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Assessment and Training of Muscular Force and Power Qualities of the Lower Limb Using Traditional and Cluster Loading

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by
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USE OF THESIS

ABSTRACT

It is widely accepted that lower body muscular force and power capabilities are of significant importance to many athletic tasks. Thus the assessment and training of these qualities are a key focus in both sports science and strength and conditioning practice. The purpose of this thesis was firstly to investigate previously discussed but poorly researched methods of assessing force and power characteristics of the lower limb particularly focusing on the analysis of the force-time and power-time curves during the rebound jump squat, and secondly, to investigate the effectiveness of cluster loading, an alternative resistance training paradigm, in training for lower body explosive performance. In Chapters 3 to 6 assessment issues were investigated and the studies in Chapters 7 and 8 address questions relating to resistance training using cluster loading.

The purpose of Chapter 3 was to investigate the differences between three methods previously used to calculate various force-time measures during a rebound jump squat. Method one analysed the force-time curve from minimum force to maximum force, method two analysed the concentric portion of the force-time curve only and method three analysed both the eccentric and concentric components of the force-time curve. The results suggested that for force-time variables which assess rate of force development relative to peak force significantly different values are produced dependent on analysis method (% difference = 1.1% - 364.3%), but that the values from each method are highly correlated (r = 0.93 - 1.00). However, when time-dependent variables were investigated the starting point of calculation resulted in the measurement of functionally independent physical qualities.

The purpose of Chapters 4 and 5 was to investigate the between day reliability of methods of collection and analysis of force-time and power-time data during the rebound jump squat. The calculation of various force measures from force plate data and linear position transducer data, and reliability of power measures calculated with data from these two technologies and a combined method (ground reaction force together with bar velocity) were evaluated. Results showed that all methods provided a reliable means of measuring peak force (ICC = 0.88 ï 0.96, CV = 2.3% - 4.8%) and

peak power (ICC = 0.87 ï 0.95, CV = 3.4% - 8.0%). The reliability of force-time and power-time measures varied considerably (force-time measures, ICC = 0.18 ï 0.96, CV = 5.1% - 93.6%, and power-time measures, ICC = 0.77 ï 0.94, CV = 8.0 ï 53.4) between measures and methods. Typically the force plate (and combined method for power values) provided the most stable measurement method with between day variation increasing considerably when differentiated linear position transducer data was used in calculations.

The purpose of Chapter 6 was to investigate the discriminative ability of the rebound jump squat force-time and power-time measures investigated in Chapters 3-5 in differentiating speed performance and competition level in elite and elite junior rugby union players. Results showed that the fastest and slowest sprinters over 10 m differed in peak power expressed relative to body weight. Over 30m there were significant differences in peak velocity and relative peak power and rate of power development calculated with a moving average between the fastest 20 and slowest 20 athletes. There was no significant difference in speed over any distance between elite and elite junior rugby union players, however a number of force and power variables including peak force, peak power, force at 100 ms from minimum force, and force and impulse at 200 ms from minimum force were significantly ($p < 0.05$) different between playing levels.

Chapters 7 and 8 studied the use of cluster loading for training explosive lower body performance in elite rugby union players. The purpose of Chapter 7 was to investigate the acute effect of cluster set structures on force, velocity and power during jump squat training. Mechanical responses to four different set structures were compared in elite and elite junior rugby union players; a traditional structure (four sets of six repetitions) and three cluster structures (4 x 6 x singles, 4 x 3 x doubles and 4 x 2 x triples). The cluster loading configurations were shown to significantly attenuate the decrease in peak power and peak velocity in the latter repetitions of a set of six repetitions in the rebound jump squat movement.

The purpose of the second cluster training study, Chapter 8, was to ascertain whether cluster training structures led to improved power training adaptation in the pre-season preparation of elite level rugby union players. In this study, eighteen highly trained athletes were divided into two training groups, a traditional training group and a cluster

training group prior to undertaking eight weeks of lower body resistance training. Although both a traditional and cluster training intervention significantly improved lower body maximum strength (pre-post change = 18.3% ± 10.1 and 14.6% ± 18.0 respectively), the effect of cluster training on maximum strength adaptation was possibly negative. There were no significant pre- to post-training changes in jump squat force, velocity or power values for either training group. Magnitude based inferences suggested some likely positive effects of cluster training when compared to the traditional structure for peak power and peak velocity at selected testing loads. Therefore, there was some evidence to support the possible benefit of cluster type loading in training prescription for lower body power development.

DECLARATION

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

(i) incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;
(ii) contain any material previously published or written by another person except where due reference is made in the text; or
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Date*:* 25.01.2012

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PUBLICATIONS

CHAPTER 2 (SECTION 2.3)

Hansen, K.T. and Cronin, J.B. (2009). Training loads for the development of lower body muscular power during squatting movements. *Strength and Conditioning Journal,* 31 (3), 18-33.

CHAPTER 3

Hansen, K.T., Cronin, J.B. and Newton, M.J. (2011). Three methods of calculating force-time variables in the rebound jump squat. *Journal of Strength and Conditioning Research,* 25 (3), 867-871.

CHAPTER 4

Hansen, K.T., Cronin, J.B. and Newton, M.J. (2011). The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes. *Journal of Strength and Conditioning Research,* 25 (5), 1447-1456.

CHAPTER 5

Hansen, K.T., Cronin, J.B. and Newton, M.J. (2011). The reliability of linear position transducer, force plate and combined measurement of explosive power-time variables during a loaded jump squat in elite athletes. *Sports Biomechanics,* 10 (1), 46-58.

CHAPTER 6

Hansen, K.T., Cronin, J.B., Pickering, S.L. and Douglas, L. (In Press). Do force-time and power-time measures in a loaded jump squat differentiate between speed performance and playing level in elite and elite junior rugby union players? *Journal of Strength and Conditioning Research.*

CHAPTER 7

Hansen, K.T., Cronin, J.B. and Newton, M.J. (In Press). The effect of cluster loading on force, velocity and power during ballistic jump squat training. *International Journal of Sports Physiology and Performance.*

CHAPTER 8

Hansen, K.T., Cronin, J.B., Pickering, S.L. and Newton, M.J. (2011). Does cluster loading enhance lower body power development in pre-season preparation of elite rugby union players? *Journal of Strength and Conditioning Research,* 25 (8), 2118-2126.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BW	Body Weight
CL	Confidence Limits
COM	Centre of Mass
CT	Cluster Training
CV	Coefficient of Variation
ES	Effect Size
ICC	Intraclass Correlation Coefficient
IMP	Impulse
Kg	Kilograms
m	Metre (the unit of distance)
MF	Mean Force
MP	Mean Power
m/s	Metres per Second (the unit of velocity)
ms	Millisecond (the unit of time)
N	Newton (the unit of force)
Ns	Newton Second (the unit of impulse)
PF	Peak Force
Pmax	Load that Maximises Peak Power
PP	Peak Power
PV	Peak Velocity
RFD	Rate of Force Development
RPD	Rate of Power Development
RM	Repetition Maximum
s	Seconds (the unit of time)
SSC	Stretch Shorten Cycle
TE	Typical Error
TT	Traditional Training
W	Watts (the unit of power)
Yr	Year (the unit of age)

CHAPTER 1

INTRODUCTION

1.1 THESIS RATIONALE

Lower limb muscular force and power capabilities are regarded as physical attributes essential to high level performance in many sporting endeavours. Accordingly, there has been considerable research into methods of assessment and training of lower limb muscular power. Despite this research interest, there is still extensive debate as to the most effective means of assessing and training muscular force and power, and the subsequent cross-over of training adaptations to performance in sporting tasks. Consequently, the assessment and development of lower limb force, velocity and power provides the focus of this research.

Effective prescription of resistance training programs for sports performance requires accurate assessment of strength and power qualities for diagnostic purposes (2). Currently the best data collection methodology and most important measures for quantifying performance during iso-inertial lower body movements are unclear. Measures commonly used include peak force (PF) and mean force [MF] (32, 50, 202), rate of force development [RFD] (32, 195), peak velocity [PV] (107, 112) and peak power (PP) and mean power [MP] (15, 37, 38, 41, 107, 112, 175). Research has shown that many of these variables can be measured reliably during squatting and jump squatting using ground reaction forces (32, 50, 107), displacement time data (3, 107, 112) or a combination of both (107).

Some authors (171, 185, 203) have suggested alternative measures of force and power which may be of interest and warrant further investigation. Establishing their reliability as performance measures and their importance to training prescription and sports performance may be of value to the sports scientist and strength and conditioning practitioner alike. Therefore the interrelationships between these measures and more traditional measures of force and power, and the reliability of such methods, require further investigation. Schmidtbleicher (171) used the terms absolute strength (maximal force that can be produced independent of body weight), speed strength (greatest possible impulse in shortest time period), starting strength (the ability to produce the greatest possible force in the shortest possible time period) and explosive strength (the capacity to achieve maximal increase in force per unit of time). Tidow (185) also used similar terminology applying many of the measures discussed by Schmidtbleicher to specific parts of the force-time curve. For example, Tidow described starting strength as the force developed at 30 milliseconds and explosive strength as the maximum rate of force increase per unit of time (maximum rate of force development).

Zatsiorsky and Kraemer (203) have also discussed a number of similar force-time measurements that can be used to describe muscular performance. These include the index of explosive strength (PF / time to PF), the reactivity coefficient (PF / (time to PF x body weight), the starting gradient (½ PF / time to ½ PF) and the acceleration gradient (½ PF / (time to PF-time to ½ PF). Some studies have investigated similar measures to these in correlational research (195, 202). However, research investigating the application or practical significance of these alternative measures of athletic performance is scarce. Additionally, it is unknown whether these same calculations applied to the power-time curve predict athletic performance to better effect and therefore may be better variables to monitor training changes and performance gains.

From a training perspective, strength and power adaptation due to resistance training is mediated by the mechanical stimuli associated with various loads and types of exercises. It has been suggested that the kinematics (displacement, time, velocity and acceleration) and kinetics (force, power, impulse and work) are the most important stimuli for strength and power adaptation (44) and at the very least determine the metabolic and hormonal responses to a resistance strength training session. Despite a large body of research into the kinematics and kinetics of a single repetition of various strength and power loading schemes, there is very little published data examining the kinematics and kinetics of loading schemes (multiple repetitions and sets), similar to those encountered in a resistance training session. Given the importance of exercise prescription to achieving required training outcomes, the lack of understanding of the effect of loading paradigms on test variables of interest would seem unusual.

There are however, some studies which have examined multiple repetition mechanics in the squat and jump squat (18, 46, 48, 49, 96), and in the supine squat (46, 48, 49). The majority of these studies have compared the effect of different loading schemes for total velocity, force and power, and mean repetition velocity, force and power over a set of repetitions. In general, this has shown that for a single repetition heavier loads produce greater total and mean forces. However when volume load is equated light loads lifted in a ballistic fashion produce not only greater total power and velocity but greater total forces and work (48). Perhaps of more interest in terms of understanding exercise prescription is force and power profiles of individual repetitions over a working set. For example, Baker and Newton (18) examined power outputs across a set of 10 repetitions during the jump squat, showing that the highest power output was achieved at either repetition two or three and maintained until the fifth repetition, with power output declining significantly thereafter. This provides tangible information to guide training prescription in terms of achieving maximum power output in a training scenario.

There are wide variety of training systems which are prescribed in practise to develop explosive qualities in athletes, and identifying the appropriate prescription is crucial in optimising training outcomes. An alternative loading pattern termed inter-rep rest or cluster loading has been suggested as a method of structuring resistance training well suited to developing maximal power (81). These types of loading patterns, break sets into small ñclustersò of repetitions, and have been compared to traditional loading schemes during both the clean pull (83) and the bench press (59, 127, 128) in research. Haff and co-workers (83) showed that PV during cluster loading (15-30 seconds rest between repetitions) was significantly greater than that achieved during traditional continuous loading. This research also showed traditional and cluster loading possessed different fatigue-related patterns during the sets of five repetitions, with the traditional loading technique resulting in significantly greater decreases in velocity for repetitions three, four and five. However, there is limited acute research profiling cluster patterns during lower body training. Likewise, there is limited research investigating cluster configurations applied over a training period. Thus the applications of these training structures to developing athletic performance are unclear.

1.2 SIGNIFICANCE OF THE RESEARCH

It is widely accepted that lower body muscular force and power capabilities are of significant importance to athletic performance. This is particularly true of collision sports where a balance of speed, lean mass and strength and power development is crucial. Yet to date, the importance of rate-dependent force and power variables to athletic performance has not been well researched. Despite discussion of such variables in the literature, few studies have examined these qualities in depth. Accordingly questions remain as to the relationships of force-time and power-time variables to each other and performance in athletic tasks, how these parameters are affected in a training bout and how current resistance training practices affect these variables. The majority of research to date has focused on the importance of PP (13, 52) and PF (195, 201, 202) despite contradictory evidence as to the relevance of these variables to athletic performance. Given the explosive nature of athletic performance, it seems that rate-dependent force and power qualities warrant further investigation to elucidate their importance in athletic tasks and the ability of training practices to shift these measures. Additionally, despite the widespread assertion that cluster training is well suited to developing explosive performance there is very little research investigating mechanical stimuli associated with this type of training and longitudinal training outcomes. These gaps in the research need to be addressed in order to help the practitioner apply cluster training structures appropriately. This PhD project addressed these issues specifically with a highly trained population who compete at the elite level in collision sports.

1.3 PURPOSE OF THE RESEARCH

The purpose of this research was to investigate previously discussed but poorly researched methods of assessing force and power characteristics of the lower limb particularly focusing on the analysis of the force-time and power-time curves. This included analysis of methodological issues in analysing the force-time curve, the reliability and relationships between measurement apparatus, a comparison of reliability between traditional measures (PF and PP) and temporal measures, and an analysis of which measures were the best determinants of performance level in the study population, elite level rugby players. A second aim was to investigate how current training paradigms, specifically cluster loading, affect those force and power variables deemed to be reliable and able to differentiate performance, in an acute training bout, and over a training period in the complex training environment of team sports.

1.4 RESEARCH QUESTIONS

- How does start point of analysis effect force-time values when analysing rebound jump squat data?

- What force-time and power-time qualities can be reliably assessed during the jump squat movement using apparatus currently available to strength and conditioning practitioners and researchers?
- Are alternative force-time and power-time measures better predictors of sports performance than traditional measures such as peak force and peak power in elite and elite junior rugby union players?
- How does training set structure affect the force, velocity and power profile of a set during training (multiple sets, multiple repetitions)?
- Do cluster loading patterns provide a more appropriate method of training force, velocity and power variables than traditional loading patterns?

1.5 ORIGINALITY OF THE RESEARCH

To date very few of the force-time and power-time variables discussed thus far have been investigated in elite populations who are highly trained. Likewise cluster loading patterns have not been researched using the jump squat movement patterns in an elite population. Elite level rugby union players represent a population for whom strength and power development is deemed to be of great importance and thus a considerable amount of time is committed to resistance training in athlete development and preparation. However, research into the assessment of strength and power, and into resistance training practices, in elite rugby union players is in its infancy. This research addresses strength and power assessment and training issues not previously investigated in this population. This will help provide improved understanding of methodological issues relating to assessment, and how the resistance training interventions investigated are best integrated in resistance training programming in this population.

1.6 LIMITATIONS OF THE RESEARCH

The participants in this study were all elite or elite junior rugby union players and in the most part participation was part of their prescribed strength and conditioning testing and training program. Accordingly all players had to undertake additional training to that prescribed for the purposes of this study. In some cases this may have included the use of individualised skill and conditioning programs. These factors could not be adjusted for the purposes of this research, but will be a matter of record and the information regarding physical activity levels and nutritional programs was available to the researcher at the time of data collection. Where possible testing was scheduled following at least 48 hours of training abstinence.

1.7 DELIMITATIONS OF THE RESEARCH

The findings of the studies in this project are delimited to highly trained male elite and elite junior rugby union players between the ages of 18 and 34 years. Therefore the results of these studies must be applied to other populations with caution.

1.8 STRUCTURE OF THE THESIS

This thesis addresses two components of the exercise prescription process: assessment and training. Specifically, the use of temporal measures during jump squat assessment and applying cluster loading in training are investigated. Six experimental chapters are included (Chapters 3 ï 8), containing studies which have been published or accepted for publication, specifically addressing the research questions. Each chapter is preceded by a ñPreludeò articulating the relevance of the chapter to the aims of the thesis. The chapter then follows the format of the academic journal in which it has been (or is to be) published. Full abstracts for each experimental paper can be found in Appendix E. In Chapters 3 to 6 assessment issues are investigated and the studies in Chapters 7 and 8 address questions relating to resistance training using cluster loading. The experimental chapters are preceded by a Review of Literature (Chapter 2) providing a discussion of assessment and training research relevant to the experimental chapters, and followed by a summary of findings (Chapter 9) which also includes a summary of practical applications and directions for future research. One section of the Review of Literature (section 2.3) has also been published and therefore this section follows the format of the published article.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

The development of strength and power in the lower limb is a crucial component in the physical preparation of elite level athletes. This is particularly true of collision sports where a combination of speed and strength is crucial to success. Design and implementation of the training programs to achieve these outcomes are driven by the strength diagnosis process (153). This involves a repeated cycle of needs analysis, strength and power profiling, exercise prescription and training implementation. This review of literature will address the components of this process as they relate to the development of lower body explosive force and power using iso-inertial squatting movements. Firstly, literature on current methodologies that are utilised for the quantification of lower body muscular performance will be reviewed. Second, the training of lower body maximum strength, force, velocity and power will be discussed by way of an analysis of the literature encompassing different loading approaches during squat and jump training. Next, cluster loading patterns which represent a novel method of training lower body explosive performance will be discussed. Lastly, as the subject population for this series of studies are elite rugby union players some literature investigating strength and power development in collision sports will be introduced.

2.2 ASSESSMENT OF LOWER BODY FORCE, VELOCITY AND POWER

2.2.1 Iso-inertial Assessment of Lower Body Force, Velocity and Power

The assessment of muscular strength and power serves a number of purposes for both the strength and conditioning coach and the sports scientist. These include strength diagnosis, talent identification, monitoring the efficacy of training interventions and investigating the importance of strength and power to athletic endeavours (2). Muscular strength has been defined as the ability to generate maximum maximorum external force (203), and is generally discussed as either concentric (force exerted during muscle shortening), eccentric (force exerted during muscle lengthening) or isometric (force exerted with no change in muscle length). Muscular power can be defined as the rate at which muscle can produce work (67) and is represented as the product of force and velocity.

An isometric muscle action involves the development of tension without an associated change in joint angle. Isometric assessment of force capabilities, although reliable has been shown to have only a limited relationship to functional performance (195). Iso-kinetic assessment involves the testing of muscular performance at a constant external velocity. Although also shown to be a reliable means of assessment (197), iso-kinetic testing also lacks specificity when compared to the dynamic nature of human movement which is characterised by the acceleration and deceleration of a given mass. Iso-inertial assessment of strength and power involves assessment using a constant external load (148). This type of assessment appears to have greater specificity to functional performance in that it too provides a constant external load and allows for acceleration and deceleration of that mass. Accordingly, this review and ensuing research will focus on this form of assessment. Movements which are commonly used in the iso-inertial assessment of lower body force and power include the squat and jump squat and the power clean and its derivatives (38, 41, 107).

Loaded vertical jumps or jump squats are one of the more common means of iso-inertial lower limb assessment. This assessment modality is popular amongst strength and conditioning coaches and sports scientists due to its ability to assess the force, velocity and power capabilities of the lower limb in a movement that is functionally similar to many sporting activities. That is, it provides a closed kinetic chain assessment modality where the ankle, knee, hip and trunk are extended in a manner very similar to many functional tasks. Running, jumping and whole body pushing tasks (such as those present in many collision sports) all require the combined extension of these body segments.

2.2.2 Jump Squat Assessment

Movements such as the jump squat where the athlete and / or the load are projected are termed ballistic resistance training techniques (44). Jump squats are typically performed as either concentric only (93) or as a rebound (or countermovement) jump squat with a preceding eccentric contraction (107), and thus the inclusion of a stretch-shorten cycle (SSC) in the movement. A rebound jump squat therefore has two qualities which are specific to many athletic and sporting activities. Firstly, the jump squat is ballistic in nature and second, it involves the coupling of eccentric and concentric contractions in a SSC.

A key limitation of a number of resistance training techniques lies in the incomplete acceleration of the training load. That is, during traditional resistance training movements, if the athlete is attempting to accelerate the load as quickly as possible and thus increase bar velocity, they must at some point decelerate the load. The utilisation of movements such as jump squats, as opposed to a traditional squat where the load must be decelerated at the end of the range may provide superior kinematics and subsequent kinetics. As the system load can be accelerated over a longer duration displacement, force and power of the movement are likely to be greater when the load is projected.

Unfortunately, there is limited research specifically comparing force, velocity and power profiles of traditional squats and jump squats. Therefore, the best illustrations of differences between traditional and ballistic movements come from upper body studies. Newton and co-workers (156) examined kinematics and kinetics of the bench press movement performed with a release (bench press throw) and without a release at 45% of 1RM. The bench press throw resulted in significantly greater PV (% difference = 36.5%, ES = 4.38) compared to the traditional bench press movement. PV also occurred later in the movement showing that the load was accelerated over a greater time period. Further research utilising the bench press throw by Cronin and colleagues (51), reported that at loads from 30-60% of 1RM greater peak velocities (% difference = 3.5% - 9.5%, ES = 0.25 ï 0.93) were produced during a ballistic bench press movement when compared to a traditional non-ballistic movement. However at loads above 70% of 1RM no significant difference was found. This suggests that the greatest benefit with ballistic training and testing may be restricted to light to moderate loads.

Concentric or eccentric muscle actions are rarely performed in isolation, as human movement is commonly characterised by the coupling of eccentric and concentric muscle actions in a SSC. The SSC has been shown to augment performance in the concentric phase of movement (120). This augmentation has been attributed to a number of mechanisms including the utilisation of stored elastic strain energy in the series elastic components of the musculotendinous system during the eccentric phase and neural facilitation from the myotatic stretch reflex (27, 184, 194). Other possible mechanisms for explaining performance augmentation from the SSC include a higher state of muscle activation prior to the commencement of the concentric phase increasing initial force production (31), and increased strain on crossbridges at the end of the eccentric contraction increasing stiffness of the myotendinous system also increasing initial force production (30). Most activities in both a sporting environment and during resistance training involve a SSC. The jump squat is no exception with a rebound jump squat generally showing a different kinematic and kinetic profile to a concentric only jump. For example PP was reported by Stone and colleagues (179) to be greater (1.7% - 7.7%) during a countermovement jump squat when compared with a concentric only jump squat across a spectrum of loads from 10-100% of 1RM at all loads except 40% and 100% of 1RM, the greatest difference occurring at 70% of 1RM.

However, it seems that augmentation to explosive resistance training from the SSC may be restricted to, or at least maximised during, certain parts of the lift. Bird and Hudson (24) studied a rebound squat and a concentric only squat utilising an analysis of the entire concentric phase and an analysis of only the first 200 milliseconds of the concentric contraction. The movement was performed with ñas much force and velocity as possibleò. For the entire concentric contraction method, the rebound jump squat had a significantly shorter concentric time (0.593 seconds versus 0.793 seconds). There was no significant difference in displacement of centre of mass, or PP between the two different lifting techniques. However, when analysing the first 200 milliseconds of the movement, displacement of centre of mass (COM), velocity, work and power were all significantly ($p < 0.05$) greater utilising the rebound technique. The rebound condition showed a 7% increase in PP when the entire concentric contraction was analysed versus a 310% increase in PP when measured using the initial concentric analysis measure. This research was performed at 70% of 1RM using a power squat, rather than a jump squat. Nonetheless, the augmentation in force, velocity and power from the SSC during a rebound jump squat may not be fully understood by peak values alone. Whilst a rebound movement seems to be a more sports specific assessment, compared to a concentric only jump, the best means of analysis for this more complex movement remains unclear.

2.2.3 Methods of Jump Squat Data Collection

The force plate and the linear position transducer are the two apparatus, which are most commonly used to calculate force, velocity and power during the squat and jump squat. Although other methods such as an accelerometer (112) or a V-scope which uses infrared and ultrasound technology to track displacement (178) are documented, the force plate and linear position transducer represent the two most commonly used technologies. The force plate directly measures ground reaction forces (37, 38, 50, 107). From this data, velocity of the centre of mass of the system can be integrated and power derived. The second method involves the use of one or more linear position transducers attached to an Olympic bar (37, 38, 107) or to the athlete (50). Velocity and acceleration are differentiated from the displacement-time data and so long as the system mass is known, force and power can also be calculated. A third method for calculating power combines the two data collection apparatus multiplying ground reaction force data by bar velocity (37, 38, 107). Each method requires the manipulation of data, which has implications for the validity and reliability of derived measures. These methods will be discussed in detail in the ensuing section.

In terms of reporting force-time data during a jump squat, the direct measurement of ground reaction forces using a force plate represents the most valid method, as no data manipulation is required. The force-time curve can be analysed directly from this data in a customised software analysis program. Velocity of and power applied to the COM can then be calculated using the forward dynamics or impulse-momentum approach (37, 38, 41, 107). As the sampling rate and ground reaction forces are known and initial velocity is zero, at each time point through the jump the vertical ground reaction force is divided by the mass of the system to calculate acceleration of the system. Acceleration due to gravity is then subtracted so that only the acceleration generated by the subject is multiplied by time data to calculate instantaneous velocity of the systems COM. The resultant velocity data can then be multiplied by the original ground reaction force data to calculate power applied to the systems COM.

The second method involves the use of only displacement-time data collected with one or more linear position transducers. Displacement-time data is differentiated to calculate velocity and acceleration, and then force and power can be calculated by inclusion of system mass into the formulae. The most common method of differentiating displacement data to velocity and acceleration is the finite difference technique (91, 199). Data is differentiated once to calculate velocity and then a second time to calculate acceleration. Acceleration due to gravity is added and the resultant acceleration-time curve is multiplied by the system mass to calculate force for each time point. Force is then multiplied by velocity to calculate power. Two alternative methods of calculation of power using a linear position transducer have been documented. The first involves the inclusion of only the external load and not the system mass (external load plus athletes mass) in the calculation of force (107). In the second, the calculation of force excludes the acceleration of the bar with the system mass being multiplied by gravity to calculate force. Neither of these alternative methodologies is regarded as biomechanically robust and their use does not seem widespread in the strength and conditioning literature (38, 62, 107).

The amount of data manipulation required to calculate force, velocity and power variables from displacement data represents one shortcoming of this method (38). The double differentiation of displacement required to calculate acceleration, force and power from displacement data can magnify errors caused by noise in the raw displacement signal (37, 38). To correct for this error, in most cases raw displacement data is filtered prior to differentiation to remove noise in the signal (91). For example, a commonly used type of filter is a low pass Butterworth filter (32, 107). Key to the use of this type of filter is the choice of cut-off frequency (199). The filter will remove noise above a certain cut-off frequency. The choice of cut-off frequency is important to the accuracy of the final figures differentiated from the displacement data. A high cut off frequency may allow noise in the filtered data but is less likely to smooth the true signal, where as a low cut off frequency is less likely to leave noise in the filtered signal but may filter true data (199). Despite the smoothing of data, the process of differentiation can result in the magnification of noise present in the original displacement data and lead to inaccuracies in differentiated values. Therefore there are a number of sources of possible error in the processing of data when using linear position transducer data during the jump squat.

The second shortcoming of this method lies in the biomechanical basis of the method. That is, in most cases the linear position transducer is attached to the system at the end of an Olympic bar (38, 39, 41, 107) or to the moving part of a machine (14, 92, 93) Therefore, it is assumed that the point of attachment of the linear position transducer moves in parallel with the COM of the system (107). This of course may not always be the case, particularly when an Olympic bar is being used and there is significant trunk extension in the jump and the possibility of horizontal displacement of the bar at the point of attachment. Therefore, the linear displacement transducer can provide a measure of velocity of the bar or machine at the point of attachment and an estimation of force and power output of the athlete or system. However, this is different to a force plate which provided kinematic and kinetic data related to the COM of the system.

The third method used in research and in practical applications combines the two apparatus. Ground reaction forces from the force plate are used to investigate force production, displacement data from the linear position transducer is differentiated once to calculate velocity of the bar and the two figures are combined to calculate power applied to the bar (37-39, 41, 107). This method obviously provides a valid measure of force and velocity. However, it shares the assumption of the linear displacement transducer method, in that it too assumes that the bar and centre of gravity of the system move in parallel during the jump (107). This is of course true once the athlete leaves the ground, but cannot be assumed before then. The bar is in fact positioned some way from the centre of gravity and is therefore sensitive to movement artefact due to flexion and extension of the trunk.

The validity of these three methods has been subject to substantial research in recent times. Cronin, Hing and McNair (50) showed no significant difference between values generated by the linear position transducer and the force plate for PF during a squat jump (% difference = 3.8%), countermovement jump (% difference = 2.6%) and a drop jump (% difference = 8.6%). However, Hori and colleagues (107) reported that PV was significantly different between the force plate and linear position transducer only systems (% difference = 16.8%), and PP outputs were significantly different when using the linear position transducer only (% difference = -7.7%) and the linear position transducer and force plate system (% difference = 14.5%), when compared to the force plate only system. Consistent with Cronin et al. (50), Hori et al. (107) reported no significant differences between data collection methodologies for PF.

Further research by Cormie, Deane and McBride (37) and Cormie, McBride and McCaulley (38) went a step further by including a second set of displacement data in order to control for the non-linear path of the bar during a barbell jump squat. The first study (37) compared PP, PF and PV, between the linear position transducer method, force plate plus linear position transducer method and the two linear position transducer plus force plate method, during jump squats at 30% and 90% of 1RM. In contrast to the results of Hori and colleagues (107), this study showed that during a jump squat at both loads (30% and 90% of 1RM), the linear position transducer only system significantly over estimated both PF (5.9% and 9.2% respectively) and PP (12.8% and 39.9% respectively) compared to the force plate plus linear position transducer method.

The second study (38) investigated six methods of calculating PP; one linear position transducer, two linear position transducers, one linear position transducer plus mass, force plate only, force plate plus one linear position transducer and force plate plus two linear position transducers. The squat and jump squat were investigated across a spectrum of loads from 0-85% of 1RM. Similar to the previous study (37), during the jump squat, the linear position transducer only method produced significantly higher power outputs when compared to the methods which used force plate data (% difference = 1.2% - 9.1%). The load-power relationship for the jump squat was not significantly different between methods. During the squat, PP values were again higher (% difference = 7.9% - 48.0%) when only position data was used, and the load-power relationship was significantly different between methods.

Therefore, it seems that research investigating the use of displacement data to derive force and power variables is somewhat contradictory. Where Cronin and colleagues (50) found no significant differences between force outputs measured with a linear position transducer and a force plate, more recent research has been less conclusive (37, 38, 41). Methodological differences including differences in data processing, the number of jumps collected, the movement pattern prescribed and the point of attachment of the linear position transducer may have contributed to these differences. Nonetheless, these studies have suggested that in some cases using displacement data only overestimates force and power output, and using ground reaction force data only may have a tendency to underestimate velocity. Thus the most valid method of collecting and calculating kinetic and kinematic variables remains unclear.

2.2.4 Measures Calculated From Jump Squat Data

Research into lower body force capabilities has traditionally focused on measures such as PF and MF (32, 50, 202). However, many authors have argued that it is the RFD rather than PF, which is of importance to explosive tasks. For example, it has been established that foot contact time for elite sprinters is in the region of 100 ms. Given this, it may be the RFD is of greater importance than the actual PF which may occur 600 ms into a contraction and therefore RFD should form the focus of assessment and training for athletes developing explosive qualities. Yet our understanding of the application of RFD measures is relatively limited as the relationship of RFD measures to traditional measures such as PF and PP during iso-inertial movements has received limited investigation.

A number of studies have investigated these relationships using the isometric mid-thigh pull, suggesting that RFD is not strongly related to other measures (137-139). For example, three studies (137-139) reported that RFD during an isometric mid-thigh pull was not significantly correlated to PF in that movement or maximum strength (1RM) in the squat and power clean. A training study by the same research group (198) reported that following eight weeks of jump squat training isometric mid-thigh pull RFD increased (% Change = 49%, ES = 2.73) together with jump squat PP (% Change = 28%, ES = 3.17) and PV (% Change = 32.7%, ES = 1.27) despite no changes in mid-thigh pull PF and Squat 1RM. Changes in RFD and jump squat PP were significantly correlated ($r = 0.74$). Some contradictory findings to this research have been reported. Kraska and colleagues (124) presented different results showing that athletes with greater PF produced significantly greater ($p < 0.01$) RFD and Force at 50 ms, 90 ms and 250 ms than those with a lower PF during a isometric mid-thigh pull. Thus there is some contradictory information as to whether or not RFD measures are related to traditional peak values. However, there is strong evidence that RFD and PF are unrelated and can change independently of one another during training.

These studies all investigated the isometric mid-thigh pull, a movement which as discussed lacks the specificity of iso-inertial movements such as the jump squat and its derivatives, and the relationship may be different during a more specific dynamic movement. Simple measures such as time to PF have been investigated during jumping movements (50, 157) and other research has investigated time to various points on the force-time curve relative to PF together with average and peak RFD (32). But the significance of these measures is not clear. Tidow (185) and Zatsiorsky and Kraemer (203) have introduced a number of alternative means of assessing the force-time curve which may warrant further investigation. These measures too have generally been discussed in the context of isometric assessment, so their application to iso-inertial assessment modalities and adaptation to the power-time curve to provide an additional means of assessing muscle function warrants investigation.

Zatsiorsky and Kraemer (203) discuss a number of RFD measures each of which analyses the force-time curve in a slightly different manner. The index of explosive strength is calculated by dividing the PF by the time to PF and the reactivity coefficient is calculated by dividing the time to PF by the time to PF multiplied by the athleteôs weight. Zatsiorsky and Kraemer (203) stated that the reactivity coefficient was highly correlated to jumping performance but do not present data to support this contention. Two further measures discussed are the start gradient and acceleration gradient. The start gradient is calculated by dividing 50% of PF by the time to achieve 50% PF and thus represents the RFD early in the movement. The acceleration gradient is calculated by dividing 50% of PF by time to PF minus time to 50% of PF and thus is a measure of force in the later stages of a movement. However, these measures are not widely reported in the literature focusing on lower body resistance training and therefore their application in athletic assessment and training is unclear.

One study that has investigated these measures is that of Cronin and colleagues (54). This study investigated all four variables during a ballistic supine squat and calculated correlations between them and traditional measures of PF and PF, and PP and MP. The index of explosive strength had high to very high correlations (r = 0.74 ï 0.86) with all four traditional measures, as did the starting gradient (r = 0.62 ï 0.74). The reactivity coefficient and acceleration gradient had correlations ranging from moderate to high with traditional measures (r = 0.43 ï 0.61). This study also investigated the relationship between Zatsiorsky and Kraemers RFD measures and performance of the sports specific activity of lunging. All four measures had high correlations (r = 0.59 - 0.69) with lunge performance.

The work of Tidow (185) also discussed some force-time variables which the author postulated are of significance to athletic performance. This work based analysis of the force-time curve on the available time for force production in athletics events, the 80-100 ms support phase in sprints and the 120-240 ms take-off phase in jumps. Tidow (185) argued that in explosive events, it was the ability to develop force rapidly rather than achieve high maximum forces which was key to defining performance in these and similar athletic tasks. Force-time measures purported to be of importance included speed strength which was calculated using the identical formulae to that described by Zatsiorsky and Karemer (203) for the index of explosive strength (PF divided by time to PF, explosive strength (peak RFD) and starting strength (force at 30 ms). The force or impulse at 100 ms was also discussed due to the importance of this time epoch in sprinting.

However, like the measures of Zatsiorsky and Kraemer, the measures discussed by Tidow have received relatively limited attention in the strength and conditioning literature. Research has investigated some of the variables discussed by Tidow. Wilson and co-workers (195) investigated a number of these RFD measures during isometric contractions and concentric only and countermovement jumps. This study reported that maximum isometric RFD (explosive strength) had only small to moderate correlations to the same variable measured in concentric only (r = -0.11 ï 0.57) and countermovement (r = 0.33 ï 0.36) jump squats. Additionally, no isometric force-time measures showed significant correlations with functional dynamic performance. This research will be discussed in more detail in ensuing sections, but the findings oppose some of the assertions made by Tidow regarding assessment during jumping tasks.

Schmidtbleicher (171) used similar terminology in discussing temporal aspects of the force-time curve during various isometric and iso-inertial tasks. Absolute strength was defined as the maximal force that can be produced independent of body weight, and starting strength was defined as the ability to produce the greatest possible force in the shortest possible time period (maximum impulse). Schmidtbleicher (171), like Tidow and Zatsiorsky and Kraemer used the term explosive strength to define the capacity to achieve maximal increase in force per unit of time, or maximum RFD. Thus it seems that temporal aspects of force production have been of interest in sports science and applied strength training research. However, it is not clear which parts of the force-time curve and which variables are of the most importance to athletic performance and which can be successfully applied to assessment procedures during iso-inertial movements such as the jump squat?

Mechanical power has also been widely assessed during jump squat movements. Jumping assessments do not directly measure the power output of muscle which is a product of the joint angular velocity and the net muscle moment (199). Rather, power in the context of jump squat assessment, refers to external power flow resulting from the extension of the ankle, knee and hip joints (118). Jumps are a popular mode of assessing power amongst coaches and scientists due to their ability to assess power capabilities of the lower limb in a movement that is functionally similar to many sporting activities. That is, the muscular power of the ankle, knee, hip and trunk combine to produce the external power flow measured by the apparatus. This is obviously intuitively appealing as it offers a level of sports specificity in assessment.

As with force and velocity, it is PP (highest point on the power-time curve) and MP (mean of all values on the power-time curve) values (15, 37, 38, 41, 107, 112, 175), which have been popularised in the sports science literature when investigating lower body performance. However as with force output, there has been limited attention paid to alternative analysis of the power-time curve during the jump squat. Jidovsteff and co-workers (112) investigated time to PP during a concentric only jump squat at various loads. More recently, Hori and colleagues (108) calculated the same value during a countermovement jump with power values being derived from ground reaction forces. This study also investigated average RPD, calculated by dividing PP by time to PP for the concentric phase of the jump. Other than this research the ñexplosiveò power qualities of muscle have not been widely researched so our understanding of the reliability and practical application of such measures is rudimentary at best.

2.2.5 Reliability of Jump Squat Measures and Methods

Reliability can be defined as the repeatability or reproducibility of a measure (100). Considerable debate exists in the sports science and sports medicine literature as to the best method of quantifying the reliability of a measure (3, 18). To assess training induced changes in performance, a measure must possess good absolute consistency. In assessing absolute consistency, the sources of variance in a measure can be separated using documented statistical analysis (145, 166). However, the between day reliability which combines biological and technical error is generally the most common form of analysis of absolute reliability in sports and exercise science (5, 100). To this end, Hopkins (100) has outlined a detailed argument for the use of the typical error (TE) expressed as a coefficient of variation (CV) to assess absolute consistency in measures used in sports science. The argument for the use of this statistic includes that it is dimensionless (allowing for comparisons between measures), easily interpreted by scientists and practitioners alike, and the TE is easily converted to a variance for further statistical analysis.

For other assessment tasks where an individual is assessed relative to a group, such as talent identification or identifying the most important physical qualities to a given athletic endeavour, a measure must have good relative consistency (22). This type of reliability can be assessed using the intra-class correlation coefficient [ICC] (5, 100). There are a number of types of ICCs, which can be used depending on the nature of the data. A detailed discussion of these ICCs is beyond the scope of this review and the reader is referred to the discussion of Weir (190) for a detailed analysis of these methodologies. For a practitioner assessing changes in power performance during or following the implementation of a training program, relative reliability is less important as it does not detail the within subject variation in the test or measure being used.

Studies investigating test-retest reliability of force and velocity qualities during the squat and jump squat can be observed from Table 2.1. Research has indicated that both relative consistency (ICC =0.58-0.99) and absolute consistency (CV = 1.9 ï 9.0%) of PF values has been shown to be good. The lowest values for both relative consistency (ICC = 0.58) and absolute consistency (CV = 25.5%) have been reported by Hori and colleagues (107) and Wilson and colleagues (195) respectively. The low values reported by Hori et al. were for PF derived from displacement time data, and the low reliability was attributed to the magnification of small errors during the double differentiation of data to calculate force. However, other studies (32, 50) have reported much higher relative and absolute consistency for PF data derived from displacement-time data, and reliability in these studies was comparable to the direct measurement of ground reaction forces. One other possible reason for the lower values reported by Hori and colleagues and by Wilson and co-workers is that only two trials were collected on each occasion.

Therefore, it seems the number of trials performed during jumps squat testing and the trials selected for analysis may affect the reliability of kinematic and kinetic data. Hopkins and co-workers (104) have suggested that when measuring power values there is greater variation between the first two trials collected than between subsequent trials, and accordingly at least three trials should be collected on each testing occasion and the first trial excluded from analysis. Hopkins et al. (104) in their review of reliability studies in power assessment, reported on average a CV of 1.3% between trials one and two, but only 0.2% CV between trials two and three. Thus, it may be preferable to use the average of trials two and three or the best of trials two and three in research and practise. Hopkins and colleagues (104) in the same review also showed, although the between day CV in power tests is lowest at 2.5 days, there is no real time effect in between day reliability in power tests. However the authors note that a reduction in reliability may be expected as duration between test days increases due to greater likelihood of individual change in physical status.

In terms of force-time characteristics (Table 2.1), the reliability of a number of variables has been investigated during the jump squat. Wilson and colleagues (195) reported low relative reliability for a number of force-time measures during rebound and concentric only jump squats. However, reliability for most of these measures was comparable to that generated during isometric assessment (CV = 5.0 ï 65.6%) which is regarded as the most reliable method of assessing force (2). Cronin and colleagues (50) reported that neither relative or absolute consistency of time to PF derived from displacement data differed greatly from ground reaction force data. Chiu and colleagues (32) investigated a number of different force-time variables, during both rebound and concentric only jump squats at a variety of loads. They found that the reliability of force time measures for the early part of a rebound jump squat (time to 20%, 40% and 60% PF) was less than other temporal variables, and did not achieve the specified reliability criteria. This research also showed that as load increased reliability of temporal variables tended to decrease. There were no significant differences noted between values generated from force plate and linear position transducer data.

Test-retest reliability values reported for power measures during the squat and jump squat can be observed from Table 2.2. Peak power values generally showed high absolute and relative consistency. Intraclass correlation coefficients for PP ranged from 0.70 to 0.96, with the lowest value being reported during a 40 kg rebound jump squat in the study of Hori and colleagues (107). As discussed previously with regards to force values generated in this study, the lower reliability reported in this study may be related to the decision only to collect two trials on each testing occasion. However, the same researchers reported an ICC of 0.97 when ground reaction force was used to calculate PP from integrated data. This suggests that it may be that the direct measurement of ground reaction forces is the most reliable means of measuring PP during a jump squat. However, other studies have shown that displacement data can provide a reliable measure of PP (3, 112). Thus the relative consistency of methods of collecting PP has shown considerable variation between studies.

