (18). Satisfactory squat depth was thighs parallel to the ground or a knee angle of approximately

90 degrees, which was set via the use of a plyometric box adjusted for individualized heights (30). The box squat 1RM was used to prescribe the training intensity for the squat during the training intervention (Appendix C). Data presented in the results is the average 1RM and strength-to-weight ratio (1RM/body mass) of each group from testing sessions. Body mass was recorded before each testing session to ensure the ratio was accurate.

3.3 Familiarisation session

After the initial pre-testing session, participants completed a familiarisation session which included the FE squat that was used during the study. Participants started using only the bar and worked up to 40% of their 1RM. Participants completed 1 x 6 reps with the bar only, 1 x 4 with 20% of 1RM and 2 x 3 with 40% 1RM. This was done to limit the amount of DOMS experienced during Week One where participants completed 3 x 6 with 50% 1RM. It also ensured participants were aware of the correct technique before the first training session. All participants completed this familiarisation as they had not been placed into FE or CG at this point.

3.4 Training procedure

All subjects completed a combination of strength and power resistance training (RT) sessions focusing on both the upper and lower limbs, with the main movement being the barbell back squat (training programme; Appendix C). Training was organised over two consecutive four-week cycles, with the first cycle consisting of three RT sessions/week. This first, four-week training block was the training intervention where participants either completed fast-eccentric squats (FE) or controlled-eccentric squats (CG). All exercises other than the squat were identical (tempo, reps and sets) for both groups. Participants in the control group completed the back squat with a tempo of 2/0/1/0 (i.e., 2s eccentric and 1s concentric), while the fast group used a tempo of <1/0/1/0 i.e., eccentric in less than 1s and a 1s concentric. Participants completing fast-eccentric reps were instructed to drop into the squat as fast as possible while maintaining the correct technique (as detailed above) and to control the weight on the way back up. Both groups completed the squats with the same combinations of reps and sets (3 x 6) and at the same % of 1RM. Squat load started at 50% 1RM for the first week and incremented up by 5% each week, with the final week at 65% 1RM. The actual load lifted was rounded to the nearest 2.5kg e.g., 57.5kg instead of 56.7kg. A metronome was used (https://www.metronomeonline.com/) during the squats to ensure participants stuck to the prescribed tempos.

During the second four-week training block, participants completed a maintenance programme which focused on maintaining power, speed and strength levels while minimising training volume. During this second cycle, participants completed two low-volume RT sessions/week serving as a 'deload' block while participants completed post-testing at seven, 14 and 28 days after the completion of the first block. This second block was to encourage the participants to complete all post-testing sessions.

Eccentric repetition duration was recorded via a GymAware™ unit (Kinetic Performance, Australia) to record the average eccentric rep duration. In order to standardise the squat, optimal depth was determined as thighs (femurs) parallel to the ground, and individual squat height was based on the box height used during the 1RM testing session (36). A light resistance band was placed around the squat rack at individual heights (40, 45 or 50cm) so that participants had an external cue to guide their squat depth. The band used was light enough to not interfere with the lift or influence the SSC through increased elastic tension. Training intensity was monitored throughout the training intervention via the use of Borg 1-10 rating of perceived exertion (RPE). RPEs were collected after each session to track the differences between CG and FE groups and is reported as the average (± SD) RPE of each group for each of the four weeks of the training intervention.

3.5 Statistical analysis

Statistical analysis was carried out using SPSS version 25 (SPSS inc. Chicago, IL). Results are presented as means and standard deviations (SD) unless otherwise stated. Conventional methods were used for the calculation of means and SD. A mixed between-within subjects analysis of variance (mixed ANOVA) was used to look at the effect of the training intervention (between subjects) on performance measures over time (within subjects) between BL, T1, T2 and T3. Wilks Lambda was used to determine whether there was a significant effect of time or group. As well as this, comparisons between groups were carried out by using independent samples t-test. A paired samples t-test was used to discover within-group changes. Coefficient of variation (CV; SD divided by the mean) was calculated to look at how the data changed compared to the mean over time. Statistical significance was accepted at the 5% level ($p < 0.05$).

Chapter 4: Results

4.1 Participant Data

Eleven participants completed the baseline (BL) testing and were then pairwise matched on their strength-to-weight ratio and randomly placed into either fast-eccentric group (FE; n = 6) or control group (CG; n = 5). One participant did not complete all the testing sessions due to an injury and was excluded from the data analysis (FE; n = 5). After BL testing, participants then completed a four-week training intervention (adherence = 92.5%) followed by post-testing seven days (T1), 14 days (T2) and 28 days (T3) after the intervention. Testing included 20m sprint, 0.4m drop jump (DJ), 6s peak power output (PPO), Wattbike sprint and box squat one repetition maximum (1RM). Participants were given access to an electronic training diary to which they were asked to record any individual or team training undertaken outside of the intervention. Due to only three participants completing this in full this information is not reported.

Table 4.1: Baseline Data for both intervention groups

Group	Age (years)	Height (cm)	Weight (kg)	Training Age (years)	1RM (kg)	Strength to Weight Ratio ($kg \cdot BM^{-1}$)
FE	21 (± 3)	183 (± 8)	81 (± 8)	4 (± 1)	128 (± 39)	1.68 (± 0.41)
CG	22 (± 2)	179 (± 11)	75 (± 12)	5 (± 2)	133 (± 28)	1.68 (± 0.32)

Independent t-tests showed there were no significant ($p > 0.05$) differences observed between the two groups in any of the pre-testing measures.

4.2 The effects of fast eccentric squats versus traditional squats

A mixed between-within analysis of variance (MANOVA) was used to look at the effect of the training intervention (between subjects) on performance measures over time (within subjects) between BL, T1, T2 and T3. The analysis showed that there was no significant ($p >$ 0.05) differences in any of the performance measures (strength, power or speed) between the two intervention groups at all time points. GymAware™ data showed that the average eccentric rep duration for FE was 0.59s, while for the CG it was 1.97; the eccentric rep durations were significantly ($p = 0.01$) different. After each session, the rate of perceived exertion (RPE) was collected from each individual. Independent t-tests showed there was a significant ($p < 0.05$)

difference in RPE between the two groups in Weeks Two, Three and Four of the training intervention (Figure 4.1).

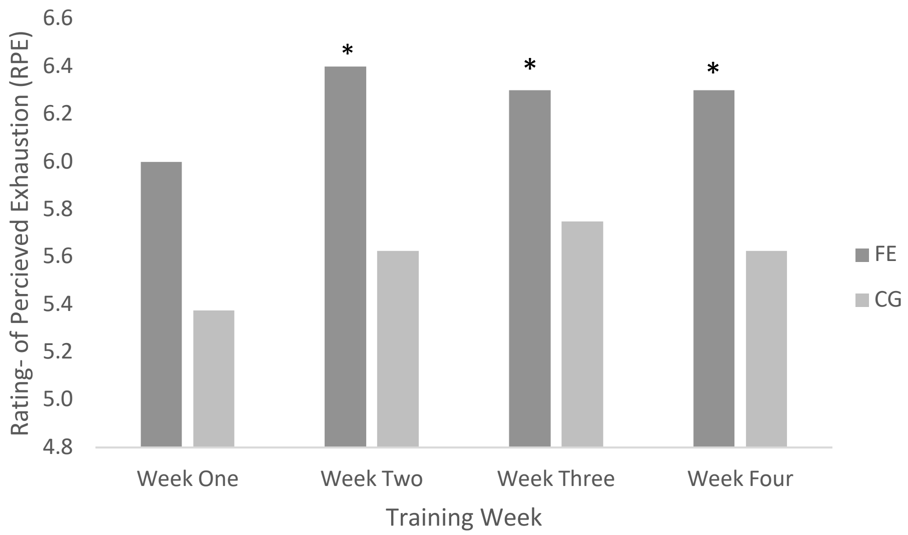

Figure 4.1: Average RPE of both intervention groups of both squat sessions within each week of the training intervention. * significant ($p < 0.05$) difference between CG and FE

4.3 Effects of the training intervention on measures of strength, power and speed

A mixed between-within analysis of variance (MANOVA) was completed to look at the effect of the training intervention over the different time points (BL, T1, T2 and T3). It was hypothesised that initially following the intervention, performance in the FE group would be significantly lower than CG due to increased fatigue. It was also thought that over the testing sessions, performance would increase as fatigue dissipated. Analysis showed that there was a significant ($p > 0.05$) effect of time on performance measures in both intervention groups, however there was no evidence of a significant decrease in performance following the FE training.

4.3.1 Strength

The CG demonstrated a significant increase ($p < 0.05$) in box squat 1RM (+11.2%) between BL and T3 (Figure 4.2). However, there were no other significant changes observed to 1RMs in either intervention group. This increase in box squat 1RM in the CG only is in accordance with the hypothesis of this study which stated that there would be a significant increase in box squat 1RM in the CG but not FE.

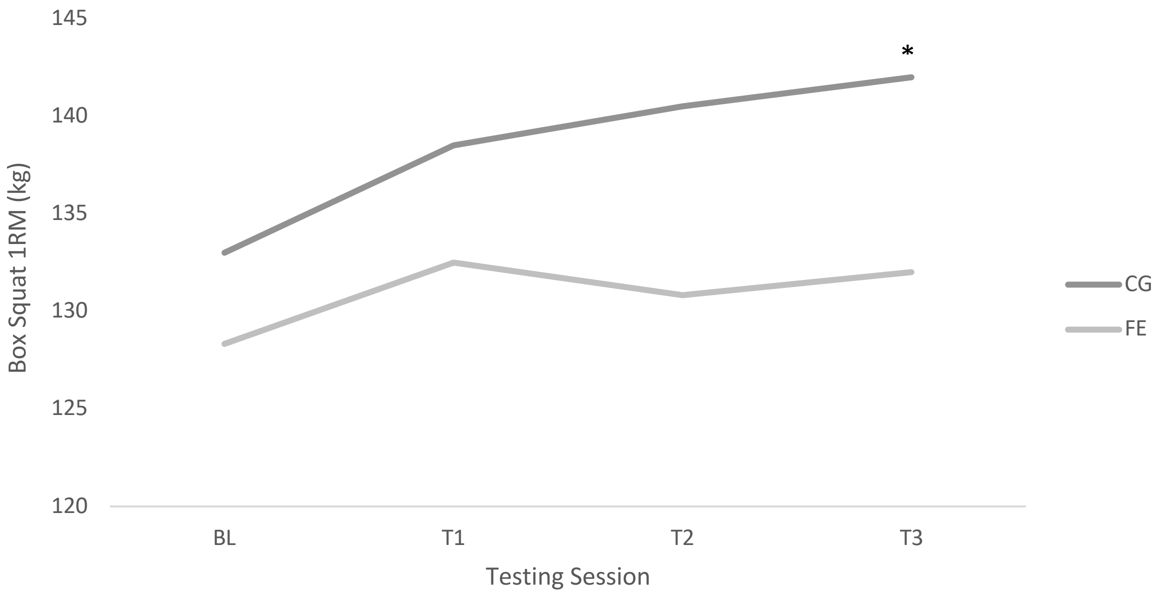

Figure 4.2: Graph showing the average 1RM of both FE and CG groups following each testing session. * denotes significant result ($p < 0.05$)

1RM = one repetition; maximum; BL = Baseline Testing; T1 = Post-Testing Session One; T2 = Post-Testing Session Two; T3 = Post-Testing Session Three

4.3.2 Power

In the 0.4m DJ test, the CG demonstrated a significant decrease ($p < 0.05$) in FT from BL to T1 T2 and T3 (Table 4.2). As well as this, the CG had a significant increase ($p < 0.05$) in PPO during the 6s PPO Wattbike test from BL to T3, T1 to T3 and T2 to T3 (Table 4.2). The FE demonstrated a significant increase ($p < 0.05$) in peak RPM during the 6s PPO Watt bike test from T2 to T3 (Table 4.2).