In terms of absolute consistency, the highest CV value (CV = 11.1%) and thus the poorest absolute reliability, was also reported for PP derived from displacement data in the study of Hori and colleagues (107). However, Jidovtseff and co-workers (112) showed that relative consistency can be improved (CV = 4.7-7.6%) if the methodology is adjusted. In the latter study, a concentric only rather than a rebound technique was employed which has been shown to improve consistency of force calculation from displacement data (32). Additionally, Jidovtseff and colleagues used a Smith press to control for horizontal displacement of the bar during the movement, and used an accelerometer in combination with a linear position transducer. This meant that force could be calculated by multiplying acceleration data by mass, rather than differentiating displacement-time data twice. This may have limited the magnification of errors implicit in the double differentiation process required when using displacement data only. However, this methodology does have shortcomings for the practitioner. As discussed, most athletic activities include a SSC and few are restricted to a linear movement (which occurs in a Smith press). Therefore, in improving reliability, specificity was reduced. From a practical perspective, the ideal scenario requires improved reliability without removing the sports specific aspects of the movement.

Table 2.1: Studies investigating reliability of force and velocity measurement during the squat and jump squat.

Authors	Subject Number	Population (sex, age, training status)	Data collection system	Movement (Equipment, Technique)	Variables	Reliability Value
Wilson et al. (195)	15	Male, 22.6 ± 4.5 yrs, recreationally trained	Force plate	CO at 110 deg and 150 deg knee angle and RB jump squats	RB Force at 30ms RB Impulse at 100ms RB Peak Force RB Peak RFD CO Force at 30ms 110 deg, 150 deg CO Impulse at 100ms 110 deg, 150 deg CO Peak Force 110 deg, 150 deg CO Max RFD 110 deg, 150 deg	CV = 70.6 CV = 44.6 CV = 25.5 CV = 53.7 CV = 47.8, 45.6 CV = 51.7, 50.9 CV = 13.2, 20.0 CV = 27.8, 36.2
Cronin et al. (50)	25	Male, 23.4 ± 4.6 yrs, recreationally trained	Linear position tranducer	CMJ, SJ, waist harness, BW only	Mean Force (SJ, CMJ) Peak Force (SJ, CMJ) Time to Peak Force (SJ, CMJ)	ICC = 0.97, 0.98 CV = 2.8, 2.1 ICC = 0.98, 0.98 CV = 2.5, 1.9 ICC = 0.89, 0.96 CV = 11.7, 4.1
Cronin et al. (50)	25	Male, 23.4 ± 4.6 yrs, recreationally trained	Force plate	CMJ, SJ, waist harness, BW only	Mean Force (SJ, CMJ) Peak Force (SJ, CMJ) Time to Peak Force (SJ, CMJ)	ICC = 0.98, 0.96 CV = 2.8, 2.2 ICC = 0.91, 0.97 CV = 3.2, 2.8 ICC = 0.88, 0.93 CV = 11.8, 7.4
Jidovtseff et al. (112)	16	Male, 23.1 ± 2.5 yrs, recreationally trained	Linear position transducer and accelerometer	Smith press, squat to 90 deg knee angle, BW + 45%, 60%, 75% and 90% 1RM	Peak Velocity	CV = 2.5-7.1
Chiu et al. (32)	6	Male & Female, 24.8 ± 3.3 yrs, recreationally trained	Linear position transducer	CO and RB jump squats, BW + 30, 50 and 70% 1RM	Peak Force Time to 20% PF	ICC = 0.99-1.0 ICC = 0.64-0.92

Table 2.1 continued

					Time to 40% PF	ICC = -0.11-0.93
					Time to 60% PF	ICC = -0.17-0.94
					Time to 80% PF	ICC = 0.70-0.95
					Time to 100% PF	ICC = 0.99-0.95
					Peak RFD	ICC = 0.80-0.94
					Average RFD	ICC = 0.70-0.98
					Time to peak RFD	ICC = -0.03-0.95
Chiu et al. (32)	6	Male & Female, 24.8 ± 3.3 yrs, recreationally trained	Force plate	CO and RB jump squats, BW + 30, 50 and 70% 1RM	Peak Force	ICC = 0.99-1.0
					Time to 20% PF	ICC = 0.47-0.93
					Time to 40% PF	ICC = 0.3-0.94
					Time to 60% PF	ICC = -0.14-0.95
					Time to 80% PF	ICC = 0.64-0.93
					Time to 100% PF	ICC = 0.85-0.92
					Peak RFD	ICC = 0.89-0.95
					Average RFD	ICC = 0.90-0.98
					Time to peak RFD	ICC = 0.16-0.91
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Linear position transducer (BW not included)	Olympic bar RB jump squat to self-selected depth, BW + 40kg	Peak Force	ICC = 0.71 CV = 2.7
					Peak Velocity	ICC = 0.84 CV = 2.5
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Force plate	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Peak Force	ICC = 0.94 CV = 1.8
					Peak Velocity	ICC =0.96 CV = 1.2
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Linear position transducer (BW + external load, System mass)	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Peak Force	ICC = 0.58 CV = 9.0
					Peak Velocity	ICC = 0.84 CV = 2.5
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Linear position transducer and force plate	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Peak Force	ICC = 0.94 CV = 4.7
					Peak Velocity	ICC = 0.84 CV = 2.5

PF = Peak Force, PV = Peak Velocity, RFD = Rate of Force Development, BW = Body Weight, CMJ = Countermovement Jump, SJ = Squat Jump, CO = Concentric Only, RB = Rebound, CV = Coefficient of Variation, ICC = Intraclass Correlation Coefficient, RM = Repetition Maximum

Table 2.2: Studies investigating reliability of power measurement during the squat and jump squat.

Authors	**Subject Number**	**Population (sex, age, training status)**	**Data collection system**	**Movement (Equipment, Technique, Load)**	**Variables**	**Reliability Value**
Alemany et al. (3)	10	Male, 22 ± 3 yrs, recreationally trained	Linear position transducer	Smith press ("Max Rack"), 30 continuous jump squats, BW + 30%1RM.	Mean Power Peak Power	ICC = 0.89-0.96 CV = 4.4% ICC = 0.94-0.96 CV = 3.2%
Jidovtseff et al. (112)	16	Male, 23.1 ± 2.5 yrs, recreationally trained	Linear position transducer and accelerometer	Smith press, squat to 90 deg knee angle, BW + 45%, 60%, 75% & 90% 1RM	Mean Power Peak Power Time to Peak Power Peak Velocity	CV = 4.9-9.6 CV = 4.7-7.6 CV = 9.1-16.3 CV = 2.5-7.1
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Linear position transducer (BW not included)	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Mean Power Peak Power	ICC = 0.70 CV = 6.8 ICC = 0.79 CV = 4.0
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Force plate	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Mean Power Peak Power	ICC = 0.89 CV = 3.6 ICC =0.97 CV = 1.8
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Linear position transducer (BW + external load, System mass)	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Mean Power Peak Power	ICC = 0.70 CV = 11.1 ICC = 0.65 CV = 10.4
Hori et al. (107)	30	Male, 21.3 ± 2.7 yrs, novice and recreationally trained	Linear position transducer and force plate	Olympic bar, RB jump squat to self-selected depth, BW + 40kg	Mean Power Peak Power	ICC = 0.89 CV = 3.9 ICC = 0.91 CV = 3.3

BW = Body Weight, CMJ = Countermovement Jump, SJ = Squat Jump, CO = Concentric Only, RB = Rebound, CV = Coefficient of Variation, ICC = Intraclass Correlation Coefficient, RM = Repetition Maximum

2.2.6 Jump Squat Load Selection

Much of the research investigating the assessment of mechanical power using the jump squat has focused on the load that maximises peak mechanical power (Pmax). However there is a precedent for assessing and training both with absolute loads (10, 40, 86, 87) and more recently with a given percentage of the athletes body weight (174). The ensuing discussion will address the literature regarding the load that maximises mechanical power and discuss the rationale for alternative approaches. The importance of Pmax to training practice and thus its application to testing will be discussed in later sections on load selection in training.

The force-velocity relationship of muscle dictates that for a concentric action as velocity of movement increases force decreases and that the reverse is true, as force is increased velocity decreases. This relationship has been clearly demonstrated in the squat and jump squat (93, 116, 163, 205). In iso-inertial movements, as load increases force increases and velocity decreases. Therefore, the other relationship of interest in the jump squat is the load-power relationship. This interest is based on the premise in some literature that the optimal load for training of power is Pmax representing the optimal interaction of force and velocity. For some time 30% of maximum voluntary isometric contraction was described as the load which maximised mechanical power output, and was identified as the ideal training load for use in assessing and developing power during resistance training. This premise was based on research by Kaneko and colleagues (114), examining resistance training of the elbow flexors. However, research into the load-power relationship in the jump squat suggests that individuals and movement patterns differ in terms of the load (% of 1RM) at which Pmax occurs. Studies specifically examining the load at which Pmax occurred in the jump squat are summarised in Table 2.3.

Recent research has suggested the load that Pmax occurs at is as low as 0% of 1RM [BW] (41). However, much of the jump squat research has shown that Pmax occurs with load added. In a group of 22 male subjects with levels of squatting experience ranging from 7 weeks to 15 years, Stone and co workers (178) showed that for the jump squat, with and without a countermovement, Pmax occurred at only 10% of 1RM.

However, when subjects were divided into groups with and without training experience the results were somewhat different. For the five strongest subjects Pmax occurred at 40% and 20% of 1RM for the countermovement and static jumps respectively, suggesting that for stronger athleteõs PP is maximised at a higher percentage of 1RM.

Harris and co-workers (93) examined the power-load spectrum in rugby players with strength training experience, at loads ranging from 10-100% of 1RM in the jump squat exercise. This research found that mean Pmax occurred at 21.6% of 1RM, and that a 10% and 20% change in load either side of that maximum resulted in only a 2.6% and 9.9% change in power output, respectively. Inconsistencies between Stone et al. and Harris et al. include depth of squat and testing apparatus. Harris and co-workers collected their data in a custom designed machine at a knee angle of 110°. These differences in apparatus used for testing makes the comparison of results between these two studies somewhat tenuous.

Slievert and Taingahue (175) reported Pmax occurring at 40% and 60% of 1RM for a split squat jump and a traditional jump squat, respectively. The calculation of PP used in this research excluded the body weight of the athlete, only including the mass of the added load in the force calculation (force = mass x acceleration). Research has since shown that calculating the power applied to only the bar, rather than the system (athletes mass plus bar) has a significant effect on PP (107). The previous studies reported (93, 178) all included the mass of the athlete in power equations and therefore accounted for system mass. Excluding body mass from the calculation may result in a Pmax occurring at a higher load, and accordingly, the risk of prescribing too high a training load (55). It has been argued that including bodyweight in the power calculation of squat or jump squat is important as the bodyweight of the athlete accounts for a significant amount of the load projected (175).

Table 2.3: Studies evaluating load that maximises peak mechanical power output in jump squat.

Authors	**Subject Number**	**Population (sex, age, training status)**	**Calculated System Mass (Yes / No)**	**Movement (Equipment, Technique)**	**Peak Power Values (W)**	**Load Maximising Peak Power (%1RM)**
Stone et al. (178)	22	Male, 17-30 yrs, variable training experience	Yes	CO Jump Squat (Custom power rack, thigh parallel assessed visually)	5,113.07 W	10%
				RB Jump Squat (Custom power rack, thigh parallel assessed visually)	5,199.73 W	10%
Slievert and Taingahue (175)	30	Male, 20 ± 2.2 yrs, recreationally trained	No	CO Jump Squat (Smith Press, knee angle not specified)	1592.78 W	60%
				CO Split Jump Squat (Smith Press, knee angle not specified)	1549.26 W	40%
Harris et al. (90)	30	Male, 22.3 ± 2.8 yrs , highly trained	Yes	CO Jump Squat (custom machine, 110 deg knee angle)	4520 W	21.6%
Cormie et al. (38)	10	Male, 20.0 ± 1.9 yrs	Yes (excluding lower leg and feet)	RB Jump Squat (barbell, approximately 90 deg knee angle)		
				2 linear position transducers plus Force Plate	6332.09	0%
				1 linear position transducer plus Force Plate	6393.11	0%
				Force Plate only	6260.95	0%
				2 linear position transducers	6404.82	0%
				1 linear position transducer	6496.95	0%
				1 linear position transducer plus mass*	3379.56	42%

BW = Body Weight, CO = Concentric Only, RB = Rebound, RM = Repetition Maximum

* In calculation of power, Force = system mass plus acceleration due to gravity and therefore is constant throughout the movement.

There is some evidence the load that maximises mean mechanical power may be different to that which maximises peak mechanical power output. However, as with PP, research that has examined MP is fraught with inconsistencies in lifting techniques, calculations utilised and subject populations. Thus, definitive conclusions as to the load that maximises MP, and how this compares to PP are problematic. Likewise, conclusions as to the relative merits of utilising the loads that maximise mean power as opposed to PP for training are unclear. Further to this, Dugan and colleagues (62) have argued that in terms of understanding the load-power relationships, PP power, rather than MP should be utilised as it has been found to have a stronger relationship to other tests of maximal power, such as the vertical jump. Nonetheless, MP as it relates to PP does warrant discussion in the context of this review.

Baker, Nance and Moore (15) investigated the load that maximised mean mechanical power output during jump squats. These researchers found that in professional and semi-professional rugby league players, mean mechanical power output was maximised at loads of 55-59% of 1RM (which equated to 85-95kg). During this research 1RM was established using the full squat movement, yet jump squats were performed with a countermovement to a depth self-selected by the subjects. By the authors own admission this was in most cases only to a quarter or half squat depth. Therefore it seems that the movement by which power was established was different to the movement by which strength was established. Thus, it is not surprising the load that maximised power output was at the higher end of the reported spectrum. It is likely that if maximum strength were collected at the same range as power data, maximum strength would have been greater and the load that maximised average mechanical power output would have been at a lower percentage of 1RM. However, Baker and colleagues (15), attributed the high percentage of 1RM where maximal average mechanical power output occurred to the training background of the athletes, stating that trained power athletes may produce the greatest mechanical average power at a higher load than untrained athletes.

The research of Izquiererdo and co workers (110), however, does not support such a contention. This research examined mean mechanical power output during the squat movement in weightlifters, handball players, road cyclists, middle distance runners and age matched controls. They found that maximum mean mechanical power output occurred at 60% of 1RM for handball players, middle distance runners and controls, but at 45% of 1RM for road cyclists and weight lifters. One could contest that weightlifters in particular would be the athlete groups with the greatest power training background. Weightlifting requires heavy loads to be lifted at maximal velocity and road cycling, according to Izquiererdo and colleagues, requires intermittent short bursts of extremely high instantaneous power outputs (800-1000W). Thus, the assertion of Baker and colleagues (15) that power trained athletes maximise average mechanical power at a higher load was not supported by this research.

Yet the importance of identifying and assessing at the load that maximises PP and MP is unclear, particularly as some debate exists in the literature as the importance of training at Pmax (53, 55). Other approaches to load prescription during testing and training of lower body performance have been used. Sheppard and co-workers (174) have recently introduced the incremental load-power profile which involves assessing jump squat force, velocity and power using external loads relative to body weight. Their research assessed force, velocity and power during jump squats with no external load, with added load of 25% of body mass and with 50% of body mass. The rationale for utilising percentages of body weight in assessment is not made entirely clear by the authors. The authors comment that the use of a number of loads allows evaluation of program outcomes at a variety of loads. The coach is also able to achieve this by assigning testing loads relative to maximum strength. However, using percentage of body mass offers a variation that does not require the establishment of maximum strength. Intuitively, the advantage of the use of body weight percentages is the ability to assess power independent of changes in body weight and lean mass, as body mass changes the external loads used will also change.

The third approach to load selection during jump squat testing is the use of absolute loads (10, 15, 40, 85, 87, 154). For example, Hakkinen and Komi in two studies (85, 86) assessed training interventions by having subjects perform squat jumps with and without a rebound at body weight and with external loads of 20 kg, 40 kg, 60 kg, 80 kg and 100 kg. These studies evaluated the effects of two training loads, heavy resistance strength training and explosive (low load jump training) on average force, average mechanical power and vertical displacement of the athleteôs COM. By utilizing the spectrum of loads, this research was able to investigate the effect of the training interventions on muscular performance with identical conditions pre- and post-training. The previous two approaches to loading, using percentage of maximum strength and body weight necessitate that the actual external load may change during post-testing if maximum strength or body weight changes. This may not give a clear picture of the changes in force, velocity and power capabilities of the athlete.

A number of studies have tested with absolute loads but also reported maximum strength (4, 6, 16). For example, Cormie and colleagues (40) used absolute loads of body weight and body weight plus 20 kg, 40 kg, 60 kg and 80 kg to compare training outcomes following maximum power training and combined heavy load and maximum power training. By using this methodology the investigators were able to replicate testing conditions pre- and post-training whilst also quantifying the relative intensity (% 1RM) of testing loads.

In summary, a number of approaches have been used in the selection of load during jump squat assessment. Although a large body of research has focused on loads prescribed relative to maximum strength this approach has some limitations. The most important being that when testing across a spectrum of loads if maximum strength changes this will lead to changes in external loads post training which means that changes in force, velocity and power at the pre-test external load can not be assessed. The second method, using loads relative to body weight, shares this same limitation if change in body weight occurs. Using absolute loads in testing avoids these limitations and allows the assessment of the load-power relationship and kinematic and kinetic changes in identical loading conditions. If maximum strength and body weight are also assessed relative intensities can be easily calculated.

2.2.7 Relationships Between Jump Squat Force, Velocity and Power Measures and Selected Measures of Sports Specific Performance

One research method used to ascertain the ability of power assessment measures to perform assessment tasks is to investigate the relationship between measures and sports specific tasks (2). Due to the importance of sprinting speed to athletic performance in a number of sports, force and power have been related to sprinting performance using different types of dynamometry including isometric (148, 160, 193, 195, 197), isokinetic (52, 61, 197) and iso-inertial (13, 52, 90, 195, 202) methods. This section will briefly review those studies that have examined the relationship between jump squat performance and sprinting performance.

A summary of studies investigating this relationship can be observed from Table 2.4 Most of these studies have been performed with highly trained subjects, but the iso-inertial assessment utilised has varied greatly. Variations exist in measurement method and equipment, jump technique, external load and number of repetitions performed. Nonetheless a number of studies have shown significant relationships between measures of muscular performance during squat and jump squat movements and sprinting ability.

Force measures during the jump squat have been correlated to sprinting performance in a number of studies. The strongest relationships reported were from the research of Young and colleagues (202). This study investigated relationships between a number of variables and sprinting over 2.5 metres and 10 metres. It was observed that the greatest correlation with starting performance (2.5 m) was in the concentric only tests, and in the maximum dynamic strength test where the knee angle was at 120 degrees, similar to that found in the block phase of sprinting. Wilson and co-workers (195) in an investigation into isometric, concentric and SSC force-time assessments, also reported that the jumps most highly correlated to performance were concentric only jumps (as opposed to countermovement jumps where correlations ranged from $r = -0.15$ ï 0.17). The concentric jumps were also the only tests able to discriminate between good and poor performers in sprinting.

Table 2.4: Studies examining the relationship of force, velocity and power variables during the jump squat to running speed.

Authors	Subject Number	Population (sex, age, training status)	Sprint Distance	Movement (Equipment, Technique, Load)	Variables (correlated distance)	Relationship
Wilson et al. (195)	15	Male, 26 ± 4.5 yrs, recreationally and highly trained	30m	Force plate and smith press, concentric only and countermovement jump squat, 110 deg and 150 deg knee angle, BW.	CO. Force 30ms 110º CO. Imp100 110º CO. PF 110º CO. MaxRFD 110º CO. Force 30ms 150º CO. Imp100ms 150º CO PF 150º CO. MaxRFD 150º	0.06 0.06 -0.04 -0.45 -0.62 -0.49 0.08 -0.18
Young (202)	20	11 male, 9 female, 16-18 yrs, resistance training experience information not provided	2.5m, 10m	Rotary encoder and smith press, concentric only jump squat from 90 deg knee angle, countermovement jump squat from 90 deg knee angle, BW plus 9kg and concentric only jump squat 120 deg knee angle, countermovement jump squat from 120 deg knee angle, BW plus 9kg	Rel PF (2.5) Rel MP (2.5) Rel Force 100ms (2.5) Rel Force 100ms (10) Rel MP (10)	-0.86 -0.74 -0.73 -0.80 -0.79
Cronin and Hansen (52)	26	Male, 23.2 ± 3.3 yrs, highly trained	5m, 10m and 30m	Contact mat and Olympic bar, countermovement jump squat, approximately 120 deg, BW plus 30kg	PP (5) PP (10) PP (30)	-0.13 -0.11 0.15
Baker and Nance(13)		Male, 24.2 ± 3.8 yrs, highly trained	10m	Rotary encoder and smith press, 3 consecutive jump squats with countermovement, BW plus, 20, 40, 60 and 80 kg.	MP 20 MP 40 MP 60 MP 80 Rel MP 20 Rel MP 40 Rel MP 60 Rel MP 80	-0.02 -0.03 -0.07 -0.08 -0.52 -0.57 -0.53 -0.61
Harris et al.	30	Male, 22.3 ± 2.8 yrs, highly trained	10m, 30m & 40m	Linear position transducer and custom jump squat machine, concentric only single jump squat from 120 deg knee angle, BW plus 20-90% 1RM.	PV MF Rel MP Rel PF	0.41-0.32 0.45-0.33 -0.06-0.30 -0.03-0.28
Hori et al.	29	Male, 21.3 ± 2.1 yrs,	20m	Force plate, jump squat with countermovement, BW plus 40kg	PP (20) Relative PP (20)	-0.49 -0.62

CO = Concentric Only, Rel = Relative to Body Weight, PP = Peak Power, PF = Peak Force, MP = Mean Power, MF = Mean Force, PV = Peak Velocity, Imp = Impulse, RFD = Rate of Force Development, BW = Body Weight

A similarity between these two studies and a third study, that of Baker and Nance (13) lies in the fact that the highest correlation was when muscular performance variables were represented relative to body weight. The former two studies also reported some of the variables that showed the highest correlation to functional performance (in this case the acceleration phase of sprinting) were temporal variables. For example, Wilson and colleagues (195) reported that force at 30 ms during a concentric only squat jump from a starting knee angle of 150° showed the highest correlation with sprint performance (r = -0.62). Given this fact it may be that temporal variables in strength and power performance, and their relationship to functional performance, may warrant further investigation.

A number of studies have also investigated the relationship between PP and MP during the jump squat and sprinting performance. Similarly to force values, research has typically shown that jump squat power when expressed relative to body weight is significantly correlated to sprinting performance (13, 52, 106). For example, Hori and colleagues (106) calculated PP and relative PP from rebound jump squats with an external load of 40 kg performed on a force plate. When the fastest of the 29 Australian Rules Football players who participated in the research were compared to the slowest, the relative PP was significantly greater in the fast group for both a body weight countermovement jump (% difference = 11.8%) and the countermovement jump with an external load of 40 kg (% difference = 13.9%). Relative PP in both jumping conditions was also significantly correlated (r = -0.58 - -0.62) with 20 m sprint times. However, absolute PP was neither significantly different between groups nor correlated with speed performance.

2.2.8 Monitoring Acute Mechanical Responses to Training

While the jump squat is widely utilised in assessing instantaneous muscular performance in a one off movement (one repetition), it is also a movement pattern commonly used in training explosive performance. Therefore the assessment methodologies discussed thus far can also be used in the monitoring of acute training responses during the application of a training stimulus (multiple sets and multiple repetitions). It is believed that longitudinal neuromuscular adaptations to resistance training are mediated by acute mechanical responses (together with metabolic and hormonal responses) to an applied training stimulus (44, 45, 47). Mechanical responses refer to the acute kinematic and kinetic responses (such as force, power, velocity, work and time under tension) to training (44). Understanding of mechanical responses to training prescription is valuable as they provide a non-invasive means of monitoring training for the practitioner.

For the development of maximal strength and hypertrophy, it is thought that the key mechanical stimuli are total forces (84, 136), total mechanical work (123, 170) and time under tension (48, 51). Typically, these acute outcomes are achieved by heavy training loads that necessitate slow velocity of movement (43, 48, 51, 115). However, researchers also suggest comparable force and work can be achieved if volume load is equated with moderate to light loads during ballistic training (42, 48). Total forces, work and time under tension may also be of importance for high velocity ballistic training for developing muscular power (42, 48).

It is likely however, that power and velocity adaptations are mediated by different mechanical stimuli. It is suggested that the velocity and power generated during ballistic power training are the more important mechanical stimuli for power adaptation (85, 86, 113, 196). Indeed, research has shown that ballistic training programs are able to achieve comparable or superior training outcomes in terms of power development in short term training periods with less total work than high load training schemes (134, 196). For example, the research of McBride and colleagues (134) showed improved power and velocity adaptation following a training program using ballistic jump squats at 30% of 1RM compared to 80% of 1RM even though the total work performed over the training period was significantly greater in the 80% load group. However, to date mechanical responses to jump squat training prescriptions are relatively poorly understood. Further research is required to improve understanding of how best to optimise mechanical responses during this movement pattern.

2.3 TRAINING LOADS FOR THE DEVELOPMENT OF LOWER BODY MUSCULAR POWER DURING SQUATTING MOVEMENTS.

2.3.1 Lead Summary

The selection of training loads for the development of muscular force and power for athletic performance is currently an area of much interest amongst both strength and conditioning practitioners and sports scientists. This section reviews the results of training studies utilizing squat and jump squat movements in an attempt to clarify the practical application of research findings to load prescription for the development of athletic performance.

2.3.2 Introduction

A variety of loading schemes have been utilised in research to examine the most effective means of developing muscular power. Both heavy load-low velocity training (146, 172) and light load-high velocity training (68, 69, 89, 113, 134, 196) have been extensively researched in order to establish the most effective means of developing muscular power and improving muscular performance. Given that power is the product of force and velocity, it is possible that training at a heavy load will increase force output and training at a light load improve velocity. Therefore, either approach may improve the power output of musculature as long as there is not a concomitant decrease in force or velocity (depending on the training emphasis). It has been widely suggested in the literature that perhaps the load that maximises mechanical power output should be utilised for optimal improvement of power output (15, 114, 196). This may provide the ideal balance between force production and velocity of movement during power training.

Given the debate as to the optimal loading for power development, this section will review the literature investigating the effect of different training loads on force, velocity and power qualities and sports specific measures in the lower body, following lower body resistance training interventions. For the purposes of this review training studies have been categorised as heavy load (>70% of 1RM training load, n = 8), moderate load (20-70% of 1RM, n = 6) and light load (body weight only, n = 5) training and mixed load training (a combination of two or more of the above loads n = 5). To disentangle the effect of these various training loads, each section discusses the magnitude of change in maximum strength, force, velocity, power and sports specific performance, by calculating and comparing percent changes and effect sizes (ES). The ES allows us to compare the magnitude of the treatment (strength programme) on variables between studies. We describe the effects as ñtrivialò, ñsmallò, ñmoderateò and ñlargeò based on the description of effects for untrained, recreationally trained and highly trained athletes (164). Such classification means that effect sizes are not described in a uniform manner throughout the different populations (see Table 2.5).

Table 2.5: Interpretation of effect sizes relative to training status as described by Rhea (164).

Magnitude	Untrained	Recreationally Trained	Highly Trained
Trivial	< 0.5	< 0.35	< 0.25
Small	0.5 ï 1.25	0.35 ï 0.8	0.25 ï 0.5
Moderate	1.25 ï 1.9	0.8 ï 1.5	0.5 ï 1.0
Large	> 2.0	> 1.5	> 1.0

Seven databases were searched for power training studies, these included Pubmed, Medline, SPORTdiscus, Web of Science, Proquest, Meditext and Education Full Text. The selection method of the studies gathered during the literature search involved one reviewer performing the selection of studies in two consecutive screening phases. The first phase consisted of selecting articles based on the title and abstract. The second phase involved applying the selection criteria to the full-text articles. Studies were chosen if they fulfilled the following six selection criteria: 1) the study used a training method that corresponded to one of the loading schemes previously described; 2) the study detailed the training programme and utilised the squat, jump squat or unloaded jumps as the primary training and testing movement pattern; 3) the outcome measures of interest were clearly detailed; 4) studies which did not provide group means and standard deviations pre- and post-training were excluded as comparing percent changes (pre- to post-training) and effect sizes were the primary means of analysis; 5) studies were published between 1985 and 2008; and, 6) the study had to have been written in the English language and must have been published as a full-text article in a peer-review journal. Abstract only publications were not included.

2.3.3 Limitations and Delimitations of Lower Body Power Training Research

The age of subjects ranged from 18-61 years, only two studies included female subjects. However, the training status of subjects varied considerably. According to the classification system of Rhea (164), eight studies had an untrained subject population (<1 years resistance training experience), 13 studies had a recreationally trained population (1-5 years resistance training experience) and none had a highly trained population (>5 years resistance training experience). Given this fact the findings of training studies investigating power training across the loading spectrum must be applied to highly trained populations with great caution.

The design of the training interventions is obviously a key factor in the training adaptations produced during training studies. The variation within the squat / jump squat power training research reviewed is disparate, as can observed from the Tables 2.6 to 2.9. In terms of training volume, if the simplest calculation of total training volume is utilised (volume load = sets x repetitions x load), it is clearly evident that there is a large disparity in training volume both within studies investigating the effects of a particular load, and between training loads. This is further confounded by the inconsistency in selection of training frequency, number and choice of movement patterns, training tempo and rest periods. These issues are particularly evident when examining studies utilising body weight (plyometric) training techniques. Studies utilise a variety of movement patterns, which include single leg and double leg movements, vertical and horizontal movements and depth jumps, making the quantification and comparison of the overload provided almost impossible. The reader needs to be cognizant of these limitations and the comparison within and between studies must be undertaken with caution.

2.3.4 Heavy Load Training

In this section we review the literature investigating the effects of heavy load training (> 70% 1RM) squat/jump squat training on force, velocity and power output as well as functional performance.

2.3.4.1 Maximum Strength and Force Parameters

Maximum strength as measured by squat 1RM (see Table 2.6) has been shown to increase with heavy-load training (89, 134, 149, 151). Reported percent changes in 1RM range from 6.1% (151) to 21.9% (200), which represent effect sizes from 0.17 to 1.64, the latter of which can be considered a moderate training effect for the untrained population investigated. The discrepancy in training changes in maximum strength amongst training studies investigating heavy loads can be explained largely by the inconsistencies in training prescription and the differences in subject populations as already discussed. For example, Young and Bilby (200) had untrained subjects perform 4 sets at 8-12RM three times per week for seven and a half weeks at a slow tempo, which resulted in a 21.9% increase in back squat 1RM. Harris and colleagues (89) who investigated recreationally trained subjects prescribed one set of six to eight repetitions three times a week for eight weeks at 80% of 1RM resulting in a 9.8% shift in squat 1RM. Although the methods used for quantifying load were different between these two studies, it would seem clear that the study by Young and Bilby involved a greater training volume and accordingly greater strength increases would be expected. A number of studies utilised untrained subjects and consequently reported large shifts in various training parameters. For example, Young and Bilby (200) investigated an untrained population and reported a 19.9% (ES = 1.64, moderate) increase in squat 1RM. On the other hand Harris and colleagues (89) utilised a population which would be classed as recreationally trained and reported only a 9.8% (ES = 1.86, moderate) increase in squat 1RM.

A number of studies utilizing heavy loading parameters reported changes in force production capabilities (PF, MF and RFD) during both isometric and dynamic tasks. Changes in these parameters also varied greatly across training studies. Young and Bilby (200) reported a 45.5% (ES = 0.83, small) increase in RFD during a vertical jump following 7 ½ weeks of training in untrained athletes and Wilson and colleagues (196) reported a 10% increase (ES =0.21, trivial) in isometric maximum RFD following 10 weeks of training in subjects with one years resistance training experience (see Table 2.6). PF has also been measured using a variety of means pre- and post-training including isometric PF and jump squat PF at a variety of loads. However, as with maximum strength changes, the comparison of results produced by training studies is difficult due to the large variation in training prescription and subject populations. This difficulty is further confounded by the variety of movement patterns and testing loads utilised during the measurement of force parameters in the research reviewed.

Nonetheless, jump squat PF data has indicated some load specific adaptation following heavy load training. For example, McBride and colleagues (134) reported that following a training period performing jump squats at a load of 80% of 1RM subjects significantly increased ($p<0.05$) PF during jump squats at 55% and 80% of 1RM. This study reported PF increases of 4.84% (ES = 1.09, moderate), 7.37% (ES = 1.67, large) and 7.18% (ES = 1.45, moderate) for 30% 1RM, 55% 1RM and 80% 1RM testing loads, respectively. Similar findings were reported by Jones and colleagues (2001) who reported a 2.2% (ES = 0.22, trivial) increase and a 6.9% (ES = 0.50, small) increase in PF during jump squats at testing loads of 30% and 55% of 1RM, respectively. These studies, which both utilised recreationally trained subjects, tend to suggest a load specific training effect is evident in PF production with the greatest percent changes in PF production and effect sizes occurring at testing loads closest to the training loads.

Table 2.6: Effects of heavy load lower body (>70% of 1RM) squat and jump squat training on muscular power and sports specific measures.

Authors	Subject Number	Population (sex, age, training status)	Intervention (sets x reps x load, tempo)	Training Duration (number of sessions per week)	Outcome Measures	Training Effect (% change)	Effect Size	Magnitude
Young and Bilby (200)	8	Male, 19-23 yrs, untrained	4 x 8-12 x 8-12RM, **explosive**	7 ½ wks (3)	VJ max RFD	45.4%	0.83	Small
					VJ Height	4.48%	0.38	Trivial
					1 RM	19.9%	1.44	Moderate
Young and Bilby (200)	10	Male,19-23 yrs, untrained	4 x 8-12 x 8-12RM, **slow**	7 ½ wks (3)	VJ max RFD	21.2%	0.8	Small
					VJ Height	7.9%	0.43	Trivial
					1 RM	21.9%	1.64	Moderate
Wilson et al. (196)	15	21.9 ± 4.3 yrs, recreationally trained	3 x 6-10 x 6-10RM Tempo not specified	10 wks (2)	CMJ	4.75%	0.27	Trivial
					SJ	6.3%	0.32	Trivial
					Iso-kinetic PT	8.6%	0.31	Trivial
					30 metre sprint	-0.22%	-0.04	Trivial
					Isometric PF	14.4%	0.70	Small
					Isometric max RFD	10%	0.21	Moderate
Delecluse et al. (57)	22	male, 18-22 yrs, recreationally trained	3 x 10 x 10RM (wks 1-3) 3 x 6 x 6RM (wks 4-6) 4 x 4 x 4RM (wks 7-9), explosive	9 wks (2)	100 m sprint time	-0.24	-0.05	Trivial
					10m acceleration	1.07	-0.16	Trivial
					Maximum sprint velocity	-0.22	-0.04	Trivial
Murphy and Wilson (149)	15	Male, 22 ± 4 yrs, recreationally trained	4x6-10x6-10RM (wks 1-2) 5x6-10x6-10RM (wks 3-4) 3x6-10x6-10RM (wk 5) 6x6-10x6-10RM (wks 6-8) Tempo not specified.	8 wks (2)	10 kg Jump Squat PF	4.5%	0.39	Small
					10 kg Jump Squat RFD	13.15%	0.42	Small
					1RM Squat	20.86%	1.20	Moderate
					40 Metre Sprint	-2.2%	0.36	Small
					6 sec Cycle Sprint	8.9%	0.47	Small
Harris et al. (89)	13	Male, 19.4 ± 0.4 yrs, recreationally trained	Parallel Squats 1 x 5 x 50% 1RM 1 x 5 x 60% 1RM 5 x 5 x 80% 1RM ¼ Squats 5 x 5 x 80% 1RM, explosive	9 wks (4)	Squat 1RM	9.8%	1.86	Large
					¼ Squat 1RM	33.9%	7.08	Large
					VJ Height	2.3%	43.33	Large
					Average VJ Power	3.05%	0.55	Small
					Peak VJ Power	2.38%	0.49	Small
					Standing Long Jump	1.29%	0.60	Small
					10 yd sprint	1.04%	0.75	Small
					30 metre sprint	0%	0	

Table 2.6 continued

Jones et al. (113)	12	Male, 20 ± 1.57, recreationally trained	4 x 3-10 x 70- 90% 1RM (repetitions decreased and load increased as training progressed), explosive	10 wks (4)	Drop Jump PP	7.4%	0.33	Trivial
					Drop Jump PF	2.7%	0.18	Trivial
					Drop Jump PV	8.4%	0.41	Small
					SJ PP (CO)	-1.2%	-0.06	Trivial
					SJ PF (CO)	9.7%	0.60	Small
					SJ PV (CO)	-9.0%	-0.46	Small
					Jump Squat 30% 1RM PP	5.0%	0.27	Trivial
					Jump Squat 30% 1RM PF	2.2%	0.22	Trivial
					Jump Squat 30% 1RM PV	6.0%	0.47	Small
					Jump Squat 50% 1RM PP	2.9%	0.15	Trivial
					Jump Squat 50% 1RM PF	6.9%	0.50	Small
					Jump Squat 50% 1RM PV	1.3%	-0.09	Trivial
McBride et al. (134)	10	Male, 18-30 yrs, recreationally trained	4 x 5.73 x 80% 1RM, explosive	8 wks (2)	Jump Squat 30% 1RM PF	4.84%	1.09	Moderate
					Jump Squat 30% 1RM PV	-0.54%	-0.03	Trivial
					Jump Squat 30% 1RM PP	2.94%	0.61	Small
					Jump Squat 55% 1RM PF	7.37%	1.67	Large
					Jump Squat 55% 1RM PV	2.12%	0.10	Trivial
					Jump Squat 55% 1RM PP	9.29%	2.34	Large
					Jump Squat 80% 1RM PF	7.18%	1.45	Moderate
					Jump Squat 80% 1RM PV	3.73%	0.10	Trivial
					Jump Squat 80% 1RM PP	10.25%	1.67	Large
					Squat 1RM	10.18%	1.53	Large
					Agility (T test)	-2.37%	-1.30	Moderate
					Sprint 5m	6.42%	2.33	Large
					Sprint 10m	4.89%	3.00	Large
					Sprint 20m	1.57%	1.00	Moderate
Neils et al. (151)	7	Male (3), Female (4), 23.2 ± 2.9 yrs, untrained	1 x 6-8 x 80% 1RM, slow (4 sec eccentric, 2 sec concentric)	8 wks (3)	Squat 1RM	6.1%	0.17	Trivial
					SJ Height	-0.5%	-0.02	Trivial
					SJ Power	6.8%	0.16	Trivial
					CMJ Height	-1.7%	-0.02	Trivial
					CMJ Power	7.0%	0.17	Trivial

RM = Repetition Maximum, Wks = Weeks, VJ = Vertical Jump, RFD = Rate of Force Development, CMJ = Countermovement Jump, SJ = Squat Jump, PP = Peak Power, PF = Peak Force, PV = Peak Velocity, CO = Concentric Only.

2.3.4.2 Velocity

The studies of McBride and colleagues (134) and Jones and colleagues (113) are the only studies to have reported changes in velocity of a loaded movement following jump squat training (see Table 2.6). Both studies reported an increase (-0.54% - 6.6%, ES = -0.03 ï 0.47) in jump squat PV at most tested loads (see Table 2.6). The exceptions were the 30 % 1RM jump squat in the study of McBride and colleagues that resulted in a 0.54% decrease and the BW squat jump in the study of Jones and colleagues where a large 9% decrease was reported. When effect sizes are examined none were moderate to large, with the greatest being an effect size of 0.47 (small) reported by Jones and colleagues for a jump squat at 30% of 1RM. These data would suggest that the effect of heavy load training, even when the intent is to move the load as rapidly as possible, does not elicit significant increases in velocity of movement even at the prescribed training load.

2.3.4.3 Power

If this is the case, that high load training can illicit changes in force production but not velocity of movement, then one would anticipate a shift in power performance based on an increase in force capability (so long as velocity of movement was not negatively affected). Power changes following high load training have been extensively reported in the training literature during the squat and jump squat movement. McBride and colleagues (134) reported that PP increased with a moderate or large effect size after training at 80% of 1RM at both the heavier testing loads (55% and 80% 1RM). These loads corresponded with those that showed significant improvements in PF production. However, unlike McBride and colleagues, the research of Jones and colleagues (113) reported greater improvements in PP during a jump squat at 30% of 1RM than at 50% of 1RM (5% versus 2.9%), however the effect size (ES = 0.27 and ES = 0.33 for 30% and 50% 1RM respectively) at both loads would be considered trivial.

2.3.4.4 Transference to Sports Specific Tasks

Many studies have included measures of sports specific tasks such as jumping movements and sprinting over a variety of distances in their investigation of adaptation to training (see Table 2.6). Most who have utilised the vertical jump have reported that heavy load training has a positive effect on performance. Reported percent changes range from 2.3% (89) to 7.9% (200). No studies that utilised jumping movements as a sports specific assessment following heavy load training showed moderate or large effect sizes (ES = -0.02 ï 0.43). Neils and colleagues (151) was the only study that reported decreases in jumping performance following heavy load training, reporting decreases in both squat jump and countermovement jump performance.

In terms of the effects of heavy load training on sprint performance, only Murphy and Wilson (149) and Delecluse and colleagues (57) reported a decrease in sprint times of -0.22% and -0.24% respectively (improved performance) and neither reported this change as being statistically significant. Many of the studies reviewed (58, 113, 134) actually reported an increase in sprint times (decreased performance) following heavy load training. These negative performance changes ranged from a 1.07% decrease in 10 metre acceleration performance reported by Delecluse and colleagues (57) to a 6.1% (ES = 2.33, large) and 4.89% (ES = 3.00, large) decrease in 5 metre and 10 metre performance reported by McBride and colleagues (134). Therefore, it seems that even with positive adaptations in terms of maximum strength and selected force and power variables, heavy load training does not have a positive effect on power and speed related sports specific tasks.

2.3.5 Moderate Load Training

In this section we review the literature investigating the effects of moderate load (20 to 70% 1RM) squat and jump squat training on force, velocity and power output as well as performance in sports specific tasks. Typically, these loads are selected in training to maximise power output. Kaneko and colleagues (114) reported that a 30% of maximum isometric voluntary contraction maximised mechanical power output and maximised power adaptations following training. However, jump squat research has shown that the load which maximises mean and peak power output may be dependent on the athletes training age, exercise technique, equipment and data analysis calculations (15, 37, 38, 41, 62), and this has resulted in some inconsistency in determining what this load is. Nonetheless, a spectrum of loads (from 30-60% of 1RM) has been investigated in order to examine the effect of moderate loads on athletic performance.

2.3.5.1 Maximum Strength and Force Parameters

Increases in maximum squat strength (1RM) resulting from moderate load training range from 3.6% (89) to 14.1% (131), both of which represent a small effect size (ES = 0.45 and 0.64 respectively). McBride and colleagues (134) reported only an 8.2% increase in 1RM squat but this equated to a moderate effect size (ES = 1.22). Greater increases in squat strength were reported by Harris and colleagues (89). The 15.5% increase however, was measured during the ¼ squat. Again much of the difference in the results between these two studies may be explained by program design, with some notable differences in the training intervention. Possibly the most important of these differences was that the study of McBride and colleagues utilised a ballistic movement (jump squat) where as Harris and colleagues used a non-ballistic traditional squat and ¼ squat. Both of these studies investigated a subject population with some resistance training experience, which indicated that depending on training prescription, moderate load (~20-30% of 1RM) ballistic training can elicit increases in maximum strength.

Two of the studies reviewed investigated the effect of moderate load training on RFD. Wilson and colleagues (196) reported a 10.8% (ES = 0.25, trivial) decrease in isometric maximum RFD following training, whereas Kyrolainan and colleagues (125) reported 17.9% increase (ES = 0.79, small) in knee extensor maximum RFD following training. The different results reported can again be explained by differences in training prescription and testing methodology. The training program utilised by Kyrolainen and colleagues utilised jump squats at a variety of loads (30-60% 1RM), whereas Wilson and colleagues used only a 30% training load. Differences may also be explained by the testing methodology as Wilson and colleagues (196) performed isometric testing utilising the squat movement, whereas Kyrolainen and colleagues (125) performed an isolated knee extension movement. It seems that this area requires further research, particularly relating to the assessment of RFD during compound iso-inertial movements. Only then can the effect of different loading schemes and training prescription be assessed and applied to strength and conditioning practice.

McBride and colleagues (134) reported moderate to large effect sizes for PF enhancement at all testing loads following 8 weeks of jump squat training at 30% 1RM. Interestingly, the weakest training effect occurred closest to the training load (30%

1RM) with greater training effects observed at the heavier testing loads (6.0% and 5.6% change for 55% 1RM and 80% 1RM respectively). Jones and colleagues (113) on the other hand reported the greatest change in PF at 50% 1RM, which was closest to the training load (40-60% 1RM). However, none of the force changes reported by Jones and colleagues were classified as large effect sizes. Again the ballistic nature of the training prescribed by McBride and colleagues, resulted in greater force adaptations, largely one would speculate, due to the adjusted acceleration profile of ballistic movements performed at light to moderate loads (51, 156). Research has shown that during ballistic movements at moderate to light loads greater forces are produced later in the movement due to the load being accelerated for longer periods when compared to traditional movements (where deceleration starts relatively early in the movement) (51, 156). Thus, it seems that in order to elicit substantial changes in PF at moderate to light loads, movements must be performed in a ballistic manner.

2.3.5.2 Velocity

The principle of specificity would suggest that moderate to low load training performed at high velocity may be the best way to elicit increases in movement velocity. Indeed McBride and colleagues (134) found a significant ($p<0.05$) increase in PV at all three jump squat testing loads (30%, 55% and 80% of 1RM). However, as can be observed from Table 2.7, these significant changes only resulted in small or trivial effect sizeôs at all three testing loads tested. Jones and colleagues (113) also reported only trivial to small effect sizes despite a large % change (12.4%) during a 30% 1RM jump squat. These data indicate that the velocity component of power may be the most difficult to shift in training. The percent change data and effect sizes for PV following moderate load ballistic training tend to be greater than those resulting from heavy load training (Tables 2.6 and 2.7), and accordingly the moderate load method may be the preferred option for improving velocity of movement. However, as there were no moderate or large effect sizes for velocity values, it is likely that it is very difficult to elicit large changes in velocity values post training. Alternatively, it may be that current assessment procedures are not be sensitive enough to monitor changes in PV as a training outcome. Nonetheless, it seems that even when training with moderate loads, change in force (using current assessment procedures) is greater than change in velocity following a training intervention.

2.3.5.3 Power

PP has been measured using a number of methods and a variety of loads, resulting in percent changes ranging from 2.4% (ES = 0.57, small) to 16.4% (ES = 2.81, large). Interestingly, the greatest percent change in PP occurred in the study of McBride and colleagues at the 80% 1RM testing load. In this study the percent change and the ES increased as testing load increased. These findings seem to oppose those proponents of load-velocity specific adaptation, with the moderate loads utilised in this study resulting in a crossover in power adaptation from the lighter training loads to heavier loads. However, this was not evident in the study of Jones and colleagues, who reported the greatest percent change at the 30% 1RM testing load. In general, percent changes and effect sizes of PP measures were greater following moderate load training compared to heavy load training. When ballistic movements were utilised in training, a shift in both PF and PV were evident resulting in a greater overall increase in PP.

2.3.5.4 Transference to Sports Specific Tasks

A variety of sports specific tasks have been used to measure performance changes following moderate load training. Wilson (196) reported 30% 1RM to be the load which developed all round athletic performance most efficiently. They reported increases in countermovement jump (ES = 1.03, moderate, 16.8%), squat jump (ES = 1.02, moderate, 14.8%) and decreases in 30 meter sprint times (ES = -0.17, trivial -1.1%), which exceeded those resulting from both high load and plyometric training. Sprint times decreased in two out of three distances (-1.6% and -0.9% at 10 and 20 metres respectively) investigated by McBride and colleagues (134), in contrast to increases in times following high load training, although at both loads changes resulted in either trivial or small effect sizes. Accordingly, the literature (see Table 2.7) remains far from conclusive in terms of the ability of the adaptations induced from moderate load training to transfer to improvements in performance of sports specific tasks.

Table 2.7: Effects of moderate load lower body (<70% of 1RM) squat and jump squat training on muscular power and sports specific measures.

Authors	**Subject Number**	**Population (sex, age, training status)**	**Intervention (sets x reps x load, tempo)**	**Training Duration (number of sessions per week)**	**Outcome Measures**	**Training Effect (% change)**	**Effect Size**	**Magnitude**
Wilson et al. (196)	13	Male, 23.7 ± 5.8 yrs, recreationally trained	3 x 6-10 x 30% 1RM, explosive	10 wks (2)	CMJ	16.8%	1.03	Moderate
					SJ	14.8%	1.02	Moderate
					Iso-kinetic PT	7.0%	0.23	Trivial
					30 metre sprint	-1.1%	-0.17	Trivial
					Isometric PF	1.9%	0.06	Trivial
					Isometric max RFD	-10.8%	-0.25	Trivial
Lyttle et al. (131)	11	Male, 23.9 ± 6.4 yrs, recreationally trained	2-6 x 8 x 30% 1RM (sets increased from 2 up to six over 8 wk program), explosive	8 wks (2)	Squat 1RM	14.1%	0.64	Small
					SJ Height	18.3%	0.92	Moderate
					CMJ Height	7.5%	0.42	Small
					20m sprint	-1.2%	-0.20	Trivial
					40m Sprint	1.3%	0.18	Trivial
					6 sec Cycle	8.8%	0.86	Moderate
Harris et al. (89)	16	Male, 18.5 ± 0.2 yrs, recreationally trained	DB Squats 1 x 5 x 20% 1RM 1 x 5 x 25% 1RM 5 x 5 x 35% 1RM ¼ Squats 5 x 5 x 35% 1RM, explosive	9 wks (4)	Squat 1RM	3.6%	0.45	Small
					¼ Squat 1RM	15.5%	3.64	Large
					VJ Height	3.9%	230.0	Large
					Average VJ Power	2.1%	0.57	Small
					Peak VJ Power	2.4%	0.88	Moderate
					Standing Long Jump	3.4%	2.00	Large
					10 yd sprint	1.7%	1.25	Moderate
					30 metre sprint	0.7%	0.75	Small

Table 2.7 continued

Jones et al. (113)	14	Male, 20 ± 1.22, recreationally trained	4 x 5-15 x 40- 60% 1RM (repetitions decreased and load increased as training progressed), explosive	10 wks (4)	Drop Jump PP	8.7%	0.53	Small
					Drop Jump PF	2.7%	0.16	Trivial
					Drop Jump PV	6.6%	0.43	Small
					SJ PP (CO)	3.0%	0.14	Trivial
					SJ PF (CO)	-3.2%	-0.21	Small
					SJ PV (CO)	4.8%	0.25	Trivial
					Jump Squat 30% 1RM PP	5.9%	0.33	Trivial
					Jump Squat 30% 1RM PF	-0.7%	-0.03	Trivial
					Jump Squat 30% 1RM PV	12.4%	0.63	Small
					Jump Squat 50% 1RM PP	11.8%	0.49	Small
					Jump Squat 50% 1RM PF	5.3%	0.26	Trivial
					Jump Squat 50% 1RM PV	2.6%	0.22	Trivial
McBride et al. (134)	9	Male, 18-30 yrs, recreationally trained.	5 x 6.5 x 30% 1RM, explosive	8 wks (2)	Jump Squat 30% 1RM PF	3.6%	0.74	Small
					Jump Squat 30% 1RM PV	8.1%	0.22	Trivial
					Jump Squat 30% 1RM PP	9.9%	1.71	Large
					Jump Squat 55% 1RM PF	6.0%	1.21	Moderate
					Jump Squat 55% 1RM PV	7.3%	0.50	Small
					Jump Squat 55% 1RM PP	13.0%	2.27	Large
					Jump Squat 80% 1RM PF	5.6%	1.12	Moderate
					Jump Squat 80% 1RM PV	8.6%	0.23	Trivial
					Jump Squat 80% 1RM PP	16.4%	2.81	Large
					Squat 1RM	8.2%	1.22	Moderate
					Agility (T test)	-1.7%	-1.19	Moderate
					Sprint 5m	0.9%	-0.33	Trivial
					Sprint 10m	-1.6%	-0.75	Small
					Sprint 20m	-0.9%	-0.60	Small
Kyrolainen et al. (125)	13	Male, 24 ± 4 yrs, recreationally trained	Jump Squats 30-60% 1RM, plus various, plyometric exercises, 80-180 actions per session	15 wks (2)	Knee Extensors MVC PF	25.0%	1.0	Moderate
					Knee Extensors mRFD	17.9%	0.79	Small
					Drop Jump Height	23.3%	1.17	Moderate

RM = Repetition Maximum, Wks = Weeks, VJ = Vertical Jump, RFD = Rate of Force Development, CMJ = Countermovement Jump, SJ = Squat Jump, PP = Peak Power, PF = Peak Force, PV = Peak Velocity, CO = Concentric Only, PT = Peak Torque.

2.3.6 Light Load (Body Weight - Plyometric) Training

In this section we review the literature investigating the effects of light load training (body weight) squat/jump squat training on force, velocity and power output as well as sports specific assessments. The use of body weight jumping movements to develop muscular power is commonly termed plyometric training (33). In most cases plyometric training involves the coupling of eccentric and concentric muscle actions, in order to develop the athleteôs ability to utilise eccentric forces via the SSC (7, 26, 79). Research into lower body plyometric training methods has primarily focused on the ability of plyometric training to induce improvements in jump and sprint performance. Nonetheless, in the context of discussing the effect of load on power performance a brief discussion of these methods is pertinent.

2.3.6.1 Maximum Strength and Force Parameters

Only one of the reviewed studies investigated the effect of plyometric training on maximum strength performance. Fatouros (68) reported a 12.4% (ES = 2.6, large) increase in squat 1RM after training. Given that the subjects in this study (68) were untrained, the increase in maximum strength with the addition of low load ballistic training was not surprising. It can be concluded that the current literature is inconclusive in terms of the ability of plyometric training, on its own, to shift maximum strength in the lower limb in subjects with any level of training experience.

There is a dearth of research that has examined the changes in force and velocity profiles across a spectrum of loads following plyometric training programs. Wilson and colleagues (196) examined isometric maximum RFD and isometric PF in the squat movement following 10 weeks of depth jump training and reported 11.5% (ES 0.26, trivial) and 0.7% (ES = 0.02, trivial) shifts respectively. It is worthy of note that the use of an isometric test to examine training adaptation following a dynamic training intervention is not ideal, indeed the lack of specificity of such assessment practices has been highlighted in the literature (2). Testing procedures assessing force qualities utilising ballistic movements such as jumps and jump squats following this type of training intervention may be more appropriate.

2.3.6.2 Power

A number of studies have investigated power output during the vertical jump (68, 130, 159). Fatouros and colleagues (68) reported a 25.6% (ES = 1.7, moderate) increase in power output during a vertical jump following a 12 week plyometric training intervention with untrained males. This program used a variety of movement patterns and managed training load through the number of foot contacts per session (these ranged from 80 up to 220 contacts per session). However, although this study resulted in a moderate training effect, it again involved the application of a relatively intense training stimulus to untrained athletes with a large window for adaptation, and accordingly the magnitude of the power improvements is unlikely to be the same in more well trained populations.

Leubbers and colleagues (130) reported a very small post training increase in vertical jump power (0.31 % change, ES = 0.05). In comparison to the previous study, the subjects who were physically active trained for only 7 weeks (compared to 12), and undertook lower training volume in each session. Given these facts it is not surprising that there was less improvement. These results suggest that in active and trained individualsô volume and duration of training must be carefully planned in order to elicit positive power adaptation. The research of Holcomb and co-workers (98) examined changes in PP during the countermovement jump and squat jump in two training groups (countermovement jump and drop jump trained groups), resulting in improvements which produced trivial to small effect sizes (% change = 2.5% - 7.4%, ES = 0.12 ï 0.60). There were greater improvements (% change) reported following drop jump training than countermovement jump training but this was not statistically significant.

Table 2.8: Effects of light load lower body (plyometric) squat and jump squat training: muscular power and sports specific measures.

Authors	Subject Number	Population (sex, age, training status)	Intervention (sets x reps)	Training Duration (number of sessions per week)	Outcome Measures	Training Effect (% change)	Effect Size	Magnitude
Wilson et al. (196)	13	Male, 22.1 ± 6.8 yrs, recreationally trained	0.2-0.8m depth jumps, 3-6 x 6-10	10 wks (2)	CMJ	10.3%	0.55	Small
					SJ	6.5%	0.29	Trivial
					Iso-kinetic PT	1.3%	0.04	Trivial
					30 metre sprint	-0.2%	-0.03	Trivial
					Isometric PF	0.7%	0.02	Trivial
					Isometric max RFD	11.5%	0.26	Trivial
Holcomb et al. (98, 196)	10	Male, "college age", recreationally trained	0.4-0.6m depth jumps, 9 x 8	8 wks (3)	CMJ PP	6.6%	0.29	Trivial
					CMJ Height	12.3%	0.97	Moderate
					SJ PP	7.4%	0.60	Small
					SJ Height	12.2%	1.04	Moderate
Holcomb et al. (98)	10	Male, "college age", recreationally trained	CMJ, 9 x 8	8 wks (3)	CMJ PP	4.0%	0.18	Trivial
					CMJ Height	9.9%	0.63	Small
					SJ PP	2.5%	0.12	Trivial
					SJ Height	7.9%	0.55	Small
Gehri et al. (79)	7	4 male, 3 female, untrained	CMJ, 2 x 8 weeks 1-2, 4 x 8 thereafter	12 wks (2)	SJ Height	6.8%	0.25	Trivial
					CMJ Height	5.4%	0.22	Trivial
					DJ Height	8.7%	0.51	Small
Gehri et al. (79)	11	5 male, 6 female, untrained	40cm depth jump, 2 x 8 weeks 1-2, 4 x 8 thereafter	12 wks (2)	SJ Height	13.6%	0.56	Small
					CMJ Height	8.0%	0.23	Trivial
					DJ Height	21.9%	21.9	Large
Potteiger et al. (159)	8	Male, 21.3 ± 1.8 yrs, untrained	Vertical Jump, 5 x 10 – 17 x10, Bounding 1 x 30m - 5 x 30m, Broad Jump 1 x 15m – 4 x 30m, Depth Jump (40cm), 1 x 4 – 8 x 10.	8 wks (3)	VJ Peak Power	2.9%	1.36	Moderate
					VJ Average Power	5.8%	0.66	Small

Table 2.8 continued

Fatouros et al. (68)	10	Male, 20.1 ± 1.4 yrs, untrained	Squat Jumps, Hurdle Jumps, , hops and bounds, 80 contacts per session wks 1-2, 1 x 220 contacts, 1x 150 contacts, 1 x 120 contacts weeks 3 onward	12 wks (3)	VJ Height	11.3%	2.5	Large
					VJ Power	25.6%	1.7	Moderate
					Squat 1 RM	12.4%	2.6	Large
Luebbers et al. (130)	19	Male 22.7 ± 3.1 yrs, untrained	VJ 5-17 x 10 Bounding 1-4 x 30m SLJ 1-4 x 15-30m Drop Jump 2-7 x 10	7 wks (3)	VJ height	-0.31%	-0.03	Trivial
					VJ Power	0.31%	0.05	Trivial
					Margaria Power	6.3%	0.40	Trivial

RM = Repetition Maximum, Wks = Weeks, VJ = Vertical Jump, RFD = Rate of Force Development, CMJ = Countermovement Jump, SJ = Squat Jump, PF = Peak Force, CO = Concentric Only, PT = Peak Torque, SLJ = Single Leg Jump.

2.3.6.3 Transference to Sports Specific Tasks

Again, the most common measures of sports specific performance in the training literature were jumping and sprinting tasks. Jumping tasks including the vertical jump, squat jump and countermovement jump, resulted in post-training changes ranging from a decrease of 0.31% (ES = -0.03, trivial) reported by Luebbers and colleagues (130) in the vertical jump to an increase of 13.6% (ES = 0.56, small) in the squat jump reported by Gehri and colleagues (79). Fatouros and colleagues (68) reported a slightly smaller 11.3% increase in vertical jump height (ES=2.5). This was the only large effect size reported for vertical jump performance amongst the studies reviewed, with the ES for the results classified as either moderate or small. Again, the variation in results reported reflects the disparity in the subject populations utilised and the design of the training interventions. For example, when comparing Luebbers and colleagues (130) and Gehri and colleagues (79). Although the subject populations were similar, the training volume and exercise selection were very different. In the study of Gehri and colleagues (79) the training intervention included only multiple countermovement jumps, whereas the study of Leubbers and co-workers included a variety of movements, which amounted to a higher total training volume.

Results with regards to sprint performance post-training were also inconclusive. Wilson and colleagues (196) reported only a 0.2% (ES = -0.03, trivial) improvement in a 30 metre sprint post training. The sports specific task affected the most by plyometric training was the Margaria stair climb test used by Luebbers and colleagues (130) who reported a 6.3% (ES = 0.40, trivial) improvement in performance post-training. Therefore, the results of the reviewed studies make conclusions as to the efficacy of plyometric training in improving functional performance measures difficult. Once again this is confounded by the variation of training interventions and subject populations investigated.

2.3.7 Mixed Load and Complex Training

Given the research discussed thus far it may be that the use of mixed load training offers the óbest of both worldsô in terms of providing the ability to develop both high movement forces and high movement velocities. Mixed load training for lower body power development has been utilised in a number of forms. These include the utilisation of heavy, moderate and light loads within a given training session (155), alternating training loads between training sessions (154) and complex training which involves super setting heavy and moderate or light loads during training (130). Intuitively these training systems are appealing as they offer the opportunity for training to be done across the force-velocity-power spectrum. Nonetheless, despite the popularity of the squat and jump squat movements in training practice there is limited research investigating mixed load training in this movement pattern. In this section I review the literature investigating the effects of mixed load squat/jump squat training on force, velocity and power output as well as sports specific performance.

2.3.7.1 Maximum Strength, Force Parameters and Velocity

There was a large range in maximum strength (squat 1RM) amongst the mixed load training studies reviewed. These ranged from an increase in squat 1RM of 1% (ES = 0.1, trivial) reported by Newton and colleagues. (155) to 47.8% (ES = 3.69, large) reported by Tricoli (187). Tricoli and colleagues and Lyttle and colleagues (131) who reported the second highest increase in 1RM strength (12.7%, ES = 0.8, small-moderate) both prescribed a training program utilizing a combination of maximum strength training and depth jumping. On the other hand Newton and colleagues (155) used mixed resistance training loads within a single session (Table 2.9).

Newton and colleagues (155) reported an 11.3%, 5.4% and 5.4% increase in jump squat PF for BW, BW + 20kg and BW + 40kg, respectively (raw data was not provided to calculate effect sizes). These changes during squat jumps represented significant changes ($P<0.05$) in the jump squat group as compared to a control group which performed traditional high load resistance training only. However, Newton and colleagues (154) reported changes in PF during jump squats at a variety of loads ranging from 4% to 29% (see Table 2.9), but reported mean data only for some variables, so calculation of effect sizes for changes in force and power variables was not possible. These researchers also reported a 23% (ES = 1.6, moderate) and 26% (ES = 0.6, small) change in isometric squat PF in younger and older men, respectively following mixed load jump squat training.

Table 2.9: Effects of mixed load lower body squat and jump squat training on muscular power and sports specific measures.

Authors	Subject Number	Population (sex, age, training status)	Intervention (sets x reps x load, tempo)	Training Duration (number of sessions per week)	Outcome Measures	Training Effect (% change)	Effect Size	Magnitude
Lyttle (131)	11	Male, 23.8 ± 5.4, recreationally trained	Squats 1-3 x 6-10 x 6-10RM Depth Jump 1-3 x 1 x 0.2m-0.6m	8 (2)	1RM Squat	12.7%	0.8	Moderate
					40m Sprint	-0.7%	-0.2	Trivial
					20m Sprint (rolling)	0.4%	0.1	Trivial
					SJ	14.2%	0.7	Small
					CMJ	9.6%	0.5	Small
					Running Jump	8.0%	0.6	Small
					6 sec Cycle	7.1%	0.6	Small
Newton et al. (155)	16	Male, 19 ± 2.0, recreationally trained	2 x 6 x 30% 1RM, explosive 2 x 6 x 60% 1RM, explosive 2 x 6 x 80% 1RM, explosive	8 (2)	1RM Squat	0.9%	0.1	Trivial
					VJ Height	5.8%	1.0	Moderate
					3-Step Jump Height	6.4%	0.8	Moderate
Harris et al. (89)	13	Male, 19.8 ± 1, recreationally trained	Day 1 & 3; Squat 5 x 5 x 60-80%, ¼ Squats 5 x 5 x 60-80% Day 2 & 4; DB Squats 5 x 5 x 30% Mid thigh pull 5 x 5 x 60-80%	9 (4)	Squat 1RM	11.6%	1.2	Moderate
					¼ Squat 1RM	37.7%	6.4	Large
					VJ Height	2.9%	60.0	Large
					Average VJ Power	2.8%	0.5	Small
					Peak VJ Power	2.6%	0.7	Small
					Standing Long Jump	1.6%	0.6	Small
					10 yd sprint	-2.3%	-1.4	Large
					30 metre sprint	-1.4%	-0.7	Small
*Newton et al. (154)	8	Male, 29.8 ± 5.3, untrained.	Day 1; 3-6 x 8-10 x 8-10RM, slow Day 2; 3-6 x 3-5 x 3-5RM slow-mod Day 3; 3-6 x 6-8 x Low Load, explosive	10 (3)	Isometric Squat PF	23%	1.6	Moderate
*Newton et al. (154)	10	Male, 61.0 ± 4.4 yrs, untrained	Day 1; 3-6 x 8-10 x 8-10RM, slow Day 2; 3-6 x 3-5 x 3-5RM slow-mod Day 3; 3-6 x 6-8 x Low Load, explosive	10 (3)	Isometric Squat PF	23%	0.6	Small

Table 2.9 continued

Tricoli et al. (187)	12	Male, 22 ± 1.5 yrs, recreationally trained.	**Weeks 1-4;** DL Hurdle Hops 6 x 4 Alt. SL Hurdle Hop 4 x4 40cm Drop Jump 4 x4 Half squat 4 x 6 x 6RM **Weeks 6-8;** DL Hurdle Hops 10 x 4 Alt. SL Hurdle Hop 6 x 4 40cm Drop Jump 6 x4 Half squat 4 x 6 x 6RM	8 wks (3)	Squat Jump CMJ 10m Sprint 30m Sprint Agility Half Squat 1RM	2.7% 5.7% 2.7% 0.8% -3.6% 47.8%	0.23 0.59 0.47 0.15 -0.83 3.69	Trivial Small Small Trivial Moderate Large

RM = Repetition Maximum, Wks = Weeks, VJ = Vertical Jump, CMJ = Countermovement Jump, SJ = Squat Jump, PF = Peak Force, CO = Concentric Only.

*Sets of data from the same study comparing younger and older subjects.

2.3.7.2 Power

Changes in PP following mixed load training ranged from 2.6% (ES = 0.7, small) reported by Harris and colleagues (89) to a 36% increase reported by Newton and colleagues (154) following mixed load jump squat training with untrained older men. The research of Newton and colleagues indicated that greater increases in jump squat PP occurred at higher training loads (see Table 2.9) following mixed load training. Although, this may be a result of the untrained population having a low baseline power output at the higher testing loads. It has previously been reported that athletes with a strength training history my produce greater power outputs at greater loads (15). Accordingly it is very difficult to make definitive conclusions as to the effect of mixed load training on power output for elite populations from the research currently available.

2.3.7.3 Transference to Sports Specific Tasks

Changes in jump performance following mixed load training ranged from a 2.9% (ES = 60.0, large) increase in vertical jump reported by Harris and colleagues (89) to a 14.2% (ES = 0.7, small) increase in squat jump height reported by Lyttle and colleagues (130). The research of Harris and colleagues (89), despite a small percentage increase pre- to post-training in vertical jump reported a very large effect size. However, this large effect size was largely due to a very small pre-training standard deviation in vertical jump height (pre-training mean vertical jump = 62.2cm, SD = 0.03cm, post-training mean vertical jump = 64.0cm). The difficulty in comparing mixed load studies is highlighted in the comparison of these two studies. Lyttle and colleagues utilised high load squat training, combined with plyometric depth jumping in the same session, Harris and colleagues utilised training loads from 30-80% of 1RM on different training days. Further, difficulty in comparing programs results from a diverse range of assessment techniques, with a number of different jumping methodologies utilised.

With regards to sprint performance, similar to other training loads, results were inconclusive. For example, Tricoli and colleagues (187) reported a 2.7% (ES = 0.47, small) and 0.8% (ES = 0.15, trivial) increase in times for 10 and 30 metre sprints respectively, indicating a drop in performance. However, Harris and colleagues (89) reported a -2.3% (ES = -1.4, moderate) change in 10 yard sprint times indicating improved performance following mixed load training. Intuitively, one would have expected Tricoli to report more favourable results in sprint speed, as the training prescription utilised in this study involved a combination of heavy load squats and plyometric movements. The integration of plyometrics into the training program provided greater eccentric loading and greater velocity specificity than the 30-80% 1RM loads prescribed by Harris and colleagues (89), and accordingly a more favourable sprint training response may have been expected.

2.3.8 Comparing Loading Methodologies

A key point apparent in reviewing the literature is that the strength and conditioning professional must be cautious in applying research findings regarding the prescription of various power training loads and schemes. One factor making the application of research findings problematic is the variation in total training volume utilised in the training interventions studied. For example, Wilson and colleagues (196) investigated all three training modes, high load training, moderate load and plyometric training, in a study which is widely cited in the literature. Examination of the training parameters prescribed for these subjects showed considerable variation in the total training volume performed in each loading scheme. Both the high and moderate load groups were prescribed 4 sets of 6-10 repetitions. However, one group trained at the load that was proposed to maximise PP (Pmax, ~30% 1RM) and the other at a 6-10RM load (~65-75% of 1RM) resulting in one group performing significantly greater training volume (sets x repetitions x load). The third group performed drop jump training which made quantification of comparative total training volume almost impossible. Given this, it would seem that comparison of training results between training groups is somewhat tenuous as the quality of overload provided by each training program is different. Future research needs to quantify the effect of program design on the nature and volume of overload during power training in more detail, and equate total training volume in some manner when investigating training loads.

In an attempt to provide a comparison between the four training approaches examined in this review, the number of moderate and large effect sizes for each of the variables discussed for each training technique is compared in Table 2.10. It can be observed from the table that heavy load explosive training is the most effective strategy of those investigated if a shift in maximum strength (1RM) in the squat movement is the desired training outcome. However, in and of it self, it is not the most effective loading pattern and/or exercise for the development of performance in sports specific tasks such as jumping and sprinting. Moderate load explosive squat / jump squat training seems to be as effective as heavy load training at developing force parameters (such as PF during ballistic movements), and effective in developing muscular power. Although moderate load training was the most effective load investigated in developing jump performance, the literature is still inconclusive as to its efficacy in developing sprint performance, as only one moderate effect size was evident for this task. However, results relating to sprint performance should be interpreted in the context that a myriad of factors, other than the production of lower limb force and power, effect sprint performance. Light load (body weight) training seems the least effective of all the loading schemes investigated reinforcing the fact that the magnitude of the resistance is an important stimulus to adaptation. Mixed load training appears a promising loading scheme for improving force capability and functional performance, the ideal mixture of loading an area for future research.

Table 2.10: Comparison of number of moderate and large effect sizes for different loads in reviewed papers.

	Heavy Load		**Moderate Load**		**Light Load**		**Mixed Load**	
	Moderate	Large	Moderate	Large	Moderate	Large	Moderate	Large
1RM	2	3	1	1		1	2	1
Force	2	1	3				1	
Velocity								
Power	2		1	3	2			
Jump		1	4	1		2	2	1
Sprint			1				1	

2.3.9 Summary and Conclusions

The study of power is a major area of interest in sport and exercise science. Not surprisingly therefore, the development of power has been the subject of a great deal of research and subsequent conjecture. Much of the conjecture can be attributed to the: a) great variation in methodologies among research; b) lack of consistency between laboratories in terms of the rationale and execution of power assessment (2); c) difficulty in identifying those training methods that best facilitate improvements in power; and, d) scarcity of research investigating the best methods of transferring power gains to sports specific tasks.

Reviewing the research into the assessment and development of power reveals a great deal of variation in the methodologies used by various researchers. The scope of this variation makes comparisons difficult and hence definitive conclusions practically impossible. For example, the vast majority of research has been relatively short in duration (8-12 weeks) and therefore the application of findings to long-term training is questionable as the influence of neural and morphological mechanisms change with training duration. Research in this area is also typified by a wide spectrum of loading parameters that include differences in: (a) volume, (b) intensity ï contraction force, (c) total work output, (d) tempo of concentric-eccentric contractions, (e) frequency, (f) rest/recovery time ï density, and (g) type of contractions. Suffice to say, the strength and conditioning practitioner in selecting training loads must review the research, critically evaluating the aforementioned methodological inconsistencies. This evaluation must then be combined with practical experience, and individual strength profiling of their athletes to apply appropriate load selection to their program design.

Nonetheless, cognizant of these limitations, the author has tried to make sense as to which training loads best facilitate improvements in strength, power and sports specific performance through the use of effect statistics. As a result of this analysis, some broad conclusions are possible. It seems that heavy load training may elicit an improvement in the ability to generate high forces with some transference to power and little transference to functional performance such as jumping and sprinting. The use of moderate loading schemes appears the optimal load to maximise power and may contribute to gains in sports specific performance. Moderate load training appears particularly effective if ballistic techniques are used i.e. jump squat. A mixed method approach (combination training), which is an integration of heavy and moderate, or heavy and light load training appears a promising approach for developing the force and sports specific capability of muscle. There seems little benefit in the use of lightweight, plyometric training in isolation. The findings of this review may prompt new insights into training practice and research directions. However, it more likely confirms the value of some of the practices already used by strength and conditioning coaches, whereby a variety of loads are utilised in a periodised approach to training based on training age, needs analysis and strength profiling of the athlete and competition structure.

2.4 CLUSTER LOADING

2.4.1 Introduction

The practitioner can manipulate a number of acute program variables in resistance training prescription to change the training stimuli and subsequent performance adaptations (70). As discussed in the preceding section, training load, movement pattern and volume all effect training adaptation and require careful consideration in training prescription. A further acute program variable that can be adjusted by the practitioner in program design is the duration of rest between sets. Typically different rest periods are prescribed depending on whether strength endurance, hypertrophy, maximum strength or power are the desired training outcome (70). Cluster or inter-rep rest training represents an alternative configuration to traditional rest structures during resistance training. This training structure involves the manipulation of work and rest periods, breaking sets into small clusters of repetitions. It has been suggested as being a means of providing training variation, which may be well suited to the development of muscular power (81, 127, 128). This section, after briefly reviewing the literature on rest periods during resistance training, will review the small body of literature on cluster loading.

2.4.2 Rest Periods

Rest periods between sets during resistance training are regarded as one of the key training variables manipulated to adjust the training stimulus applied during training. Typical published guidelines suggest 30 to 60 seconds rest when training for local muscular endurance, less than 90 seconds when training for muscular hypertrophy, and rest periods of greater than two minutes when training for maximum strength and power (70, 183). Guidelines for rest periods in power training are based on the time-course of phosphocreatine (PCr) replenishment (95, 191). Failure to allow replenishment of PCr leads to a reliance on muscle glycogen and a decrease in muscle ph (increased lactate accumulation), which ultimately leads to decreased force and velocity of muscle shortening (126). However, there remains a paucity of research investigating rest periods during different loading schemes for the development of muscular power. The majority of the literature is focused on rest periods during maximum strength and hypertrophy training.

Much of the research into the effect of rest periods during a training bout have focused on repeatability of performance or effect on number of repetitions performed (126, 132, 192). Research into rest periods during 1RM testing in the back squat has shown no significant difference in test repeatability when either one minute, two minutes or five minutes rest was allowed between test efforts (132). Willardson and Burkett (192) examined the number of repetitions completed during the squat exercise at an 8RM load with one minute, two minute and five minute rest periods. The five minute rest period allowed for the completion of a significantly greater number of repetitions compared to the one and two minute rest periods. However, Rahimi and colleagues (162) also showed no significant difference between either volume load or blood lactate responses when comparing the effect of 30, 60 and 120 second rest periods during squatting at 85% of back squat 1RM. Thus it seems that rest periods of three minutes or more may allow for the greatest volume load to be performed. If total training volume were of importance then longer rest period would be preferable.

The shortcoming of the aforementioned studies lies in the lack of mechanical information provided. Especially in a power training scenario, the velocity of movement is likely to be integral to achieving the desired training outcome (85, 86, 113, 196). This concept is not reflected in a description of the ability to sustain repetitions in a set, and accordingly these studies may hold little practical information to those training to develop muscular power and velocity of movement. Total forces, power and work are also not discussed in the literature presented thus far and an investigation of such qualities may deliver greater insight for the practitioner.

As studies investigating the mechanical responses to rest periods during lower body power training are scarce, upper body research may provide information of value. Abdessemed and co-workers (1) studied the effect of inter-set rest periods during the bench press movement (10 sets x 6 repetitions, 70% 1RM) in 10 untrained males. Results showed that from the forth to the tenth set a one minute rest period resulted in a significantly greater drop in mean set power compared to a three or five minute rest period. The first three repetitions of each set were not affected; however repetitions four to six showed significant decrements in the one minute rest condition. Whether the responses for the lower body, where greater muscle mass are involved are similar is unclear. However, this research does suggest that if the key mechanical stimulus for training explosive performance is achieving high peak powers in training, then longer rest periods are desirable.

Investigations of metabolic responses to varying rest periods during lower body power training are also scarce. Crewther and colleagues (42) investigated metabolic responses to ballistic supine squats at 45% of 1RM with subjects performing sets of six repetitions with three minutes rest between sets consistent with published guidelines for power training. This study showed significant increases in lactate accumulation as a by-product of anaerobic glycolysis across sets of six repetitions. The reported lactate concentrations were equivalent to those generated in an equi-volume maximum strength protocol and deemed sufficient to inhibit PP. This study did not compare this protocol to longer rest periods so it is unclear what effect longer rest periods have on lactate responses to jump squat training. However, it does suggest that even with three minutes of rest, lactate accumulation is sufficient to inhibit quality of power performance.

Again upper body data may be of use in elucidating metabolic responses associated with changes in repetition power due to varying rest periods. In the aforementioned study of Abdessemed and co-workers (1), the decreased power output in the one minute rest condition was associated with significant increases in blood lactate accumulation. However, the authors concluded that acidosis was not the direct cause of fatigue, and insufficient recovery time leading to decreased PCr stores may have contributed to the power decrements. However, research has also shown that the inhibition of force capabilities following as few as five to nine maximal contractions is due to the accumulation of blood lactate (188).

To elucidate the effect of rest periods on training outcomes, Robinson and colleagues (165) investigated the effect of rest intervals of either three minutes, 90 seconds or 30 seconds during five weeks of lower body strength training on maximum strength and power. The three minute groupȇs improvement in back squat 1RM of 7% was significantly greater than the other training groups. There were no significant differences between groups in changes in power measures. Research by Freitas de Salles and co-workers (73) also showed that strength increases following training in the leg press movement were significantly greater with three and five minute rest periods compared to one minute rest periods. Average volume load following training also increased in the three and five minute rest periods. These studies suggest that greater strength increases occur with longer rest and this may be associated with increased volume load with the implementation of longer rest. However, the effect of rest periods on power performance remains unclear.

2.4.3 Acute Studies Investigating Cluster Loading

Cluster loading structures involve training sets being broken into small clusters of repetitions with short rest periods in between. The rationale for the use of this training system is that the kinematics and kinetics of the set may be improved through the short rest between clusters minimising neuromuscular fatigue during the working set (81). Lawton and co-workers (128), investigated the effect of cluster loading on power output during training utilising the bench press movement. Subjects performed a 6RM test, plus one of three different loading patterns, 6 x 1 repetition (20 seconds rest), 3 x 2 repetitions (50 seconds rest) and 2 x 3 repetitions (90 seconds rest). Results showed significantly greater total power outputs in all of the cluster configurations (% difference = 21% - 25%) when compared to the 6RM continuous loading scheme.

In the only published study investigating acute mechanical responses to cluster loading in the lower body, Haff and co-workers (83) studied cluster set configurations during the clean pull movement. The clean pull involves the initial phase of the power clean where the bar is lifted from the floor to just above waist level. The cluster-loading pattern in this study involved 15-30 seconds rest between repetitions. Peak velocity during the cluster configuration was significantly greater than that achieved during traditional continuous loading. Average PV was significantly greater (% difference = 7.9% - 8.2%) across a set of five repetitions for the cluster configuration compared to the traditional set configuration. Traditional and cluster loading also resulted in different fatigue-related patterns during the sets of five repetitions with an increased ability to sustain velocity during cluster configurations. The traditional loading pattern resulted in significantly greater decreases in PV for repetitions three, four and five. Given the suggestion that neural mechanisms may be an important mediator of adaptation to ballistic training (169, 204) it is possible that cluster loading may allow improved quality of movement during explosive movements potentially enhancing training outcomes.

2.4.4 Training Studies Investigating Cluster Loading

Cluster loading patterns have also been investigated via longitudinal training paradigms. Lawton and co-workers (127) investigated the difference in total concentric time between continuous loading (4 x 6 repetitions) and cluster loading (8 x 3 repetitions). Concentric time was significantly greater during continuous loading (36.03 ± 4.03 seconds versus 31.74 ± 4.71 seconds). Following training, the continuous training group displayed significantly greater increases (% change = 9.7% versus 4.9%) in 6RM strength than the cluster group, but there were no significant difference in power output in the bench press throw at 20 kg, 30 kg and 40 kg loads, between the two training groups. These authors concluded that the greater time under tension (as indicated by greater concentric time) in the continuous training group resulted in greater total forces and accordingly greater increases in maximal strength (as indicated by the significantly greater increases in 6RM).

Given that there was no significant difference in power improvements between the two groups investigated by Lawton and colleagues (127), it would follow that the cluster group were able to make greater improvements in the velocity of movement. That is, both groups were instructed to accelerate the load as fast as possible, yet continuous training resulted in greater time under tension as measured by concentric time. Therefore, it would seem that each group improved on a different aspect of the power equation, with the same outcome in terms of power output. The continuous group had greater time under tension (greater concentric time) and (as stated by the authors) were likely to have improved in terms of force production capability. Whereas the cluster group had greater concentric movement velocity (less concentric time) and may well have improved power through increased velocity of movement. However this is somewhat speculative and further longitudinal investigations into cluster loading are required in order to ascertain the relative merits of this training system for power development. This includes investigation of lower body movement patterns at a variety of training loads.

2.5 STRENGTH AND POWER DEVELOPMENT FOR RUGBY UNION AND RUGBY LEAGUE

2.5.1 Collision Sports

Sports such as rugby union, rugby league and American football can be defined as collision sports (78, 135, 142). These sports are characterised by explosive activities performed at high speed with repeated collisions between athletes (56, 60, 64, 65). Therefore, lean mass, strength, power, speed and agility are all important to high level performance in these and similar sports (9, 12, 19, 74). Rugby union and rugby league, due to the high in-play time (56, 64, 117) also require that athletes have high levels of aerobic and anaerobic endurance (63, 76, 143, 173). This endurance component in these sports makes them somewhat unique and presents a number of challenges for the strength and conditioning practitioner in developing athletes. Although, the cohort in the following research studies were all elite level rugby union players, due to the similarities between rugby league and rugby union, and the limited body of literature in rugby union the literature investigating strength and power in both sports will be discussed.

2.5.2 Descriptive Studies

A number of studies have investigated the physical qualities which differentiate high level performance in rugby league and rugby union (9, 12, 17, 19). Firstly, by comparing elite and sub-elite rugby league players, it has been established that a number of strength and power characteristics differentiate playing level in elite and sub-elite rugby league players (9, 12, 17, 19). These differentiating factors include upper and lower body maximum strength, upper and lower body PP output and sprint momentum (average sprinting velocity over 10 m multiplied by body mass). Speed performance has not been shown to be able to differentiate between performance level (19) in professional rugby league players, but there is contradictory research as to the ability of tests of agility to differentiate performance level in this population (19, 75). Therefore, it seems that possibly due to the importance of ñwinningò collisions in these sports that possessing high levels of strength and power are crucial to achieving success in collision sports and therefore these physical attributes require considerable attention in training.

A high level of maximum strength has been shown to be important to the ability to develop high power output (146, 177, 178). This has been shown to be true in elite rugby league players (14). Baker and Nance (14) showed that mean mechanical power during a jump squat had a high correlation ($r = 0.81$) with maximum back squat strength. This relationship between maximum strength and power output at light to moderate loads has also been reported in upper body strength in professional and college aged rugby league players (9). Thus it seems that in this population, the development of maximum strength is an important part of the process of developing explosive capabilities and needs to be integrated into resistance training prescription.