4.3.3 Speed

The CG demonstrated a significant increase ($p < 0.05$) in 5m sprint time from BL to T1, T2 ($p = 0.01$) and T3 (Table 4.2). As well as this, 10m sprint split was also significantly increased from BL to T1 ($p = 0.03$). In the FE group, both 10m and 20m splits were significantly increased ($p = 0.05$) from T1 to T3. These results show no positive changes to sprint times at any of the splits (5, 10 and 20m) in either group across all testing sessions.

Table 4.2: Table showing the averages (± SD) of all testing measures for both intervention groups over all four of the testing sessions pre, + 7, + 14 and + 28 days of intervention.

		Sprint (s)			Drop Jump			6s PPO Watt Bike		Squat
		5m	10m	20m	CT (s)	FT (s)	RSI (AU)	PPO (W)	RPM	1RM (kg)
Control	BL	0.98 ± .06	1.73 ± .10	3.02 ± .17	0.18 ± .04	0.53 ± .02	3.05 ± .54	1176 ± 258	137 ± 8	133 ± 28
	T1	1.01 ± .07*	1.77 ± .11*	3.08 ± .19	0.17 ± .01	0.50 ± .01*	2.95 ± .2	1171 ± 172	130 ± 15	139 ± 22
	T2	1.02 ± .06*	1.75 ± .09	3.06 ± .16	0.17 ± .01	0.51 ± .01*	3.07 ± .26	1214 ± 281	136 ± 53	141 ± 27
	T3	1.02 ± .05*	1.77 ± .08	3.08 ± .15	0.17 ± .01	0.50 ± .02*	2.99 ± .29	1285 ± 262^{*1,2}	137 ± 9	142 ± 24*
Eccentric	BL	1.01 ± .07	1.75 ± .11	3.06 ± .2	0.19 ± .03	0.52 ± .03	2.91 ± .56	1078 ± 198	131 ± 10	128 ± 39
	T1	1.00 ± .08	1.75 ± .13	3.05 ± .22	0.17 ± .03	0.49 ± .02	2.86 ± .47	1045 ± 220	121 ± 16	133 ± 37
	T2	1.02 ± .08	1.76 ± .09	3.07 ± .21	0.17 ± .03	0.51 ± .02	2.99 ± .53	1040 ± 200	128 ± 7	129 ± 35
	T3	1.02 ± .09	1.77 ± .15^{1}	3.07 ± .25	0.17 ± .03	0.52 ± .06	2.99 ± .65	1081± 391	131 ± 92^{2}	132 ± 43

CT = contact time; FT = flight time; RSI = reactive strength index; PPO = peak power output; RPM = revolutions per minute; 1RM = one repetition; maximum; BL = Baseline Testing; T1 = Post-Testing Session One; T2 = Post-Testing Session Two; T3 = Post-Testing Session Three

* Denotes a significant difference compared to pre-testing value ^{1} Denotes a significant difference from post-testing one ^{2} denotes a significant difference compared to post-testing two ^{3} denotes a significant difference compared to post-testing three

4.4 Individual variance

One of the aims of this study is to consider the individual variance in performance that occurs following a high intensity training intervention. Although there was no significant ($p > 0.05$) group differences and only a number of significant ($p < 0.05$) differences over time after the four-week training intervention, it was clear from the data that individuals respond differently to eccentric training (Figure 4.3 & 4.5). Some individuals appear to have responded positively to the FE training intervention; however, due to the increased individual variance in performance following the intervention, this was not well demonstrated in the group data.

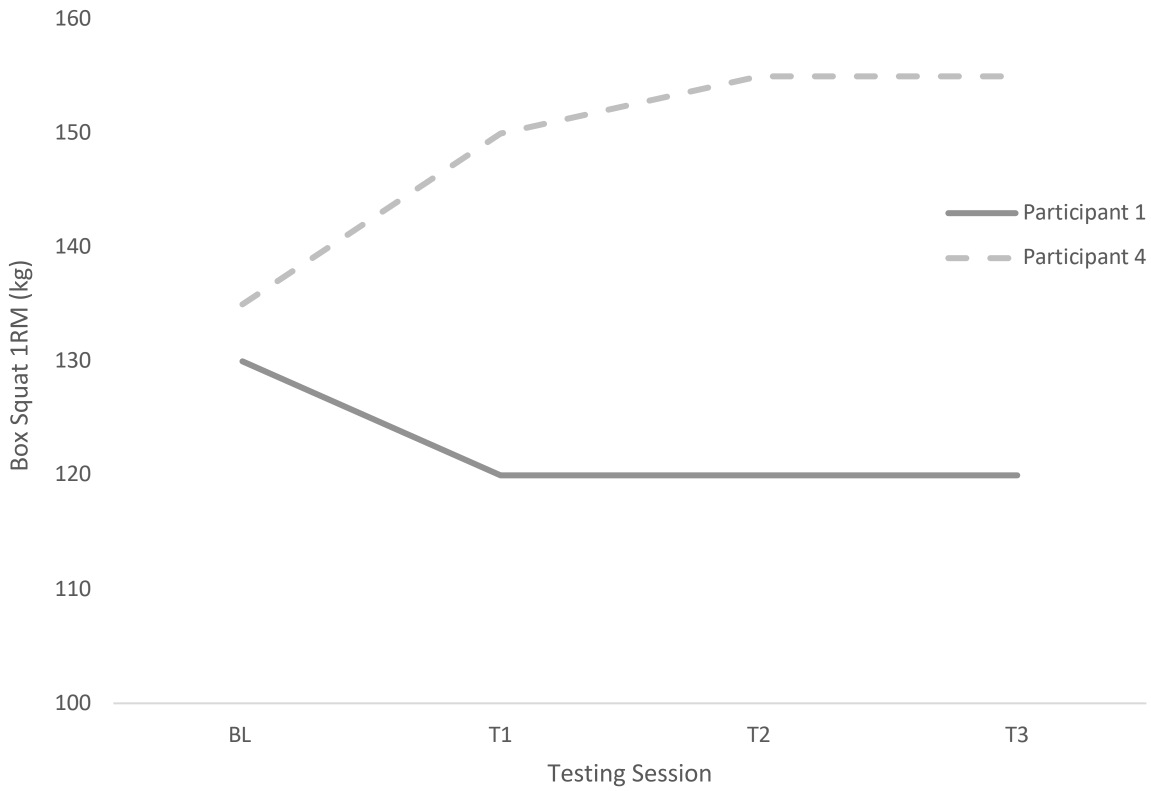

Figure 4.3: Line graph showing the change in Box Squat 1RM of two participants from the FE group over the course of the study

There was a large disparity in changes to Box Squat 1RM between individuals in the FE group (coefficient of variation [CV]; BL = 30%, T1 = 28%, T2 = 27%, T3 = 33%) compared to the CG (CV; BL = 21, T1 = 16, T2 = 18, T3 = 17). Looking at the individual differences that occurred with box squat 1RM (Figure 4.3), although participant 4 has increased their 1RM by 20kg from BL to T3, participant 1 has decreased their squat by 10kg from BL to T1 and it has stayed there for T2 and 3. This increased individual variance in responses is obscured when the mean group data is considered, which makes it hard for data interpretation as there is no general trend within some of the testing measures.

One of the testing measures which, from an applied perspective, showed a positive performance trend following the FE intervention was the 0.4m drop jump. Figure 4.4 illustrates the change in RSI over the course of the testing sessions. The graph shows a general trend of increased RSI over the course of the study.

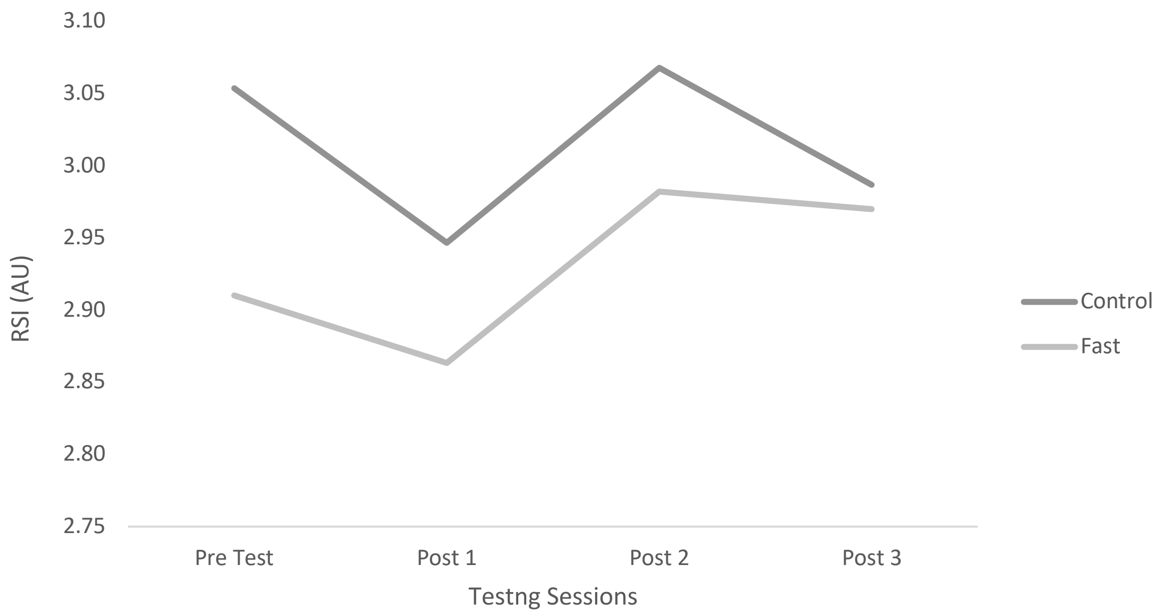

Figure 4.4: Line graph comparing the average RSI of the CG and FE group over the four testing sessions.

However, it is important to consider the factors that determine RSI (CT and FT) and how these may have responded over time. If the RSI, CT and FT from two different participants (A and B) in the FE group (Figure 4.5) are examined over the four testing sessions, it is clear that there were very different responses in both CT and FT over time. The graph, although showing no significant ($p > 0.05$) changes over time, does show a positive performance outcome in participants A: an increase in RSI due to a decrease in CT along with an increase in overtime FT.

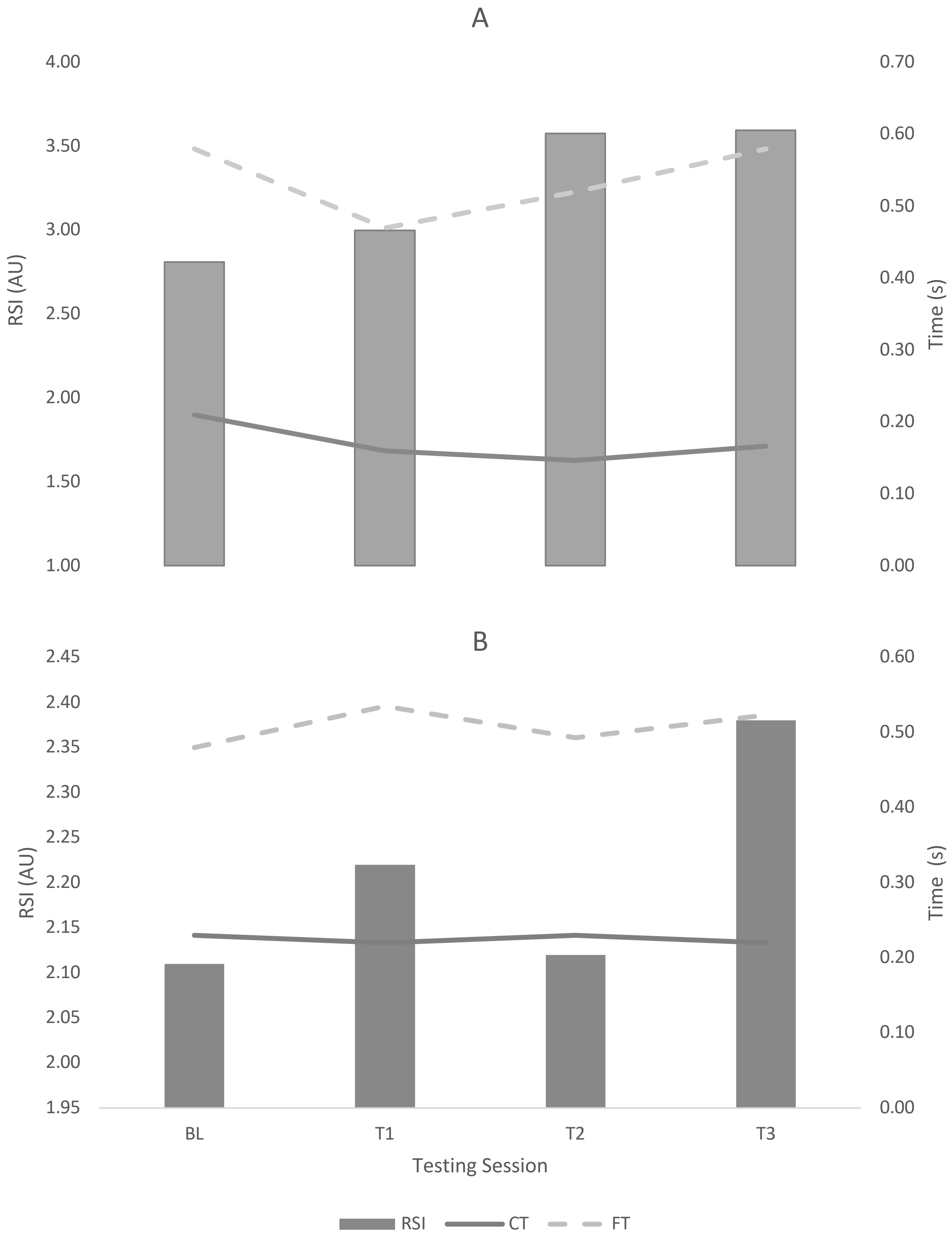

Figure 4.5: Line and Bar graph showing average RSI, CT and FT during 0.4m drop jumps from two different participants within the FE group over the four testing sessions.

Chapter 5: Discussion

This research sought to explore the effect of a four-week intervention using fast-eccentric squats with submaximal loads on measures of strength, power and speed. The study also investigated the effect of fatigue following eccentrics by including a recovery period, obtaining measures at +7, +14 and +28 days after the cessation of the training intervention. Finally, this research explored the individual variation in performance that occurred following the FE intervention. Eleven power sports athletes volunteered for the study, completed baseline testing and were assigned to either a fast-eccentric squat group (FE; n = 6, with only 5 completing all post-testing sessions) or a traditional squat control group (CG; n = 5). Participants trained three times per week for four weeks.

5.1 The Effects of Fast Eccentric Squats versus Traditional Squats

Fast-eccentric squats did not appear to offer any advantage over traditional squats. No significant ($p > 0.05$) differences between training groups were observed for any testing measures either before or after the training interventions. This goes against previous findings that FE training leads to greater performance outcomes than concentric-only or traditional RT (38,106). Typically, studies that find significant improvements in strength and/or power from submaximal and maximal eccentric training at high velocities have utilised dynamometry (38,106,134). An anomalous study in this regard was that of Stasinaki et al. (126) who found fast-eccentric-only squats completed at 70% of concentric 1RM led to a significant increase ($p < 0.05$) in squat 1RM (+14.5%), rate of force development (RFD) and quadriceps fascicle length. Stasinaki et al. (126) demonstrated, however, that fast-eccentric-only training led to signiiacntly greater increases ($p < 0.05$) compared to slow-eccentric-only training.

The workload within Stasinaki et al.'s study included two sessions per week with each session involving 9 sets of 9 reps at 70% 1RM (total reps per week = 162, 972 over the six week study) of fast-eccentric-only squats. This is a lot higher eccentric training volume than that of the current study, where participants completed 36 fast-eccentric reps per week (144 reps over the four weeks). This shows a huge disparity between eccentric traning volumes between the two groups, and this may be a reason why such different results were seen in Stasinaki et al.'s study and the current study. Stasinaki et al's (126) findings would suggest that the loads utilised during the current study - 50% of concentric 1RM week one, 55% week two, 60% week three and 65% week four was insufficient to elicit the expected adaptations. However, from watching the participants in the current study perform the fast-eccentric squats at 50, 55, 60 and 65% of 1RM, it is questionable whether particpants would have been able to complete fast-eccentrics with 70% of 1RM (126) from Week One and be able to overcome the large eccentric pre-stretch in order to complete the concentric phase. One of the conclusions from Stasinaki et al (126) is that fast-eccentric squats should be progressed over a training block, starting as low as 30-40% of concentric 1RM. Participants in Stasinaki et al.'s study were able to tolerate the high load (70%) due to there being no concentric action, and therefore not having to overcome this excessive braking force. However, Stasinaki et al. also had four participants drop out of the study due to intense muscle soreness, which is likely due to the high load and volume utilised or the fact that the participants were untrained and, therefore, more succeptible to exercise-induced muscle soreness (102).

Despite Stasinaki et al. (126) demonstrating that fast-eccentric-only squats significantly increases strength, RFD and fascicle length, there were no apparent changes to CMJ performance. Previous research has demonstrated that tradtional strength training leads to an increase in CMJ performance, with a positive correlation between 1RM and CMJ height and power production (68,104). The significant changes seen by Stasinaki et al. would typically lead to enhanced jumping performance due to one's ability to apply more force into the ground (increased strength) and apply the force at a faster rate (increased RFD and fascicle length).

However, the fast-eccentric-only squats used by Stasinaki et al. (126) meant that participants did not complete the concentric phase of the squat, which may have influenced the results seen. It is suggested that Stasinaki et al. (126) found no significant changes to CMJ performance due to the fast-eccentric-only squats not including the stretch shortening cycle (SSC). SSC movement is characterised by an initial eccentric pre-load followed by a concentric propulsion phase. SSC performance is influenced by a number of factors including an increased amount of time to produce force, the interaction of contractile and elastic elements, the potentiation of contractile elements, storage and utilisation of elastic energy and the activation of stretch-reflex responses (19). Fast-eccentric training likely leads to a greater ability to control a rapid, forceful eccentric pre-stretch and, therefore, the ability to utilise a greater percentage of stored elastic energy (28). In Stasinaki et al.'s (126) study, although the participants who completed fast-eccentric-only training may have been better at controlling a rapid and forceful eccentric pre-stretch during the CMJ, they potentially were inefficient at switching from the eccentric pre-stretch into the concentric propulsion phase (8).

It is suggested that future research looking at fast eccentrics and/or SSC performance should include both DJs and CMJs in their testing battery. This should be done to get a better picture of lower body power and how the training intervention impacts both fast and slow SSC performance. Another test which should be included in the testing battery following fast-eccentric training is the eccentric utilisation ratio (EUR). EUR is the ratio of CMJ-to-static squat jump and gives an indication of how well an individual utilises the eccentric pre-stretch during a CMJ (93). It can be used, therefore, to determine SSC performance (55).

The fast-eccentric isoinertial squat used in the current study is believed to not meet the requirements for a true eccentric action (117). Ross (117) stated that fast-eccentrics completed by "shutting off" the musculature and turning it back on to stop the movement (also called a drop catch) are not true fast-eccentric movements due to the inability of individuals to have muscular tension throughout the full range of movement. It is suggested, therefore, that one of the factors that may influence SSC performance following eccentric training is the loading pattern (e.g., AEL) rather than velocity per se, especially if the goal is to increase SSC performance. The ability to complete a heavy eccentric pre-stretch (supramaximal; above concentric 1RM; 25) coupled with a lighter (submaximal) concentric propulsion phase may be the most optimal way to enhance SSC performance. Previous research has demonstrated that this type of AEL training is effective at inducing increases in both strength and jumping performance (3,122,141). The suggested mechanisms behind supramaximal AEL are postulated to be mainly neural; however, the exact mechanisms are still relatively unknown (140). The neural mechanisms suggested by Wagle et al. (140) are due to the supramaximal eccentric phase being closer to eccentric 1RM and, therefore, requiring a greater amount of activation, especially of high threshold motor units (HTMU). The activation of HTMU during overloaded eccentrics leads to a greater level of concentric potentiation due in large part to a greater level of neural drive and an increased amount of stored elastic energy (99,140).