The relationship between strength and power performance and sprinting in elite rugby league and rugby union players (13, 52, 92) has also been investigated. Baker and Nance (13) reported moderate but significant correlations (r = 0.52 ï 0.61) between 3RM back squat and jump squat mean power at a variety of loads, and 10 and 40 metres sprint times. Likewise, Cronin and Hansen (52) reported that relative power output during a squat jump with an external load of 30 kg was significantly correlated (r = 0.43 ï 0.55) with 5 metre, 10 metre and 30 metre sprinting speed. Therefore, it seems that the development of strength and power in these sports may also be an important component of speed development. However, it should be noted researchers suggest that in order to augment sprint speed performance it is likely that strength and power needs to be developed relative to bodyweight. Given the aforementioned importance of dominating collisions, the anthropometric, speed, strength and power requirements for any given player require careful consideration in collision sports.

2.5.3 Challenges in Power Training Prescription for Collision Sports

The prescription of strength and power in high level rugby union and rugby league players is complex for the practitioner with a number of programming challenges. Firstly the typical training schedule involves a number of different training components additional to strength and power development including endurance training, speed and skill development, and team organisation (10, 35). This additional training imposes many different physiological demands on the athlete, which can adversely affect power development via the interference principle (94, 97).

Given these considerable additional training demands there is a likelihood of interference to strength and power development in the training of rugby union and rugby league players. There is a large body of research into the interference effects of concurrent endurance training on strength and power development. This research is contradictory as to the ability to develop lower body mechanical power when high volume endurance training stimuli are being applied simultaneously with power training prescription. Lower body mechanical power as measured by the vertical jump has been shown to increase during concurrent training (97). However, other research, conducted specifically with professional rugby league players undertaking pre-season training, has shown that despite increases in maximum strength, lower body power decreased during concurrent endurance training (94).

Indeed, it has been suggested that it may be physiological mechanisms related to power production that are most effected by high intensity endurance training, and therefore muscular power and speed may be the physical qualities most vulnerable to interference with concurrent training (121). Harris and colleagues (93), studied power development in highly trained subjects (professional rugby league players) showing decreases in machine jump squat power (% change = -6% to -17.1%) and velocity (% change = -2.4% to -7.5%) following a concurrent training program despite increases in maximum strength. This finding is supported by the research of Hennessy and co-workers (97) who also found negligible (<1%) improvements in lower body power despite improvements in maximum strength during concurrent strength and endurance training in rugby players. In this study the strength only group managed to improve strength and power. Therefore, there is some evidence for collision sport athletes to support the contention of Kraemer and colleagues (121) that power development may be hindered due to interference effects from other training components.

An additional challenge for the practitioner in developing strength and power in elite rugby league and rugby union players is the length of the competitive seasons. Typically these sports are characterised by long in-season periods (typically 25 ï 35) weeks with relatively short pre-season preparations [typically 8 ï 12 weeks] (10, 77, 94). For example, Gabbett (77) reporting on the relationship between training load and injury incidence in professional rugby league players documented the season structure for a club in the Australian National Rugby League (NRL). This season included a 13 week pre-season followed by a 33 week in-season period. Due to the intensity of week-to-week matches and tissue damage due to collisions (80, 141, 176) the prescription of high volume strength and power training in-season was problematic. Yet, the pre-season preparatory period where resistance training frequency and volume can be increased represents a relatively short time frame for the development of lower body power, particularly in highly trained athletes.

2.5.4 Training Studies

Generally researchers suggest that strength and power can be maintained during the in-season period in elite rugby league and rugby union players. Baker (10) studied the effect of combined strength and endurance training in-season on strength and power performance of professional rugby league players. The athletes undertook two strength and power training sessions per week, three energy system conditioning (endurance training) sessions per week and five skill practise sessions per week. The researchers reported no significant changes in jump squat PP over a 29-week season in 14 professional rugby league players. Argus and colleagues (4) investigated changes in strength and power over the course of a 13 week in-season period in 32 professional rugby union players. Argus et al. reported a small increase in lower body (box squat) strength through the course of the study (8.5%), but a small decrease (-3.3%) in lower body power (jump squat with external loads of 55-60% of 1RM). The authors attributed the decreases in lower body power found in the study to interference from the multiple training components undertaken by the subjects during the study.

Given the documented challenges in improving strength and power through the in-season period in elite rugby league and rugby union players, it would seem that achieving adaptation in the pre-season period is of great importance. However, although detailed models for the pre-season development of strength and power have been discussed (35), published research on pre-season strength and power training is somewhat limited. This is likely to be due to the challenges inherent in conducting research in a professional team sport environment (147).

However, Harris and colleagues (94) in a study introduced above, compared the training effect of jump squat training at 80% 1RM versus training at the load that maximised PP output over a seven week training period in the pre-season preparation period of elite rugby league players. This study showed that both groups increased maximum strength (15.3% and 9.0% for the 80% 1RM and PP groups, respectively), but that both groups decreased in all explosive measures (PF, PV, PP and impulse) during the seven weeks of the study. This study had a number of the limitations in research design previously outlined (147) as being inherent in team sport research with elite athletes (e.g. small subject numbers, short duration). However, the study did reinforce the difficulty in making short-term changes in explosive performance in collision sport athletes.

It is clear that sports such as rugby union and rugby league require athletes to develop strength and power, yet there are notable challenges in training prescription for the practitioner. It has been documented that over sustained training periods (four years) strength and power are developed in tandem in this population (16). However, it seems that short-term changes in lower body maximum strength both in-season and pre-season are not necessarily mirrored by short-term changes in explosive qualities. It is possible that the interference effects discussed previously are one important reason for this. However, it seems that given the importance of explosive qualities (RFD, power and velocity of movement) that future research may benefit from investigating methods of developing these qualities in short term training periods in collision sport athletes.

2.6 SUMMARY AND IMPLICATIONS

Assessment of explosive qualities of the lower limb is an important component of strength diagnosis in athletes. The rebound jump squat is a popular mode of assessment as it has a number of qualities inherent in athletic activities; it is ballistic in nature, includes the coupling of eccentric-concentric contractions in a SSC and it is a compound movement involving extension of the ankle, knee, hip and trunk. It has the added advantage for the practitioner of being able to be implemented with a variety of external loads. This provides a flexible assessment methodology in profiling the force, velocity and power capabilities of the athlete. However, there remain a number of methodological issues in the implementation of jump squat assessment protocols. The reliability and validity of methods of data collection, and analysis of force and power measures, other than the traditional peak and mean values, is not well researched. Therefore our understanding of the prognostic/diagnostic value of assessing a rebound jump squat is somewhat limited.

Likewise, the development of lower body force, velocity and power capabilities is an important training component for many athletes. Repeated application of a resistance training stimulus aims to improve muscular performance through longitudinal adaptations in the neuromuscular system. Acute mechanical responses to a training bout are all thought to play a role in mediating these neuromuscular adaptations. Monitoring these mechanical responses provides a cost-effective and non-invasive means of assessing the applied training stimulus. However, mechanical responses to various training interventions used to develop explosive performance are relatively poorly researched. There is some evidence to suggest that, unlike developing maximum strength where high force and total work are important for adaptation; in developing power high PPs are the most important mechanical responses to ensure training adaptation.

The practitioner is able to manipulate a number of acute program variables in order to optimise the mechanical responses for a given training objective. This involves the manipulation of training load, volume and rest periods. Whilst it is likely that a spectrum of external loads should be used for the development of lower body power performance, it seems unlikely that high volume training is required to elicit short term enhancement of lower body power at light to moderate loads. Rather quality of performance is paramount and maximising velocity and power should be prioritised. Rest periods need to be designed to allow for sufficient metabolic recovery to occur. One proposed method of structuring power training to ensure maximum power and velocity of movement is cluster training, which allows for short rest periods between small clusters of repetitions. However both acute and longitudinal responses to cluster training remain relatively poorly researched.

Collision sports such as rugby union and rugby league are an example of sports where the development of strength and power plays an important role in athlete development and preparation. These sports require a balance of strength, power and speed for high level performance, and thus assessment and training strategies are of paramount importance in athlete development programs. The ensuing research studies in this thesis will address methodological issues related to jump squat assessment and the importance of various jump squat measures in this population. Additionally, as cluster structures may represent an appropriate training prescription for elite rugby union players, acute responses to a cluster intervention will be investigated and the implementation of a cluster training program during pre-season preparation of elite players will be investigated.

CHAPTER 3

THREE METHODS OF CALCULATING FORCE-TIME VARIABLES IN THE REBOUND JUMP SQUAT

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3.1 PRELUDE

The jump squat is a movement commonly utilised in athletic assessment. For the most part peak and mean force, velocity and power values are derived from jump data. However, the review of literature has established that a number of other measures can be derived from jump squat force-time curves that may be of interest to the practitioner. The review of literature also introduced the importance of the SSC to athletic performance, and that performing a rebound jump squat with an SSC intuitively has greater specificity to many athletic tasks. However the analysis of the force-time curve of a rebound jump squat is more complex than a concentric only jump. This chapter specifically addressed this methodological issue investigating the various published start points for analysis of the force-time curve during a rebound jump squat.

3.2 INTRODUCTION

Both concentric only (32, 174, 195, 202) and countermovement (rebound) jump squats (32, 105, 174, 195, 202) have been used in the assessment of force and power output of the lower limb in athletes. Although peak and mean force have traditionally been the values of most interest in strength and conditioning research, a number of studies have investigated rate dependent (force-time) variables during jumping movements. However, during the rebound jump squat, the force-time curve has been analysed using a number of different methods and the rationale for the selection of these methods has not been clearly articulated. For example, Chiu and co-workers (32) operationally defined the lowest point on the force curve as the start of the isometric phase during a rebound (countermovement) jump squat and analysed a selection of rate dependent force variables from this point forward. This approach includes analysis of parts of the eccentric phase and the concentric phase of the movement, whereas other research has included the entire eccentric and the entire concentric phase in force-time analysis (36, 50), or included the concentric phase only (39). This diversity of methodology certainly makes comparison of studies investigating force-time data problematic as the variation in start point for calculation of force-time variables is likely to produce significantly different results.

Additionally a large number of variables have been measured in the analysis of the force-time curve. Firstly, a number of variables have been suggested or described that investigate the development of force relative to PF, such as average rate of force development (32), described by Tidow as speed-strength (185), and those described by Zatsiorsky and Kraemer (203) which include the index of explosive strength, the reactivity coefficient, the starting gradient and the acceleration gradient. A number of variables have also been reported investigating specific time intervals on the force time curve. For example, force and impulse at 100 ms and force at 30 ms have been discussed in the literature (185, 195, 201, 202). It is likely that that the selection of analysis methods will have a large impact on the subsequent values for many of these variables and thus the information provided to the practitioner.

Despite the use of a number of methods to analyse the force-time curve, there is limited research based information by which the practitioner is able to select the appropriate method of force-time analysis for their use. Thus, the purpose of this study was to investigate the differences between the three methods previously used to analyse force-time values during a rebound jump squat. This will help provide information by which the practitioner and sports scientist can select the appropriate method for analysis to provide the most relevant information for their requirements for research purposes and strength and conditioning practice.

3.3 METHODS

3.3.1 Experimental Approach to the Problem

In order to ascertain the effect of three different methods of analysing the force-time curve on a number of previously reported force-time variables, 25 full-time professional elite level rugby union players performed three loaded (40 kg) rebound jump squats on a portable force plate. Each of the three analysis methods uses different start points on the force-time curve. The magnitude of this effect on the variables of interest was quantified using repeated measures ANOVA and Pearson correlation coefficients.

3.3.2 Subjects

Twenty five male, elite level rugby union players aged between 18 and 34 years of age, volunteered to participate in this study. Mean age, height and weight were 24.4 ± 4.9

yrs, 1.8 ± 0.1 m, and 98.6 ± 12.0 kg respectively. All subjects had undertaken a structured resistance training program for at least three years and therefore could be described as either recreationally or highly trained (164). Testing was conducted as part of the subjectsô pre-season strength and conditioning program. All subjects were informed of the risks and benefits of participation in the research, informed that they could withdraw at any time, and signed informed consent forms. All procedures were approved by Edith Cowan Universityös Human Research Ethics Committee.

3.3.3 Data Collection and Analysis

Following a standardised warm-up, each subject performed three single repetition jump squats with a 20 second rest between repetitions using an external load of 40 kg, using a technique identical to that described by Hori and colleagues (107). Forty kilograms represented a load that all subjects were familiar with as they used in both in training and testing. The athletes used this external load as it represented approximately 20% of the squat 1RM of the population from which the subjects were drawn. This load sits within a spectrum of loads whereby power is reported to be maximised in ballistic tasks (41, 93, 178). The jump technique involved the subjects standing at a self-selected foot width with an Olympic bar placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately performed a maximal jump. Subjects were instructed to keep the depth of countermovement consistent between jumps and ñjump for maximum heightò on each repetition. All subjects were familiar with the jump squat movement as they previously performed it as part of their testing and training programs. All jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA). Ground reaction force data were sampled at 500 Hz via an analogue to digital converter (16-Bit, 250 kS/s National Instruments, Austin, TX.) and collected by a laptop computer using custom built data acquisition software (Labview 8.2, National Instruments, Austin, TX.). Data were then transferred to a customised data analysis program for calculation of the force variables of interest (Labview 8.2, National Instruments, Austin, TX).

From the resultant ground reaction force data the various temporal and kinetic variables of interest were determined. These variables included time to PF, the index of explosive strength (PF / time to PF), reactivity coefficient (PF / (time to PF x body mass)) as described by Zatsiorsky and Kraemer (203), impulse at 100 ms, rate of force development to 100 ms and absolute force at 50 ms. Additionally, a moving average was used to find the greatest RFD within a 50 ms interval. This moving average RFD was conducted over a window length of 50 ms from the start point of analysis until PF. Test re-test reliability of these variables was established with ICCs which ranged from 0.85 ï 0.96. These reliability values will be discussed in more detail in Chapter 4.

Each variable was calculated using the following three methods (see Figure 3.1):

Method 1: Minimum force to maximum force prior to take-off, encompassing latter portion of the eccentric phase and the entire concentric phase. Analysis commenced at the lowest point on the force-time curve (32).

Method 2: This method measured the concentric phase only. Analysis commenced at the lowest point on the displacement curve integrated from GRF data (39).

Method 3; This method encompassed the entire eccentric and concentric phases. Analysis was initiated from the start of the eccentric phase on the force-time curve (36, 50).

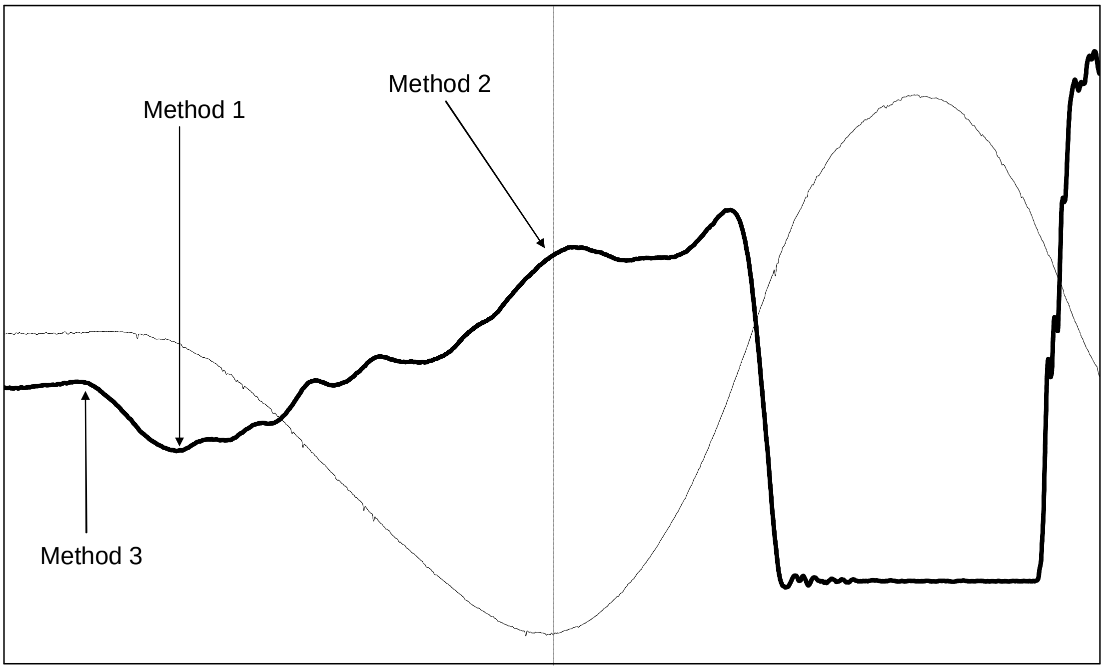

Figure 3.1: Typical jump squat force-time curve (thick line) with displacement overlayed (thin line) showing start point of calculation of force-time variables for methods 1 (minimum force), 2 (start of concentric phase) and 3 (start of eccentric phase). Vertical line represents start of concentric phase based on displacement curve.

3.3.4 Statistical Analyses

All statistical analysis was performed on the mean of trials two and three. The first trial was excluded from analysis as it has been previously shown that in assessment of muscular power the CV between the first two trials collected is 1.3 times that between subsequent trials (104). Means and standard deviations were used as measures of centrality and spread of data. A repeated measures one-way ANOVA with Tukey post hoc comparisons was used to determine the differences between calculation methods for the force-time variables. Additionally, the strength of association between calculation methods was calculated using a Pearson product moment correlation coefficient. Correlations were described as trivial (0.0-0.1), low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), very high (0.7-0.9) and practically perfect (0.9-1.0) (34, 99).

3.4 RESULTS

Means and standard deviations for all methods and variables can be observed from Table 3.1. There were significant differences between calculation methods for all variables. For time to PF, impulse at 100 ms and force at 50 ms the difference was significant ($p < 0.001$) between all calculation methods (% difference 29.0 - 75.0). For RFD at 100 ms methods 1 and 2 (% difference 45.6) were not significantly different from one another, but method 3 was significantly different from methods 1 and 2 (% difference 171.8 and 175.7 respectively). For RFD calculated with a moving average, index of explosive strength and the reactivity coefficient, methods 1 and 3 were not significantly different (% difference 1.1% - 26.8%) from one another, but method 2 was significantly different ($p < 0.001$) from both methods 1 and 3 (% difference 48.7% - 364.3%).

Inter-correlations between methods can be observed from Table 3.2. The magnitude of these correlations ranged from 0.09 (force at 50 ms, method 1 versus method 2, trivial) to 1.00 (RFD calculated with a moving average, method 1 versus method 3, practically perfect). Time to PF, the index of explosive strength and the reactivity coefficient had very high or practically perfect correlations between all three methods ($r = 0.81$ ï 0.97).

Table 3.1: Mean ± SD values for three methods of analysing the force-time curve for a selection of rate-dependent force variables.

	Method 1	**Method 2**	**Method 3**
TTPF (ms)	$637 \pm 242^{\ddagger\#}$	$295 \pm 175^{\S\#}$	$822 \pm 265^{\S\ddagger}$
RFD 100 ($N.s^{-1}$)	$4{,}329 \pm 3{,}600^{\#}$	$2{,}355 \pm 1531^{\#}$	$-3{,}109 \pm 2{,}314^{\S\ddagger}$
RFD-MA ($N.s^{-1}$)	$9{,}720 \pm 5{,}990^{\ddagger}$	$4{,}991 \pm 3{,}613^{\S\#}$	$9{,}617 \pm 6{,}024^{\ddagger}$
IES	$2{,}214 \pm 1{,}083^{\ddagger}$	$7{,}298 \pm 8{,}004^{\S\#}$	$1{,}603 \pm 554^{\ddagger}$
RC	$23.3 \pm 12.4^{\ddagger}$	$78.0 \pm 92.5^{\S\#}$	$16.8 \pm 6.47^{\ddagger}$
I100 (N.s)	$81.2 \pm 18.2^{\ddagger\#}$	$219 \pm 32.3^{\S\#}$	$125 \pm 17.1^{\S\ddagger}$
FA50 (N)	$776 \pm 199^{\ddagger\#}$	$2{,}162 \pm 324^{\S\#}$	$1{,}256 \pm 161^{\S\ddagger}$

TTPF = time to peak force, RFD 100 = rate of force development at 100 ms, RFD-MA = moving average rate of force development, IES = index of explosive strength, RC = reactivity coefficient, I100 = impulse at 100 ms, FA50 = absolute force at 50 ms.

§ Significant difference from method 1 ($p < 0.001$)

‡ Significant difference from method 2 ($p < 0.001$)

Significant difference from method 3 ($p < 0.001$)

Table 3.2: Inter-correlations between calculation methods for the force-time variables investigated.

	Method 1 v Method 2		**Method 2 v Method 3**		**Method 1 v Method 3**	
	r		**r**		**r**	
TTPF	0.94	Practically Perfect	0.93	Practically Perfect	0.97	Practically Perfect
RFD 100	-0.27	Low	0.48	Moderate	-0.47	Moderate
RFD-MA	0.27	Low	0.28	Low	1.00	Practically perfect
IES	0.86	Very High	0.81	Very High	0.94	Practically Perfect
RC	0.86	Very High	0.83	Very High	0.95	Practically perfect
I100	0.22	Low	0.65	High	0.76	Very High
FA50	0.09	Trivial	0.67	High	0.67	High

TTPF = time to peak force, RFD 100 = rate of force development at 100 ms, RFD-MA = moving average rate of force development, IES = index of explosive strength, RC = reactivity coefficient, I100 = impulse at 100 ms, FA50 = absolute force at 50 m

3.5 DISCUSSION

In terms of force-time analysis an isometric or concentric only assessment provides for relatively simple analysis for the practitioner or sports scientist. A rebound jump squat however, with coupling of eccentric and concentric contractions otherwise known as a SSC, adds to the complexity of the analysis evidenced by the different analytic techniques used by various researchers. Thus, we chose to investigate three methods of investigating force-time qualities of a loaded rebound jump squat. Results showed that the method of analysis chosen significantly affects the data values for a number of variables but not necessarily the rank order. Accordingly, the practitioner or sports scientist should consider carefully the portion of the force-time curve and the variables of interest when selecting calculation methods. Furthermore if comparison between athletes programmes and/or research is of interest, interpretation of data must be made cognizant of the different methods used and subsequent limitations.

Methods 1 and 3, which included components of the eccentric phase, were not significantly different in three out of the seven variables investigated. Additionally these three variables, RFD calculated with a moving average, index of explosive strength and the reactivity coefficient had practically perfect or very high correlations using the two methods, suggesting the two analysis methods (1 and 3) are measuring very similar physical qualities in the case of these three variables. In the case of RFD calculated with a moving average which uses a 50 ms moving window through the portion of the force-time curve analysed, this is to be expected, as method 3 runs the moving average through the entire curve. Method 1 only excludes the negative force component of the eccentric phase of the jump and accordingly the 50 ms window with the greatest RFD should be common between the two methods (methods 1 and 3). The RFD calculated with a moving average using methods 1 and 3 also showed only a trivial correlation with concentric only RFD calculated with a moving average (Method 2). RFD calculated with a moving average was significantly greater for methods 1 and 3 (9720.4 ± 5989.9 and 9616.9 ± 6024.2 respectively) compared to method 2 (4990.7 ± 3613.2) showing that the greatest RFD occurs during the eccentric phase of the movement.

With the exception of time to PF, the remaining variables (RFD at 100 ms, impulse at 100 ms and force at 50 ms) investigated specific parts of the force-time curve relative to a starting point. Thus, the significant differences between the values generated are to be expected. Additionally these variables generally had lower correlations (trivial to high) between methods, suggesting that the physical qualities each method is assessing (for each variable) are independent of one another. The exception to this was the correlation between impulse at 100 ms calculated using methods 1 and 3 which was very high (r = 0.76). This suggests that when calculating time-limited temporal variables, the practitioner or sports scientist must be cognizant that the start point for calculation, and thus the portion of the force-time curve measured, must be carefully considered.

The rationale for selection of these methods in previous research analysing the force-time curve during rebound jump squats has received limited discussion. The combination of eccentric and concentric phases in analysis is of interest due to the importance of the eccentric phase of the movement to initial force production in the concentric phase of SSC movements (24, 51, 152). Specifically, Bobbert and colleagues (25) using a simulation model concluded that the countermovement during jumping allowed the muscular system to develop a higher level of active state and force prior to the start of shortening (concentric phase) thus increasing the work over the initial portion of the concentric phase. Methods 1 and 3 offer the practitioner or sports scientist analysis of both components as a functional unit, the preceding eccentric force and resultant concentric force. This allows analysis which is highly specific to many sports which involve SSC tasks. From a practical viewpoint, it is possible that method 1 offers greater ease of identifying the start point during analysis, which in turn may increase reliability of measurement. This may explain why this is traditionally the more popular method of eccentric-concentric analysis of the force-time curve. Given the results of this study, showing a strong relationship between the two methods (1 and 3) for many variables, it would seem method 1 may be preferred if in fact its reliability is greater.

Analysis of the concentric only phase (method 2) may also however provide information of interest. The propulsive phase of many SSC movements is still the crucial element in performance. That is, the resultant concentric forces during a SSC movement often dictate performance. For example, in the acceleration phase of sprinting where approximately 12% of the stance phase is comprised of the eccentric (braking) phase with the remainder consisting of propulsion (144), the concentric forces generated during the propulsive phase are critical in the development of stride length and thus sprint performance. Therefore, it would seem likely that rate dependent variables calculated using method 2 may offer some valuable information in the assessment of athletic performance. For many athletes it could be argued that force production capabilities in the concentric phase of a SSC activity are crucial to high level performance and should be included in athletic assessment. Therefore, conceivably either method could be selected by the practitioner for analysis using time-dependant variables such as those investigated in this study (impulse at 100 ms, force at 50 ms, RFD at 100 ms). Selection should be dependent on the demands of the sport for which the athlete is being assessed and the information required by the practitioner or sports scientist. Further investigation of the relationship between rate dependent variables across different portions of the force-time curve and functional performance may also be warranted.

In summary, our data has shown that force-time variables which assess rate of force development relative to PF (such as index of explosive strength and reactivity coefficient) produce significantly different values, but these values are generally highly correlated meaning the rank order of the population is similar, whether the concentric phase is included in the analysis, or the eccentric and concentric phase are included in the analysis. However, when time limited values are investigated the starting point of calculation results in the measurement of functionally independent physical qualities and the practitioner or sports scientist should select analysis methods with this in mind.

3.6 PRACTICAL APPLICATIONS

The rebound jump squat is a common movement utilised in the assessment of lower limb muscular force and power. The use of time dependent force measures potentially offers the strength and conditioning professional greater diagnostic information in athletic assessment compared to the traditionally used measure of PF. However, when using time dependent measures, the practitioner must be aware that the point on the force-time curve from which variables are calculated will, in many cases, determine the information provided and whether you can compare results between athletes and/or studies. Accordingly, method selection should be based on needs analysis of the task for which the athlete is being assessed. For tasks where concentric force development is deemed to be critical to performance, variables calculated relative to PF (e.g. index of explosive strength, reactivity coefficient and time to PF) can be analysed using either method. However, if variables are calculated for a specific time period (e.g. impulse at 100 ms, RFD at 100 ms, force at 50 ms), analysis should commence at the start of the concentric phase (method 2). If the eccentric and concentric phase is of interest as a functional unit then method 1 should be used for all calculations.

CHAPTER 4

THE RELIABILITY OF LINEAR POSITION TRANSDUCER AND FORCE PLATE MEASUREMENT OF EXPLOSIVE FORCE-TIME VARIABLES DURING A LOADED JUMP SQUAT IN ELITE ATHLETES

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4.1 PRELUDE

For an athletic assessment methodology to be successfully implemented in a practical setting, it must have good reliability. In the Review of Literature (Chapter 2) a number of force-time measures that have been discussed in the literature were introduced. It was also established that research evaluating the reliability of these alternative force-time measures using common assessment methodologies, such as the rebound jump squat is limited. Additionally, in Chapter 3 we have identified significant differences between analysis methods in calculating force-time measures from rebound jump squat data. To enable the application of these methodologies in practice the reliability of measures using common data collection technologies needs to be addressed. This Chapter addressed the reliability of a number of the measures discussed in the literature and investigated in Chapter 3 in order to identify those measures and methods of data collection and analysis that have sufficient reliability to be applied in practice.

4.2 INTRODUCTION

Lower body iso-inertial (constant gravitational load) assessment is utilised in sports science and strength and conditioning for a number of diagnostic purposes. These purposes include monitoring the efficacy of training interventions, the identification of deficiencies in muscular function, identifying individuals who may be suited to a particular athletic endeavour (talent identification) and, quantifying the relative significance of strength and power qualities to a given event or sport (2). Currently the best methods of assessing muscular force qualities during iso-inertial SSC lower body movements remains controversial. There is great diversity in the terminology and methodologies used for quantifying the force capability of muscle and a variety of technologies have been used in the literature to measure force.

Measures such as MF and PF are commonly used by researchers, clinicians and strength and conditioning coaches. However, these measures do not consider RFD which is thought important to muscular performance for some activities (195, 201, 202). There are many measures and methods of calculating RFD that can be used to represent the temporal qualities of force production. For example, RFD can be calculated as the slope between two time points or utilising a moving average over a selected portion of the force-time curve. Measures such as starting strength, initial RFD and explosive strength have also been described in the literature (171, 185, 203). Additionally, Zatsiorsky and Kraemer (203) used terms such as the index of explosive strength, reactivity coefficient, starting gradient, and acceleration gradient to describe RFD. These measures all represent similar constructs but analyse different portions of the force-time curve. Impulse, as the product of the average force over a given time period (or contraction) and the time over which the force is applied (67) represents the area under the force-time curve. This measure has received little research interest, yet it describes the application of force relative to time and thus may be of interest in the strength diagnosis process. Despite this abundance of measures, and their utilisation in research and practice, little is known about their reliability and interrelationships when applied to movement patterns commonly used in iso-inertial assessment.

In addition, a diverse range of technologies has been used for measurement and analysis of force and force-time variables during lower body movements in strength training research. Two measurement apparatus are commonly employed in iso-inertial assessment of muscular force. The first involves the direct measurement of ground reaction force using a force plate (32, 50, 107, 195, 202). The second incorporates differentiation of displacement data from a linear position transducer using a known system mass to estimate force (32, 50, 107). The validity of the linear position transducer in estimating peak and mean force has been the subject of some conjecture in the literature. Some studies have found it provides a valid estimation of peak and mean force (32, 50). Other studies have suggested that differentiated linear position transducer data, although highly correlated with ground reaction force data, significantly overestimates PF (37). To date the only study (32) to compare force-time measures between the two technologies during a loaded jump squat reported strong ICCs (ICC = 0.75 ï 1.0) for a number of temporal measures, albeit with a small subject population (n = 6).

Both technologies (the force plate and linear position transducer) used in the measurement of force output during jumping movements have previously been reported to be reliable. The relative consistency of force plate measurement of MF and PF as quantified by the ICC in previous studies has ranged from 0.91 to 1.0 (32, 50). The absolute consistency of these variables represented as a CV has ranged from 1.8% to 3.2% (50, 107). Linear position transducer measurement of MF and PF has been reported to be have more variability with ICCôs ranging from 0.58 to 1.0 (32, 107) and CVs ranging from 1.9% to 9% (50, 107). Similarly, various temporal variables have been reported as reliable during jumping movements for both the force plate and linear position transducer. For example, Chiu and colleagues (32) reported ICCôs ranging from -0.14 to 0.91 for force plate measurement and -0.11-0.95 for linear position transducer measurement of various force-time measures during concentric-only and rebound jump squats at a variety of loads. Variables investigated in Chiuôs research included time to 20%, 40% 60% and 80% of PF, as well as peak and average RFD. Although, Chiu et al. reported high inter-session reliability for a number of these variables with both the linear position transducer and force plate, the analysis was based on six subjects with a recreational training background. Thus, there remains limited research using elite level subjects documenting the reliability of variables calculated using force-time data in the jump squat movement.

The purpose of this study was to calculate the inter-day reliability of PF and a variety of force-time measures during a loaded jump squat, comparing their reliability using two technologies, the force plate and the linear position transducer. This study is the first reported in the literature to use a relatively large number of well-trained athletes. The results will provide the strength and conditioning practitioner with information as to the repeatability of measurement of temporal aspects of force production using force plate and linear position transducer technology. Furthermore, the comparison between technologies will allow insight into the accuracy/validity of linear position transducer technology in quantifying the variables of interest. Given this technology is a much cheaper alternative to the force plate, the findings of this analysis will be of interest to practitioners seeking advanced assessment of force capability.

4.3 METHODS

4.3.1 Experimental Approach to the Problem

In order to investigate the inter-session reliability of force plate and linear position transducer measurement of a number of force-time variables, twenty-five subjects performed three loaded rebound jump squats over two testing sessions spaced one week apart. Data were collected simultaneously with a force plate and linear position transducer and subsequently a number of force-time measures were calculated. Thereafter the test-retest reliability, in terms of relative and absolute consistency, was calculated for each variable with each technology. Additionally, interrelationships between variables that were shown to be reliable were examined to compare the measurements of force and force-time values between the two technologies.

4.3.2 Subjects

Twenty-five male, elite level rugby union players aged between 18 and 34 years of age volunteered to participate in this study. Mean age and height was 23.6 ± 4.8 yrs and 1.8 ± 0.1 m, and body weight on days one and two was 98.6 ± 12.0 kg and 98.8 ± 11.9 kg respectively. Testing was conducted as part of the subjectsô pre-season strength and conditioning program. All subjects were informed of the risks and benefits of participation in the research, that they could withdraw at any time, and signed informed consent forms. All procedures were approved by Edith Cowan Universityôs Human Research Ethics Committee.

4.3.3 Procedures

Subjects were required to report for data collection on two occasions seven days apart. Data were collected at the same time of day and activity patterns in the 48 hours prior to each data collection session were replicated. Following a standardised warm-up, each subject performed three single repetition jump squats with a 20 second rest between repetitions at an external load of 40 kg, using a technique identical to that described by Hori and colleagues (107). This involved the subjects standing at a self-selected foot width with a loaded Olympic bar placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately performed a maximal jump. Subjects were instructed to keep the depth of countermovement consistent between jumps and ñjump for maximum heightò on each repetition. All subjects were familiar with the jump squat movement as a regular part of both training and testing programs.

All jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA). The force plate was calibrated using the manufacturerôs calibration matrix. Prior to data collection the force plate was zeroed and data collected with the plate unloaded was used to calculate off-sets for each channel, which were subsequently applied to the data acquisition software. A linear position transducer (HX-VPA-200, Unimeasure, Oregon ï mean sensitivity 0.499mV/V/mm, linearity 0.05% full scale) which measured vertical displacement with an accuracy of 0.01cm was attached to the end of an Olympic weight-lifting bar placed on the subjectôs back. The linear position transducer was calibrated to a known distance prior to data collection. Displacement and ground reaction force data were sampled simultaneously at 500 Hz via an analogue to digital converter (16-Bit, 250 kS/s National Instruments, Austin, TX.) and collected by a laptop computer using custom-built data acquisition and analysis software (Labview 8.2, National Instruments, Austin, TX.).

4.3.4 Data Analysis

Displacement time data was filtered using a 4th order dual pass digital filter with a cut-off frequency of 4Hz (199). Filtered displacement-time data was used to calculate velocity and acceleration using the finite-difference technique (199). The summation of system acceleration and acceleration due to gravity, multiplied by the system mass was then used to calculate force. These procedures are similar to those reported in previous research using displacement data to calculate force variables (32, 107). From this data and the force plate ground reaction force data, temporal and kinetic variables of interest were determined for the portion of the force-time curve from minimum force to maximum force (see Figure 4.1), encompassing the latter portion of the eccentric phase and the concentric phase of the movement (32). PF, time to PF, fifty percent force, time to fifty percent force and body mass were the variables used to calculate measures of explosive force according to the formulae of Zatsiorsky and Kraemer.

Index of Explosive Strength = peak force / time to peak force
Reactivity Coefficient = peak force / (time to peak force x body mass)
Start Gradient = fifty percent force/ time to fifty percent force

Acceleration Gradient = fifty percent force / (time to peak force - time to fifty percent force)

Additionally a number of time-limited variables were calculated using the same portion of the force-time curve (force minimum to maximum) (32). These variables included the force at 50 ms, 100 ms and 200 ms and impulse at 100 ms, 200 ms and 300 ms. Additionally, RFD was calculated during the following four time intervals; 0-100 ms, 0-200 ms and 0-300 ms. To calculate these variables zero was designated as the start of the movement (minimum force) and a simple rate equation was then used to determine RFD:

[(force at end time)-(force at start time)]/[(time at end time)-(time at start time)]

As the time at start time was defined as 0 in all cases, the equation subsequently became:

[(force at end time)-(force at start time)]/[time at end time]

A moving average was also used to find the greatest RFD within a 50 ms interval. This moving average RFD was conducted over a window length of 50 ms from the start point of analysis until attainment of PF.

Additionally the moving average RFD, impulse and absolute force values were calculated for the concentric portion of the force-time curve. However, due to the variable concentric phase duration between subjects time to PF (time to PF = 39 ï 912 ms for the force plate and 0- 333 ms for the linear position transducer respectively), time epochs of greater than 100 ms were excluded from analysis. For the purposes of these calculations, the start of the concentric phase was identified by the lowest point on the displacement curve (39) which coincided with zero velocity (see Figure 4.1).

4.3.5 Statistical Analyses

All statistical analyses were performed on the mean of trials two and three with the first trial excluded from analysis (104). Means and standard deviations were used as measures of centrality and spread of data. The data obtained were analysed using SPSS statistical software (SPSS 15, Chicago, Ill.). Test re-test reliability of each variable measured with the force plate and the linear position transducer was calculated using a two-way random absolute agreement ICC. Additionally, data was log transformed and the percent change in the mean and the CV calculated (99). Subsequently, a paired t-test was used to investigate differences between PF measurement with the two technologies (force plate and linear position transducer). For the variables deemed to have acceptable relative consistency (ICC > 0.9) or absolute consistency (CV < 10%), the strength of association between variables was established using a Pearson's product moment correlation coefficient. Correlations were described as trivial (0.0-0.1), low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), very high (0.7-0.9) and practically perfect (0.9-1.0) (34, 99).

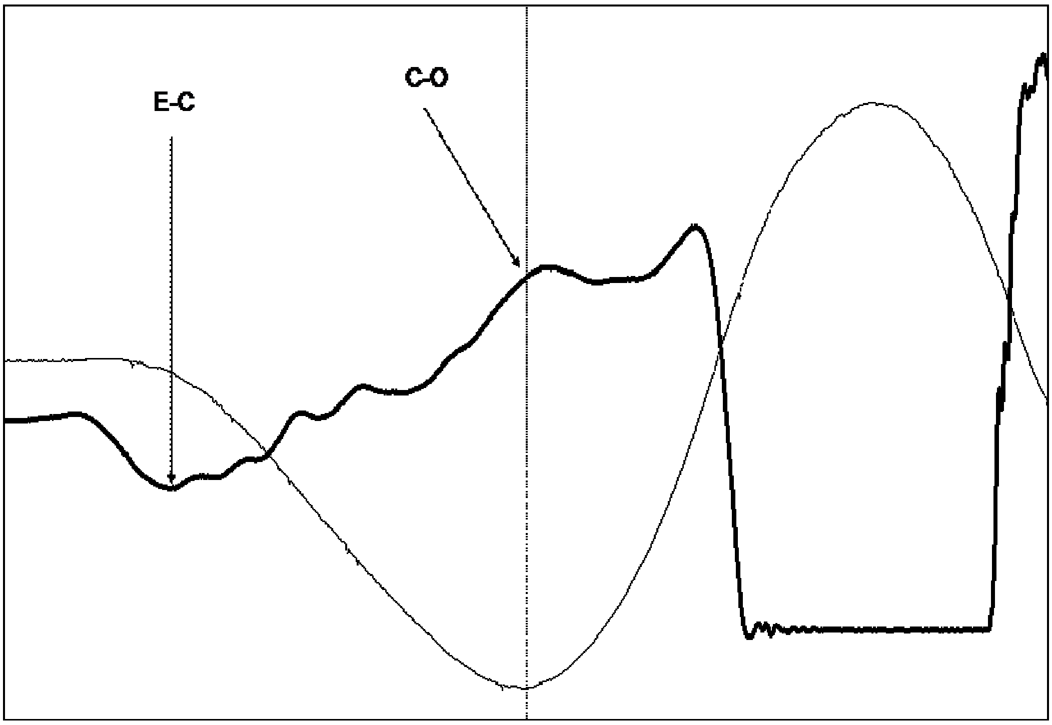

Figure 4.1: Jump squat force-time curve (thick black line) with displacement overlayed (thin line) showing start point of calculation of force-time variables eccentric-concentric (E-C) and concentric (C-O) only methods (broken line represents zero displacement and start point for C-O method).

4.4 RESULTS

PF values for days one and two together with reliability values can be observed from Table 4.1. The ICCs were greater with the force plate compared to the linear position transducer and the percent change in the mean lower. The CV was also considerably greater (209%) with the linear position transducer compared to the force plate. PF values differed (~11-13%) significantly between force plate and linear position transducer measurements on both days ($p < 0.05$). However, the correlation between the two measurement technologies was very high and high for days one and two, respectively (see Table 4.2).

Table 4.1: Mean (± SD) values and between session reliability for peak force (N) measured with force plate and linear position transducer.

	Force plate	**Linear Position Transducer**
Day 1 Mean (N)	2,530 ± 68.1	2,819 ± 290§
Day 2 Mean (N)	2,528 ± 53.9	2,860 ± 283§
ICC (Day 1-Day 2)	0.96	0.88
Change in Mean (%)	-0.5	1.49
TE as a CV (%)	2.3	4.8

ICC = intraclass correlation coefficient, TE = typical error, CV = coefficient of variation
§Significantly different to force plate values ($p < 0.05$)

Table 4.2: Inter-relationships (Pearson correlation coefficients ï r) between measures of peak force (PF) measured with force plate and linear position transducer on day one and day two of testing.

	r	**Classification**
PF Day 1 (PT-FP)	0.88	Very High
PF Day 2 (PT-FP)	0.67	High

Test re-test reliability data for time to PF and Zatsiorsky and Kraemers force-time variables can be observed from Table 4.3. Typically higher ICCs and lower CVs were associated with the force plate measurements. Time to PF was the time dependent variable found to be most stable (ICC = 0.95 to 0.96, change in the mean = 0.69 to 2.37% and CV = 6.5 to 14.3%) across testing occasions for both technologies and the acceleration gradient the least stable (ICC = 0.51 to 0.61, change in the mean = -5.1 to 8.0% and CV = 30.5 to 40.2%).

The test-retest reliability of time-limited variables for eccentric-concentric and concentric only analysis can be observed from Tables 4.4 and 4.5, respectively. In terms of eccentric-concentric analysis, the ICCs for these variables ranged from 0.97 for force plate measurement of force at 200 ms to 0.33 for linear position transducer measurement of RFD calculated with a moving average. The variable with the greatest absolute consistency was force plate impulse at 300 ms (CV = 4.3%) and the lowest was force plate measurement of RFD at 100 ms (CV = 51.8%). Typically values calculated over a greater time period displayed greater absolute and relative consistency, for example force plate impulse at 100 ms had an ICC of 0.88 and CV of 11.0% compared to 0.94 and 4.3% for impulse at 300 ms. Generally, force plate data resulted in greater ICCôs and lower CVs than linear position transducer measurement. For concentric only analysis, greater reliability of the RFD variables (moving average RFD and RFD at 100 ms) was associated with the force plate (ICC = 0.83-0.94, CV = 17.3-51.5%), whereas for remaining variables (impulse at 100 ms, force at 50 ms and force at 100 ms) reliability was similar between the two technologies.

The inter-correlation matrix between the most reliable variables can be observed from Table 4.6. Inter-correlations ranged from 0.02 (force plate eccentric concentric force at 200 ms and force plate concentric only moving average RFD with linear position transducer concentric only force at 100 ms) to 1.00 (force plate concentric only impulse at 100 ms with force plate concentric only force at 50ms and linear position transducer concentric only impulse at 100 ms with linear position transducer concentric only force at 50 ms). Correlations between force plate measurement of PF and force-time measures calculated from ground reaction force data ranged from trivial to high (r = -0.07 - 0.59). PF measured with the linear position transducer showed a number of high to very high correlations with force-time values. Concentric only absolute force values measured both within and between technologies also had very high or practically perfect correlations with one another (r = 0.93 - 0.96), and with concentric only impulse at 100 ms (r = 0.72 ï 1.0).

Table 4.3: Test re-test reliability values for force plate and linear position transducer measurement of time to peak force and force-time measures adapted from Zatsiorsky and Kraemer.

	Force Plate					**Linear Position Transducer**				
	Mean Day 1	**Mean Day 2**	**ICC**	**Change in mean (%)**	**TE as a CV (%)**	**Mean Day 1**	**Mean Day 2**	**ICC**	**Change in mean (%)**	**TE as a CV (%)**
TTPF (ms)	637 ± 242	666 ± 241	0.96	2.37	6.5	547 ± 203	556 ± 236	0.95	0.69	14.3
IES	2,214 ± 1,083	2,026 ± 757	0.86	-5.6	15.0	3,083 ± 1,285	3,177 ± 1,299	0.87	2.52	20.6
RC	23.3 ± 12.4	21.4 ± 9.2	0.89	-5.4	15.2	32.2 ± 13.5	33.2 ± 15.2	0.89	1.92	20.9
S-Grad	2,191 ± 1,237	2,093 ± 1,025	0.90	-3.9	22.2	3,047 ± 1,312	3,044 ± 1,456	0.85	-5.52	40.5
A-Grad	2,615 ± 1,204	2,396 ± 892	0.70	-5.1	30.5	3,721 ± 1,413	4,107 ± 1,912	0.51	8.0	40.2

TTPF = Time to Peak Force, IES = Index of Explosive Strength, RC = Reactivity Coefficient, S-Grad = Starting Gradient, A-Grad = Acceleration Gradient, ICC = intraclass correlation coefficient, TE = typical error, CV = coefficient of variation

Table 4.4: Test re-test reliability values for force plate and linear position transducer measurement of time dependent force-time measures for the eccentric and concentric phases.

	Force Plate					**Linear Position Transducer**				
	Mean Day 1	**Mean Day 2**	**ICC**	**Change in mean (%)**	**TE as a CV (%)**	**Mean Day 1**	**Mean Day 2**	**ICC**	**Change in mean (%)**	**TE as a CV (%)**
RFD-100 (N.s^{-1})	4,329 ± 3,600	4,491 ± 3,102	0.90	15.1	51.8	6,676 ± 3,489	7,538 ± 3,654	0.66	14.8	47.5
RFD-200 (N.s^{-1})	5,064 ± 2,806	5,232 ± 2,438	0.90	11.3	31.5	7,039 ± 3,561	7,507 ± 3266	0.89	11.2	27.3
RFD-300 (N.s^{-1})	4,450 ± 1,966	4,544 ± 1,863	0.91	4.0	21.1	6,020 ± 2,545	6,203 ± 2404	0.89	7.63	24.8
RFD-MA (N.s^{-1})	9,720 ± 5,990	9,734 ± 5,710	0.94	0.2	22.3	13,570 ± 5,702	13,947 ± 4,257	0.33	7.39	44.5
I100 (N.s)	81.2 ± 18.2	79.1 ± 18.0	0.88	-2.7	11.0	68.3 ± 23.5	68.6 ± 20.3	0.82	1.71	20.8
I200 (N.s)	218 ± 31.0	216 ± 27.6	0.93	-0.7	5.1	217 ± 32.3	223 ± 31.7	0.72	3.08	10.0
I300 (N.s)	399 ± 58.0	398 ± 49.0	0.94	0.04	4.3	420 ± 66.2	430 ± 60.7	0.84	2.57	7.9
FA-50 (N)	776 ± 199	758 ± 185	0.85	-1.76	14.2	645 ± 269	646 ± 216	0.79	3.78	29.6
FA-100 (N)	1,054 ± 237	1,043 ± 214	0.93	-0.71	8.2	1,076 ± 212	1,129 ± 230	0.53	4.76	16.0
FA-200 (N)	1,631 ± 343	1,638 ± 291	0.92	0.95	7.5	1,808 ± 455	1,866 ± 411	0.89	3.96	11.9

RFD = Rate of Force Development, MA = Moving Average, I = Impulse, FA = Force at, ICC = intraclass correlation coefficient, TE = typical error, CV = coefficient of variation

Table 4.5: Test re-test reliability values for force plate and linear position transducer measurement of time dependent force-time variables for the concentric phase only.

	Force Plate					**Linear Position Transducer**				
	Mean Day 1	**Mean Day 2**	**ICC**	**Change in mean (%)**	**TE as a CV (%)**	**Mean Day 1**	**Mean Day 2**	**ICC**	**Change in mean (%)**	**TE as a CV (%)**
RFD-100 (N.s^{-1})	2,355 ± 1,531	2,345 ± 1,518	0.83	-2.08	51.5	1,206 ± 1,861	793 ± 2094	0.68	48.0	93.6
RFD-MA (N.s^{-1})	4,991 ± 3,613	5,387 ± 4,161	0.94	7.17	17.3	5,877 ± 2,467	5,937 ± 2,727	0.18	-17.93	76.5
I100 (N.s)	219 ± 32.3	211 ± 35.1	0.86	-3.68	8.9	262 ± 34.2	259 ± 33.7	0.81	-1.05	8.5
FA-50 (N)	2,162 ± 324	2,093 ± 357	0.86	-3.6	9.2	2,590 ± 339	2,559 ± 338	0.80	1.07	8.8
FA-100 (N)	2,251 ± 330	2,176 ± 352	0.87	-3.6	8.2	2,621 ± 318	2,569 ± 331	0.86	-1.87	7.7

RFD = Rate of Force Development, MA = Moving Average I = Impulse, FA = Force at, MA = Moving Average, ICC = intraclass correlation coefficient, TE = typical error, CV = coefficient of variation

Table 4.6: Inter-Correlation (Pearsons Correlation Coefficient) matrix between most reliable variables investigated.

	FP PF	FP TTPF	FP S-Grad	FP EC RFD-300	FP EC RFD-MA	FP EC I200	FP EC I300	FP EC FA 100	FP EC FA 200	FP CO RFD-MA	FP CO I100	FP CO FA 50	FP CO FA100	PT PF	PT TTPF	PT EC I200	PT EC I300	PT CO I100	PT CO FA50	PT CO FA 100
FP PF	1																			
FP TTPF	-0.23	1																		
FP S-Grad	0.31	-0.84*	1																	
FP EC RFD-300	0.39	-0.79	0.83*	1																
FP EC RFD-MA	0.13	-0.59	0.74*	0.72	1															
FP EC I200	0.40	-0.10	0.33	0.26	0.55	1														
FP EC I300	0.54	-0.51	0.70*	0.74*	0.77*	0.83*	1													
FP EC FA 100	0.26	-0.07	0.29	0.19	0.52	0.94#	0.72*	1												
FP EC FA 200	0.47	-0.64	0.77*	0.92#	0.79*	0.56	0.91#	0.45	1											
FP CO RFD-MA	-0.07	0.00	-0.10	-0.23	0.26	0.19	0.03	0.10	-0.14	1										
FP CO I100	0.57	-0.76*	0.69	0.79*	0.48	0.24	0.63	0.14	0.70*	-0.13	1									
FP CO FA 50	0.54	-0.77*	0.70*	0.80*	0.51	0.25	0.64	0.15	0.71*	-0.11	1.00#	1								
FP CO FA100	0.59	-0.72*	0.60	0.66	0.36	0.24	0.56	0.13	0.59	-0.07	0.97#	0.96#	1							
PT PF	0.88*	-0.48	0.56	0.61	0.33	0.46	0.70*	0.32	0.65	-0.16	0.80*	0.79*	0.80*	1						
PT TTPF	-0.22	0.91#	-0.69	-0.73*	-0.46	0.10	-0.34	0.12	-0.51	0.06	-0.8*	-0.80*	-0.76*	-0.46	1					
PT EC I200	0.36	0.10	0.20	0.24	0.24	0.69	0.64	0.56	0.50	-0.13	0.07	0.06	0.05	0.41	0.28	1				
PT EC I300	0.56	-0.52	0.70*	0.84*	0.61	0.56	0.88*	0.43	0.91#	-0.24	0.68	0.68	0.60	0.75*	-0.42	0.70*	1			
PT CO I100	0.56	-0.35	0.15	0.30	-0.15	-0.07	0.19	-0.29	0.24	-0.03	0.65	0.62	0.72*	0.64	-0.44	0.09	0.34	1		
PT CO FA50	0.54	-0.33	0.12	0.28	-0.17	-0.07	0.18	-0.29	0.23	-0.05	0.63	0.60	0.70*	0.62	-0.41	0.10	0.33	1.00#	1	
PT CO FA 100	0.63	-0.40	0.25	0.32	-0.06	0.02	0.27	-0.19	0.26	0.02	0.64	0.61	0.72*	0.73*	-0.45	0.17	0.42	0.94#	0.93#	1

EC = Eccentric-Concentric, CO = Concentric Only, PT = Linear Position Transducer, FP = Force Plate, RFD = Rate of Force Development, I = Impulse, FA = Force at, MA = Moving Average, PF = Peak Force, PV = Peak Velocity

*Very High Correlation, $^{\#}$Practically Perfect Correlation

4.5 DISCUSSION

This study investigated two technologies (the force plate and linear position transducer) that are used for the measurement and analysis of force-time variables during the loaded jump squat. A comparison of the reliability of many of the variables measured with these two technologies has not been previously reported in the literature. It was found that the traditional measure of PF and other temporal variables can be measured reliably with both the force plate and the linear position transducer. Furthermore, many of the force-time variables deemed to be reliable in this research, particularly when measured with the force plate, were not highly related to the traditional measure of PF. This suggests they are measuring functionally independent qualities which may offer the practitioner or sports scientist new information in the strength diagnosis process.

Relative consistency of PF measured with the force plate and linear position transducer were similar to values reported previously in similar movements (32, 50, 107). The force plate measurement of PF resulted in an ICC of 0.96. Previously reported values have ranged from 0.94 reported by Hori and colleagues (107) during a 40 kg jump squat using methods identical to those utilised in the current study, to 1.0 reported by Chiu and colleagues (32) during rebound jump squats at both 50% and 70% of 1RM. Compared to the force plate, relative consistency of PF measured with the linear position transducer (ICC = 0.88) was slightly lower. Hori and colleagues (107) also reported lower reliability (ICC = 0.58) using differentiated linear position transducer data with system mass included in calculations. This ICC reported by Hori and colleagues for linear position transducer force measurement was considerably lower than the current study and other previous studies (32, 50). This lower reliability may be explained by Hori and colleagues only collecting two jump trials. Hopkins and colleagues (104) have shown that in assessment of muscular power the CV between the first two trials collected is 1.3 times that between subsequent trials. Therefore, collecting three trials and excluding the first may increase reliability during data collection.

Absolute consistency was also greater when using the force plate to measure PF compared to estimating PF from linear position transducer data. As a measure of variation within the rank order of a population, the ICC provides a measure of relative consistency (190). In order to assess absolute consistency of measurement between testing sessions the CV was also calculated. It could be argued that this is perhaps the most important value to the strength and conditioning practitioner interested in measuring training outcomes as this measure quantifies within subject variation and thus provides an indicator of the noise in the measure (100). In the current study, CVs of 2.3% and 4.8% were calculated for the force plate and linear position transducer PF, respectively. This shows that although both technologies can be deemed reliable for measuring PF in a practical setting, the within subject variation is more than twice that of the force plate when calculating PF from linear position transducer data. Therefore, the force plate offers much greater precision for the practitioner and conclusions on training outcomes can be made with much greater certainty (101).

The CV for PF values reported in the current study are similar to those previously reported in the literature. Cronin and colleagues (50) reported for a countermovement jump CVs of 2.2% and 2.5% for force plate and linear position transducer measurement, respectively. This research involved attaching the linear position transducer to a harness around the waist of the athlete and accordingly trunk extension was not included in the position measurement (as it was in the current study). The inclusion of trunk extension in position analysis may have increased variation in movement leading to the worse CV reported for the linear position transducer in our research. Hori and colleagues (107) reported higher CVs for linear position transducer measurement of PF (9.0%). As the methodology used in the present study was very similar to that of Hori and colleagues, the most likely explanation for their findings relate to the fact that Hori and colleagues only collected two jump trials which, as noted previously, may have increased variation in measurement. Therefore, some practical solutions exist for the coach or scientist trying to minimise within subject variation when estimating force from linear position transducer data. First, variation present in the linear position transducer estimation of force can be minimised if at least three trials are collected. Second, if the linear position transducer is attached closer to the athletes centre of gravity or to a smith press (which ensures vertical movement of the bar only), rather than to the end of an Olympic bar (as in the current study), variation may also be reduced.

Although PF values for the force plate and linear position transducer were significantly different on both days one and two, a very high and high correlation was evident between technologies on days one and two, respectively (r = 0.88 and 0.67). This is consistent with previous research (32, 50, 107) which has shown significant correlations between the two technologies utilised in this study. Therefore either technology could be deemed acceptable for monitoring PF in a practical setting. However, our results are consistent with previous research which has shown that PF is significantly overestimated when using differentiated linear position transducer data (37, 38). Therefore, although both technologies offer acceptable reliability and are highly correlated, comparison between linear position transducer values and force plate values should be avoided in both practical and scientific settings.

The current study investigated the reliability of a wide range of temporal variables. In previous research into the reliability of the measurement of force-time variables during the rebound jump squat, Chiu and colleagues (32) suggested that an ICC greater than 0.7 represents acceptable reliability. In the study of Chui and colleagues, some of the variables investigated achieved this standard but many did not. In the current study, all variables measured with the force plate reached the standard of relative reliability (ICC ≥ 0.70) chosen by Chiu and co-workers, and all except six measured with the linear position transducer achieved this standard. In any case, it may be argued that an ICC of 0.70 is not a high enough standard for the application of measures such as these in a practical situation, and an ICC of at least 0.90 would be more appropriate. A total of eleven force-time variables measured with the force plate had ICCs greater than 0.90, compared with only one for the linear position transducer (time to PF). It has been suggested that the double differentiation involved in the use of position data magnifies small errors in measurement, reducing measurement reliability (62, 105, 107). Our results would support such a contention when calculating not only PF, but also temporal aspects of force production. Therefore the force plate would seem the most reliable means of measuring force-time variables, and offers the widest variety of reliable measures.

It has been suggested previously that a CV of less than 10% indicates sufficient absolute consistency in biomechanical variables (6, 36, 50, 109, 140, 186). In the current study, a total of eight variables measured with the force plate and five with the linear position transducer had CVs below this threshold. The force plate was again the more reliable means of measurement. The variables which showed the best absolute consistency with the force plate were impulse at 300 ms for the eccentric-concentric phase (CV = 4.3%) and impulse at 200 ms using the same analysis method (CV = 5.1%). The linear position transducer does offer some reliable measurement options. However, as with the measurement of PF, within subject variation for most variables was considerably greater when estimating force values from linear position transducer data. The variable which had the greatest absolute consistency with the linear position transducer was force at 100 ms using the concentric only method (CV = 7.7%). To the authorsô knowledge, these findings regarding the absolute consistency of force plate and linear position transducer force-time variables have not been reported previously in the literature. These measures present the practitioner with a number of possibilities in terms of tracking changes in temporal aspects of force production during strength and power training.

Many of the temporal variables investigated displayed problematic absolute consistency (CV > 10%) yet acceptable relative consistency (ICC > 0.9). For example, RFD at 100 ms measured with the force plate had an ICC of 0.9 but a CV of 51.8%. These inconsistencies can most likely be attributed to how each measure of reliability is calculated and the characteristics of the subject population. That is, since the ICC is essentially a comparison of rank order, a high re-test correlation (ICC) can be generated from a heterogeneous sample and a lower ICC from a homogeneous sample (100). Despite the fact that the subjects in the current study were all elite rugby players, the age, height and weight of these subjects did vary greatly. Due to the varying physical demands of different positions and therefore the anthropometric characteristics of players, this variation is characteristic of rugby union teams and creates a relatively heterogeneous sample. This heterogeneity of the cohort may have lead to the high ICCs. It may be surmised therefore that the CV values for RFD measures may be of more value to the strength and conditioning practitioner. Indeed Hopkins (100) has argued that the CV and percent change in the mean, as a measure of within-subject variation, are the most important reliability values. Therefore, the use of those variables which had high relative consistency, but poor absolute consistency should be restricted to similar populations to that used in this study (professional rugby union players) or applications where determining the rank order of the population is the primary objective of assessment.

The results of correlations between reliable linear position transducer and force plate variables suggests that differences exist between the actual force-time curve from vertical ground reaction force data and the force-time curve estimated from linear position transducer data. These potential differences in the force-time curves generated using the different technologies are evidenced by different inter-relationships amongst force-time variables calculated with the two technologies. Firstly, the inter-correlations matrix showed that for the force plate, correlations between PF and force-time variables ranged from small to high with many being either small or moderate. Conversely, when measured with the linear position transducer a number of force-time variables had a high or very high correlation with PF. This adds further support to the contention that force capabilities measured with the two technologies (force plate and linear position transducer), despite strong relationships between many variables, should be viewed as different qualities and comparisons between data collected with different apparatus should be avoided.

Additionally, it can be observed from the inter-correlations outlined in Table 4.6, that many of the qualities measured for the concentric phase, particularly with the force plate, have practically perfect correlations. Tidow (185) defined starting strength as the force at 30 ms, and stated that this quality is unrelated to explosive strength defined as the force or impulse at 100 ms. Our findings showed very high or practically perfect correlations between force at 50 ms and force at 100 ms using both the force plate and linear position transducer. Given this, it would seem unlikely that during this specific movement force at 30 ms is unrelated to these values. Investigation may be warranted to specifically investigate the relationship between force or impulse at 30 ms (starting strength) and 100 ms (explosive strength). However, in a practical setting it is likely that the measurement of only one of these concentric variables may suffice.

Another point of interest in the inter-correlation matrix related to the moving average RFD variable, which uses a moving average to identify the greatest RFD in a 50 ms period through the force-time curve. When applied to the concentric phase of the movement (using force plate data), this moving average had only a trivial to moderate (r = 0.00 ï 0.33) correlation with all other variables. It may be that the moving average RFD represents a physical quality that is unrelated to the other variables investigated in this study. Therefore, this variable warrants further investigation to clarify its value in strength and conditioning practice.

4.6 PRACTICAL APPLICATIONS

This study supports previous research which suggests that both the force plate and linear position transducer offer a reliable means of assessing lower limb muscular performance. Some, but not all variables investigated in this study showed acceptable absolute consistency for use in tracking training in strength and conditioning practice. Variables which fell within the 10% threshold previously suggested as being a minimum CV value included PF, time to PF, and force and impulse at various points on the force-time curve. Although many of the RFD measures investigated (for example, moving average RFD, starting gradient) had acceptable relative consistency (ICC), most of these measures absolute consistency (CV) was problematic and therefore these variables should be used by the strength and conditioning practitioner with caution. The use of variables with acceptable relative consistency but poor absolute consistency should be limited to applications where determining the rank order of the population in the specific measure is the primary objective. The practitioner also needs to be cognizant that the reliability of variables is not consistent between technologies and often reliability is considerably reduced when estimating force values from position data. This includes much greater within subject variation when estimating force from linear position transducer data. Therefore for the practitioner, definitive conclusions on training outcomes are less likely when using the linear position transducer for testing purposes. Although the linear position transducer is a reliable means of measuring some force variables in the jump squat it may not be a valid means of measurement. Not only does the overestimate PF, but also there is some evidence of differences in the force-time curve generated by each technology. Accordingly comparisons between values generated with the linear position transducer and the force plate should be avoided.

CHAPTER 5

THE RELIABILITY OF LINEAR POSITION TRANSDUCER, FORCE PLATE AND COMBINED MEASUREMENT OF EXPLOSIVE POWER-TIME VARIABLES DURING A LOADED JUMP SQUAT IN ELITE ATHLETES

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5.1 PRELUDE

Assessment in movements such as the jump squat has typically focused on peak and mean power output. Further analysis of the power-time curve is limited. In Chapter 4 the reliability of a number of poorly understood force-time measures was investigated and methods of data collection and analysis compared for the rebound jump squat movement. It is possible that many of these force-time measures investigated, if applied to the power-time curve may be practically beneficial to strength and conditioning practitioners and sport scientists. However, in order to utilise these measures in any practical or scientific setting their reliability first needs to be established. Therefore, this chapter evaluated the reliability of a number of power-time measures using common data collection technologies during the rebound jump squat.

5.2 INTRODUCTION

Power can be defined as the rate of performing work and is equal to the product of force and velocity (67). Jump squats are a popular mode of assessment with coaches and scientists due to their ability to assess the power capabilities of the lower limb in a movement that is functionally similar to many sporting activities. That is, the muscular power of the ankle, knee, hip and trunk combine to produce the external power flow measured by the apparatus (118). These jumps can be performed either as countermovement jumps where a preceding stretch shorten cycle is permitted (107) or as concentric only jumps where no stretch shorten cycle is included (93).

The power applied to the COM of the system during a jump squat can be calculated from ground reaction force data collected via a force plate using forwards dynamics (107). Other methods which are also documented as being utilised in both a scientific and practical setting to calculate power during jump squats include the double differentiation of displacement data from a linear position transducer attached to an Olympic bar and a methodology which calculates power applied to the system through multiplying the direct measurement of ground reaction forces by velocity differentiated from the displacement of an Olympic bar (62). In most cases the resulting mechanical power output is then expressed as instantaneous PP (the highest point on the power-time curve) or as mean power [the average power output from each time point on the power-time curve] (62).

As power flow during jump squats is typically expressed as a peak or mean value, temporal aspects of power production have received very little research interest. Temporal aspects of force production have been the subject of interest during both isometric and iso-inertial movements (32, 50, 82, 195, 202, 203). Just as with force output, rate-dependent variables of power application may be of importance to human performance. Although there is a small body of research reporting reliability of RPD measures (108, 112), the absence of comprehensive investigation into the reliability and validity of power-time measures has meant that their use in both clinical and research applications has been limited.

Iso-inertial (constant gravitational load) assessments such as the jump squat have a number of uses in sport science. These include (i) monitoring the effectiveness of training interventions, (ii) the identification of deficiencies in muscular function, (iii) identifying individuals who may be suited to a particular athletic endeavour (talent identification), and (iv) quantifying the relative significance of strength and power qualities to a given event or sport (2). To assess training induced changes in performance (aforementioned use i), a measure must possess good absolute consistency, often represented by the typical error expressed as a coefficient of variation (CV) (100, 119, 161) . For other assessment tasks where an individual is assessed relative to a group (such as aforementioned applications ii, iii and iv) a measure must have good relative consistency (22). This type of reliability can be assessed using the ICC (5, 100).

In order for temporal measures of power to be used in the tracking of training induced changes in performance and in tasks where the rank order of the population is of interest, absolute and relative consistency needs to be established. The purpose of this research was to examine the between day reliability of force plate and linear position transducer technology for quantifying PP and a number of time dependent power variables in the loaded jump squat.

5.3 METHODS

5.3.1 Participants

Twenty five male elite level rugby union players aged between 20 and 34 years of age, volunteered to participate in this study. Mean age and height was 24.4 ± 4.9 yrs, 1.8 ± 0.1 m and, body weight was 98.6 ± 12.0 kg on day one and 98.8 ± 11.9 kg on day two. All subjects were informed of risks and benefits of participation in the research and signed informed consent forms. Procedures were approved by the institutional Human Research Ethics Committee.

5.3.2 Equipment

All jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA), previously validated as an accurate means of collected ground reaction force data (189). A single linear position transducer (HX-VPA-200, Unimeasure, Oregon ï mean sensitivity 0.499mV/V/mm, linearity 0.05% full scale) which measures vertical displacement with an accuracy of 0.01cm was attached to an Olympic weight lifting bar to the right of the athlete. Displacement and ground reaction force data were sampled simultaneously at 500 Hz via an analogue to digital converter (16-Bit, 250 kS/s National Instruments, Austin, TX.) and collected by a laptop computer using custom built data acquisition and analysis software (Labview 8.2, National Instruments, Austin, TX.).

5.3.3 Procedures

Subjects performed three single repetition loaded rebound jump squats over two testing sessions one week apart. Data were collected at the same time of day and activity patterns in the 48 hours prior to each data collection session were standardised around mode of training and daily structure. Total training load prior to each session was replicated and quantified using the session rating of perceived exertion (RPE) method (72). Subjects were also instructed to standardise dietary intake and sleep patterns as much as possible prior to each testing session. At each session, following a standardised warm-up which included running activities with incremental increases in intensity, dynamic stretching and sub-maximal jumps, each subject performed three single rebound jump squats with a 20 second rest between repetitions at an external load of 40 kg using a methodology previously described by Hori and colleagues (107). This involved the subjects standing at a self-selected foot width with a loaded Olympic bar placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately performed a maximal jump. Subjects were instructed to keep the depth of countermovement consistent between jumps and ñjump for maximum heightò on each repetition. All subjects were familiar with the jump squat movement as they previously performed it as part of both training and testing programs.

Data were collected simultaneously with the force plate and linear position transducer and subsequently analyzed using only force plate data, only linear position transducer data or a combination of data from both technologies. A selection of power-time measures were calculated from these three approaches. Thereafter the between day reliability, in terms of relative and absolute consistency, was calculated for each measurement method.

5.3.4 Data Analysis

Three methods were used to calculate power output using the force and displacement data. The first involved the use of linear position transducer data only, the second force plate data only and the third a combination of velocity of the bar differentiated from linear position transducer displacement data and ground reaction force data from the force plate. The linear position transducer method involved displacement time data being filtered using a 4th order dual pass digital filter with a cut-off frequency of 4Hz (199). Filtered displacement-time data was used to calculate velocity and acceleration using the finite-difference technique (199). The summation of system acceleration and acceleration due to gravity, multiplied by the system mass was then used to calculate force. Power was subsequently calculated by multiplying force by velocity. These procedures are similar to those reported in previous research using displacement data to calculate mechanical power in the jump squat movement (32, 38, 107).

The force plate method involved the use of the impulse-momentum (forwards dynamics) approach to calculate the system power as outlined previously in the literature (38, 62). As the initial velocity of the system was zero, at each time point throughout the jump, the vertical ground reaction force was divided by the mass of the system to calculate acceleration of the system. Acceleration due to gravity was then subtracted so that only the acceleration generated by the subject was multiplied by time data to calculate instantaneous velocity of the systems COM. The resultant velocity data was then multiplied by the original ground reaction force data to calculate power. The third method, the combined method, involved multiplying velocity utilizing the methods outlined for the linear position transducer by the vertical ground reaction force data for each time point in the movement (38, 62).

It has been suggested that due to the time-course of many athletic activities, PF is not achieved and accordingly it is RFD which is of paramount importance to performance (185, 203). A number of measures have been described for analysis of the force-time curve and it is possible that these same measures could be applied to the power time curve. Similarly to PF, the time-course of many athletic activities does not allow PP to be attained. Accordingly, index of explosive power, power reactivity coefficient, power starting gradient and power acceleration gradient were calculated for each measurement method for the portion of the power-time curve from minimum power to maximum power (32). PP, time to PP, fifty percent PP, time to fifty percent PP and body mass were variables used to calculate explosive power variables adapted from the formulae of Zatsiorsky and Kraemer (203) for force-time analysis using the following formulae:

Index of Explosive Power = peak power / time to peak power

Power Reactivity Coefficient = peak power / (time to peak power x body mass)

Power Start Gradient = fifty percent power/ time to fifty percent power

Power Acceleration Gradient = fifty percent power / (time to peak power - time to fifty percent power)

Additionally, a moving average was used to find the greatest RPD within a 50 ms interval. This moving average was conducted over a window length of 50 ms from the start point of analysis (minimum power) until PP. RPD was also calculated 100 ms from minimum power and 100 ms into the concentric phase of the jump, where the start of the concentric phase was identified as the lowest point on the displacement curve (39). A simple rate equation was used to determine RPD:

[(power at end time)-(power at start time)]/[(time at end time)-(time at start time)]

As the time at start time was defined as 0 in all cases, the equation subsequently became:

[(power at end time)-(power at start time)]/[time at end time]

The final variable calculated was power at 100 ms into the concentric phase (analysis initiated at minimum displacement). 100 ms was selected as an appropriate time period for these measures based on the purported importance of this time epoch to explosive athletic tasks (185). Therefore power and RPD at this time in the jump may also be of practical significance.

5.3.5 Statistical Analyses

All statistical analysis was performed on the mean of trials two and three. The first trial was excluded from analysis as it has been previously shown that in assessment of muscular power the CV between the first two trials collected is 1.3 times that between subsequent trials (104). Means and standard deviations were used as measures of centrality and spread of data. Data were analysed using SPSS statistical software (SPSS 15, Chicago, Ill.). Between day relative consistency of each variable was calculated using a two way random absolute agreement ICC. Additionally, in order to investigate absolute consistency, data was log transformed and the percent change in the mean and the the typical error of the estimate expressed as a CV was calculated (103). Subsequently, a one way analysis of variance was used to investigate differences in PP and PV between the three approaches. For power-time variables deemed to have acceptable relative consistency (ICC > 0.9) or absolute consistency (CV < 10%) with multiple measurement methods, the strength of association between measurement methods was established using a Pearson product moment correlation. Correlations were described as trivial (0.0-0.1), low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), very high (0.7-0.9) and practically perfect (0.9-1.0) (34, 99).

5.4 RESULTS

Reliability values for PP and PV can be observed from Table 5.1, together with descriptive statistics for each measurement method. The PP value differentiated from linear position transducer data and that from the combined method were significantly greater than the force plate value on both days (see Table 5.1) and PV measured by the linear position transducer was significantly greater than that measured with the force plate. However, the correlations between the three measurement methods were either very high or practically perfect for PP, and high to very high for PV (see Table 5.2).

Table 5.1: Mean values and between session reliability for three methods of measuring peak power and peak velocity.

	PV (m/s)		**PP (W)**		
	Force Plate	**Linear Position Transducer**	**Force Plate**	**Linear Position Transducer**	**Combined**
Day 1 Mean (+/-SD)	1.68 ± 0.14§	2.39 ± 0.17$^{\#}$	3,988 ± 497§*	5,268 ± 728$^{\#}$	4,864 ± 726$^{\#}$
Day 2 Mean (+/-SD)	1.66 ± 0.16§	2.38 ± 0.20$^{\#}$	3,917 ± 524§*	5,159 ± 852$^{\#}$	4,886 ± 749$^{\#}$
ICC (Day 1 - Day 2)	0.93	0.89	0.94	0.87	0.95
Change in Mean (%)	-1.7	-0.28	-2.48	-2.46	-1.05
TE as a CV (%)	3.4	3.7	4.6	8.0	4.8

ICC = intraclass correlation coefficient, TE = typical error, CV = coefficient of variation, PV = Peak Velocity, PP = Peak Power

§ Significantly different to linear position transducer values ($p < 0.05$).

* Significantly different to combined values ($p < 0.05$).

$^{\#}$ Significantly different to force plate values ($p < 0.05$).

Table 5.2: Pearsons correlation coefficient (r) between three methods of measuring peak velocity (PV) and peak power (PP)

	r	**Classification**
PV Day 1 (Linear Position Transducer ï Force Plate)	0.67	High
PV Day 2 (Linear Position Transducer - Force Plate)	0.76	Very High
PP Day 1 (Linear Position Transducer - Force Plate)	0.83	Very High
PP Day 1 (Linear Position Transducer ï Combined)	0.93	Practically Perfect
PP Day 1 (Combined & Force Plate)	0.81	Very High
PP Day 2 (Linear Position Transducer - Force Plate)	0.84	Very High
PP Day 2 (Linear Position Transducer ï Combined)	0.94	Practically Perfect
PP Day 2 (Combined & Force Plate)	0.84	Very High

Test re-test reliability for RPD measures including Zatsiorsky and Kraemers measures applied to the power-time curve, time to PP and PV, and RPD calculated with a moving average, can be observed in Table 5.3. ICCôs ranged from 0.77 (power acceleration gradient with the linear position transducer) to 0.94 (power reactivity coefficient with the force plate and the combined method). Typically absolute consistency was greatest with the combined method. CVôs ranged from 8.0% (time to PV with the combined method) to 18.0% (power reactivity coefficient with the force plate). Test re-test reliability data for RPD 100 ms from minimum force and, and absolute power 100ms into the concentric phase of the jump can be observed from Table 5.4. Typically the absolute consistency of these measures was poor (CV = 16.2 ï 53.4). Relative consistency was generally high and comparable between methods and measures (ICC = 0.77 ï 0.90).

Correlations between measurement methods in those power-time measures deemed to have acceptable absolute or relative consistency can be observed from Table 5.5. Eleven of the thirteen correlations were classified as practically perfect. The correlation between all three methods of calculating the power reactivity coefficient were practically perfect (r = 0.95 ï 0.98), as were those between methods of measuring index of explosive power (r = 0.93 ï 0.98).

Table 5.3: Test re-test reliability values for three methods of measuring time to peak velocity and power-time measures

	Mean Day 1	Mean Day 2	ICC	Change in mean (%)	TE as a CV (%)
Force Plate					
TTPV (ms)	565 ± 196	579 ± 214	0.94	2.27	9.7
TTPP (ms)	535 ± 197	549 ± 215	0.94	2.45	10.4
RPD-MA (W/s)	16,578 ± 4,062	16,743 ± 4,347	0.89	0.99	14.7
IEP (W/s)	8,431 ± 2,842	8,035 ± 2,756	0.91	-5.08	12.8
P-RC (W/s/kg)	88.4 ± 34.7	84.6 ± 34.1	0.94	-4.88	13.0
P-S-Grad (W/s)	7,074 ± 2,797	6,729 ± 2,650	0.86	5.59	18.0
P- A-Grad (W/s)	11,305 ± 3,295	11,068 ± 3,352	0.92	-1.45	13.5
Linear Position Transducer					
TTPV (ms)	496 ± 130	527 ± 168	0.90	5.1	9.4
TTPP (ms)	436 ± 132	465 ± 167	0.94	5.52	10.7
RPD-MA (W/s)	28,927 ± 7,147	29,976 ± 8,053	0.75	3.18	13.9
IEP (W/s)	13,234 ± 4,263	12,296 ± 4,084	0.89	-8.39	16.5
P-RC (W/s/kg)	138 ± 50.3	129 ± 49.7	0.91	-8.39	16.5
P-S-Grad (W/s)	9,477 ± 3,349	8,811 ± 3,168	0.87	-8.67	18.9
P- A-Grad (W/s)	23,255 ± 6,600	22,437 ± 7,549	0.77	-5.37	21.6
Combined					
TTPV (ms)	514 ± 185	532 ± 169	0.90	3.87	8.0
TTPP (ms)	473 ± 185	490 ± 168	0.91	4.0	8.5
RPD-MA (W/s)	27,863.8 ± 5,512.6	27,879 ± 5,397	0.91	0.29	8.6
IEP (W/s)	12,785 ± 3,773	12,048 ± 3,674	0.91	-5.87	11.6
P-RC (W/s/kg)	133 ± 45.1	126 ± 45.4	0.94	-5.67	11.8
P-S-Grad (W/s)	9,020 ± 3,043	8498 ± 3046	0.85	-6.29	13.8
P- A-Grad (W/s)	22,237 ± 4,903	22,438 ± 5,141	0.90	3.71	11.8

ICC = Intraclass Correlation Coefficient, CV = Coefficient of Variation, TE = Typical Error, TTPV = Time to Peak Velocity, TTPP = Time to Peak Power, RPD ï MA = Rate of Power Development Moving Average, IEP = Index of Explosive Power, P-RC = Power Reactivity Coefficient, P-S-Grad = Power Starting Gradient, P-A-Grad = Power Acceleration Gradient.

Table 5.4: Test re-test reliability values for three methods of measuring time limited (100 ms) power-time measures

	Mean Day 1	Mean Day 2	ICC	Change in mean (%)	TE as a CV (%)
Force Plate					
RPD-100 ms (W/s)	6,350 ± 4,851	6,093 ± 3,813	0.86	-0.18	40.4
CO RPD-100 ms (W/s)	12,910 ± 5,559	11,906 ± 5,895	0.87	-17.9	53.4
CO P-100 ms (W)	1,384 ± 555	1,252 ± 603	0.84	-8.22	21.7
Linear Position Transducer					
RPD-100 (W/s)	10,740 ± 6,199	10,400 ± 6,624	0.77	-5.98	45.5
CO RPD-100 (W/s)	23,520 ± 8,128	22,942 ± 7,964	0.93	-3.41	13.9
CO P-100 ms (W)	2,312 ± 795	2,236 ± 865	0.86	-6.28	25.2
Combined					
RPD-100 (W/s)	8,717 ± 5,635	8,354 ± 5,535	0.87	-7.35	44.0
CO RPD-100 (W/s)	20,827 ± 6,283	20,114 ± 6,900	0.90	-5.27	16.2
CO P-100 ms (W)	2,234 ± 633	2,129 ± 700	0.85	-6.4	17.9

ICC = Intraclass Correlation Coefficient, CV = Coefficient of Variation, TE = Typical Error, RPD = Rate of Power Development, CO = Concentric Only

Table 5.5: Pearsons correlation coefficient comparing power-time measures which achieved minimum reliability criteria between methods

	Force Plate - Linear Position Transducer	Force Plate - Combined	Combined - Linear Position Transducer
TTPV	0.92#	0.94#	0.95#
TTPP	0.92#	0.94#	0.95#
IEP	-	0.94#	-
P-RC	0.93#	0.96#	0.97#
P-A-Grad	-	0.75*	-
CO RPD-100 ms	-	-	0.99#

TTPV = Time to Peak Velocity, TTPP = Time to Peak Power, IEP = Index of Explosive Power, P-RC = Power Reactivity Coefficient, P-A-Grad = Power Acceleration Gradient, RPD = Rate of Power Development, CO = Concentric Only

*Very High Correlation, #Practically Perfect Correlation

5.5 DISCUSSION AND IMPLICATIONS

This study investigated three methods for assessing the external power flow generated during loaded jump squats, and the reliability of calculating power-time variables from this data. From the results it can be concluded that there are a number of power-time variables that can be reliably measured using the methods investigated in this study during a loaded rebound jump squat. However, many variables showed acceptable relative consistency only and thus their use in both clinical and research applications has some limitations.

Force plate measurement of PP had the greatest absolute consistency and the linear position transducer the least. Previous authors have suggested an inter-day CV of 10% as being acceptable absolute consistency for biomechanical variables (6, 36, 50, 109, 140, 186). Accordingly the calculation of PP using all three methods could be considered reliable in a test re-test situation. However, for the practitioner, interpreting changes in PP from linear position transducer data following a training intervention, the reported CV of 8.0% requires a substantial change in performance for one to be sure of a beneficial effect.

To further elucidate the benefit of a training intervention, the smallest worthwhile change which represents the smallest change which may be of benefit to athletic performance can be calculated for the measure (smallest worthwhile change = 0.2 x between subject standard deviation) (36, 66, 101, 161). Applied to the measure of PP the smallest worthwhile change with each method investigated in this study ranges between 2.5% (force plate) and 3% (linear position transducer). If the noise in the test (CV) is greater than the smallest worthwhile change, the training effect must be greater than the noise to conclude a beneficial training effect (101). Therefore in the case of the linear position transducer method, any change in PP less than 8.0% should be termed unclear (101). For the combined method and the force plate method with CVs of 4.8% and 4.6%, respectively a beneficial (or harmful) effect can be interpreted with a smaller shift in PP and thus an unclear performance change is less likely. Therefore, these technologies (force plate and combined) provide the practitioner or coach with a more accurate means of measurement of PP and should be the preferred methods of use.

The combined method and the force plate method proved to have the greatest relative consistency (ICC = 0.95 and 0.94, respectively) and the linear position transducer the least (ICC = 0.87). These ICC values were similar to those previously reported in the literature for jumping movements (3, 36, 107, 112). The greater reliability associated with the force plate and combined methods has been previously attributed to the double differentiation required to calculate power from position data which may magnify noise present in the original position signal, increasing error of measurement (38, 62). However, all three measurement methods had relative consistency that would be deemed acceptable for practical assessment applications where between subjects variation is being investigated such as talent identification or identifying key power qualities for a given athletic task.

Results showed significantly different PP values were generated from the force plate when compared to each of the other two methods of measurement. However, all methods had very high or practically perfect correlations between them (r = 0.81 ï 0.94) showing that the rank order of the population will be very similar regardless of method. The only method to provide a valid measurement of the rate of work (power) applied to the entire system is the force plate method (107). This is because it can not be assumed that the COM of the system and the bar to which the linear position transducer is attached move in parallel prior to take off during a jump squat (107). With the bar being positioned on the shoulders of the athlete, a relatively long way from the COM and at the end of an extending chain of rotating segments, the velocity of the bar may be exaggerated relative to the velocity of the COM. The resulting differences in force-time, velocity-time and power-time curves for each method are illustrated Figures 5.1, 5.2 and 5.3, respectively. In theory either technology could be used for power assessment in a practical situation, so long as data are not compared with that generated from other methods. However, although the use of the linear position transducer and combined methods are currently popular in practice, where possible, force plate data should be the preferred method as this is the only valid measure of the power applied to the COM of the system. The use of position data should be, where possible, restricted to the measurement of bar velocity.