However, Douglas et al. (30) found that slow AEL training was superior to fast AEL training at increasing performance in strength, power and speed tests. This finding goes against previous findings (38,106,126) as well as the hypotheses of both Douglas et al.'s study and the current study. It was suggested in Chapter 2 (2.4.2) that the findings from the investigation undertaken by Douglas et al. (30) were potentially due to the fast-eccentric tempo of 1s used;. which was not fast enough when compared with previous studies. For example, Paddon-Jones et al. (106) initially showed that fast eccentrics completed at 180 °/s using dynamometry produced significant increases ($p < 0.05$) in strength, CSA and percentage of type IIx fibers. The eccentric movement velocity used for fast-eccentrics in Douglas et al.'s (30) study was 90 °/s (angular velocity = change in joint angle divided by the time taken). The FE group in the current study utilised a mean eccentric movement velocity of 157 °/s, which was closer to the speed used by Paddon-Jones et al. (106). The current study demonstrated that this movement velocity was still not enough to elicit any significant benefits compared to the CG (mean eccentric movement velocity 46 °/s). This is likely to be indicative of the loading pattern used rather than the fast velocities used; therefore, future research should evaluate fast-eccentric isoinertial training which is not equivalent to a drop catch. A suggested method of training is partner AEL training, whereby the strength and conditioning coach manually (via their own bodyweight) adds weight to the bar during the eccentric phase and releases it during the concentric phase. However, the issue with researching this type of training is the inability to quantify the external load applied during the concentric phase. However, this type of manual AEL may be a better way to train as the strength and conditioning coach can dictate the speed of the eccentric by adding more load i.e., pressure or taking some load away. This ensures that the athlete maintains control of weight and, therefore, has muscular tension throughout the range of motion.

During the four-week training intervention, individual rates of perceived exertion (RPE; borg 1-10 scale) values were recorded for all participants to obtain a subjective measure of how hard each session felt. The FE group reported, on average, a significantly higher ($p < 0.05$) RPE (Figure 4.1) after training sessions compared to the CG in Weeks Two, Three and Four. Given the subjective nature of the scale, this increase in RPE could be due to a number of factors. It is suggested, however, that the stress placed on the lower body during the FE squats, was the primary reason for the increase in RPE. This increased RPE, in combination with the absence of any performance advantages over CG, mean that including fast-eccentric submaximal squats in an individual's training programme may be less than optimal.

5.1.1 Effects of the Training Intervention on Measures of Strength, Power and Speed

Following the completion of the four-week training intervention, all performance tests were repeated at +7, +14 and +28 days following the cessation of the training intervention. As eccentric training can be associated with significant muscle soreness (46) and low frequency fatigue (LFF; 10), the post-training testing was conducted to investigate the influence of recovery on performance measures. Douglas (28) suggested that decreased performance following a fast-eccentrics intervention may be due to increased fatigue and muscle soreness. Furthermore, it has been shown that just a single bout of eccentric training leads to symptoms of muscle damage including strength loss, pain and muscle tenderness (94). It was expected, therefore, that the FE training would significantly impair performance at T1, but that over T2 and T3 performance would recover to BL levels or above. This proved not to be the case. There were no significant decreases in performance in the FE group at T1, as well as no significant increase in performance from T1 to T2 or 3. The hypothesis that FE training would lead to a greater amount of fatigue compared to CG and, therefore, to decreased performance at T1 was rejected.

5.1.2 Strength

Time under tension (TUT) is the amount of time a muscle is active during RT, and is a principle that underpins the prescription of RT due to its impact on training volume (145). That is, RT with a higher TUT represents an increased training volume, which has been shown to elicit greater increases in both strength and hypertrophy (145). No significant (p > 0.05) strength differences were observed in the current study between the two groups at any of the test sessions, although the CG demonstrated a significant increase ($p < 0.05$) in box squat 1RM from BL to T1. Within the current study, there was a significant ($p < 0.05$) difference in the average eccentric rep duration between the two groups (FE = 0.59s & CG = 1.97s) and estimated total eccentric time under tension over the four-week training intervention (FE = 86s & CG = 283s). Although the TUT for the CG was significantly higher ($p < 0.05$) than the FE, there were no significant differences in strength outcomes between the two groups. This finding goes against previous research which states that increased TUT leads to greater increases in strength (114,125). More recently, however, Schoenfeld et al. (121) demonstrated that differing training volumes (1 set, 3 set or 5 set per session) completed three times per week for eight weeks, led to no significant ($p > 0.05$) between-group differences in strength (1RM). It has been shown through research that is difficult to compare studies due to the differing volumes, intensities and exercises used as well as the participant recruitment strategies (e.g., strength trained vs non trained) (24).

Typically, within training intervention studies, training volume between intervention groups is manipulated via sets, rests or tempo, to ensure that TUT is equivalent between training groups (4,28,47,52). In the current study, however, training volume was not equated and based on estimated TUT; the CG had a significantly higher ($p < 0.01$) training volume than the FE. This was a deliberate strategy to evaluate whether FE would lead to significantly different increases in strength, power and speed even when less volume of work was completed. This is due to FE being a novel stimulus for RT adaptations (28) that is commonly used with individuals with a higher training age and who have progressed through a prior exercises and programmes. Individuals with high training ages may reach a point of diminishing returns, whereby meaningful adaptations to RT (especially strength) are hard to achieve due to individuals being close to their genetic ceiling (63). At this point, athletes will often respond to a training stimulus that is novel and will continue to adapt positively. In this regard, the fast-eccentrics used within the current study could serve as a novel stimulus for RT. As there was no significant difference in strength increases between the two groups, this study could warrant the use of FE squats in order to create some variety within RT, especially when an athlete has a high training age. However, due to the intensity of the exercise coupled with the increased reported RPE (Figure 4.1), it is suggested that this type of training be implemented with caution and within a pre-season block rather than competition.

5.1.3 Power

Power output is an important consideration for strength and conditioning coaches, especially for performance in power-based sports. Fast-eccentric (FE) training was expected to improve DJ performance (FT, CT or RSI) while CG training was not. In the present study, neither group demonstrated positive significant DJ improvements over the study timeline. The only notable change was the CG decreasing FT significantly ($p < 0.05$) from BL to T1, T2 and T3. These findings are similar to those of Douglas et al. (30). Their study showed that both fast and slow traditional RT, as well as slow AEL, led to no clear changes to DJ performance. However, they did find that fast AEL demonstrated a possibly higher RSI (ES = 0.37) and likely lower CT (ES = -0.82).

For the present study, it was expected that FE training would result in an increase in RPM and the CG would improve PPO during the 6s PPO Wattbike test. Both groups were thus expected to have significant increases ($p < 0.05$) in 6s PPO Wattbike sprint performance. However, the only significant ($p < 0.05$) change observed was for the CG group which demonstrated a significant increase in PPO at T3 compared to BL, T1 and T2. This finding was in accordance with hypothesis number two (Chapter One); however, there were no significant differences between groups. It is suggested that this increase in PPO at T3 is likely due to the increase in box squat 1RM also seen at T3 (115,116). Rønnestad et al. (115,116) demonstrated that well-trained cyclists significantly increased ($p < 0.05$) their PPO during a 30s Wingate test following an RT training intervention aimed at increasing strength, compared to the control group who completed no RT. The authors (115,116) suggested that increased leg strength meant that participants were able to generate more force within the first ~5s of the Wingate, thus increasing PPO.

5.1.4 Speed

There were no positive changes in sprint times recorded for any of the splits (5, 10 and 20m), for either training group, at any of the measurement points. There was, however, a significant increase ($p < 0.05$) in 5m split times in the CG from BL to T1, 2 and 3. The FE group demonstrated no significant changes to sprint times. Most interventions that have investigated the effect of RT on sprint performance, and find a positive outcome, typically involved a high volume of plyometric and sprint specific training, especially when the participants are trained athletes (53,88,112). However, the findings from the current study are in agreement with Blazevich and Jenkins (10), who found that increased concentric movement speed (concentric phase completed as fast as possible) during lower body RT demonstrated no significant differences in 20m sprint times when compared to slow movement speeds (2s eccentric and concentric phases). The current findings are also similar to those found by Douglas et al (30), who found no clear changes to sprint performance (ES = 0.7-0.14; unclear) following fast traditional RT. They also showed decreased sprint performance (ES = 0.65-0.77; likely higher) following fast AEL training, while slow AEL training led to an improvement in 20 and 40m times (ES = -0.35 & -0.44 respectively). The RT principle of specificity which underpins exercise prescription suggests that participants in power sports should train fast to be fast (10). However, findings from previous studies (10,30) as well as the current study found no improvements in sprint performance following a block of fast training. It is suggested, therefore, that the principle of specificity refers to the mode of training rather than the velocity of training e.g., squatting to improve squat strength (CG in current study) and sprinting to improve sprinting (119).

It is suggested that a four-week RT programme is not sufficiently long enough to elicit adaptations that would lead to a significant increase in sprint performance, especially when the athletes are involved in sports where sprinting is not a primary part of the sport (except sprinters). Although the FE training may induce adaptations that are beneficial for sprint performance such as increased lower limb stiffness, such adaptations usually require a longer time frame (75); the current study did not examine changes to lower limb stiffness.

5.2 Individual Variation in Performance Following Fast Eccentric Training

One of the aims of this study was to access the individual variation in performance that occurred following FE training. This aim was based on anecdotal strength and conditioning experiences (Jacobs, M., personal communication, 2019). It has been shown that individuals respond very differently to the same RT programme, with individuals being categorised as either low responders or high responders (87). It is thought that the factors that influence this response rate include genetics, the training programme undertaken and lifestyle factors (87).

Despite the absence of significant performance improvements in a 0.4m DJ in either training group, the variability of the FE group (CVs of RSI; BL = 19%, T1 = 16%, T2 = 17%, T3 = 20%) suggests that individuals may have responded quite differently to this training stimulus. The variability was evident in Figure 4.5 which depicts the DJ results from two FE participants (A & B) with markedly different training responses. At BL testing, both participants had a CT >0.20s (A = 0.21, B = 0.22), which in terms of power-based sports is considered a less than optimal CT (130).

As stated in Chapter 2 (2.3.1), a positive performance increase in DJ performance for power athletes is a decrease in CT along with increased FT. Such a positive performance was evident in participant A following the FE training intervention (figure 4.4A). Participant A decreased their CT over the surveillance period leading to a net increase in RSI. Although these changes were not found to be significant within the group statistical analysis, from an applied and practical stand point, this individual responded positively to the training intervention.

In the current study, large individual differences can be seen in Figures 4.3 and 4.5, with some individuals showing positive performance outcomes while others experienced negative or no change. This meant that when the mean data was analysed and reported, there were no significant findings. This large individual difference was demonstrated by the coefficient of variation (CV) values in Chapter 3. The observed individual differences likely came from the differing lifestyle factors of the participants, which included previous RT history and the sport participants played. As participants were completing sport and fitness training in parallel with the study's training intervention, there was no control over total training loads or composition of training. Participants came from a number of different sporting codes (basketball, volleyball, sprinting and judo), which were all at different stages of their seasonal preparation. With basketball and volleyball being in the pre-season phase, these participants would have been completing a lot more training outside of the study compared to the sprinters who had finished their competitive season just prior to the commencement of the current study. This is a potential confounding factor due to the nature of the sports participants play. Basketball and volleyball players completing large volumes of team trainings would have completed a large amount of extra plyometric work. This could have either increased performance outcomes due to increased amount of power training, or decreased it due to increased training load (26). It was planned for individuals to complete training diaries to try and monitor for this effect; however, only three participants were compliant with this and kept up-to-date training diaries. It was therefore decided not to report on this aspect of their training.

5.3 Limitations:

This training study focused on eccentric training and testing of competitive power sport athletes while they were immersed in their sporting preparation. Consequently, there are a number of limitations to this study that need to be acknowledged and considered. One of the main limitations of the current study was the number of participants who completed the study (n = 11). The more participants a study has, the more generalisable the findings are to the population in question. For the current study however, due to the time of the year when recruitment took place, the pool of participants which could have fitted the criteria were away due to university holidays or had competitions/too many prior engagements due to pre-season etc. . One limitation, which has already been addressed, was the fact that participants came from a number of different sporting backgrounds. Future research should look to work exclusively with one team, as was the case in the study by Douglas et al. (30). This way, although the volume of work outside of the study may not be able to be controlled (depending on coach etc.), at least all participants will complete similar amounts and types of training outside of the intervention.

The time constraints on the current study meant that the length of the training study had to be carefully managed; this was partly due to needing 28 days of lower volume training while participants completed three post-testing sessions. Although four to six weeks has been previously shown to be long enough to elicit significant increases in strength/power (22,122), a longer study timeline could have elicited adaptations such as increased lower limb stiffness, which has been shown to occur over ~8 weeks (75). Time constraints also meant that individuals participating in the study could not be progressed through a periodised eccentric programme, such as the one suggested by Ross and Douglas (118). They recommended moving in a progressive manner from traditional RT, into slow eccentrics (traditional concentric/eccentric loading pattern), overloaded eccentrics (AEL), fast eccentrics (faster than 180degrees/s in overloaded eccentric phase), ballistic training (focus on moving light loads fast both eccentrically and concentrically). This meant that individuals in the FE group may not have had a sufficient eccentric RT base to be able to cope with the intensity of the eccentric training, despite having at least two years of RT experience. The impact this could have had on the study is increased fatigue following the fast eccentrics and an increased risk of injury. An example of this occurring is found the study completed by Stasinaki et al (126), whereby four participants pulled out of the study within a week of the familiarisation session due to intense muscle soreness. In the current study, a familiarisation session and a progressive four-week programme that started light (50% 1RM), meant that injury risk and the extent of EIMD/DOMS was minimised.

5.4 Practical Applications:

The findings from the current study suggest that there is no added benefit from FE training compared to the CG on measures of strength, power and speed. Furthermore, the increased average RPE (Figure 4.1) seen in the FE group coupled with the potential for increased EIMD and DOMS make this mode of RT hard to place within a periodised programme. It is suggested that the use of eccentrics are progressed using Ross and Douglas' (118) model and utilised within a general and/or specific phase rather than competition/peaking. Although the current study found no significant decrease in performance following a four-week FE training intervention, individual variation in performance following the FE intervention means that eccentric training should be individually dosed. Future research should investigate the effects of increased movement velocity within different modes AEL for example; weight releasers, bands or manual load, whereby the eccentric phase is supramaximal, while the concentric phase is submaximal. As well as utilising AEL, the testing used to look at the effects of fast AEL training on power performance should include a host of jumping tests such as DJs, CMJ and EUR to get a better understanding of the changes that occur following fast-eccentric training.

Chapter 6: References

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Appendix A: Ethics Approval

Ethics Review Record

Student Names: Ricci Persico

Study Title: Fast Accentuated Eccentric Loading of the Squat and the Effects of the Myosin Heavy Chain IIx Overshoot Phenomenon

1. Have the researchers addressed issues for Maori?
Yes ✓ **No**
I understand consultation has occurred prior to this being submitted, ideally that should be documented in this document.
2. Have they undertaken Kaitohutohu consultation?
Yes ✓ **No**

3. Are there any vulnerable participants being researched
Yes **No** ✓
and have issues around inclusiveness been addressed?
Yes ✓ **No**

4. Does the study include any contentious methods (e.g. interviews, questionnaires where subjects could be identified?)
Yes (outline below) **No** ✓

Outline of contentious methods/issues:
-
-

Controls that have been set in place to ensure ethical practice (e.g. risk assessment, participant info sheet, consent form, warm-up):

Version 2 (11/12/13)

Ethics Review Record

5. Are you satisfied that the researchers have managed their contentious methods and the study can proceed?

Yes ☐ **No** (outline below)

Modifications required before study commences (these will be communicated to the student):
(continue on another sheet if required)

(Once completed please sign below)

Signed: **Date: 2 Nov 2018**............

Version 2 (11/12/13)

Appendix B: (recruitment poster)

OTAGO
POLYTECHNIC
Te Kura Matatini ki Otago

Calling Power Trained Athletes

(Basketball, Volleyball, Sprinting & Jumping)

Fast Eccentric Loading of the Squat and the Effects of the Myosin Heavy Chain IIx Overshoot Phenomenon

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This Project Aims To:

1) Determine the effect of movement speed during fast eccentric squats performed as part of a power based programme on measures of strength, power and speed
2) Look at the effects of rest after completing a chronic eccentric focused resistance training intervention on performance measures

To Participate You Must:

1) Compete in any of: Basketball, volleyball, sprinting or jumping sports at regional level or above
2) Have a minimum resistance training age of 2 years
3) Be able to commit to a 4 week high volume training intervention followed by 28 days of lower volume training

What is Required:

1) Complete 3 training sessions a week for 8 weeks (24 total sessions)
2) Keep a training diary of all training done during study period (outside of study sessions)
3) Not complete any resistance training outside of sessions involved in study

What you will get:

1) Train within a high performance setting at the HPSNZ Dunedin gym
2) Structured programming with the intention of increasing strength, speed and power

To find out more please email me [email redacted] or phone [number redacted]

Appendix C: (training intervention)

Intervention Programme

		Week Beginning:			Monday 4th March		Monday 11th March		Monday 18th March		Monday 25th March	
Full Body 1 (Strength)	Movement Preperation		Exercise	Tempo	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load
		1	Squat (GA)	X/0/1	3x6	50%	3x6	55%	3x6	60%	3x6	65%
		2A	S/A DB Bench	2/0/1	3x6 e/s	SS	3x6 e/s	SS	3x6 e/s	SS	3x6 e/s	SS
		2B	S/A Cable Pull	2/0/1	3x5 e/s	SS	3x5 e/s	SS	3x5 e/s	SS	3x5 e/s	SS
		3A	Banded TKE	2/0/1	3x5 e/s	SS	3x5 e/s	SS	3x5 e/s	SS	3x5 e/s	SS
		3B	SL DB Calf Raise	2/2/2	3x8 e/s	SS	3x8 e/s	SS	3x8 e/s	SS	3x8 e/s	SS
		4	Core Finisher	2/0/1	x2	BW	x2	BW	x2	BW	x2	BW
Full Body 2 (Power)	Movement Preperation		Exercise	Tempo	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load
		1	Box Jumps	X	3x1	BW	3x1	BW	3x1	BW	3x1	BW
		2	Med Ball Drops	X	3x4	SS	3x4	SS	3x4	SS	3x4	SS
		3A	KB Swing	X	3x5	SS	3x5	SS	3x5	SS	3x5	SS
		3B	Broad Jump	X	3x3	BW	3x3	BW	3x3	BW	3x3	BW
		4	Banded Pull Up	X	3x4	BW	3x4	BW	3x4	BW	3x4	BW
Full Body 3 (Strength)	Movement Preperation		Exercise	Tempo	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load
		1	Squat (GA)	X/0/1	3x6	50%	3x6	55%	3x6	55%	3x6	60%
		2A	Landmine Press	2/0/1	3x5 e/s	SS	3x5 e/s	SS	3x5 e/s	SS	3x5 e/s	SS
		2B	DB Pullover	2/0/1	3x6	SS	3x6	SS	3x6	SS	3x6	SS
		3A	RDL	2/0/1	3x6	SS	3x6	SS	3x6	SS	3x6	SS
		3B	Lateral Lunge	2/0/1	3x6 e/s	BW	3x6 e/s	BW	3x6 e/s	BW	3x6 e/s	BW
		4	UB Circuit	-	x3		x3		x3		x3	

X = as fast as possible SS = self selected weight GA = GymAware

Appendix C: (maintenance programme)

Programme Number Two - Maintenance												
1RM/Height		Maintanence & Testing			Week One		Week Two		Week Three		Week Four	
Full Body Power (Monday)	Movement Preperation		Exercise	Tempo	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load
		1A	Squat	1/0/1	Rest		3x3	65%	3x3	65%	3x3	65%
		1B	Box Jump	X			3x3	BW	3x3	BW	3x3	BW
		2A	Bench Press	1/0/1			3x4		3x4		3x4	
		2B	Med Ball Slam	X			3x6		3x6		3x6	
		3A	Landmine Press	1/0/1			3x4 e/s		3x6 e/s		3x6 e/s	
		3B	S/A Cable Pull	1/0/1			3x4 e/s		3x6 e/s		3x6 e/s	
Full Body Power (Wednesday)	Movement Preperation		Exercise	Tempo	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load	Sets x Reps	Load
		1A	Bench Throws	X	Rest		3x4		3x4		3x4	
		1B	Banded Pull Up	X			3x4		3x4		3x4	
		2	S/L Box Jumps	X			3x3 e/s	BW	3x3 e/s	BW	3x3 e/s	BW
		3	DB Curls	1/0/1			3x20		3x20		3x20	
		4	Tricep Ext.	1/0/1			3x20		3x20		3x20	
Testing	Movement Preperation	TESTING 1) 20m Sprint x3 2) 40cm Drop Jump x3 3) 6s PPO Watt Bike x1 4) Box Squat 1RM			Testing Session Thurs/Fri		Testing Session Thurs/Fri		No Testing		Testing Session Thurs/Fri	
					Post Testing #1 (+7 days post)		Post Testing #2 (+14 days post)		No Testing This Week (+21 days post)		Post Testing #3 (+28 days post)	

Appendix D: Article for Publication

This chapter contains duplicated material from throughout the thesis above. It serves as the skeleton of an article that will be created from this thesis to the Journal of Strength and Conditioning Research.