To the authorsô knowledge the reliability of very few of the power-time variables investigated in this study have been previously reported. In terms of the variables adapted from Zatsiorsky and Kraemer (203), index of explosive power and power reactivity coefficient showed a high level of relative consistency (ICC = 0.89 ï 0.94) for all three measurement methods. Additionally, power acceleration gradient had ICCôs greater than 0.90 when measured with both the force plate and combined methods. The only remaining variables to show high relative consistency were time to PV and time to PP. Absolute consistency was highest with the time to PV and time to PP variables which were generally below 10%. The only other variable to show high absolute consistency was RPD calculated with a moving average for the combined method. Thus the practitioner has a number of possible temporal variables available for use in a practical setting. Yet for most of these variables a relatively large change in performance would be required in order for the practitioner or researcher to conclude a beneficial or harmful change following a training intervention. Therefore, again, in a clinical setting many of these parameters are best applied to applications where the individual is being assessed relative to a group or population.

Correlations for power-time variables between technologies showed that, in the measures where acceptable reliability was shared, there was good agreement between methods of measurement. Therefore, despite the aforementioned biomechanical differences between methods, those athletes who show good results with one method will typically perform well with the other methods. As with the measurement of PP, this suggests that the practitioner could in theory use either technology to collect data for the calculation of power-time values, so long as comparisons are not made between data generated from different methods.

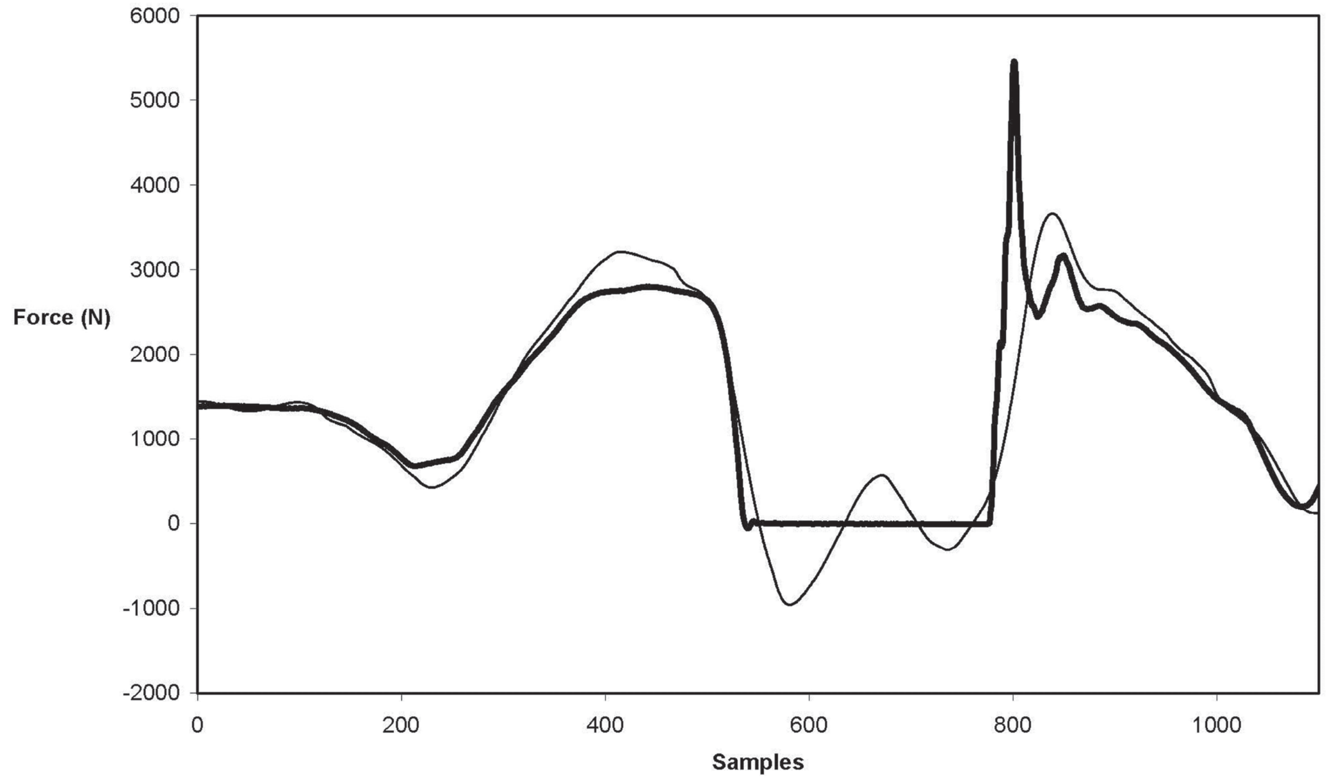

Figure 5.1: Sample force-time curve collected from the force plate (thick black line) overlayed with force-time curve estimated from linear position transducer data (thin line)

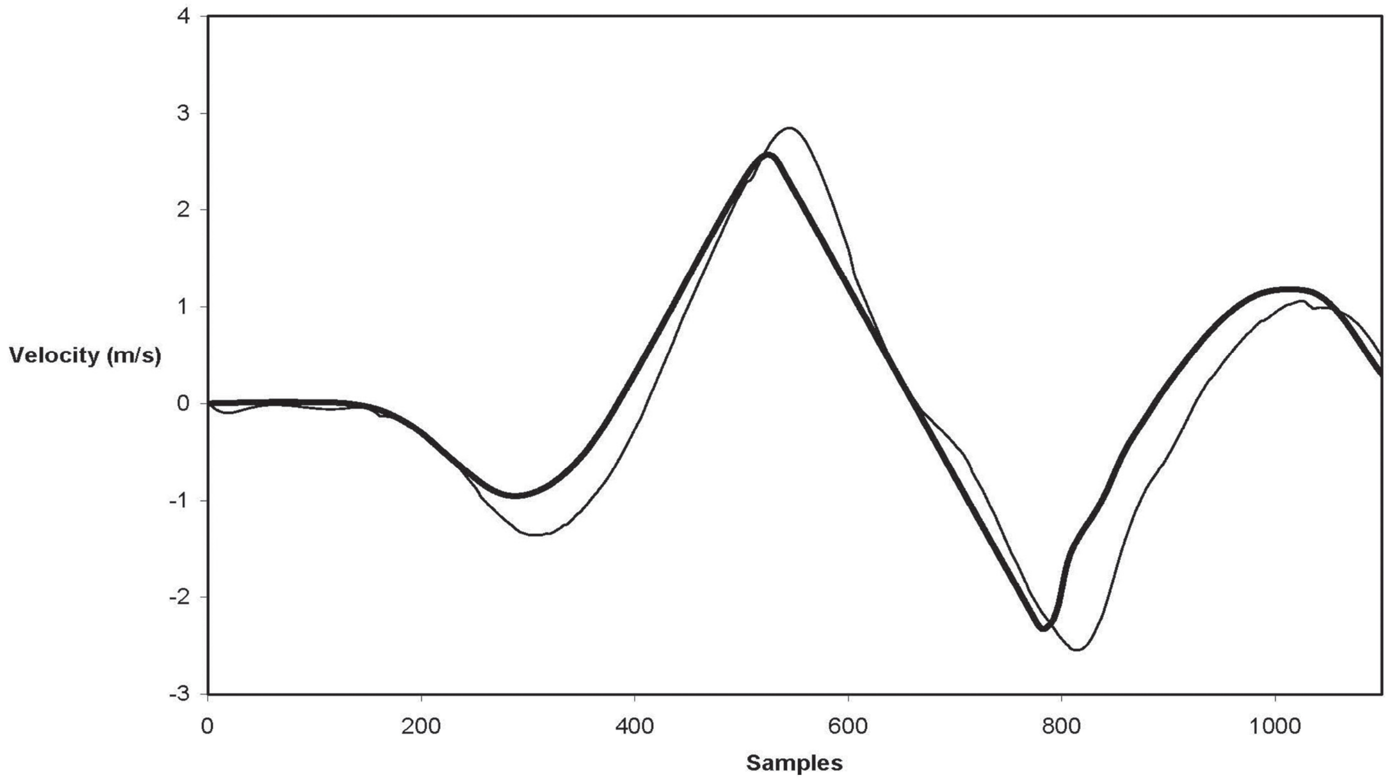

Figure 5.2: Sample velocity-time curve of the athletes centre of mass from integrated force plate data (thick black line) overlayed with velocity-time curve differentiated from linear position transducer data (thin line)

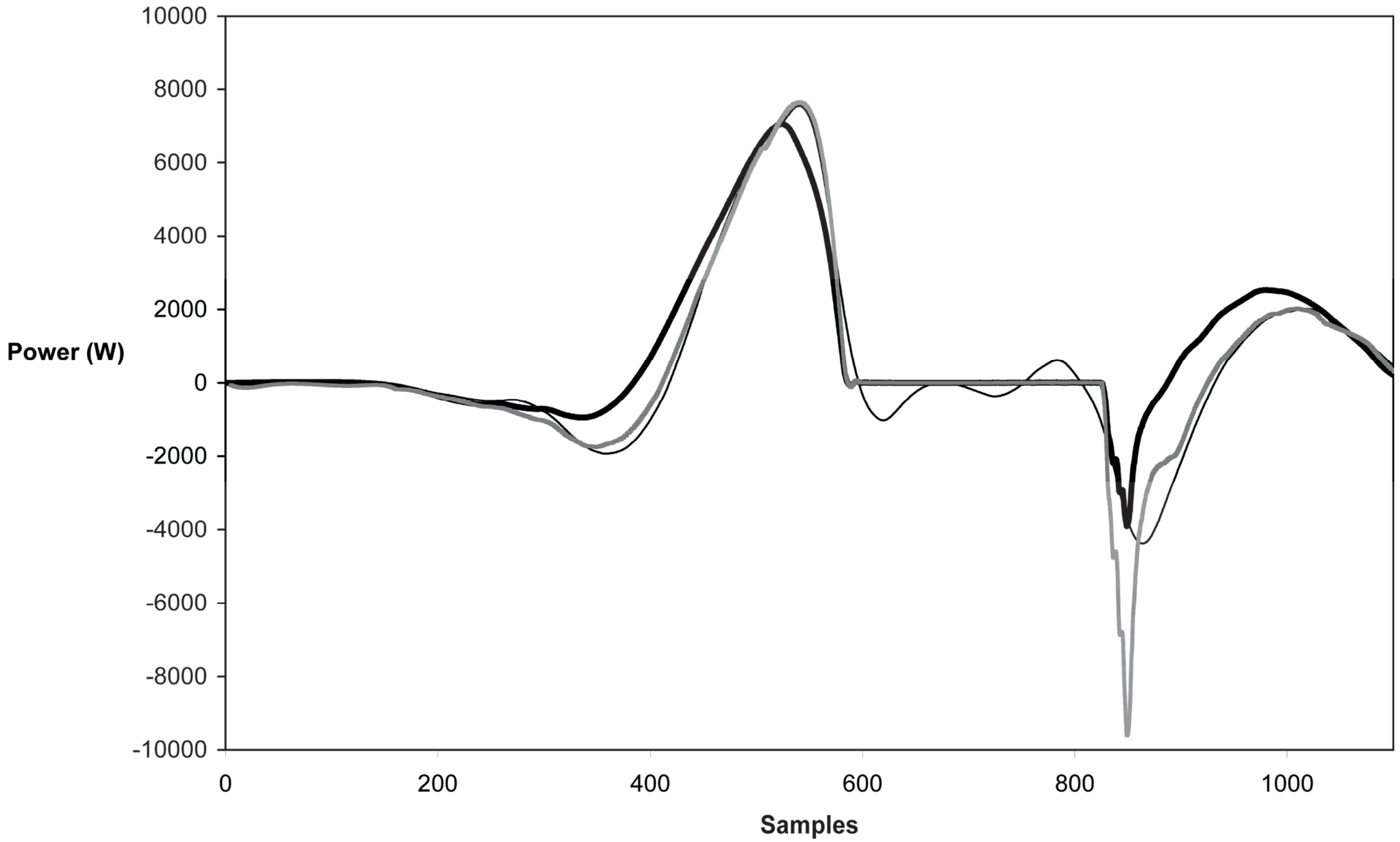

Figure 5.3: Sample power-time curves from (i) integrated force plate data (thick black line), (ii) differentiated linear position transducer data (thin line), and (iii) differentiated linear position transducer data combined with force plate data (shaded line)

5.6 CONCLUSIONS

A number of the measures investigated in this study have sufficient relative consistency for applications such as talent identification, identifying deficiencies in muscular function and quantifying the relevance of a given power quality to a particular sporting endeavour, where the rank order of the population is of interest. These measures include PP and PV (with all methods), plus time to PP and velocity, RPD calculated using a moving average, and a number of Zatsiorsky and Kraemersô force-time values applied to the power-time curve, with selected technologies. For monitoring individual performance in order to assess the effectiveness of training interventions the practitioner has fewer options. PP and PV with all measurement methods, time to PP and velocity with the force plate and combined methods, and RPD calculated with a moving average with the combined method, were the only variables to have absolute consistency which would make their use in this application viable. In general the force plate and combined methods were most stable and offer the greatest precision of measurement in practice. Finally, although the three methods of measuring PP and power-time variables investigated in this study are strongly correlated in this population, the practitioner needs to be mindful of the differences in the biomechanical basis of the three methods of collection and analysis of data. Accordingly, in a practical situation, although each methodology could be used, comparison between data calculated using the different methods should be avoided.

CHAPTER 6

DO FORCE-TIME AND POWER-TIME MEASURES IN A LOADED JUMP SQUAT DIFFERENTIATE BETWEEN SPEED PERFORMANCE AND PLAYING LEVEL IN ELITE AND ELITE JUNIOR RUGBY UNION PLAYERS?

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6.1 PRELUDE

The monitoring of strength and power is a part of most physical preparation programs for the population being investigated in this thesis, elite and elite junior rugby union players. In Chapters 4 and 5 a selection of force and power measures were investigated to ascertain their reliability. A number were found to have sufficient absolute and or relative consistency to be utilised in athletic assessment. In order to further understand the practical value of those measures found to be reliable, the relative importance of these measures to sports specific tasks and to athletic success needed to be ascertained. Therefore, this study investigated the relationship of the most reliable measures from Chapters 4 and 5 to sports specific performance and playing level in rugby union players.

6.2 INTRODUCTION

The preparation of athletes in collision sports such as rugby union, rugby league and American football traditionally involves a large strength and power training component. Effective prescription of resistance training programs for athletic performance in these sports therefore relies heavily upon accurate assessment of strength and power qualities. This assessment process has recently been termed strength diagnosis (153). The assessment of strength and power, or strength diagnosis, quantifies the importance of a given strength quality to an athletic activity, identifies deficiencies in muscular function, monitors training interventions and aids in the identification of individual talent in a given athletic endeavour (2).

Currently the most common method of assessment of closed chain, multi-joint lower limb strength and power uses iso-inertial dynamometry (107, 149, 150), although the use of both isometric (195) and iso-kinetic (197) dynamometry are also documented. In spite of the current popularity of iso-inertial dynamometry, the best measures for assessing force, velocity and power qualities of performance during iso-inertial lower body movements remain unclear. Measures commonly used include PF and MF (32, 50, 202), PV (107, 112) and PP and MP (15, 37, 38, 41, 107, 112, 175). Yet the validity of some of these measures has been a point of debate in the literature (55, 118). One shortcoming is that they do not consider the temporal aspects of force measurement such as RFD.

Temporal measures are thought to be important to muscular performance for a number of explosive activities. A number of temporal measures of force have been discussed in the literature yet their ability to differentiate performance levels and track training-induced changes has not been well documented. For example, Tidow (185) suggested that starting strength (force or impulse produced at 30 ms), explosive strength (steepest point on the force-time curve or maximum RFD), and force or impulse at 100ms were crucial to performance in explosive tasks. However, the rationale for the selection of these qualities is not clear. The selection of starting strength as a crucial strength quality seems to be arbitrary (185). Likewise many of the RFD measures discussed by Zatsiorsky and Kraemer (203) [index of explosive strength, reactivity coefficient, starting gradient, and acceleration gradient] have received limited attention in the literature when measured using iso-inertial dynamometry, and their application to strength and conditioning practice has not been discussed in the literature in any great depth. Finally RPD measures have received some limited research attention of late (39, 108), but their reliability and validity, and thus their application for the strength and conditioning professional requires further research.

Previous research has attempted to establish the discriminative ability of a number of tests of muscular function by differentiating between performance levels in a nominated functional task (13, 52, 61, 90, 106). For example, numerous studies have investigated the ability of force and power values during jumping movements to differentiate sprinting performance over a variety of distances (13, 52, 92, 106). Yet very few studies have addressed the relationship between temporal aspects of force and power and sprinting performance or addressed the ability of these temporal measures to differentiate between performance levels. Young and colleagues (202) investigated relationships between a number of force and force-time variables during jumps with and without a countermovement, and speed over 2.5 and 10 metres in male and female track and field athletes. They found that PF, MP and force at 100 ms all expressed relative to bodyweight (where the absolute force or power value is divided by the body weight of the athlete) were significantly correlated (r = -0.73 to -0.86) with 2.5 m speed (from a block start). Force at 100 ms and MP output (both relative to body weight) were also significantly correlated (r = - 0.80 and -0.79 respectively) with 10 m performance. Wilson and colleagues (195) also investigated relationships between sprint ability in athletes from a variety of team and individual sports, and temporal aspects of force production, in both concentric only and countermovement jumps, and isometric contractions. In this study the only variable to correlate significantly with sprint performance (30 m) was force at 30 ms in a concentric only jump squat (r = -0.616). Unfortunately, both these studies were conducted with relatively small subject populations (15-20 subjects), and the reliability of many of the measures discussed were either below what would be deemed acceptable or not stated. Additionally, neither study addressed RPD measures, which also warrant investigation.

The ability of tests of strength and power to discriminate between performance levels in specific sports has also interested strength and conditioning researchers (8, 10, 19, 174). For example, Baker (12) found that PP in a jump squat with an external load of 20 kg was significantly greater in professional rugby league players than other playing levels. Sheppard and co-workers (174) reported that PP and relative PP were significantly different between senior elite and elite junior volleyball players. However, there remains little information about the efficacy of iso-inertial force-time and power-time values in differentiating performance levels of athletes.

The best mode of muscular assessment in collision sports, such as rugby union, which require a combination of both speed and strength, is not well documented. The purpose of this study was to investigate the discriminative ability of force-time and power-time measures, specifically investigating their ability to differentiate speed performance and competition level in elite and elite junior rugby union players. This will help identify the force and power measures which are determinants of speed (as a key aspect of performance in many collision sports) and playing level, in this population. These measures are likely to be the most appropriate for assessment of force and power capabilities in collision sports as well as key foci in programming for performance enhancement.

6.3 METHODS

6.3.1 Experimental Approach to the Problem

Forty full-time rugby union players from a professional club performed three jump squats with an external load of 40 kg on a portable force plate and three maximal sprints over thirty metres. Force-time and power-time curves from the jump squats were analysed for a number of temporal variables and sprint times were recorded from a standing start over 5 m, 10 m and 30 m. Subsequently, the groupôs force-time and power-time variables were analysed in two ways to ascertain the ability of these variables to differentiate performance level in the group. Firstly, subjects were ranked from one to forty in speed performance for each of the three sprint distances investigated. An independent sample t-test was then used to investigate if there were significant differences between the fastest 20 and slowest 20 players over each distance in jump squat force-time and power-time variables. Secondly, the group was divided based on their playing levels using methods similar to those reported by Baker (19). This involved the players being classed as elite or elite junior based on their playing level. Those who played in the first team (Aviva Premiership squad) were categorised as elite, and those in the academy squad yet to play first team rugby were categorised as elite junior. An independent sample t-test was used to investigate if there were significant differences between the two playing levels in jump squat force-time and power-time performance and speed performance.

6.3.2 Subjects

Forty male elite and elite junior rugby union players, between 18 and 34 years of age, volunteered to participate in this study. Mean age, height and body mass for the elite group and the elite junior group together with pooled data for all subjects can be observed from Table 6.1. All elite subjects had a strength training background of greater than five years and thus are described as highly trained using the definitions of Rhea (164). All elite junior subjects had a strength training history of between two and five years and thus can be described as recreationally trained using the aforementioned definition system. Testing was conducted as part of the subjectsô pre-season strength and conditioning program. All subjects were informed of risks and benefits of participation in the research and signed informed consent forms. Procedures were approved by the institutional Human Research Ethics Committee.

Table 6.1: Mean (± SD) age, height and weight for elite, elite junior and all subjects

	Age (years)	Height (m)	Weight (kg)
Elite (n = 25)	26.2 ± 4.5	1.8 ± 0.1	99.7 ± 12.4
Elite Junior (n = 15)	19.3 ± 1.4	1.8 ± 0.1	93.8 ± 10.7
All Subjects (n = 40)	23.7 ± 5.0	1.8 ± 0.1	97.5 ± 12.0

6.3.3 Procedures

Subjects attended two testing sessions 48 hours apart. Both sessions were performed at the same time of day and were the first exercise bout of the day. No high exertion training was performed between sessions, but some low intensity rugby skills training was undertaken by all subjects.

6.3.3.1 Sprint Testing

On day one of testing subjects performed a standardised warm up consisting of sprint technique drills, dynamic stretching and sub-maximal sprints which lasted approximately 20 minutes. They then performed three maximal sprints over 30 m. Sprint times over 5 m, 10 m and 30 m were measured using electronic timing gates (Smart Speed, Fusion Sport, Queensland, Australia). These sprint distances were chosen as they are common in rugby union (64). The Smart Speed timing light system is a double beam modulated visible red-light system with polarising filters and consists of four sets of gates. Athletes started in a two point crouched position with the left toe 30 cm back from the starting line and the right toe approximately in line with the heel of the left foot. Sprints were visually assessed by a strength and conditioning coach to ensure subjects did not ñrock backò prior to the sprint start. In the case of a rock back being observed, the repetition was repeated. All sprints were performed on an indoor rubber based artificial training surface and all subjects wore rubber-soled track shoes. Approximately four minutes rest was allowed between sprints. The two best times for each distance were averaged and used for analysis.

6.3.3.2 Jump Squat Testing

In session two, following a standardised warm-up, each subject performed three single repetition jump squats with 20 seconds rest between repetitions at an external load of 40 kg using a methodology similar to that described by Hori and colleagues (107). This involved the subjects standing at a self-selected foot width with an Olympic bar placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately preformed a maximal jump. Subjects were instructed to keep the depth of countermovement consistent between jumps and ñjump for maximum heightò on each repetition. All subjects were familiar with the jump squat movement as they previously performed it as part of both training and testing programs. All jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA). Ground reaction force data were sampled at 500 Hz via an analogue to digital converter (16-Bit, 250 kS/s National Instruments, Austin, TX.) and collected by a laptop computer using custom built data acquisition and analysis software (Labview 8.2, National Instruments, Austin, TX.).

6.3.3.3 Force-time Analysis

From the resultant vertical ground reaction force data, PF and time to PF were determined. Subsequently a number of force-time variables were calculated with analysis commencing at the lowest point on the force-time curve encompassing the latter portion of the eccentric phase and the concentric phase of the movement (32). PF and time to PF were used to calculate the reactivity coefficient using the formulae of Zatsiorsky and Kraemer (203) (PF / (time to PF x Body Mass)). A moving average was also used to find the greatest RFD within a 50 ms interval. This moving average RFD was conducted over a window length of 50 ms from the start point of analysis until attainment of PF.

Impulse was calculated over 30 ms, 100 ms and 200 ms time intervals and absolute force at 30 ms, 100 ms and 200 ms from the lowest point on the force curve (eccentric-concentric - EC). Additionally, impulse and absolute force variables for the concentric phase were also calculated. The concentric phase was defined as starting at the lowest point on the displacement-time curve (32). Both impulse and absolute force were calculated over 30 ms and 100 ms from the start of the concentric phase. All force variables were expressed as absolute values and relative to body weight as both approaches have been used previously in the literature (195, 202). All force-time variables had either an ICC of greater than 0.85 and/or a CV of less than 10%.

6.3.3.4 Power-time Analysis

Power-time data were calculated from ground reaction force data using the impulse-momentum (forwards dynamics) approach to calculate the system power as outlined previously in the literature (38, 62). As the initial velocity of the system was zero, at each time point throughout the jump, vertical ground reaction force was divided by the mass of the system to calculate acceleration of the system. Acceleration due to gravity was then subtracted so that only the acceleration generated by the subject was multiplied by time data to calculate instantaneous velocity of the systems centre of mass. The resultant velocity data were then multiplied by the original ground reaction force data to calculate power.

From the integrated power and velocity data PP, PV, time to PP and time to PV were determined. Additionally, two RPD measures were calculated. The calculations were initiated at minimum power encompassing the latter portion of the eccentric phase and the concentric phase of the jump. The first variable calculated was RPD using a moving average, which was calculated over a window length of 50 ms from the start point of analysis until PP. The second variable was the reactivity coefficient described by Zatsiorsky and Kraemer (203) for the force-time curve, applied to the power-time curve (power reactivity coefficient = PP / (time to PP x body mass)). As with the force-time variables, all power variables were expressed as absolute values and relative to body weight as both approaches have been used previously in the literature (106). All power-time variables had either an ICC of greater than 0.85 and/or a CV of less than 10%.

6.3.4 Statistical Analyses

All statistical analyses for force and power variables were performed on the mean of trials two and three with the first trial excluded from analysis (104). Statistical analyses of speed times were performed on the mean of the two fastest trials. Means and standard deviations were used as measures of centrality and spread of data. The data obtained were analysed using SPSS statistical software (SPSS 15, Chicago, Ill.). In the first instance, all subjects were ranked from one to 40 based on the average of their two best sprint times for each distance. An independent sample t-test was then used to ascertain significant differences between groups for force and power variables of interest at each distance. Additionally, independent sample t-tests were conducted between the elite group (n = 25) and the elite junior group (n = 15), also to ascertain whether these groups differed significantly in the force and power variables of interest. An alpha level of 0.05 was used for all statistical comparisons.

6.4 RESULTS

Mean sprint times over the three distances (5 m, 10 m, and 30 m) for the fast and slow groups can be observed from Table 6.2. The difference between the two groups was significant at all distances (8.2%, 8.2% and 8.0% for 5 m, 10 m and 30 m respectively). Mean values for force variables for the fast and slow groups over each distance can be observed from Table 6.3. The only force-time variable to show a significant difference between the fast and slow groups was eccentric-concentric impulse at 200 ms where the fast group at 10 m was significantly lower (9.1%) than the slow group at 10 m. Mean values for power variables for the fast and slow groups can be observed from Table 6.4. Relative PP was significantly greater in the 10 m fast group and the 30 m fast group (10.8% and 13.9%, respectively). Additionally PV and relative moving average RPD were significantly greater (7.4% and 24.4%, respectively) in the 30 m fast group.

Table 6.2: Mean (±SD) sprint times for fastest and slowest subjects over 5 m, 10 m and 30 m.

	Fastest 20 (Mean ± SD)	**Slowest 20 (Mean ± SD)**	**p-value**
5 m (s)	1.10 ± 0.03	1.19 ± 0.05	0.00
10 m (s)	1.83 ± 0.05	1.98 ± 0.07	0.00
30 m (s)	4.23 ± 0.02	4.57 ± 0.04	0.00

Table 6.3: Mean (±SD) force variables and p-values for fastest 20 and slowest 20 players over 5 m, 10 m and 30 m.

	5 m			10 m			30 m		
	5 m Fast (Mean ± SD)	**5m Slow (Mean ± SD)**	**p-value**	**10m Fast (Mean ± SD)**	**10m Slow (Mean ± SD)**	**p-value**	**30m Fast (Mean ± SD)**	**30m Slow (Mean ± SD)**	**p-value**
PF (N)	2,533 ± 224	2,665 ± 224	0.07	2,551.7 ± 225.5	2,647 ± 232.0	0.20	2,580 ± 207	2,627 ± 266	0.55
PF / BW (N.kg)	27.6 ± 2.6	26.2 ± 2.6	0.61	27.7 ± 2.52	26.1 ± 28.5	0.50	28.3 ± 2.1	25.9 ± 2.25	0.21
EC TTPF (ms)	660 ± 245	651 ± 233	0.91	669 ± 243	642 ± 235	0.72	618 ± 253	670 ± 219	0.50
CO TTPF (ms)	329 ± 162	321 ± 168	0.87	336 ± 156	314 ± 174	0.67	296 ± 166	342 ± 167	0.40
EC RFD-MA (N.s)	9,137 ± 5,118	9,210 ± 4,244	0.94	9,335 ± 5,042	8,833 ± 4,319	0.74	9,956 ± 5,396	8,641 ± 3,831	0.39
Rel EC RFD-MA (N.s.kg)	106 ± 56.9	83.9 ± 41.4	0.28	101 ± 55	88.4 ± 45.8	0.59	109.5 ± 59.4	85.3 ± 36.7	0.23
EC RC (N.s.kg)	23.7 ± 11.1	23.6 ± 12.4	0.99	24 ± 11	23.6 ± 12.2	0.49	27.1 ± 12.1	21.6 ± 10.4	0.15
EC-FA30 ms (N)	702.7 ± 204	745 ± 284	0.60	692 ± 196	755 ± 287	0.42	683 ± 222	727 ± 251	0.57
Rel EC-FA30 ms (N.kg)	7.3 ± 2.4	7.6 ± 2.4	0.50	7.6 ± 2.4	7.3 ± 2.4	0.90	7.5 ± 2.5	7.1 ± 2.2	0.81
EC-FA100 ms (N)	1,037 ± 205	1,094 ± 186	0.45	1,020 ± 204	1,110 ± 180	0.15	1,040 ± 235	1,077 ± 157	0.58
Rel EC-FA100 ms (N.kg)	11.2 ± 2.3	10.8 ± 1.6	0.52	11.1 ± 10.9	10.9 ± 1.4	0.62	11.4 ± 2.5	10.6 ± 1.4	0.20
EC-FA200 ms (N)	1,581 ± 365	1,715 ± 344	0.24	1,575 ± 361	1722 ± 345	0.20	1,624 ± 395	1,689 ± 337	0.59
Rel EC-FA200 ms (N.kg)	17.7 ± 4.4	16.4 ± 3.7	0.37	17.1 ± 4.2	17.0 ± 3.9	0.99	17.9 ± 4.7	16.7 ± 3.3	0.42
CO-FA30 ms (N)	1,975 ± 330	2,150 ± 340	0.11	2,007 ± 357	2,118 ± 326	0.31	2,039 ± 341	2,110 ± 354	0.54
Rel CO-FA30 ms (N.kg)	22.2 ± 4.0	20.6 ± 4.2	0.23	21.8 ± 4.0	21.0 ± 4.3	0.57	22.5 ± 4.4	20.9 ± 3.5	0.21
CO-FA100 ms (N)	2,120 ± 356	2,303 ± 340	0.11	2,157 ± 379	2,265 ± 332	0.34	2,185 ± 364	2,260 ± 364	0.53
Rel CO-FA100 ms (N.kg)	23.8 ± 4.1	22.2 ± 4.8	0.26	23.4 ± 4.5	22.5 ± 4.53	0.52	24.1 ± 4.7	22.4 ± 4.0	0.25
EC-I30 ms (Ns)	20.9 ± 7.1	21.9 ± 9.6	0.70	20.5 ± 9.7	22.2 ± 9.7	0.52	20.2 ± 7.7	21.3 ± 8.6	0.66
EC-I100 ms (Ns)	81.2 ± 14.2	85.9 ± 23.9	0.45	80.0 ± 13.5	87.2 ± 24.0	0.25	79.8 ± 16.0	84.2 ± 21.0	0.47
EC-I200 ms (Ns)	215 ± 29.1	228 ± 28.9	0.14	212 ± 28.2	231 ± 28.2	0.04*	215 ± 31.3	225 ± 27.5	0.31
CO-I30 ms (N)	61.1 ± 9.9	66.6 ± 10.6	0.10	62.1 ± 10.9	65.7 ± 10.1	0.28	63.0 ± 10.2	65.4 ± 11.1	0.49
CO-I100 ms (N)	205 ± 33.8	223 ± 34.1	0.10	209 ± 36.5	220 ± 32.8	0.32	212 ± 34.7	219 ± 35.8	0.52

Rel = Relative to body weight, EC = Eccentric-Concentric, CO = Concentric Only, PF = Peak Force, TTPF = Time to Peak Force, RFD-MA= Rate of Force Development calculated with a moving average, RC = Reactivity Coefficient, FA = Force at, I = Impulse

*Difference between groups statistically significant $p < 0.05$

Table 6.4: Mean (±SD) power and velocity variables and p-values for top 20 and bottom 20 players over 5 m, 10 m and 30 m.

	5 m			**10 m**			**30 m**		
	Fastest (Mean ± SD)	**Slowest (Mean ± SD)**	**p-value**	**Fastest (Mean ± SD)**	**Slowest (Mean ± SD)**	**p-value**	**Fastest (Mean ± SD)**	**Slowest (Mean ± SD)**	**p-value**
PP (W)	4,015 ± 579	4,089 ± 629	0.70	4,096 ± 589	4,008 ± 618	0.65	4,184 ± 494	3,992 ±	0.32
Rel PP (W.kg)	43.9 ± 40.2	40.2 ± 7.5	0.11	44.4 ± 6.3	39.6 ± 7.23	0.03*	45.9 ± 4.8	39.5 ± 7.0	0.00*
PV (m/s)	1.70 ± 0.16	1.66 ± 0.19	0.43	1.72 ± 0.16	1.64 ± 0.19	0.15	1.76 ± 0.11	1.63 ± 0.19	0.02*
EC TTPP (ms)	545 ± 197	533 ± 190	0.86	542 ± 202	536 ± 184	0.94	512 ± 198	548 ± 185	0.56
EC TTPV (ms)	574 ± 196	564 ± 188	0.87	572 ± 201	567 ± 182	0.93	542 ± 196	579 ± 184	0.56
EC RPD-MA (W.s)	17,900 ± 5,380	17,597 ± 5117	0.86	18,326 ± 5,389	17,170 ± 5,043	0.50	19,600 ± 4,466	16,555 ± 5,365	0.07
Rel EC RPD-MA (W.s.kg)	201 ± 66.5	171 ± 59.3	0.14	200 ± 65.4	172 ± 60.9	0.17	217 ± 57.7	164 ± 56.9	0.01*
EC RC (W.s.kg)	91.9 ± 40.3	90.2 ± 41.4	0.89	95.5 ± 43.3	86.6 ± 37.7	0.49	103 ± 41.3	84.1 ± 37.0	0.15

Rel = Relative to body weight, EC = Eccentric-Concentric, PP = Peak Power, PV = Peak Velocity, TTPP =Time to Peak Power, TTPV = Time to Peak Velocity, RPD-MA = Rate of Power Development calculated with a moving average, RC = Reactivity Coefficient

*Difference between groups statistically significant $p < 0.05$

Mean sprint times over the three distances (5 m, 10 m, and 30 m) for the elite and elite junior groups can be observed from Table 6.5. There were no significant differences between the two groups at any of the three distances. Mean values for force variables for the elite and elite junior groups can be observed from Table 6.6. In terms of absolute values, PF, moving average RFD, eccentric-concentric force at 100 ms and eccentric-concentric force at 200 ms were all significantly greater (% difference = 10.3% to 37.4%) in the elite group compared to the elite junior group. In terms of relative values, moving average RFD, eccentric-concentric force at 30 ms and eccentric-concentric force at 200 ms were all significantly different between the two groups. Relative moving average RFD and force at 200 ms were significantly greater in the elite group (34.5% and 19.0%, respectively) compared to the elite junior group. Conversely, relative eccentric-concentric force at 30 ms was significantly greater (25.0%) in the elite junior group. Mean values for the power variables for the elite and elite junior groups can be observed from Table 6.7. PP and moving average RPD were significantly greater (12.6% and 21.2%, respectively) in the elite group when compared to the elite junior group.

Table 6.5: Mean (±SD) sprint times for elite and elite junior subjects over 5 m, 10 m and 30 m.

	Elite (Mean ± SD)	**Elite Junior (Mean ± SD)**	**p-value**
5 m (s)	1.15 ± 0.07	1.12 ± 0.04	0.19
10 m (s)	1.91 ± 0.10	1.87 ± 0.08	0.15
30 m (s)	4.40 ± 0.25	4.39 ± 0.16	0.91

Table 6.6: Mean (±SD) force variables and p-values for elite vs. elite junior players.

	Elite	**Elite Junior**	**p-value**
PF (N.kg)	2704 ± 196	2425 ± 176	0.00*
Rel PF (N.kg)	27.4 ± 2.7	26.0 ± 2.3	0.12
EC TTPF (ms)	617 ± 216	720± 261	0.19
EC RFD-MA (N.s)	10,567 ± 5,199	6,612 ± 1,783	0.01*
Rel EC RFD-MA (N.s.kg)	109 ± 57.6	71.3 ± 20.4	0.02*
EC RC (N.s.kg)	26.1 ± 12.4	19.6 ± 9.2	0.08
EC-FA30 ms (N)	683 ± 269	792 ± 187	0.17
Rel EC-FA30 ms (N.kg)	6.8 ± 2.4	8.5 ± 1.8	0.03*
EC-FA100 ms (N)	1,117 ± 216	979± 116	0.03*
Rel EC-FA100 ms (N.kg)	11.3 ± 2.3	10.5 ± 1.1	0.22
EC-FA200 ms (N)	1,806 ± 339	1,385 ± 196	0.00*
Rel EC-FA200 ms (N.kg)	18.4 ± 4.3	14.9 ± 2.2	0.01*
CO-FA30 ms (N)	2,124 ± 336	1,961 ± 339	0.15
Rel CO-FA30 ms (N.kg)	21.6 ± 4.3	21.1 ± 3.8	0.69
CO-FA100 ms (N)	2254 ± 354	2, 139 ± 369	0.33
Rel CO-FA100 ms (N.kg)	23.0 ± 4.6	23.0 ± 4.4	0.97
EC-I30 ms (Ns)	19.8 ± 9.1	24.0 ± 6.3	0.12
EC-I100 ms (Ns)	82.2 ± 21.4	85.8 ± 16.4	0.58
EC-I200 ms (Ns)	231 ± 29.4	205 ± 21.7	0.01*
CO-I30 ms (Ns)	66.0 ± 10.3	60.2 ± 10.2	0.09
CO-I100 ms (Ns)	220 ± 34.7	205 ± 34.7	0.19

Rel = Relative to body weight, EC = Eccentric-Concentric, CO = Concentric Only, PF = Peak Force, TTPF = Time to Peak Force, RFD-MA= Rate of Force Development calculated with a moving average, RC = Reactivity Coefficient, FA = Force at, I = Impulse

*Difference between groups statistically significant $p < 0.05$

Table 6.7: Mean (±SD) power and velocity variables and p-values for elite vs elite junior subjects

	Elite	Elite Junior	p-value
PP (W)	4,254 ± 549	3716 ± 534	0.00*
Rel PP (W.kg)	43.2 ± 7.3	40.0 ± 6.6	0.17
PV (m/s)	1.7 ± 0.2	1.6 ± 0.2	0.14
EC TTPP (ms)	510 ± 176	587 ± 210	0.23
EC TTPV (ms)	541 ± 174	616 ± 209	0.22
EC RPD-MA (W.s)	19,283 ± 5,212	15,190 ± 4135	0.01*
Rel EC RPD-MA (W.s.kg)	109 ± 57.6	71.3 ± 20.4	0.11
EC RC (W.s.kg)	199 ± 67.8	165 ± 52.6	0.12

Rel = Relative to body weight, EC = Eccentric-Concentric, PP = Peak Power, PV = Peak Velocity, TTPP =Time to Peak Power, TTPV = Time to Peak Velocity, RPD-MA = Rate of Power Development calculated with a moving average, RC = Reactivity Coefficient

*Difference between groups statistically significant $p < 0.05$

6.5 DISCUSSION

This study aimed to establish the discriminative ability of force and power values calculated from the force-time and power-time curve of a loaded rebound jump squat. Specifically we investigated two qualities; the ability of these values to differentiate between the fastest and slowest sprinters in the population of elite rugby union players, and, secondly, the differences in force-time and power-time parameters between elite and elite junior players. Both absolute and relative force values and absolute power values differentiated playing levels, whereas only power values expressed relative to body weight were able to differentiate speed performance. These are novel findings which have not been published previously with these measures in this population.

Our results do not suggest that any force variables expressed as a relative or absolute value are able to differentiate speed performance over any of the distances investigated. These findings are similar to other studies which have shown that force variables in a rebound jump squat are not strongly related to speed performance over 30 metres in team sport athletes (92, 195). The only force variable to be significantly different between the fastest and slowest group in the current study was impulse at 200 ms, which was significantly greater in the slow group. Although not statistically significant, a number of force variables were greater in the slow group. These results are likely to be a reflection of the weight of the players in the two groups with heavier players typically being slower, but due to their greater mass being able to generate greater absolute force values. A clear strong correlation (r = 0.64) has previously been reported between 30 m and 40 m sprint times and body weight in a population of professional rugby union and rugby league players (92) with faster players typically weighing less. This finding may be a reflection of the body composition of larger players who may carry greater fat mass, although this was not quantified in the study of Harris and colleagues (92) or in the current study.

The fact that RFD values, even when expressed relative to body weight, were not significantly greater in fast athletes when compared to slow athletes over all sprint distances contradict the suggestions of Tidow (185) who postulated that these physical qualities are crucial to athletic performance. This may be related to the biomechanical differences between the jump squat and sprinting, particularly in the acceleration phase of the sprint. The literature suggests that a good sprinter is capable of directing ground reaction forces as horizontally as possible (144) in the acceleration phase of the sprint, whereas a rebound jump squat requires that the athlete direct ground reaction forces vertically. Thus where sprinting is dependent on horizontal impulse, jumping patterns are dependant on vertical impulses.

Peak power and moving average RPD when expressed relative to body weight and PV were all significantly greater in faster athletes when compared to slower athletes over 30 m. Additionally, PP relative to body weight was significantly greater over 10 m in the fast group. These findings are consistent with previous studies which have reported significant relationships between PP relative to body weight in loaded jump squats and speed performance over similar distances in team sport athletes (13, 52, 106). The finding that the difference in these variables was greatest at 30 m may again be due to the movements being functionally more similar over the longer distance (10 m -30 m). That is, as the sprint progresses the vertical braking forces during the stance phase increase (144), and thus the contribution of the SSC to sprint performance increases (111). Therefore, common between sprinting (after the initial steps) and a rebound jump squat is the ability of the athlete to utilise the SSC. The most notable difference between the two movements (sprinting and jumping) being that sprinting requires that the resultant force and power must be directed horizontally and jumping requires that they must be directed vertically. These findings have implications for the strength and conditioning professional in that relative power, RPD and velocity may be better used to identify talent and monitor training in explosive sports. This also suggests that in sports where running speed is of importance resistance training should be focused on generating PV and, PP and RPD relative to body mass in training rather than high absolute forces which has been the traditional approach in resistance training for explosive sports.

Moving average RPD was the only temporal variable able to differentiate fast athletes from slow over any distance. This variable is calculated by conducting a moving average over the power-time curve, and thus represents the peak RPD over this time period (50 ms). The fact that faster sprinters generated greater values in moving average RPD suggests that unlike force development the ability to generate power rapidly or ñexplosivelyò during jumping is functionally similar to the ability to generate power and velocity explosively when sprinting. However, it is noteworthy that although moving average RPD was able to differentiate speed performance over 30 m, PP and PV also differentiated speed performance at this distance. Therefore, for the practitioner using the jump squat to assess lower body muscular function, the use of PP and PV which are simpler to calculate and have greater reliability may be sufficient and the calculation of a moving average RPD may not be necessary. Nonetheless, the application of this measure to strength and conditioning practice warrants further investigation.

Our results showed no significant difference between elite and elite junior rugby union players in terms of speed performance over 5 m, 10 m and 30 m. Previous research by Baker and Newton (19) reported similar findings in a population of professional rugby league players. Since they are collision sports, it could be argued that momentum is crucial to performance in both rugby union and rugby league and thus the ability to generate momentum rather than speed will differentiate performance level. Baker and Newton in the aforementioned research reported sprint momentum, calculated by multiplying body mass by the average sprint velocity over 10 m. In this quality there was a significant difference between national level athletes and state level athletes. In the current study the elite group was heavier (99.7 ± 12.4 kg) than the elite junior group (93.8 ± 10.7 kg) and thus it is likely that their ability to generate momentum would be greater.

There were however significant differences between elite and elite junior players in force and power capabilities. Absolute PF plus a number of temporal force variables were found to be significantly greater in elite players. Additionally, absolute PP and moving average RPD were significantly greater in the elite group with no significant difference found in relative values. With regards to PP, these findings are consistent with a number of previous studies, which have reported that lower body PP is significantly greater in elite compared to elite junior athletes (12, 19, 174). Although a number of force-time values and moving average RPD were significantly different between groups, given that PF and PP were also able to differentiate groups, it may be that as with speed performance, the use of these traditional variables is sufficient in strength and power assessment in rugby union and other similar sports. Temporal analysis of the force-time and power-time curves may not be necessary.

Whereas with speed performance only relative values differentiated faster times, absolute values differentiated between elite and elite junior rugby players. This is likely to be due principally to the greater mass of the elite group when compared to the elite junior group. The current study did not directly quantify lean mass and fat mass in the various groups compared. Nonetheless, it may be surmised that the greater body weight of the elite group compared to the elite junior group was due to greater lean mass, leading to the greater absolute values in the aforementioned measures through an increased ability to generate force. Future research would benefit from quantifying lean mass and fat mass and comparing between groups. From a practical perspective it can be concluded that, whereas resistance training for an athlete training for speed should be focused on developing power relative to body mass, a developing rugby union player may be best served to focus on increasing absolute force and power capabilities through increasing lean mass and maximum force production (without compromising speed performance).

It should be noted that caution is necessary when interpreting these results. In comparing strength and power characteristics between Olympic lifters, power lifters and sprinters, McBride and colleagues (133) reported that strength and power profiles reflected the training approaches of each group. This being the case, the fact that absolute force and power values were greater in elite rugby players may simply reflect the high training age of these players and the strong influence of high resistance training utilised in rugby union in recent years to increase lean mass and strength in players. Should training focus in this population shift to a greater emphasis on velocity and relative power in athletic development, the physical attributes differentiating elite from elite junior players may also change.

6.6 PRACTICAL APPLICATIONS

One purpose of strength and conditioning assessment is to determine those predictor variables that are fundamental to performance in sport-specific tasks, such as the sprint ability of rugby union players. For the purposes of guiding resistance training prescription and assessing athletic development it is important for coaches to identify the force and power variables crucial to performance. In the cohort of rugby union players investigated in this study, peak velocity and PP and RPD relative to body weight, differentiated fast from slow players. These variables therefore can be used by the strength and conditioning coach to guide programming and track training adaptation during resistance training for speed development. Resistance training programs for speed development should be designed to focus on the velocity of movement in training. The mass of the player is also a critical consideration given the predictor variables were expressed relative to body weight. Decreasing fat mass will increase the power to weight ratio. Accordingly the coach needs to consider the ideal anthropometry of the player related to their positional requirements.

Another focus of strength and conditioning assessment is to determine the variables that distinguish elite from sub-elite athletes. This is particularly important in talent identification and serves to focus training prescription around variables that are thought critical to ñeliteò performance. For the rugby union players used in this study, a number of force and power variables differed significantly between playing levels. These included PF, PP, force at 100 ms from minimum force and force and impulse at 200 ms from minimum force. The additional 6 kg body mass of the elite players no doubt affected the magnitude of many of these variables and the significant differences between groups. When testing and training rugby union players it would seem most appropriate therefore for the coach to target absolute force and power measures. For the purposes of player development and training strategies for rugby union players to transition to elite status, adding lean mass is likely to be most beneficial. However, given the metabolic demands of rugby union it is likely that this strategy of increasing lean mass is only appropriate to a certain point which is likely to be position specific. The practitioner must also be cognizant that the variables which differentiate performance level and sprint ability in rugby union players may vary if different jump squat loads are utilized in assessment procedures.

CHAPTER 7

ACUTE EFFECTS OF CLUSTER LOADING ON FORCE, VELOCITY AND POWER DURING BALLISTIC JUMP SQUAT SESSIONS

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7.1 PRELUDE

Following the identification of key force and power measures indicative of athletic success, it is important to identify training interventions, which are able to positively change these measures. As there are a wide variety of resistance training interventions which are utilised in resistance training prescription to enhance these athletic qualities understanding the application of each intervention is crucial. In Chapter 6, it was found that measures such as peak power and velocity and RPD expressed relative to body weight can differentiate speed performance in elite and elite junior rugby union players, and that absolute measures such as PF and PP were able to differentiate between performance levels in this population. One resistance training intervention which has been suggested as being well suited to the development of such qualities is cluster loading. As acute mechanical responses to resistance training interventions are thought to be crucial to subsequent strength and power adaptation, in the first instance it is important to identify how an intervention such as cluster loading affects the mechanics of a training bout. This chapter addresses this question, investigating cluster loading during ballistic jump squat training in elite and elite junior rugby union players.

7.2 INTRODUCTION

Program variation during resistance training can be achieved by manipulating one or more of a number of acute program variables which contribute to the volume and intensity of a resistance training session and dictate acute mechanical and metabolic responses to training (70). These variables include sets, repetitions, load, exercise selection and rest periods. One alternative training configuration to traditional resistance training for the practitioner is termed cluster or inter-rep rest training. This training structure involves the manipulation of work and rest periods, breaking sets into small clusters of repetitions, which may alter the training stimulus associated with a given resistance training session. It has been suggested as being a means of providing training variation, which may be well suited to the development of muscular power (81, 127, 128).

Mechanical and metabolic stimuli both play a role in the development of strength and power. Although the importance of actual muscular fatigue and associated accumulation of metabolites in strength adaptation is unclear (71, 167), it is possible the acute build up of metabolites during resistance training is a precursor to endocrine (122, 182) and neural (181, 182) responses to training. There is also evidence that mechanical stimuli such as total forces (84, 136) and total mechanical work (123, 170) are important in strength development. These mechanical and metabolic stimuli may also be of importance for high velocity ballistic training for developing muscular power (42, 48). However, it is also possible that the velocity and power generated during ballistic power training are the more important mechanical stimuli for adaptation (85, 86, 113, 196). Indeed, researchers have suggested that ballistic training programs are able to achieve comparable or superior training outcomes in terms of power development in short term training periods with less total work than high load training schemes (134, 196). For example, the research of McBride and colleagues (134) showed improved power and velocity adaptation following a training program using ballistic jump squats at 30% of 1RM compared to 80% of 1RM even though the total work performed over the training period was significantly greater in the 80% load group. This research also ensured minimal fatigue during training by terminating training sets if a 15% drop in power output was observed.

Additionally, there is some evidence that adaptation to ballistic performance may be principally mediated by neural mechanisms, with intramuscular (86, 134) and intermuscular (158) neural adaptations contributing to performance improvements following high velocity training. It is by way of these mechanisms that cluster loading may be advantageous during training. Cluster loading configurations break sets into small ñclustersò or groups of repetitions in an attempt to improve the force, velocity and power profile of the training bout. In a recent discussion of cluster training structures the authors postulated that this in turn may lead to improved training outcomes, particularly in the training of ballistic performance (81). The short rest periods between clusters may provide enhanced metabolic recovery between sets, leading to an improved kinematic and kinetic profile in the latter repetitions of the set compared to traditional loading paradigms. If neural adaptations are important determinants of ballistic performance, it is possible that cluster loading may allow improved quality of movement during ballistic movements potentially enhancing training outcomes.

As with many resistance training configurations, however, there is limited information available regarding the kinematic and kinetic profiles of cluster training. Research has compared cluster loading patterns to traditional loading schemes during both the clean pull (83) and the bench press (59, 127, 128). Haff and co-workers (83) reported that PV during cluster loading (15-30 seconds rest between repetitions) was significantly greater than that achieved during traditional continuous loading. This research also showed traditional and cluster loading possessed different fatigue-related patterns during the sets of five repetitions, with the traditional loading technique resulting in significantly greater decreases in velocity for repetitions three, four and five. Similar findings have been reported in upper body movements. Lawton and colleagues (128) reported significantly greater repetition power outputs during the bench press using cluster loading schemes at a 6RM load compared to a traditional continuous loading scheme. Thus it seems that there is evidence that cluster loading may affect the mechanical profile of the training set. However, at this stage the information is limited to specific movement patterns and loads.

Further investigation is required to establish the effects of cluster loading on the kinetics and kinematics of resistance training interventions for the development of explosive power. Therefore, the purpose of this study was to investigate the effect of cluster loading (repetition work: rest ratios) on force, velocity and power during jump squat training. These findings should provide information regarding the acute effect of cluster loading on the kinematics and kinetics of this movement pattern, which is commonly used for the development of lower limb power in athletes.

7.3 METHODS

7.3.1 Subjects

Twenty male, elite and elite junior rugby union players volunteered to participate in this study. Subject age, height and weight were 19.7 ± 1.9 yrs, 1.83 ± 0.1 m and 93.9 ± 0.1 kg, respectively. All subjects were informed of the risks and benefits of participation in the research, that they could withdraw at any time, and signed informed consent forms. Edith Cowan Universityꞌs Human Research Ethics committee approved all procedures.

7.3.2 Design

In order to investigate the effect of set structure on kinematics and kinetics, a cross over design was utilised whereby 20 subjects performed four training sessions within a two week period. Each training session consisted of four sets of six repetitions of the jump squat at an absolute external load of 40 kg. Each subject performed a training session using a traditional set structure and three different cluster configurations in a randomised order. A selection of kinematic and kinetic variables was then derived from ground reaction force data and differences between training interventions in terms of repetition kinematics and kinetics were investigated.

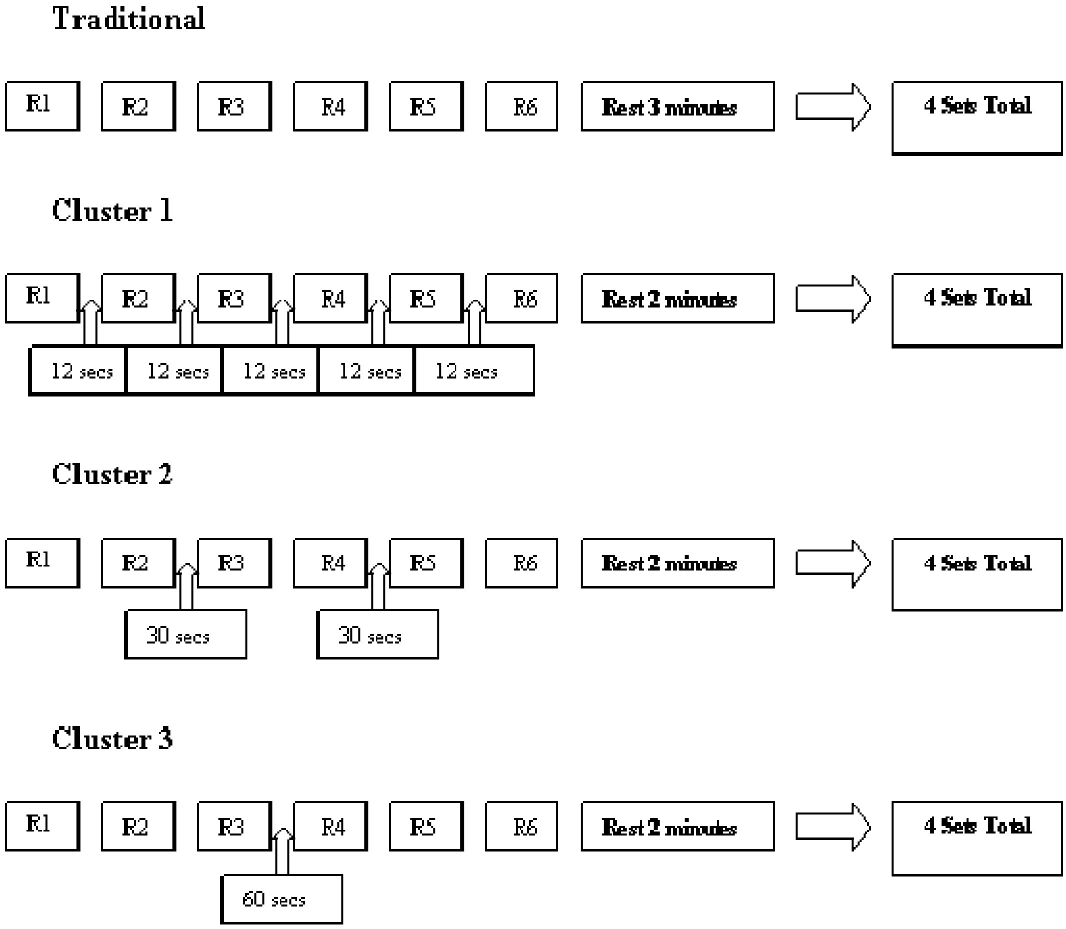

Figure 7.1: Traditional and three cluster loading set structures.

7.3.3 Methodology

Subjects were required to report for data collection on four occasions at least 72 hours apart within a two week period. Prior to all data collection subjects performed a standardised warm-up, which included running activities with incremental increases in intensity, dynamic stretching and sub-maximal jumps. Subjects then performed four sets of six jump squats using four different set configurations. Six repetitions was selected as training volume as it has been shown that beyond six repetitions, power output in the jump squat in similar populations decreases (18). The set configurations can be observed from Figure 7.1. All training sessions were equated for volume using the volume load method (sets x repetitions x load). The first involved a traditional configuration (TT) of four sets of six repetitions with three minutes rest between sets, the second (CT1) four sets of six singles (one repetition) with 12 seconds rest between repetitions and two minutes rest between sets, the third (CT2) four sets of three doubles (two repetitions) with 30 seconds rest between pairs and two minutes between sets, and the third (CT3) four sets of two triples (three repetitions) with 60 seconds rest between triples and two minutes between sets. Piloting showed that one set of six repetitions in the TT condition took 15 seconds to complete. The timings for cluster conditions were subsequently designed so that each set commenced three minutes and 15 seconds following the commencement of the previous set. Therefore total work to rest ratios were standardised against the TT condition (15 seconds work to three minutes rest). Subjects were allowed to rest the bar on the rack between clusters during all cluster configurations.

The exercise technique was similar to that described previously in the literature for the measurement of force and power during single rebound jump squats (107). This involved the subjects standing at a self-selected foot width with an Olympic bar loaded with 40 kg placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately performed a maximal jump. Subjects were instructed to attempt to keep the depth of countermovement consistent between jumps and ñjump for maximum heightò on each repetition. Subjects were required to reset to their original start position prior to all jumps. Consistency of counter movement depth was visually assessed by the researcher and where necessary feedback was provided to the subject. As with previous research (36), the depth of countermovement was not controlled as this technique (self-selected countermovement depth) reflects the technique most likely to be utilised in a practical situation thereby maximizing the practical application of study findings. However, to ensure findings were not affected by variation in countermovement depth between conditions, the vertical displacement of the systems centre of mass during the countermovement was calculated for each repetition and averaged for each set configuration. This analysis showed no significant differences between set configurations in vertical displacement during the countermovement which averaged 0.20 m for all four configurations. Forty kilograms represented a load that all subjects were familiarised with as they used in both in training and testing. This external load was used by the athletes as it represented approximately 20% of the squat 1RM of the population from which the subjects were drawn. This load sits within a spectrum of loads whereby power is reported to be maximised in ballistic tasks (41, 93, 178). Jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA). Ground reaction force data were sampled at 500 Hz via an analogue to digital converter (16-Bit, 250 kS/s National Instruments, Austin, TX.) and collected by a laptop computer using custom-built data acquisition and analysis software (Labview 8.2, National Instruments, Austin, TX.).

Power data was calculated from ground reaction force data using the impulse-momentum (forward dynamics) approach to calculate the system power as outlined previously in the literature (62). As the initial velocity of the system was zero, at each time point, vertical ground reaction force was divided by the mass of the system to calculate acceleration of the system. Acceleration due to gravity was then subtracted so that only the acceleration generated by the subject was multiplied by time data to calculate instantaneous velocity of the systemꞌs centre of mass. The resultant velocity data was then multiplied by the original ground reaction force data to calculate power. PF (ICC = 0.96, CV = 2.3), PP (ICC = 0.94 , CV = 4.6%), PV (ICC = 0.93, CV = 3.4%) and RPD calculated with a 50 ms moving average (ICC = 0.89, CV = 14.7%) were calculated from the resultant force, power and velocity curves.

7.3.4 Statistical Analyses

For the purposes of statistical analysis repetition averages were calculated for each variable for each subject. That is, the average across all four sets of each repetition (one to six) was calculated and used for analysis. Means and standard deviations were used as measures of centrality and spread of data for repetition data for each variable. A spreadsheet designed for the analysis of controlled trials (102) was utilised for further statistical analyses. The statistics derived from the spreadsheet included the p-value calculated using the unequal-variances unpaired t-statistic, and percent difference with 90% confidence limits (CL) and Cohens effect size calculated from log-transformed data. These statistics were calculated comparing each set structure for each repetition (one to six) and comparing repetition one to each subsequent repetition for each set configuration. Effect sizes were described as trivial (<0.2), small (0.2 - 0.5), moderate (0.5 - 0.8) and large (> 0.8) (34, 99). Alpha levels of 0.05 and 90% confidence limits are used where appropriate.

7.4 RESULTS

Significant differences ($p < 0.05$) between set structures in mean repetition values were identified for PP. PP was significantly lower for the TT condition when compared to CT1 and CT3 for repetition four, and all cluster configurations for repetitions 5 and 6. These differences can be observed from Figure 7.2 and a summary of percent changes with 90% confidence limits, effect sizes and p-values can be observed from Table 7.1. Percent changes (± 90% CL) in PP from repetition one to subsequent repetitions for all set configurations can be observed from Figure 7.3. There were significant differences ($p < 0.05$) between repetition one and all subsequent repetitions for all set configurations with the exception of repetition four for CT3 and repetition five for CT2 which were not significantly different from repetition one for their respective configurations. The greatest percent changes from repetition one were for repetitions three to six in the TT condition (% change = -6.0 to -11.8). These differences can be observed from Figure 7.3. Effect sizes for repetitions five and six were both large (ES = -0.83 to -1.0).

Significant differences ($p < 0.05$) between set structures in mean repetition values were also identified for PV. PV was significantly lower for the TT condition compared to CT3 at repetition four, significantly lower compared to CT2 and CT3 at repetition five, and significantly lower compared to all cluster conditions for repetition five. These differences can be observed from Figure 7.4 and a summary of percent changes with 90% confidence limits, effect sizes and p-values can be observed from Table 7.2. Percent changes (± 90% CL) in PV from repetition one to subsequent repetitions for all set configurations can be observed from Figure 7.5. For the TT condition there was a significant decrease ($p < 0.05$, ES = -0.24 to -0.99) in PV from repetition one to all subsequent repetitions. There were no significant differences for CT1 between repetition one and any subsequent repetitions. However, there were significant differences ($p < 0.05$) between repetition one and repetitions two, three and four for CT2, and between repetition one and repetition six for CT3.

There were no significant differences found in mean repetition PF (Figure 7.6) and RPD between set configurations. There were also no significant differences between repetition one and subsequent repetitions for any set configuration for RPD. However, there were significant differences between repetition one and selected subsequent repetitions for TT, CT2 and CT3 for PF. These differences can be observed from Figure 7.7. PF decreased significantly from repetition one to all subsequent repetitions for the TT configuration ($p < 0.05$, ES = -0.20 to -0.41). Additionally, for CT2 repetitions two, four and six, PF was significantly reduced ($p < 0.05$, ES = -0.19 to -0.26) from repetition one, and for CT3, repetition six was significantly reduced ($p < 0.05$, ES = -0.23) from repetition one.

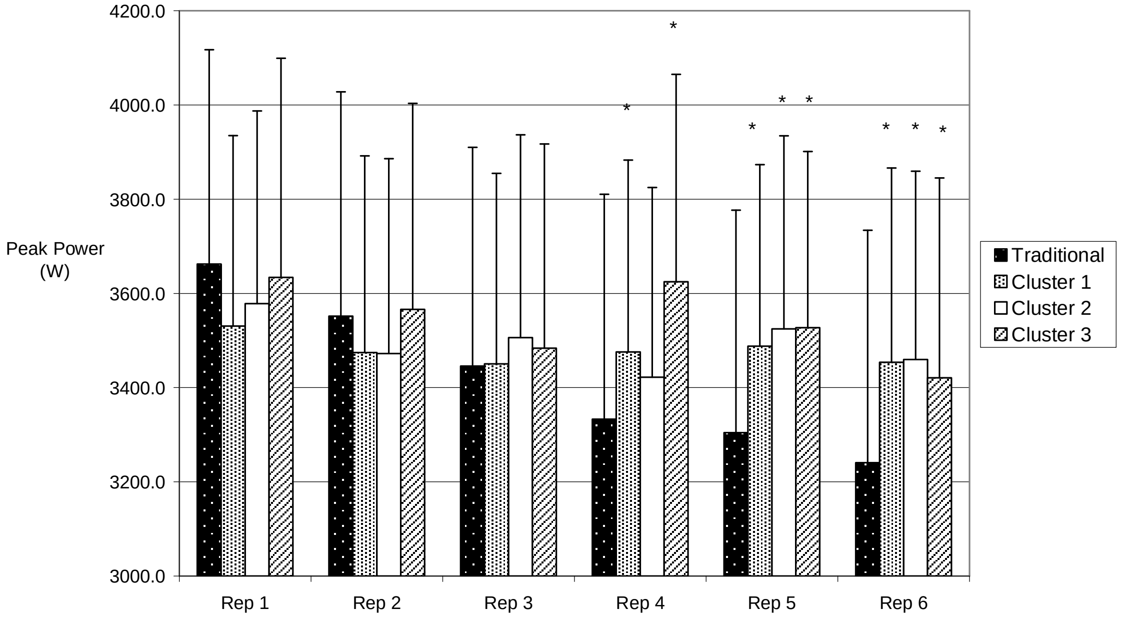

Figure 7.2: Mean (± SD) repetition peak power for each set configuration.
* Significantly different from control ($p < 0.05$)

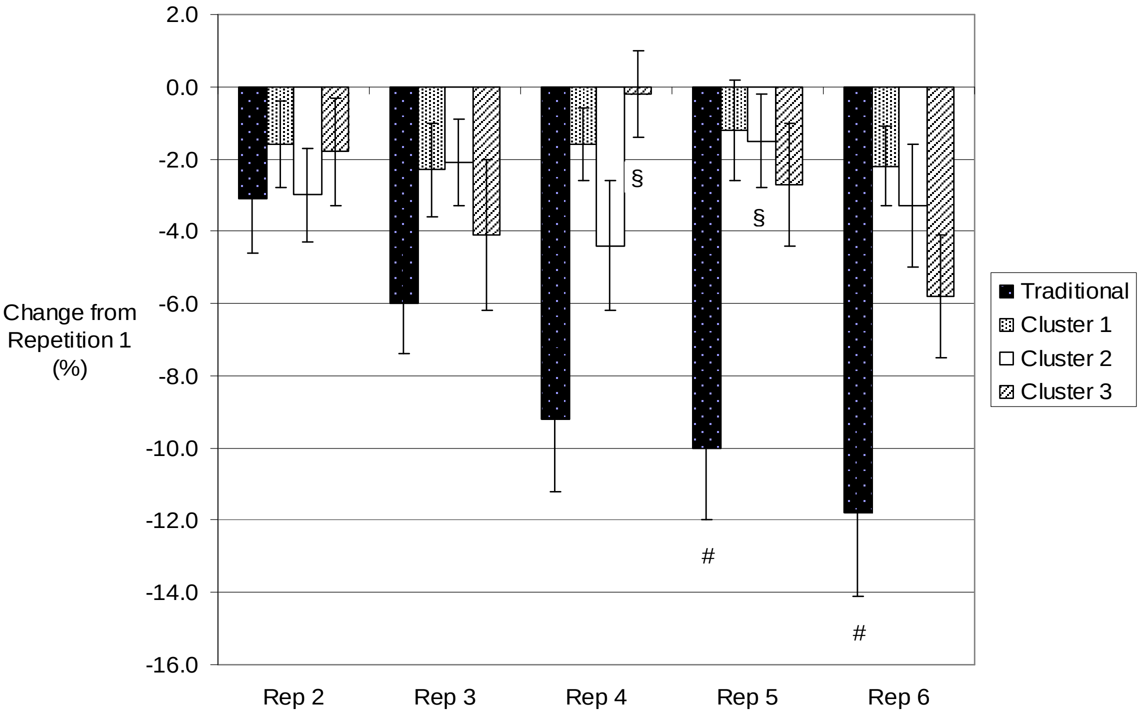

Figure 7.3: Percent change (± 90% CL) from log transformed data for peak power between repetition one and subsequent repetitions for each set configuration.
§ no significant difference from repetition one (all other differences are significant).
#Effect size for change from repetition one is large (> -0.8)

Table 7.1: P-value, percent change (± 90% CL) and effect sizes (ES) for three cluster loading configurations when compared to the traditional configuration for repetitions four, five and six for peak power.

	Repetition 4				Repetition 5				Repetition 6			
	P Value	**% Change**	**± 90% CL**	**ES**	**P Value**	**% Change**	**± 90% CL**	**ES**	**P Value**	**% Change**	**± 90% CL**	**ES**
Cluster 1	0.05	4.6	3.7	0.3	0.03	6.0	4.4	0.4	0.01	7.0	4.5	0.4
Cluster 2	0.08	3.0	2.8	0.2	0.00	7.0	3.8	0.5	0.01	7.2	3.9	0.5
Cluster 3	0.00	9.0	3.8	0.6	0.00	7.2	3.5	0.5	0.01	5.9	3.3	0.4

CL = Confidence Limits

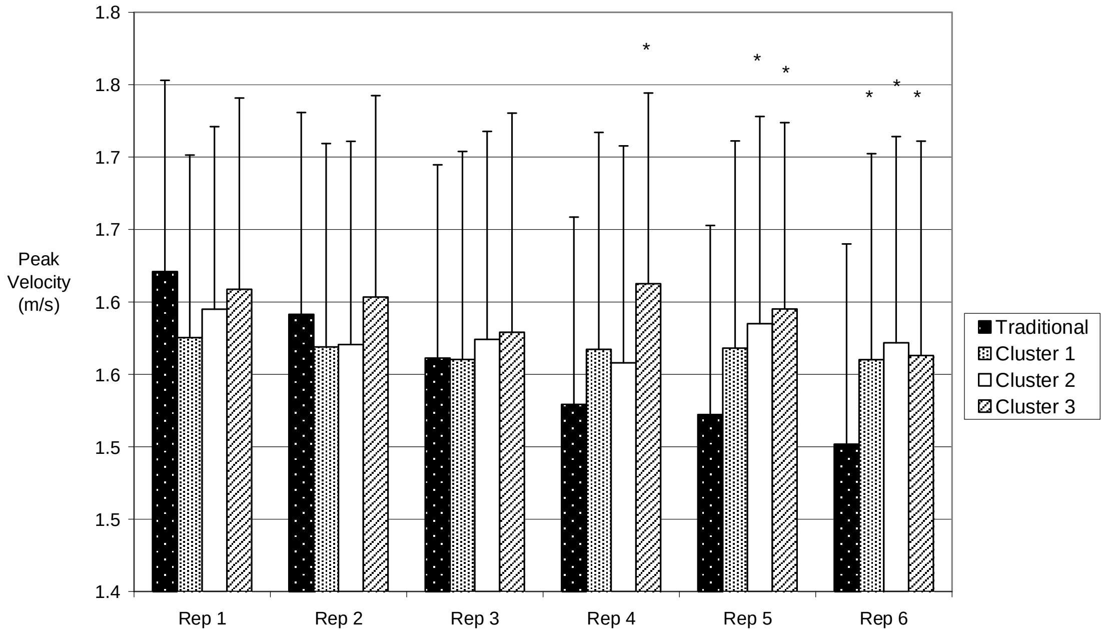

Figure 7.4: Mean (± SD) repetition peak velocity of the centre of mass for each set configuration.
*Significantly different from control ($p < 0.05$)

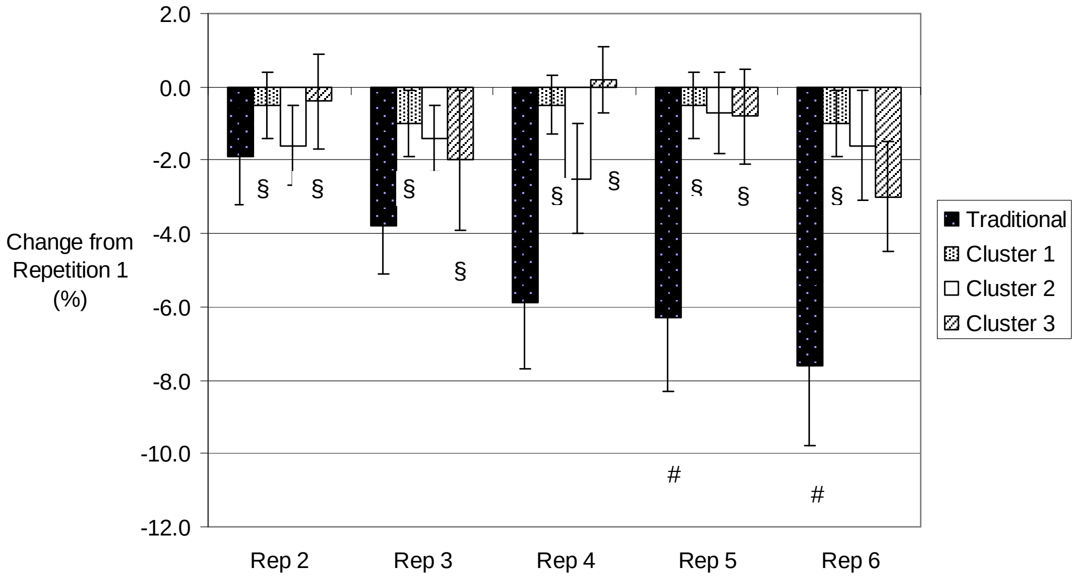

Figure 7.5: Percent change (± 90% CL) from log transformed data for peak velocity between repetition one and subsequent repetitions for each set configuration.
§ no significant difference from repetition one (all other differences are significant ($p > 0.05$)).
#Effect size for change from repetition one is large (> -0.8)

Table 7.2: P-value, percent change (± 90% CL) and effect sizes (ES) for three cluster loading configurations when compared to the traditional configuration for repetitions four, five and six for peak velocity of the centre of mass.

	Repetition 4				**Repetition 5**				**Repetition 6**			
	P Value	**% Change**	**± 90% CL**	**ES**	**P Value**	**% Change**	**± 90% CL**	**ES**	**P Value**	**% Change**	**± 90% CL**	**ES**
Cluster 1	0.11	2.7	2.7	0.2	0.09	3.2	3.1	0.3	0.04	4.1	3.1	0.3
Cluster 2	0.12	1.9	2.1	0.2	0.02	4.2	2.8	0.4	0.01	4.9	2.8	0.4
Cluster 3	0.02	3.3	2.3	0.3	0.01	5.0	2.7	0.4	0.01	4.2	2.6	0.4

CL = Confidence Limits

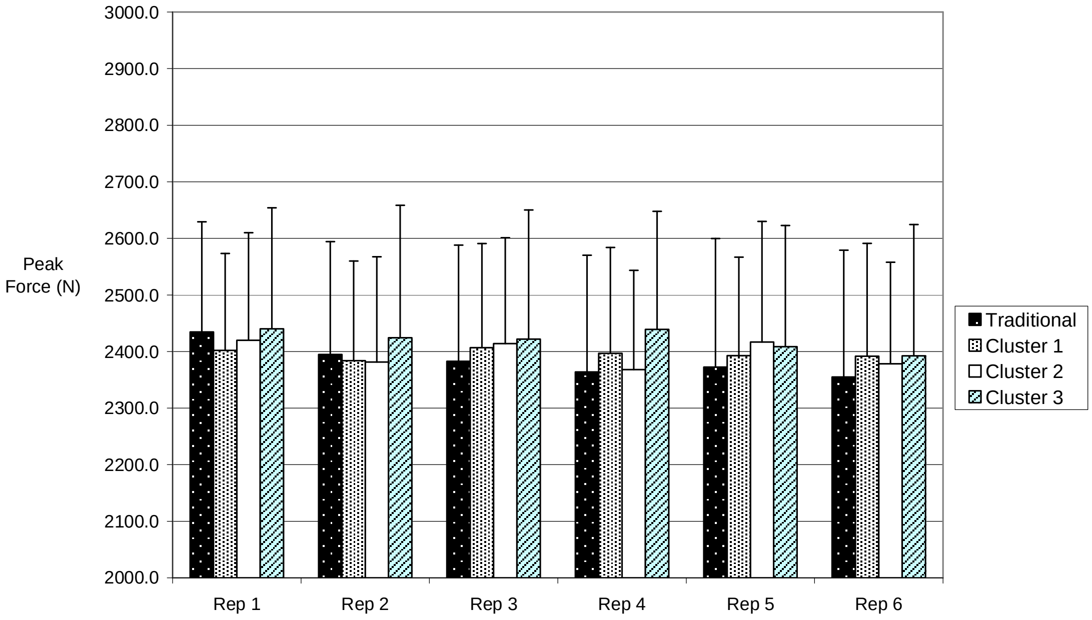

Figure 7.6: Mean (± SD) repetition peak force for each set configuration.

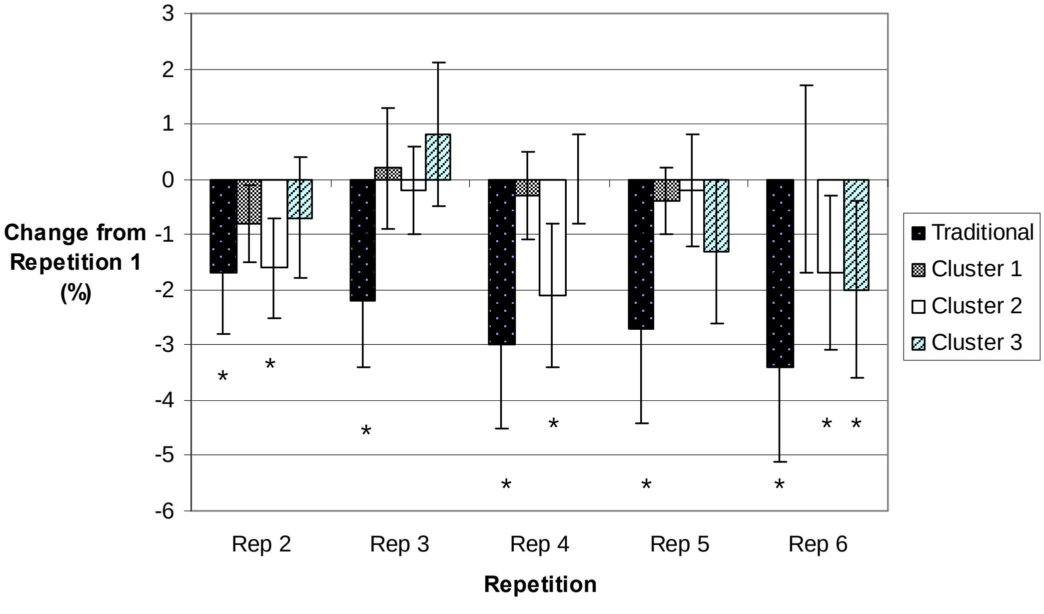

Figure 7.7: Percent change (± 90% CL) from log transformed data for peak force between repetition one and subsequent repetitions for each set configuration.
* Significant difference from repetition one (p > 0.05).

7.5 DISCUSSION

This study aimed to establish the effects of cluster loading on force, power and velocity profiles of a number of set configurations, specifically investigating the differences between a traditional loading paradigm and three alternative ñclusterò configurations. Our results indicate that where power and velocity decrease significantly in the latter repetitions of a traditional set of six repetitions of the loaded jump squat, this decrease can be attenuated by using cluster configurations. This may have training implications for the planning and prescription of training for muscular power using ballistic activities, but these implications are dependent on the key mechanical and metabolic stimuli. Should, maximizing power and velocity in ballistic training be key to adaptation, cluster loading paradigms may offer a viable training option for lower body power development.

From the results of this study it is evident that the use of a number of cluster configurations was able to decrease the decline in PP output during a set of six jump squats. For all set configurations, the greatest PP occurred with the first repetition. This is in contradiction to the research of Baker and Newton (18) which suggested that the highest power output across a set of 10 jump squats was achieved at either repetition two or three and maintained until the fifth repetition. However, it is in agreement with Haff et al. (83) who reported PP in a set of five repetitions of the clean pull to occur in the first repetition. From the data presented it can be observed that the cluster configurations clearly attenuated the decrease of PP through the set after repetition one. This is evidenced by the large effect sizes for repetitions five and six for the TT condition when repetition one was compared to subsequent repetitions (see Figure 7.3). Although significant differences were evidenced when comparing repetition one with subsequent repetitions for cluster configurations, none of these resulted in moderate or large effect sizes. Therefore, it seems likely that cluster configurations are superior for maintaining quality of effort (in terms of PP) during the jump squat movement.

Decreases in PV were also attenuated by the use of cluster training configurations when compared to traditional loading schemes. Similar to PP, the only large or moderate effect sizes for differences between repetition one and subsequent repetitions were with repetitions five and six during the traditional set configuration (see Figure 7.5). Therefore, it seems that all three cluster configurations in the present study were able to improve the velocity profile of a set of six jump squats. These findings are consistent with the findings of Haff and colleagues (83) who reported that a 15 ï 30 second rest between repetitions of a clean pull at 90% of 1RM resulted in significantly greater PV.

No significant differences between any of the set configurations at any repetition were found in force output. Therefore, in terms of PF, each set configuration provided a similar stimulus. Results did show however that the force was significantly decreased from repetition one to all subsequent repetitions in TT and for selected repetitions for the cluster configurations. For example, the second repetition of each pair in CT2 was significantly decreased compared to the first repetition of the set. Previous authors (81) have postulated that PCr can be replenished during the short rest provided during cluster loading configurations, whereas traditional configurations result in greater depletion of PCr and therefore increased use of muscle glycogen and production of lactic acid. Research has suggested that the inhibition of force capabilities following as few as 5 ï 9 maximal contractions is due to the accumulation of blood lactate (188). The research of Salin and Ren (168) supports the contention of Haff and colleagues (81), showing that decreases in muscular ATP and PCr concentrations were associated with increased lactate concentrations and significant decreases in force following maximal contractions. With the addition of 15 ï 30 second rest intervals between knee extension contractions force output returned to 80-90% of initial values. These same mechanisms may explain the differences in PP and PV profiles between configurations.

Whereas it is likely that some level of metabolic fatigue is necessary for resistance training for developing muscular size (hypertrophy training) and strength (122, 181, 182), the same may not be true of training for power. Indeed a number of researchers have suggested that the key mechanical stimuli in the development of muscular power is generating high PV and PP (85, 86, 113, 196) and achieving this does not necessarily entail fatigue and associated metabolic stress. Research investigating traditional loading configurations using ballistic movements suggests that the lactate accumulation inhibits muscle function. Crewther and colleagues (42) investigated metabolic responses to ballistic supine squats at 45% of one RM with subjects performing sets of six repetitions with three minutes rest between sets, similar to the traditional loading configuration in the current study. It was reported that significant increases in lactate accumulation occurred as a by-product of anaerobic glycolysis across sets of six repetitions. The reported lactate concentrations were equivalent to those generated in an equi-volume maximum strength protocol and deemed sufficient to inhibit PP. This metabolic stress associated with a traditional ballistic training configuration, as is purported to be during maximum strength training, may be a pre-cursor to neural and endocrine adaptations for power development. In this case cluster loading may inhibit these adaptations making a traditional configuration a more appropriate prescription. However, should PP and PV be important mechanical stimuli, mediating neural responses to training cluster configurations would represent the more appropriate training prescription.

Results clearly showed that cluster configurations resulted in increased repetition PP in the latter repetitions of the set compared to traditional loading. However no difference in repetition PP or PV was evident between clusters (see Figures 7.2 and 7.4). This suggests that any of the cluster configurations investigated could be used to enhance PP in ballistic tasks. These findings are consistent with previous research focusing on power output in upper body strength movements. Lawton and colleagues (128) investigated the use of singles, doubles and triples to improve power output in a 6RM bench press, also showing that none of the cluster configurations were obviously superior in maximising power outputs. Likewise, in the current research PV was not significantly different between the three cluster configurations. However, the cluster one configuration was the only configuration where there was no significant drop off in PV from repetition one to six. Therefore, this may be the preferable configuration for maximizing velocity of movement. However, further research is needed to confirm this possibility.