The Effect of Fast Eccentric Back Squats on Measures of Strength, Power and Speed in Power Trained Individuals

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The Effect of Fast Eccentric Back Squats on Measures of Strength, Power and Speed

Abstract:

The aim of this study was to investigate the effect of increased eccentric movement velocity on measures of strength, power and speed. A secondary aim was to examine the effect of recovery on performance. Eleven participants were randomly assigned to a fast-eccentric group (FE; n = 6) or control group (CG; n = 5). Participants completed a four-week intervention, training three times per week. Using submaximal back squats, the FE group performed the eccentric phase as fast as possible (average = 0.59s) and the CG completed the eccentric phase over two seconds. Testing measures included Box Squat One Repetition Maximum (1RM), 20m sprint, 6s Peak Power Output (PPO) Wattbike test and 0.4m Drop Jump (DJ). Testing was completed seven days prior to the start of the intervention (BL) and then seven (T1), fourteen (T2) and twenty-eight (T3) days following the intervention. There were no significant ($p > 0.05$) between-group differences in performance, however, the FE group reported on average a significantly ($p < 0.05$) higher Rate of Perceived Exertion (RPE) following RT sessions. Within-group differences were found over time, with the CG demonstrating a significant ($p < 0.05$) increase in 1RM from BL to T3 (+11.2%). The CG also significantly ($p < 0.05$) increased 5m sprint time and decreased DJ flight time (FT) from BL to T1, T2 and T3. The findings from this study suggest that training with an increased eccentric movement velocity during submaximal back squats leads to no added benefit to strength power or speed compared to traditional training.

Key Words: Strength and Conditioning, Resistance Training, Eccentric Training, Fast Eccentrics

INTRODUCTION

In power-based sports such as sprinting and throwing events, (17) the ability to generate maximal force over a short duration (power) is considered crucial for performance (23). Power athletes have between ~50-250ms to apply force (43), so it is critical that they are able to exert a high forces within this brief time frame. Resistance training (RT) methodologies that have been shown to enhance power production include: low-load high-velocity training (4), high-load low-velocity training (2), plyometrics (45), and more recently, eccentric focused training (11, 29, 42).

Eccentric muscle actions involve the active lengthening of a muscle e.g. the quadriceps during leg flexion (12). The complex integration of an eccentric action with a concentric action is termed the stretch shortening cycle (SSC) (6). During SSC movement, elastic energy from stretching the musculotendinous unit (MTU) is stored during the eccentric action. This stored elastic energy is recoverable during subsequent concentric contractions, leading to potentiation of the concentric contraction. Other SSC factors known to enhance this potentiation are an increased amount of time to produce concentric force, potentiation of contractile elements and the activation of stretch-reflexes (8). Although part of everyday movements such as gait, the SSC is considered an integral part of fast and cyclic movements such as sprinting and jumping (15). A fast and powerful eccentric pre-stretch within a SSC movement leads to a greater level of contraction potentiation (9,49), which has been shown to increase jump performance (9).

SSC ability can be quantified using a drop jump (6) and deriving a reactive strength index (RSI) by dividing flight time (FT) by contact time (CT). In power-based sports (17), RSI can be improved by decreasing CT while increasing or keeping FT constant. Some evidence suggests that increased eccentric strength may influence RSI due to the MTU's ability to absorb and utilise greater amounts of elastic energy, as well as the ability to control a rapid eccentric pre-load (5). However, resistance training (RT) methods tend to emphasise concentric training with loading dictated by one's concentric repetition maximum (1RM). However, it has been demonstrated that eccentric 1RM, is on average 20% greater than concentric 1RM (29). Eccentric training studies have demonstrated that eccentric-only, compared to concentric-only training produces greater increases in both strength (eccentric and concentric) and muscle cross sectional area (3,31). Recent research has focused on the movement velocity of the eccentric phase (11,42) and/or overloading the eccentric phase (13,29). Eccentric training with increased eccentric movement velocity has been shown to increase the percentage and CSA of type II muscle fibres (31) and increase muscle fascicle length (42). Both of these adaptations help facilitate a right shift in the force-velocity curve, meaning individuals are able to produce more force at a higher velocity (18).

Paddon-Jones et al (31) used dynamometry to investigate the effects of increased movement velocity during eccentric-only training. They showed that increased movement velocity led to greater eccentric strength gains at both the fast and slow speeds as well as a significant ($p < 0.05$) increase in the percentage of type IIx muscle fibres in the trained muscle. Douglas et al (13) investigated the effect of both accentuated eccentric loading (AEL) and increased eccentric movement velocity on strength, power and speed, finding that slow AEL training was superior to fast traditional and fast AEL training. Douglas et al (13) argued that the AEL and fast eccentrics used in their study may have exceeded the fatigue–recovery relationship. It is widely accepted that eccentric training leads to greater levels of exercise induced muscle damage (EIMD), delayed onset muscle soreness (DOMS) and low frequency fatigue, than concentric training (22,40). Although no studies have investigated recovery from training fatigue and soreness following an eccentric training intervention and its effects on performance, Douglas et al (13) speculated that a fast eccentric training block would likely be followed by a period of decreased performance secondary to fatigue and muscle damage.

No studies have sought to replicate the speeds used by Paddon-Jones et al (180 °/s) with traditional isoinertial RT. Hence the current study aimed to investigate the effect of increased eccentric movement velocity with isoinertial barbell back squats.

The purpose of this study was to investigate:

1. the effect of isoinertial submaximal fast eccentric or controlled eccentric squats on measures of strength, power and speed

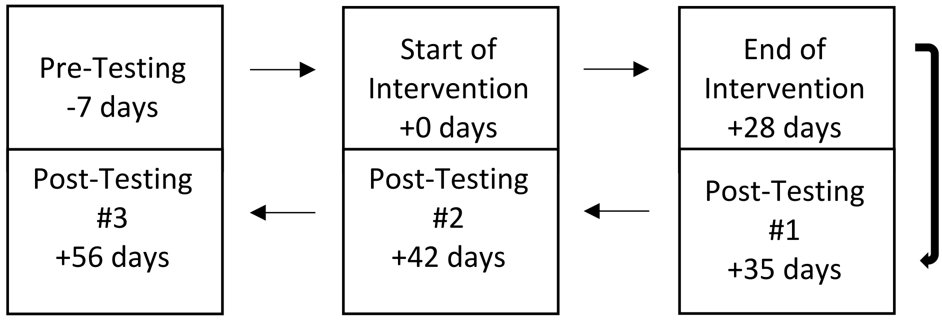
2. the effect of recovery following high intensity eccentrics and controlled eccentrics, on measures of strength, power and speed

3. the individual variations in performance following a period of high intensity eccentrics

METHODS

Experimental Approach to the Problem:

An experimental study design was employed, involving two training groups and an 8-week training block. Participants were pairwise matched based on their strength to weight ratio (1RM box squat/body mass) and randomly assigned to either a fast-eccentric (FE) or control (CG) training group.



Subjects

Participants were sought from the power-based sports of basketball, volleyball, sprinting and throwing (17). Eleven power trained athletes (9 male, 2 female) consented to participate. All were injury free for at least six months prior to the study, had a resistance training age >2 yrs, were older than 18 yrs, and were competing at a regional or national level within their chosen sport (mean ± SD; age: 21 ± 2 years; height: 182 ± 7 cm; mass: 78 ± 13 kg; Training Age: 5 ± 1 years; Strength to weight ratio: 1.69 ± 0.32). In accordance with ethical approval, participants were provided with an information sheet describing the study and signed a consent form before being assigned to a training group or participating in baseline testing. The research design was reviewed and approved by the institutional Ethics Committee.

Measures:

Strength, power and speed were assessed at baseline (BL; 7 days pretraining) and at 7 (T1), 14 (T2) and 28 (T3) days after completion of the initial 4-week training cycle. The testing order adhered to on each occasion was; standardised warm up, 20m Sprint, 40cm Drop Jump, 6s Watt Bike PPO test, and Box Squat 1RM. Testing was conducted at a standardised time of day for each testing session.

Warm up.

Participants completed a thorough supervised 15-minute warm up in preparation for each testing session (44). Participants then completed a near maximal 20m sprint to conclude their warm up. Test specific warm ups were conducted before each test and are detailed below.

Sprint splits.

For the measurement of sprint speed, participants completed three x 20m sprints, with timing gates placed at 5, 10 and 20m (Swift Speedlight Timing Gates, San Francisco). A rollout distance of 0.50 m was used to ensure the distance-time data was comparable with industry standard timings (13). Rest time between each 20m rep was 120s (19). Participants 5, 10 and 20m split times (s) were recorded to the nearest 0.01s for each sprint and presented as the average (± SD) of the three trials at each split.

40cm Drop Jump (DJ).

For the measurement of reactive strength, participants completed three bilateral DJs from a 0.4m height (13). Participants completed three submaximal jumps from the testing height, followed by three maximal effort test DJs, with 30s rest between jumps (11). Participants were instructed to keep their hands on their hips (akimbo) and to ensure that they stepped forward off the box (not stepping down or jumping up). Participants were instructed to minimize their ground contact time while maximizing their jump height, but to prioritise a brief ground contact time (13). Trials performed with poor technique (e.g. excessive knee valgus, loss of balance, or prolonged ground contact) were excluded and replaced. DJs were recorded using a SWIFT ezeJump Contact Mat (Swift Performance, San Francisco). Peak power (W), contact time (s) and flight time (s) from each trial were extracted from data using the manufacturer's software, which calculated RSI (flight time divided by contact time). The validity of the ezeJump contact mat has been demonstrated by Maulder and Cronin (26) who found no significant ($p = 0.001$) differences for measures of both flight and contact time between the ezeJump contact mat and a force platform. The FT, CT and RSI were measured to the nearest 0.01s and are presented as the average (± SD) of the three jump trials.

6s Watt Bike Peak Power Output (PPO) Test.

Participants completed one 6 sec sprint on a Wattbike (Wattbike Ltd, Nottingham, UK). Participants completed a 3 min warm up on the Wattbike prior to the first trial. Wattbike resistance was set based on each participant's weight and gender as per the manufacturer's instructions (47). The first minute was at 80rpm, with subsequent minutes at 90rpm and 100rpm. Participants rested for 60s before completing the sprint. During the sprint, participants were instructed to remain seated and to drive their legs as hard as possible. Peak Power Output (PPO) and Peak Cadence (PRPM) were recorded from the 6 sec test. The use of a 6 sec all out Wattbike sprint has been validated by Herbert et al (21), who found no significant ($p > 0.05$) difference between PPO after a 30s Wingate, a modified 10s Wingate or a 6s PPO test.

Box Squat 1RM.

Lower body strength was measured with a 1RM barbell box squat (BBBS). Prior to testing, four warm up sets, adapted from Pearson and McGuigan (27) were completed. At BL a warm up consisted of 8-10 reps at 30% of the participant's estimated 1RM, 4-6 reps at 50%, 2-4 reps at 75% and 1 rep at 90% of 1RM with the intention of reaching a maximal lift within 3-4 lifts. Participants rested in between sets and attempts for 3 mins (27). During subsequent testing, warm up reps were based on the previously recorded 1RM. To ensure appropriate technique participants were cued to maintain a wide set up squat stance (feet wider than shoulder width), natural feet position (close to that of their sport), unrestricted knee movement with heels remaining in contact with the ground throughout the movement, and a lordotic spinal. The target squat depth of thighs parallel to the ground or a knee angle of approximately 90 degrees, was guided by a plyometric box adjusted for individual heights (13). A light resistance band placed at individual heights provided participants with an additional external cue for squat depth. The band used was light enough to not interfere with the lift or the SSC. The BBBS 1RM was used to prescribe the training intensity for the squat during the training intervention. Results are presented as 1RM and strength:weight ratio (1RM/body mass) where body mass was recorded before each testing session.

Training familiarisation.

After BL testing and before training group assignment, all participants completed a familiarisation session designed to introduce the FE movement, ensure correct technique, and limit DOMS. In this session participants completed 6 reps with the bar only, 4 reps @ 20% 1RM, and 2 x 3 reps @ 40% 1RM.

Training procedures.

All participants completed strength and power resistance training (RT) exercises for both the upper and lower limbs, with the eccentric phase manipulated during the BBBS only. Training was structured as two consecutive four-week cycles. For the first four-week block participants trained three times per week and completed either fast-eccentric BBBS (FE) or controlled eccentric BBBS (CG) two times per week. All participants completed all exercises, other than the BBBS, using identical tempo, reps and sets. During the second 4-week block, participants completed a maintenance programme, continuing RT two times per week and without an eccentric emphasis. The second training block was to encourage the participants to complete all post-testing (T1, T2, T3).

Participants in the CG completed BBBS with a tempo of 2/0/1/0, (i.e. 2s eccentric and 1s concentric, no pauses), while the fast group used a tempo of <1/0/1/0. Average eccentric repetition duration was recorded using GymAware™ (Kinetic Performance, Australia). Participants completing FE reps were instructed to drop into the squat as fast as possible while maintaining correct technique and to control the weight on the return. Both groups completed 3 x 6 at the same percentage of 1RM. Squat loads started with 50% 1RM for the first week and incremented 5% each week. Loads were rounded to the nearest 2.5kg. Training intensity was monitored after each session using the Borg rating of perceived exertion (RPE 1-10). RPEs were reported as the average (± SD) RPE of each group after each week of training.

Statistical Analysis.

Analysis was completed using SPSS version 25 (SPSS inc. Chicago, IL). Results are presented as mean and standard deviation unless otherwise stated.. A Mixed Between-Within Analysis of Variance (MANOVA) was used to examine the effect of eccentric training at BL, T1, T2 and T3. When significant differences between groups were found, paired samples t-test were used to describe within group changes. Statistical significance was accepted at the 5% level ($P < 0.05$).

RESULTS:

Eleven participants completed the baseline (BL) testing and were then pair wise matched on their strength to weight ratio and randomly placed into either fast-eccentric group (FE; n = 6, age 21 ± 3, height, 183 ± 8, weight = 81 ± 8, training age = 4 ± , 1RM = 128 ±39) or control group (CG; n = 5, age = 22 ±2, height = 179 ± 11, weight = 75 ± 12, training age = 5 ± 2, 1RM = 133 ± 28). No significant ($p > 0.05$) differences were observed between groups for any BL measure. One participant did not complete all testing sessions due to an injury and was excluded from subsequent data analysis (FE; n = 5). Adherence to the four-week training intervention was good (92.5% of sessions attended). Participants were asked to record all individual or team training undertaken outside of the intervention using an electronic training diary. Adherence was poor with only three participants completing this in full. That information has not been reported.

The effects of FE versus CG

MANOVA analysis demonstrated no significant ($p > 0.05$) differences for any of the performance measures across all time points. The average eccentric rep duration of 0.59s for FE was significantly faster ($p = 0.01$) than the 1.97s recorded for CG reps. The FE group reported significantly higher ($p < 0.05$) RPEs after each session at weeks 2, 3 and 4 of the training intervention (figure 1).

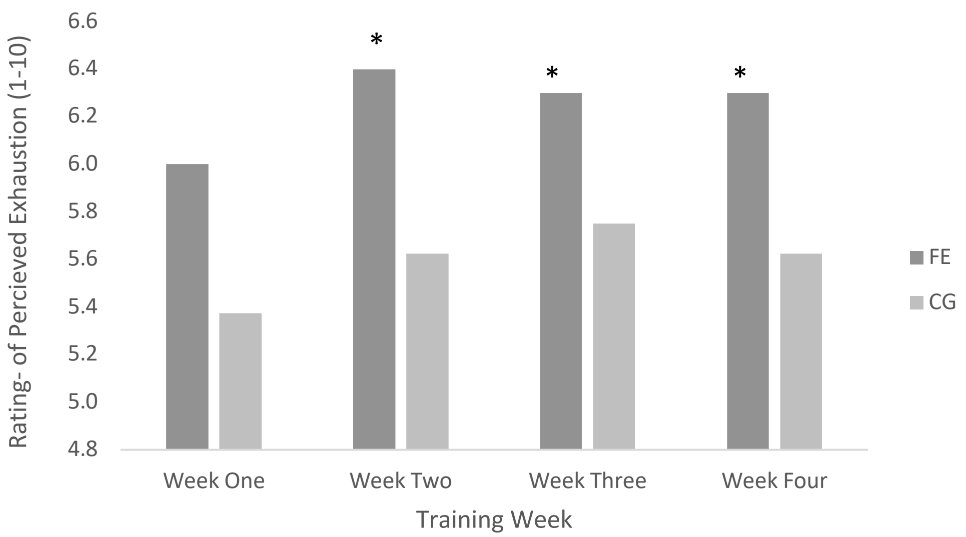


Figure 1: Average post-session RPEs * significant ($p < 0.05$) difference between CG and FE

Training responses

Strength.

The CG demonstrated a significant increase ($p < 0.05$) in BBBS 1RM (+11.2%) between BL and T3. No other significant changes in 1RMs were observed for either intervention group (Table 1).

Power.

The CG group (Table 1) demonstrated a significant reduction ($p < 0.05$) in FT from BL to all post-test. The CG also had a significant increase ($p < 0.05$) in PPO during the 6s PPO Watt bike test from BL to T3 T1 to T3 and T2 to T3. The FE group demonstrated a significant ($p = 0.05$) increase in peak RPM during the 6s PPO Watt bike test from T2 to T3.

Speed.

No positive changes to sprint times were observed for any of the splits (5, 10 and 20m) for either group across all testing sessions. The CG were significantly slower ($p < 0.05$) for 5m sprints from BL to T1, T2 ($p = 0.01$) and T3, and for 10m sprints from BL to T1 ($p = 0.03$). The FE group had similar results, with significantly slower ($p = 0.05$) 10m and 20m splits from T1 to T3.

Table 1: Table showing the averages ± standard deviations for both intervention groups over all four of the testing sessions pre, + 7, + 14 and + 28 days of intervention.

		Sprint (s)			Drop Jump			6s PPO Watt Bike		Squat
		5m	10m	20m	CT (s)	FT (s)	RSI	PPO (W)	RPM	1RM (kg)
Control	BL	0.98 ± .06	1.73 ± .10	3.02 ± .17	0.18 ± .04	0.53 ± .02	3.05 ± .54	1176 ± 258	137 ± 8	133 ± 28
	T1	1.01 ± .07*	1.77 ± .11*	3.08 ± .19	0.17 ± .01	0.50 ± .01*	2.95 ± .2	1171 ± 172	130 ± 15	139 ± 22
	T2	1.02 ± .06*	1.75 ± .09	3.06 ± .16	0.17 ± .01	0.51 ± .01*	3.07 ± .26	1214 ± 281	136 ± 53	141 ± 27
	T3	1.02 ± .05*	1.77 ± .08	3.08 ± .15	0.17 ± .01	0.50 ± .02*	2.99 ± .29	1285 ± 262*[1,2]	137 ± 9	142 ± 24*
Eccentric	BL	1.01 ± .07	1.75 ± .11	3.06 ± .2	0.19 ± .03	0.52 ± .03	2.91 ± .56	1078 ± 198	131 ± 10	128 ± 39
	T1	1.00 ± .08	1.75 ± .13	3.05 ± .22	0.17 ± .03	0.49 ± .02	2.86 ± .47	1045 ± 220	121 ± 16	133 ± 37
	T2	1.02 ± .08	1.76 ± .09	3.07 ± .21	0.17 ± .03	0.51 ± .02	2.99 ± .53	1040 ± 200	128 ± 7	129 ± 35
	T3	1.02 ± .09	1.77 ± .15[1]	3.07 ± .25	0.17 ± .03	0.52 ± .06	2.99 ± .65	1081± 391	131 ± 9[2]	131± 43

* Denotes a significant difference compared to pre-testing value [1] Denotes a significant difference from post testing one [2] denotes a significant difference compared to post testing two. [3] denotes a significant difference compared to post testing three

DISCUSSION

This research sought to explore the effect of a four-week training intervention utilising either fast or controlled eccentric isoinertial squats, with submaximal loads on measures of strength, power and speed. The study also investigated the effect of recovery following the four-week training intervention, and how this effected performance in the strength, power and speed tests. Eleven power sports athletes volunteered for the study. Following baseline testing they were assigned to either a fast-eccentric squat group (FE; n = 6, with only 5 completing all post testing sessions) or a traditional squat control group (CG; n = 5). Participants trained three times per week for four weeks.

The Effects of Fast Eccentric Squats versus Traditional Squats

Fast eccentric squats did not appear to offer any advantage over traditional squats with no significant differences observed between training groups for any measures at any time point. This goes against previous findings that FE training leads to greater performance outcomes than concentric-only or traditional RT (14,31). Typically, studies that find significant improvements in strength and/or power from submaximal and maximal eccentric training at high velocities have utilised some form of isokinetic dynamometry (14,31). Stasinaki et al (42) were the exception finding that fast eccentric-only squats at 70% concentric 1RM led to improved squat 1RM by 14.5%, improved rate of force development (RFD) and quadriceps' fascicle length. These researchers (42) trained participants with fast eccentric-only squats, twice per week using 9 x 9 reps @ 70% 1RM. Their eccentric training volume (972 reps over 6 weeks) was markedly higher than the current study (144 reps over the four weeks). This disparity may explain the differences in results. The findings by Stasinaki et al (42) also suggest that the loads utilised during the current study (50-65% 1RM) may have been insufficient to elicit the expected adaptations. Observations from the current study suggest that participants would likely have struggled to complete and control fast eccentrics @ 70% of 1RM from week one and be able to complete the concentric phase. Stasinaki et al (42) recommend that fast eccentric squats should be progressed over a training block, starting as low as 30-40% of concentric 1RM. Stasinaki et al (42) noted that four participants dropped out of the study due to intense muscle soreness. This may have been due to the high loads and volume utilised, or the fact that the participants were untrained and therefore more succeptible to exercise induced muscle soreness (30).

Ross (35) questions whether fast-eccentric isoinertial movements, as used in the current study, meet the requirements for a true eccentric action. He (35) states that fast eccentrics completed by "shutting off" the musculature and turning it back on to stop the movement (also known as a drop catch) are not true fast-eccentric movements due to the inability of individuals to have muscular tension throughout the full range of movement. It is therefore suggested that one of the factors that may influence SSC performance following eccentric training is the loading pattern (e.g. AEL) rather than velocity per se, especially if the goal is to increase SSC performance. The ability to complete a heavy eccentric pre-stretch (supramaximal; above concentric 1RM) coupled with a lighter (submaximal) concentric propulsion phase may be a better way to enhance SSC performance. Previous research has demonstrated that this type AEL training is effective at inducing increases in both strength and jumping performance (1,39). The suggested mechanisms behind supramaximal AEL are postulated to be mainly neural, however, the exact mechanisms are still unclear (46). The neural mechanisms suggested by Wagle et al (46) are due to the supramaximal eccentric phase being closer to eccentric 1RM and therefore requiring a greater amount of activation, especially of high threshold motor units (HTMU). The activation of HTMU during overloaded eccentrics leads to a greater level of concentric potentiation due to a greater level of neural drive and increased storage of elastic energy (29,46).

Douglas et al (13) found that slow AEL training was superior to fast AEL training for increasing performance in strength, power and speed tests. This finding goes against previous research (14,31,42). The fast-eccentric tempo of 1s used by Douglas et al (13) was likely not fast enough when compared with previous studies. For example, Paddon-Jones et al (31) showed that fast eccentrics completed at 180 °/s using dynamometry produced significant ($p < 0.05$) increases in strength. Douglas et al (13) used 90 °/s. The FE group in the current study had a mean eccentric movement velocity of 157 °/s, which was closer to the speed used by Paddon-Jones et al (31). However, the current study demonstrated that this movement velocity was still insufficient to elicit any significant benefits compared to the control group. This is likely to be indicative of the loading pattern used rather than the eccentric movement velocities.

Although the FE group's higher reported perceived exertion could be due to a number of factors, it is suggested that the lower body stress from FE squats was the primary reason for the higher RPEs. These perceptions in combination with the absence of any performance advantages, mean that including fast-eccentric isoinertial submaximal squats in a training programme may offer no advantage.

Effects of Training Intervention on Measures of Strength, Power and Speed

All performance tests were repeated following the cessation of the eccentric training intervention at T1, 2 and 3. As eccentric training can be associated with significant muscle soreness (16) and low frequency fatigue (LFF) (10), the post-training testing was conducted to investigate the influence of recovery on performance measures. Douglas et al (13) suggested that these factors may have decreased performance following their fast-eccentrics intervention. It has been shown that a single bout of eccentric training leads to symptoms of muscle damage including strength loss, pain and muscle tenderness (28). It was therefore expected that the FE training would significantly impair performance at T1, but that performance would recover to BL levels or above at T2 and T3. This proved not to be the case. There were no significant changes in performance in the FE group across all test sessions, so fatigue and soreness did not appear to impact performance.

Strength

Time under tension (TUT) is a principle that underpins the prescription of RT, due to its contribution to training volume (48). A higher TUT represents an increased training volume and has been shown to elicit greater increases in both strength and hypertrophy (48). Within the current study the average eccentric rep duration (FE = 0.59s & CG = 1.97s; $p < 0.05$) and estimated total time under eccentric tension during the four-week training intervention (FE = 86s & CG = 283s; $p < 0.05$) demonstrate the TUT for the CG was significantly ($p < 0.05$) higher. However, there were no significant differences in strength outcomes between the two training groups. This finding is contrary to previous research where increased TUT led to greater increases in strength (32,41). Schoenfeld et al (38) however, demonstrated that differing training volumes (1, 3 or 5 sets/session, three times per week for eight weeks), led to no significant ($p > 0.05$) between-group differences in strength (1RM). Comparing training studies is difficult due to differing volumes, intensities and exercises, as well as the training age or participants (10).

In the current study training volume was deliberately not equated to evaluate whether FE as a novel training stimulus would lead to superior increases in strength, power and speed even when less volume was completed. Although there was no significant difference in strength changes between the groups, this study demonstrated that FE squats could provide some RT variety especially for athletes with higher training ages. However, the intensity of the exercise and the higher reported RPEs suggest that this type of training be implemented with caution and within a pre-season block rather than competition.

Power:

Power output is an important consideration for strength and conditioning coaches. Fast eccentric (FE) training was expected to provide superior DJ performance (FT, CT or RSI) improvements compared with traditional training. In the present study neither method significantly improved DJ parameters. These findings are similar to those of Douglas et al (13). who found that both fast and slow traditional RT, as well as slow AEL, did not improve DJ performance. They did find that fast AEL demonstrated a possibly higher RSI (ES = 0.37) and likely lower CT (ES = -0.82).

It was expected in the present study that FE training would improve RPM on the watt bike test, and that CG would improve PPO. The only change observed was for the CG group which demonstrated a significant increase ($p < 0.05$) in PPO at T3 compared to BL, T1 and T2. This finding was in accordance with the hypothesis, however there were no significant differences between groups. It is suggested that this increase in PPO at T3 is likely due to the increase in Box Squat 1RM also seen at T3 (33,34). Rønnestad et al (33,34) demonstrated that well-trained cyclists significantly increased ($p < 0.05$) their PPO during a 30s Wingate test following a RT training intervention aimed at increasing strength, compared to the control group who completed no RT. The authors (33,34) suggest that increased leg strength meant that participants were able to generate more force within the first ~5s of the Wingate, thus, increasing PPO.

Speed:

There were no positive changes in sprint times recorded for any of the splits (5, 10 and 20m), for either training group, at any of the measurement points. Most interventions that have found a positive effect of RT on sprint performance have typically involved a high volume of plyometric and sprint specific training, especially when the participants are trained athletes (20,25). However, the findings from the current study are in agreement with Blazevich and Jenkins (4), who found that faster concentric movement velocity during lower body RT demonstrated no significant differences in 20m sprint times when compared to slow movement speeds. Douglas et al (13) found no clear changes to sprint performance (ES = 0.7-0.14; unclear) following fast traditional RT but slow AEL training led to an improvement in 20 and 40m times (ES = -0.35 & -0.44 respectively).

The RT principle of specificity suggests that participants in power sports should train fast in order to be fast. However previous studies (4,13) as well as the current study found no improvements in sprint performance following a block of fast training. It is therefore likely that mode specificity may be more important than velocity specificity. That is, squatting to improve squat strength, and sprinting to improve sprint speed (37). A four-week RT programme may not be sufficient to elicit adaptations that would lead to a significant increase in sprint performance, especially when the participants were involved in sports where sprinting was not a primary part of the sport. Although FE training may induce adaptations that are beneficial for sprint performance such as increased lower limb stiffness, such adaptations usually require a longer time frame (24), and the current study did not examine lower limb stiffness.

Limitations:

This training study focused on eccentric training and testing of competitive power sport athletes while they were immersed in their sporting preparation. Consequently, there were a number of limitations that need to be acknowledged and considered. Participants came from a number of different sporting backgrounds and the volume of work outside of the study likely differed by sport and the seasonal stage. The participants' sporting preparations also meant that the length of the training study had to be carefully managed to allow 28 days of lower volume training while participants completed three post testing sessions. Although four to six weeks has been shown to be sufficient to elicit significant increases in strength/power (39), a longer training period could have elicited greater adaptations such as increased lower limb stiffness, which has been shown to occur over ~8 weeks (24). Time constraints also meant that individuals participating in the study could not be progressed through a periodised eccentric programme. Ross and Douglas (36) recommend moving in a progressive manner from traditional RT, into slow eccentrics overloaded eccentrics (AEL), fast eccentrics, to more ballistic training. In the present study the FE participants may not have had a sufficient RT base to be able to cope with the intensity of the eccentric training.

Practical Applications:

The findings from the current study suggest that FE training offers no added benefit over CG on measures of strength, power and speed. The increased average RPEs reported by FE participants mean that this mode of RT is difficult to place within a periodised programme. It is suggested that the use of eccentrics are progressed as suggested by Ross and Douglas (36) and utilised within a general and/or specific phase rather than during competition or peaking phases. Future research should look to evaluate fast eccentric isoinertial training whereby the eccentric load is applied throughout the range of movement. A suggested method of training is partner AEL training whereby the strength and conditioning coach manually (via their own bodyweight) adds weight to the bar during the eccentric phase and releases it during the concentric phase. It is also suggested that future research on fast eccentrics and SSC performance should include both DJ and CMJ assessments to provide a better representation of lower body power and intervention impacts on both fast and slow SSC performance.

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