7.6 PRACTICAL APPLICATIONS

Ballistic movements are commonly utilised to develop lower body muscular power in athletic populations. Whereas hypertrophy and strength training adaptation is dependent on mechanical stimuli such as total forces and mechanical work, which are likely to induce some level of metabolic fatigue, it is possible that for the development of muscular power during ballistic training, mechanical qualities such as PV and PP are important (possibly mediating neural adaptations). Our results have shown that decreases in power and velocity of movement associated with the latter repetitions of a set of jump squats can be reduced by the use of cluster loading configurations. Dividing a traditional set of six repetitions into clusters of either one, two or three repetitions can attenuate decreases in power and velocity of movement throughout the set. However, the practitioner needs to be aware that, should other mechanical stimuli and associated metabolic responses be important precursors to power development (or be a desired training outcome) a traditional set configuration may represent the more appropriate training prescription. Additionally, this research did not directly examine metabolic, endocrine and neural responses to training, which underpin adaptation. Future research should investigate these responses to cluster configurations together with longitudinal training adaptations to provide further information on the mechanisms that reduce neuromuscular fatigue during cluster loading and further clarify their application to training.

CHAPTER 8

DOES CLUSTER LOADING ENHANCE LOWER BODY POWER DEVELOPMENT IN PRE-SEASON PREPARATION OF ELITE RUGBY UNION PLAYERS?

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8.1 PRELUDE

Elite, highly trained athletes often need to undertake advanced resistance training methods in order to ensure continued adaptation. In Chapter 7 we identified that cluster loading patterns result in different kinematic and kinetic patterns during a jump squat training bout, improving the maintenance of power and velocity in the latter repetitions of a set. This may improve power adaptation following a training period and therefore represent appropriate training prescription in a highly trained athlete. Typically rugby union players undertake short pre-season preparation periods comprising a combination of resistance training methods. If a structure such as cluster loading is to be utilised in this population, it is important to ascertain the effectiveness of the training paradigm in this context. This study, therefore, investigated the utilisation of a cluster loading intervention during a typical pre-season in elite rugby union players.

8.2 INTRODUCTION

Strength and power are physical attributes that have been shown to be crucial to high level performance in collision sports such as rugby league, rugby union and American Football (9, 12). The development of strength and power is therefore an important component of training programs for the preparation and development of elite level athletes in these sports. Given the complex nature of resistance training prescription for collision sports, training interventions require careful consideration in order to ensure training outcomes are achieved. Cluster loading, sometimes termed inter-repetition rest training, describes a training system whereby the rest periods are manipulated, breaking sets into small clusters of repetitions (81, 127, 128). It has been previously suggested that these training structures may be well suited to the development of lower body explosive performance (81) and thus may be appropriate for use in collision sport athletes.

There are a number of factors inherent in the preparation of high level rugby union and rugby league players, which make training prescription for power development complex for the practitioner. Firstly, these sports are characterised by long in-season periods (typically 25 ï 35) weeks with relatively short pre-season preparations (typically 8 ï 12 weeks) (10, 77, 94). Thus, the pre-season preparatory period where resistance training frequency and volume can be increased represents a relatively short time frame for the development of lower body power, particularly in highly trained athletes. Additionally, in many collision sports there is the added complexity of the considerable demands of other training components such as metabolic conditioning, speed and skill development, and team organisation (10, 35). This additional training imposes many different physiological demands on the athlete, which can adversely affect power development (94, 97). Therefore, the investigation of strength and power interventions applied in this context is crucial to improving understanding of athletic development in these and other similar sports. Although the design of strength and power programs in rugby league and rugby union has been the subject of considerable research (4, 10, 23), to the authors knowledge no studies have investigated the use of cluster loading in collision sports.

It has been postulated that breaking sets into small ñclustersò of repetitions may improve the kinematic and kinetic (force, power, velocity) profile of a training set. This in turn may lead to improved training outcomes, particularly in the training of ballistic performance (81). To this end, investigations of the acute effect of cluster structures have suggested an improved set velocity and power profile during both lower body and upper body movements (59, 83, 128). These improvements have been attributed to the ability of the short rest periods between clusters to allow metabolic recovery resulting in improved kinematics and kinetics in the latter repetitions of the set when compared to traditional loading paradigms. This improved set profile may be beneficial as there is some evidence that adaptation to ballistic performance may be principally mediated by neural mechanisms, with intramuscular (86, 134) and intermuscular (158) neural adaptations contributing to performance improvements following high velocity training.

However, there is very little research tracking training outcomes after the implementation of cluster loading programs. Studies have suggested that various cluster loading configurations in untrained subjects confers no beneficial effect in terms of maximum strength adaptation when compared to traditional training structures (29, 167). In elite junior basketball players Lawton and colleagues (127) compared upper body strength and power adaptations in the bench press movement between a cluster intervention and a traditional training structure over a six week training period. This research showed that a traditional structure resulted in significantly greater gains in maximal strength (9.7%) compared to the cluster structure (4.9%) but there were no significant differences in power adaptation between interventions. However, there remains no published research with cluster set structures applied to lower body power training when ballistic movements are included.

The purpose of this study was to investigate whether cluster arrangements led to improved training adaptations when compared to a traditional set structure during the pre-season preparation of highly trained elite level rugby union players. Despite suggestions that cluster loading is well suited to the development of mechanical power, to date there is limited research investigating training outcomes with these set configurations applied alongside loading parameters commonly used in the training of mechanical power in athletes. The current study addressed this gap in the research using highly trained rugby union players for whom lower body power is a key physical attribute.

8.3 METHODS

8.3.1 Experimental Approach to the Problem

In order to compare traditional and cluster loading for the development of strength and power, 18 elite rugby union players undertook eight weeks of resistance training using the squat and clean movement patterns. Players were randomly allocated to one of two groups, a traditional training group (TT) and a cluster training group (CT). Training was undertaken during the pre-season training phase, which represents the time of the year when their greatest resistance training volume is typically undertaken. To ascertain the effect of the training interventions on lower body strength and power performance, preceding and following the training intervention players undertook force, velocity and power profiling of the jump squat at a variety of light to moderate external loads and maximum strength was assessed in the back squat movement. Training outcomes were evaluated using effect statistics and percentage change in maximum strength, force, velocity and power. Differences in training outcomes between groups were assessed using two way analysis of variance and 90% confidence limits from which a qualitative inference of the effect of the cluster intervention was derived.

8.3.2 Subjects

Eighteen highly trained elite male rugby union players undertaking pre-season training prior to the start of their competitive season agreed to participate in this study. This represented the total number of available subjects who fulfilled the study inclusion criteria. These criteria were as follows: (i) the athlete was scheduled to be present for the entire training block; (ii) the athletesô individual training goals agreed by conditioning and coaching staff and the athlete were congruent with the training prescription for the study; and, (iii) the study prescription was deemed appropriate for the athlete considering musculoskeletal screening results and injury history. Average age and height were 26.8 ± 4.5 yrs and 1.89 ± 0.1 m respectively, and average body mass was 103.5 ± 8.6 kg and 104.3 ± 8.5 kg pre- and post-training, respectively. All subjects had the procedures, benefits and risks of participation explained to them and provided informed consent. All procedures were approved by the Edith Cowan University Human Research Ethics Committee.

8.3.3 Procedures

Prior to starting the training intervention and at the completion of the training intervention, subjects undertook assessment of jump squat force, velocity and power across a spectrum of loads and back squat maximum strength testing. Jump squat testing and strength testing took place on separate days at least 48 hours apart with jump squat assessment preceding maximum strength assessment. All athletes had three weeks of active rest at the completion of the previous competitive season followed by three weeks of prescribed self-directed preparatory strength and conditioning before the study commenced.

8.3.3.1 Power Testing Procedures

Following a standardised warm-up, each subject performed three single repetition jump squats at body weight and three external loads, 20 kg, 40 kg and 60 kg (in a randomised order) using a technique identical to that described by Hori and colleagues (107). Absolute loads were chosen for analysis as of primary interest were the changes in the athletes ability to apply power to an absolute load irrespective of changes in body weight and maximum strength during the course of the training period. A similar spectrum of loads has previously been used in an investigation of power training in novice subjects (40) and in the assessment of lower body mechanical power of collision sport athletes (10). The jump technique involved the subjects standing at a self-selected foot width with an Olympic bar placed on their upper trapezius immediately below C7. The subject then performed a countermovement to a self-selected depth and immediately preformed a maximal jump. Subjects were instructed to keep the depth of countermovement consistent between jumps and ñjump for maximum heightò on each repetition. All subjects were familiar with the jump squat movement as they previously performed it as part of both training and testing programs.

All jumps were performed on a portable force plate (Accupower, AMTI, Watertown, MA). Ground reaction force data were sampled at 500 Hz via an analogue to digital converter (National Instruments, Austin, TX.) and collected by a laptop computer using custom built data acquisition software (Labview 8.2, National Instruments, Austin, TX.). Data were then transferred to a customised data analysis program for calculation of the kinematic and kinetic variables of interest (Labview 8.2, National Instruments, Austin, TX).

8.3.3.2 Strength Testing Procedures

Maximum strength was assessed through predicting back squat 1RM from a 2 ï 6 RM lift. Methods were similar to those previously outlined for assessment of squat maximum strength in professional rugby union players (4). This involved each athlete performing three sets of 2 - 6 repetitions at incrementally increasing loads before one set was performed to failure in the 2 ï 6 repetition range. Each repetition was performed to a visually assessed knee angle of 90 degrees. One repetition maximum was then predicted using a documented equation (28). This calculation method has been shown to have a practically perfect correlation (r = 0.97) to actual back squat 1RM (129). Our data shows the methodology is a reliable means of assessing back squat 1RM in the study population (ICC = 0.90, CV = 5.9%).

8.3.3.3 Jump Squat Data Analysis

Power applied to, and the velocity of the centre of mass of the system were calculated from ground reaction force data using the impulse-momentum (forwards dynamics) approach outlined previously in the literature (62). As the initial velocity of the system was zero, at each time point throughout the jump, vertical ground reaction force was divided by the mass of the system to calculate acceleration of the system. Acceleration due to gravity was then subtracted such that only the acceleration generated by the subject was multiplied by time data to calculate instantaneous velocity of the systems centre of mass. The resultant velocity data was then multiplied by the original ground reaction force data to calculate power. From the resultant force-time, velocity-time and power-time curves the following three variables were calculated for each repetition;

Peak Force; the highest point on the force-time curve calculated from ground reaction force data (between day reliability, ICC = 0.96, CV = 2.3%).

Peak Power; the highest point on the power time curve calculated from ground reaction force data (between day reliability, ICC = 0.94, CV = 4.6%).

Peak Velocity of the Centre of Mass; the highest point on the velocity-time curve integrated from ground reaction force data (between day reliability, ICC = 0.93, CV = 3.4%).

8.3.3.4 Training Intervention

Subjects were randomly allocated to either a traditional training group (TT, N = 9) or a cluster training group (CT, N = 9), which utilised cluster loading patterns. Descriptive statistics for each group can be observed from Table 8.1. There were no significant differences between TT and CT groups for any of the subject characteristics. All athletes undertook twice weekly supervised lower limb strength and power training. Training programs for TT and CT can be observed from Tables 8.2 and 8.3, respectively. All athletes performed two strength and power exercises using the squat and clean movement patterns plus additional supplementary exercises primarily focused on the abdominals, back extensors, gluteals and hamstrings.

Table 8.1: Subject characteristics (Mean ± SD) for traditional and cluster loading groups.

	Traditional Training	**Cluster Training**
Age (yrs)	25.7 ± 4.5	27.8 ± 4.5
Height (m)	1.93 ± 0.1	1.85 ± 0.1
Pre Training Body Weight (kg)	107.3 ± 6.7	99.7 ± 10.5
Post Training Body Weight (kg)	108.4 ± 6.3	100.1 ± 10.7

Only the two compound strength and power lifts were clustered for those in the CT group. All of these movements were executed with the intent to accelerate the load as quickly as possible for both training groups. A mixed methods paradigm was utilised for the squat movement (88). This involved the use of loads ranging from 80-95% of 1RM for the first six weeks of training and a combination of heavy load squats (80-85% 1RM) and light to moderate load ballistic jump squats (0 ï 20% 1RM) in weeks seven and eight. Jump squat loads were structured using a descending system with the heaviest load performed in the first set and the lightest in the final set (11). The clean pull and power clean movements used high loads (80-95% 1RM) throughout the training program. However, as the movement changed from a clean pull to a power clean for weeks five to eight of training the absolute load lifted in this movement pattern generally dropped considerably during the second half of the training program. There were no significant differences in prescribed average volume load (sets x repetitions x load) per session between training groups for the squat (TT = 4.5 sets x 5 repetitions x 84.7% 1RM, CT = 4.5 sets x 4.9 repetitions x 84.7% 1RM), clean (TT = 5 sets x 4.9 repetitions x 86.5% 1RM, CT = 5 sets x 4.8 repetitions x 86.5% 1RM), or jump squat movement (3 sets x 3 .7 repetitions x 10% 1RM for both groups). A total of 16 lower limb sessions were scheduled for each subject over the course of the study. An average of 99% of training was completed by the TT group and an average of 98% of training sessions were completed by the CT group. All sessions were supervised by a strength and conditioning coach, who stipulated training load and recorded repetitions and load completed, and timed rest periods.

All participants continued with upper body strength training (2 x per week), aerobic and anaerobic conditioning (2 x per week), speed training (2 x per week), skills training (2 x per week) and team organisation (2 x per week) as part of their pre-season preparation program. Average weekly training time over the course of the study was 8.5 hours. Total training load including all components of training (resistance training, speed training, metabolic conditioning, skills training and team organisation) was periodised during the course of the study and training load was quantified using the session rating of perceived exertion method (72). Subjects were asked to keep nutritional intake consistent through the course of the study and did not undertake supplementation additional to prescribed recovery protocols. Hydration status was assessed intermittently through the study in order to provide feedback to athletes on hydration status.

Table 8.2: Training program for traditional training group.

			Set 1			Set 2			Set 3			Set 4			Set 5	
Week	**Core Lifts**	**Reps**	**Load (%1RM)**	**Rest (secs)**	**Reps**	**Load (%1RM)**	**Rest (secs)**	**Reps**	**Load (%1RM)**	**Rest (secs)**	**Reps**	**Load (%1RM)**	**Rest (secs)**	**Reps**	**Load %1RM**	**Rest (secs)**
1 & 2	Front Squat	8	80	180	8	80	180	6	85	180	6	85	180	4	90	180
	Clean Pull	8	80	180	8	80	180	6	85	180	6	85	180	4	90	180
3 & 4	Back Squat	7	80	180	5	85	180	5	85	180	5	90	180	3	95	180
	Clean Pull	7	80	180	5	85	180	5	85	180	5	90	180	3	95	180
5 & 6	Box Squat	6	80	180	5	85	180	4	90	180	3	90	180	3	95	180
	Power Clean	6	80	180	5	85	180	4	90	180	3	90	180	3	95	180
7 & 8	Back Squat	5	80	180	4	80	180	3	85	180						
	Jump Squat	4	20	180	4	10	180	3	0	180						
	Power Clean	5	80	180	4	85	180	4	90	180	4	90	180	3	95	180

Reps = repetitions, secs = seconds, RM = repetition maximum

Table 8.3: Training program for cluster training group.

		Set 1			Set 2			Set 3			Set 4			Set 5		
Week	**Core Lifts**	**Clusters x Reps**	**Load (%1RM)**	**Rest (Clusters / Sets)**	**Clusters x Reps**	**Load (%1RM)**	**Rest (Clusters / Sets)**	**Clusters x Reps**	**Load (%1RM)**	**Rest (Clusters / Sets)**	**Clusters x Reps**	**Load (%1RM)**	**Rest (Clusters / Sets)**	**Clusters x Reps**	**Load (%1RM)**	**Rest (Clusters / Sets)**
1 & 2	Front Squat	1 x 6	80	0 / 180	2 x 3	80	30 / 120	2 x 3	85	30 / 120	2 x 3	85	30 / 120	2 x 3	90	30 / 120
	Clean Pull	1 x 6	80	0 / 180	2 x 3	80	30 / 120	2 x 3	85	30 / 120	2 x 3	85	30 / 120	2 x 3	90	30 / 120
3 & 4	Back Squat	1 x 5	80	0 / 180	1 x 5	85	0 / 180	1 x 2, 1 x 3	85	20-30 / 120	1 x 2, 1 x 3	90	20-30 / 120	1 x 2, 1 x 3	95	20-30 / 120
	Clean Pull	1 x 5	80	0 / 180	1 x 5	85	0 / 180	1 x 2, 1 x 3	85	20-30 / 120	1 x 2, 1 x 3	90	20-30 / 120		95	20-30 / 120
5 & 6	Box Squat	1 x 6	80	0 / 180	1 x 6	85	0 / 180	3 x 1	90	10 / 120	3 x 1	90	10 / 120	3 x 1	95	10 / 120
	Power Clean	1 x 6	80	0 / 180	1 x 6	85	0 / 180	3 x 1	90	10 / 120	3 x 1	90	10 / 120	3 x 1	95	10 / 120
7 & 8	Back Squat	1 x 5	80	0 / 180	1 x 4	80	0 / 180	1 x 3	85	0 / 180						
	Jump Squat	2 x 2	20	20 / 120	2 x 2	10	20 / 120	3 x 1	0	10 / 120						
	Power Clean	1 x 5	80	0 / 180	1 x 4	85	0 / 180	2 x 2	90	20 / 120	2 x 2	90	20 / 120	3 x 1	95	20 / 120

Reps = repetitions, secs = seconds, RM = repetition maximum

Note; Repetitions are expressed as number of clusters x number of repetitions in each cluster, rest is expressed in seconds with the first number denoting rest between clusters and the second number rest between sets

8.3.4 Statistical Analyses

All statistical analyses for force, velocity and power variables were performed on the mean of trials two and three with the first trial excluded from analysis (104). Means and standard deviations were used as measures of centrality and spread of data. In the first instance, the CT and TT groups were compared using a repeated measures two way analysis of variance (ANOVA) for all strength and jump squat measures. Post-hoc analysis was performed using the Holm-Sidak method. An alpha level of 0.05 was used for all statistical comparisons. Additionally, the difference between the TT and CT groups was calculated (% change) and uncertainty in the effect was expressed as 90% confidence limits (CL) with a qualitative inference of the effect of the cluster intervention (20, 21). If the confidence interval overlapped the thresholds for small positive and negative effects, the outcome was deemed unclear. This statistical approach has been previously used to make magnitude based inferences in similar studies and in similar populations (4, 94, 180). Effect sizes (ES) [ES = pre-test minus post-test divided by the standard deviation of the pre-test] were also calculated for force, velocity, power and maximum strength. Thresholds outlined by Rhea (164) specifically for highly trained athletes were used to describe effects as trivial ($ES < 0.25$), small (ES = 0.25 ï 0.5), moderate (ES = 0.5 ï 1.0) and large ($ES > 1.0$).

8.4 RESULTS

Mean pre- and post-training scores for back squat 1RM, PP, PV and PF for both training groups can be observed from Table 8.4. There were significant ($p < 0.05$) increases in back squat 1RM for both the CT (% change = 14.6 ± 18.0%, ES = 1.0) and TT (% change = 18.3 ± 10.1%, ES = 2.2) groups (Figure 8.1). Post-training back squat 1RM was significantly greater ($p < 0.05$) in the TT group compared to the CT group. However, the training effect of both interventions on maximum strength was large (ES = 1.0 ï 2.2). PF at the external load of 60 kg was also significantly greater ($p < 0.05$) in the TT group post-training.

Table 8.4: Mean (± SD) maximum strength, peak power, peak velocity and peak force for the traditional and cluster groups pre- and post- the 8 week training intervention.

	Traditional		Cluster	
Load	**Pre Training**	**Post Training**	**Pre Training**	**Post Training**
Maximum Strength				
Back Squat 1RM (kg)	203 ± 16.6	240 ± 25.0Àÿ	191 ± 25.0	216 ± 25.3À
Peak Power (W)				
0 kg	4,697 ± 461	4,790 ± 434	4,542 ± 599	4,716 ± 448
20 kg	4,326 ± 532	4,531 ± 432	4,143 ± 475	4,262 ± 306
40 kg	4,147 ± 540	4,169 ± 412	3,867 ± 306	4,146 ± 298
60 kg	3,943 ± 604	4,049 ± 505	3,660 ± 341	3,822 ± 213
Peak Velocity (m/s)				
0 kg	2.18 ± 0.16	2.19 ± 0.15	2.22 ± 0.20	2.30 ± 0.17
20 kg	1.88 ± 0.16	1.92 ± 0.15	1.91 ± 0.15	1.95 ± 0.13
40 kg	1.65 ± 0.16	1.65 ± 0.15	1.65 ± 0.12	1.72 ± 0.11
60 kg	1.46 ± 0.17	1.48 ± 0.16	1.44 ± 0.09	1.49 ± 0.08
Peak Force (N)				
0 kg	2,359 ± 140	2,411 ± 144	2,280 ± 280	2,329 ± 222
20 kg	2,519 ± 185	2,553 ± 149	2,394 ± 244	2,412 ± 208
40 kg	2,678 ± 190	2,672 ± 124	2,536 ± 199	2,579 ± 192
60 kg	2,838 ± 199	2,881 ± 155ÿ	2,703 ± 190	2,708 ± 150

RM = repetition maximum
À Significant within group difference pre-post training
ÿ Significant difference between traditional and cluster post training

Percent changes in strength and jump squat PP, PV and PF at all loads pre- to post training for TT and CT with percent difference (± 90% CL) between groups and a qualitative inference of the magnitude of the difference are detailed in Table 8.5. Percent differences between groups can be considered as clear for back squat 1RM, PP at 20 kg and 40 kg, PV at 0 kg and 40 kg, and PF at 20 kg, 40 kg and 60 kg. Cluster loading had a likely positive effect for PP at 40 kg (% difference between groups = 6.5%) and for PV at 0 kg and 40 kg (% difference between groups = 3.3% and 4.7% respectively). Additionally the effect of the cluster intervention on PF at 40 kg was possibly positive (% difference between groups = 1.8%). The effect of the cluster intervention was possibly negative for back squat 1RM (% difference between groups = -3.7%), PF at 20 kg (% difference between groups = -0.61%), PF at 60 kg (% difference between groups = -1.3%) and PP at 20 kg (% difference between groups = -1.8%).

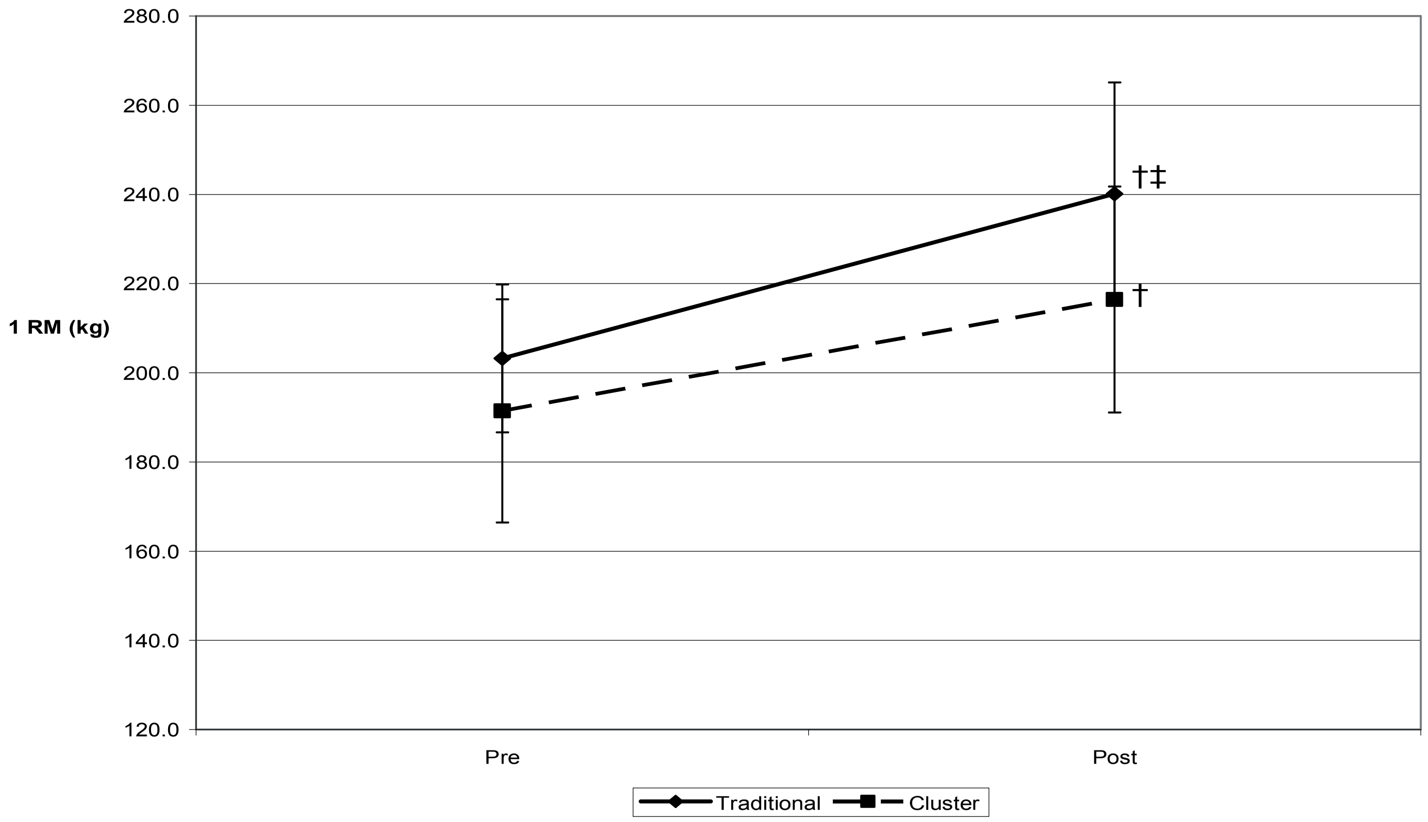

Figure 8.1: Back squat one repetition maximum (1RM) pre- to post-training for traditional training and cluster training groups.
† Significant within group difference pre-post training
‡ Significant difference between traditional and cluster post-training

Table 8.5: Mean percent change (± SD) and effect sizes for changes in maximum strength, peak power, peak velocity and peak force for the traditional and cluster groups with percent difference ± 90% confidence limits (CL) and qualitative practical inference of effect of the cluster intervention.

	Traditional		**Cluster**		**Difference Cluster - Traditional**	
Load	**Mean % Change ± SD**	**Effect Size**	**Mean % Change ± SD**	**Effect Size**	**% Change ± 90% CL**	**Qualitative Inference**
Maximum Strength						
Back Squat 1RM	18.3 ± 10.1	2.2	14.6 ± 18.0	1.0	-3.7 ± 10.5	Possibly Negative
Peak Power						
0 kg	2.3 ± 7.6	0.2	4.4 ± 7.1	0.3	2.2 ± 6.1	Unclear
20 kg	5.3 ± 7.4	0.4	3.5 ± 7.5	0.2	-1.8 ± 6.2	Possibly Negative
40 kg	1.0 ± 6.2	0.0	7.5 ± 7.0	0.9	6.5 ± 5.6	Likely Positive
60 kg	3.2 ± 5.3	0.2	4.8 ± 5.6	0.5	1.6 ± 4.5	Unclear
Peak Velocity						
0 kg	0.5 ± 3.8	0.10	3.8 ± 3.4	0.40	3.3 ± 3.0	Likely Positive
20 kg	2.5 ± 4.9	0.30	2.4 ± 3.9	0.30	-0.0 ± 4.4	Unclear
40 kg	0.0 ± 5.0	0.00	4.7 ± 6.1	0.60	4.7 ± 4.7	Likely Positive
60 kg	1.4 ± 3.6	0.10	3.5 ± 4.7	0.50	2.1 ± 3.4	Unclear
Peak Force						
0 kg	2.4 ± 6.4	0.4	2.7 ± 7.8	0.2	0.4 ± 5.9	Unclear
20 kg	1.6 ± 4.7	0.2	1.0 ± 3.4	0.1	-0.61 ± 3.4	Possibly Negative
40 kg	-0.1 ± 3.1	0.0	1.8 ± 2.4	0.2	1.8 ± 2.3	Possibly Positive
60 kg	1.6 ± 2.7	0.2	0.3 ± 2.8	0.0	-1.3 ± 2.6	Possibly Negative

RM = repetition maximum

8.5 DISCUSSION

The purpose of this study was to ascertain whether cluster set structures provided an enhanced training stimulus for lower body strength and power development when compared to a traditional training structure during the pre-season preparation of elite level rugby union players. Despite the assertion, based on acute studies focusing on cluster loading, that this technique may be ideal for the development of mechanical power, there were no previously published studies investigating lower body power development using this training approach. We found that a traditional training structure led to greater increases in maximum strength compared to cluster structures, but that cluster training may be beneficial for improving jump squat power and velocity.

Back squat 1RM increased significantly ($p < 0.05$) in both training groups over the course of the study. However, the training effect in the TT group (% change = 18.3 ±

10.1, ES = 2.2) were greater than those for the CT group (% change = 14.6 ± 18.0, ES = 1.0) and resulted in back squat 1RM being significantly greater in the TT group post-training. This corresponded to a possibly negative effect of cluster loading on maximum strength development. Although the TT group had a small amount of extra volume prescribed, this was unlikely to be enough to significantly effect training outcomes, so it seems that set structure was most likely to be the reason for these between group differences in adaptation. These findings are similar to those comparing traditional and cluster structures in developing upper body strength. Lawton and co-workers (127) reported that bench press maximum strength was increased 9.7% using a traditional set structure compared to 4.9% using a cluster structure. Our findings regarding back squat 1RM are similar to those of Lawton et al. in that maximum strength increased by 3.7% more in the traditional group. Therefore, although cluster loading was still able to elicit a large training effect for maximum strength in a highly trained group, it seems that a traditional training structure is more effective for developing maximum strength.

The theoretical basis of cluster set structures lies in the short rest periods between clusters of repetitions allowing for metabolic recovery through the replenishment of muscular PCr, improving the quality of each effort and subsequent training adaptation (81, 127, 128). Although this metabolic recovery may be beneficial for quality of movement and subsequent power adaptation, it seems that the strength adaptation may benefit from the build-up of metabolites. The literature suggests significant metabolite accumulation during high load strength training protocols (42). The importance of this metabolite accumulation to adaptation is unclear (71, 167), however there is some evidence that metabolic fatigue is an important precursor to both endocrine (122, 182) and neural (181, 182) responses to training. Therefore, it is possible decreased metabolite build up during cluster loading due to the recovery between clusters is counter-productive to strength development leading to improved strength adaption from a traditional training structure. This contention needs to be investigated using methodologies that account for the influence of metabolite accumulation on cluster loading for strength and power adaptation.

Neither training group significantly improved jump squat force, power or velocity through the course of the study. For the TT group, all effect sizes for these variables were either trivial or small. The only moderate effect sizes were for PP at 40 kg (ES =

0.9, % change = 7.5%) and PV at 40 kg (ES = 0.6, % change = 4.7%) for the CT group. Given the highly trained population who participated in the study and the relatively short training duration this is not overly surprising. The high additional training load undertaken by subjects during the training intervention may also have affected jump squat adaptation. This is a challenge inherent in the development of strength and power in sports such as rugby union. Indeed, in a similar study and population Harris and colleagues (94) reported decreases in jump squat power (% change = -6% to -17.1%) and velocity (% change = -2.4% - -7.5%) despite increases in maximum strength following high and moderate load jump squat training. It has been suggested that power development may be sensitive to interference during concurrent training (121), particularly in highly trained populations.

The design of the training intervention in terms of load selection and exercise order may have also affected power adaptation. As is typical of resistance training prescription in collision sports, the first six weeks of training was focused on high load lifting. High velocity jump squats were integrated quite late in the intervention (weeks seven and eight), which may not have allowed sufficient time for high velocity adaptation. An earlier introduction of high velocity jump squats in the training intervention may have improved the velocity and power adaptation. Additionally, jump squat training was performed following maximum strength training using a descending system with the heaviest load performed in the first set and the lightest in the final set. Although there is some support in the literature for this type of training structure (11), it may be that a training structure whereby ballistic training was performed in isolation, such as that utilised in the preceding acute study (Chapter 7) may have resulted in greater changes in explosive performance.

We found no statistically significant difference in changes in jump squat measures pre- to post-training between the TT and CT groups. However, we also used confidence limits and magnitude based inferences to assess the practical differences in training outcomes between groups. With this statistical procedure, inferences were made about the true value of the effect (of cluster loading) if a large population were sampled using 90% confidence limits (20, 21). This analysis suggested some practically positive effects in the use of cluster loading to develop power and velocity in the jump squat movement. There was a likely positive effect of CT when compared to TT for PP and

PV at 40 kg, and for PV at body weight (Table 8.5). The only PP or PV value to have a greater training effect in the TT compared to the CT group was PP at 20 kg (possibly negative effect for CT). Therefore, there was some evidence to support the contention, based on acute research and the importance of neural adaptation to ballistic performance, that cluster loading may be well suited to the development of velocity and power in ballistic movements. It may be that had the training intervention used in this study involved a longer ballistic (jump squat) training phase the advantages of cluster loading for ballistic velocity and power would have been further accentuated.

The positive effect of cluster training that was apparent for jump squat PP and PV was not evident with PF. Although at 40 kg there was possibly a positive training effect for the CT group, at 20 kg and 60 kg there was a possibly negative effect for CT, and at 60 kg PF was significantly greater for the TT group post training. Previous research has also suggested that increases in moderate load jump squat PF are associated with increases in back squat maximum strength (40, 134). That is, training interventions, which have a positive training outcome in terms of maximum strength development, may also increase PF in a ballistic movement such as the jump squat. Therefore, the traditional intervention, due to inducing greater maximum strength adaptation may be preferable in terms of training PF. It could, therefore, be concluded that to optimise ballistic power development a combination of training methods would be optimal, a traditional intervention for development of force capabilities and cluster training for the development of velocity of movement.

8.6 PRACTICAL APPLICATIONS

Due to the importance of strength and power in collision sports such as rugby union, resistance training is an important aspect of training for athletes competing at the elite level in these sports. For these athletes appropriate resistance training prescription is crucial for athletic development. In elite level rugby union players, cluster training structures do not provide a superior stimulus in the development of lower body maximum strength compared to a traditional loading structure. Although both a traditional structure and cluster structures could be prescribed for maximum strength, a traditional structure is likely to provide superior training outcomes. Cluster training does however present a viable training option for the development of lower body power at light to moderate external loads. Therefore, the practitioner should select the training structure, which is best suited to the individual training goals of the athlete. If high load performance and maximum strength is the key training objective then a traditional set structure should be used. If the development of explosive power and velocity at light to moderate loads is regarded as a more important training goal then a cluster structure may be preferable. It may be that an integrated approach that uses both loading schemes offers optimal training adaptation or at the very least offers athlete's variation that can address training monotony.

CHAPTER 9

SUMMARY AND CONCLUSIONS

9.1 SUMMARY OF FINDINGS

It is widely believed that developing the ability to express force quickly (high RFD) and achieve high PP rapidly is crucial in the training and development of elite athletes. However a relatively small body of experimental literature exists investigating the testing and training of these qualities in elite populations. The series of studies in this thesis has specifically investigated the assessment and training of lower limb explosive performance in an elite population. Firstly, we investigated previously discussed but poorly researched methods of assessing force and power characteristics of the lower limb particularly focusing on the analysis of the force-time and power-time curves during rebound jump squats. In Chapters 3, 4 and 5 methodological issues in analysing the force-time curve and the reliability of methods and measures used in jump squat assessment were evaluated. Second, we evaluated the relative importance of the most reliable measures investigated to functional performance of elite senior and junior rugby union players (Chapter 6). The final two experimental chapters investigated one of many resistance training methods which may be used to enhance the measures investigated in Chapters 3 - 5, cluster loading. Firstly, the acute mechanical stimulus were evaluated (Chapter 7) and second, the application of this training system over a short training period in an elite population was investigated (Chapter 8).

The rebound jump squat offers a sport-specific mode of power assessment due to the combined extension of the ankle, knee, hip and trunk in the movement, the ballistic nature of the movement and the presence of a SSC in the movement. It is the presence of the SSC that makes analysis of force-time characteristics of the jump more complex (compared to a concentric only movement). Therefore the first part of this thesis investigated how different analytic methods may affect findings during data analysis. The three methods for analysing the force-time curve during SSC jumps previously published were compared, investigating the effect on selected force-time measures. Results suggested that the choice of analytic methods can significantly affect force-time values for a number of measures. For force-time variables which assess rate of force development relative to PF (for example time to PF and index of explosive strength), values were significantly different between methods but these values were highly correlated whether the concentric phase is included in the analysis or both the eccentric and concentric phase are included in the analysis. However, when time-dependent variables (for example RFD at 100 ms or impulse at 100 ms) were investigated, the starting point of variable calculations resulted in significantly different numbers, which were not highly correlated suggesting the measurement of functionally independent physical qualities when different analytic methods were used.

In order for an assessment to be practically relevant / beneficial, its repeatability must be evaluated. The two most common technologies used in the assessment of jump squat force capabilities are the force plate and the linear position transducer. While both technologies have previously been shown to be reliable in measuring PF, the reliability of force-time variables measured with these technologies has not been thoroughly investigated in the literature. Our results concurred with previous research, suggesting that both the force plate and linear position transducer were reliable means of measuring PF. It was also evident that although PF values generated between the two technologies were significantly different, correlations between the two technologies were high to very high. The reliability of force-time measures varied considerably between measures and technologies. Specific measures had acceptable relative or absolute consistency with one or more technology. However, a number of measures did not have sufficient relative or absolute consistency for use in most practical or research applications. Generally, force-time variables calculated from force plate data tended to have greater relative and absolute consistency than those calculated from differentiated linear position transducer data.

These same technologies (linear position transducer and force plate) are also the most common means of measuring lower body power capabilities during the jump squat. An additional method utilised in power assessment involves the combination of force plate and linear position transducer data. The results reported in Chapter 5 were consistent with much of the previous research showing that PP can be measured reliably with any of the three methods, but that between day variation is greater when only differentiated linear position transducer data is used to measure PP. In Chapter 5 the reliability of a number of power-time measures were also investigated. Relative consistency of these power-time measures was generally comparable between methods and measures, and for many variables was acceptable. However, absolute consistency of most power-time measures was below that which would be deemed sufficient for use in research and practice where within subject changes are of interest. Results also showed that as with PF, there were significant differences between the values generated by the measurement apparatus for PP as a result of the biomechanical basis of the power calculations. Where the force plate calculates power applied to the systems COM, the linear position transducer and combined methods base power calculations on the velocity of the Olympic bar on the athleteǿs shoulders.

In terms of validating the measures of practical significance, the relative importance of force, velocity and power measures to functional activities and to athletic or sporting success needs to be quantified. Therefore, in Chapter 6, the force, velocity and power measures which differentiated speed performance and level of competition in elite and elite junior rugby players were assessed. This study found that the fastest and slowest sprinters over 10 m differed in PP expressed relative to body weight. Additionally, over 30 m there were significant differences in PV and relative PP and RPD calculated with a moving average between the fastest 20 and slowest 20 athletes. In terms of playing level, results showed no significant difference in speed over any distance between elite and elite junior rugby union players, however a number of force and power variables were significantly different between playing levels. Interestingly, whereas only power values expressed relative to body weight were able to differentiate speed performance, both absolute and relative force and power values differentiated playing levels in professional rugby union players. So where speed development requires the development of explosive qualities (specifically PP, PV and RPD) relative to body weight, due to the importance of momentum in collision sports, in the study population absolute force and power values were able to differentiate levels of competition (elite versus elite junior).

If the results of Chapters 3 to 6 are considered in their entirety, it would seem that (if replicating the data collection methodology used in these studies) traditional peak values are more appropriate measures than the temporal measures investigated. Peak power, PF and PV were generally more reliable (in both relative and absolute consistency) than the force-time and power-time measures investigated. In the sample used in these studies, they were also able to differentiate playing level and sports specific performance (sprinting). Although some temporal measures were also able to differentiate between playing level and sports specific performance, if the practitioner chose to use one or more of these measures they would be using a less reliable measure. Thus it would seem that in the population of elite rugby union players investigated in this study, further analysis of the force-time and power-time curve over and above the selection of peak values does not offer a great deal of additional value for the scientist or practitioner.

The second part of this thesis investigated the effect of a specific training intervention, cluster loading on force, velocity and power in the jump squat movement. Due to the importance of acute mechanical stimuli to subsequent neuromuscular adaptation following resistance training, we evaluated the effect of various cluster loading patterns on force, velocity and power during a ballistic jump squat at a moderate load. We found that PP was significantly lower for the traditional condition when compared to cluster configurations for the latter repetitions of a set of six repetitions. PV was also significantly less for the traditional condition compared to the cluster configurations for the latter repetitions of a set of six repetitions. Therefore, providing inter-repetition rest during a traditional set of six repetitions attenuated decreases in power and velocity of movement through the set. As many researchers have suggested that achieving high power and velocity of movement in training is an important mechanical stimulus for power adaptation, the contention that cluster loading is appropriate for explosive power training would tend to be supported by the results presented in Chapter 7.

The final part of this research investigated the application of cluster training structures to a typical pre-season lower body resistance training program in elite rugby union players. This represents a population for whom force and power capabilities are crucial to elite level performance (as established in Chapter 6). Both traditional and cluster configurations significantly increased maximum strength following the eight week training intervention. However the effect of cluster training on maximum strength adaptation was possibly negative. Like many previous studies investigating power development in similar populations, the changes in power and velocity capabilities for both the cluster and traditional training paradigms did not shift with the same magnitude as maximum strength. Indeed, there were no significant differences pre- to post-training for any jump squat force, velocity or power measures. This reinforces previous research, which has suggested that these are the more difficult qualities to change in short training periods where multiple training components are being undertaken simultaneously. However, there was a likely positive effect of CT when compared to TT for PP and PV at 40 kg and for PV at body weight. This positive training effect of cluster loading on explosive qualities may have been more pronounced had a training intervention with greater ballistic training volume (so the set profiles presented in Chapter 7 could be replicated) been implemented. However, it seems that alternative training paradigms such as cluster loading may have an application in populations such as the elite level rugby union players in this study in order to provide a change in stimulus and optimise power training adaptations.

9.2 SUMMARY OF PRACTICAL APPLICATIONS

Lower limb explosive capabilities are crucial in collision sports such as rugby union. The findings of the series of studies in this thesis have a number of important applications for strength and conditioning practitioners working in collision sports and other sports where lower limb explosive performance is of importance to elite level performance. These practical applications apply to both the assessment and training of lower limb force, velocity and power.

The jump squat is a commonly used assessment methodology in strength and conditioning practice. It is an easily implemented, compound, ballistic, SSC movement. The practitioner should be cognizant of the following key applications when applying this movement to lower limb muscular assessment in athletic populations:

i. The analysis of the force-time curve during a rebound jump squat is complex. When using time dependent measures, the point on the force-time curve from which variables are calculated will, in many cases, determine the information provided and whether you can compare results between athletes and/or studies.

Accordingly, method selection should be based on needs analysis of the task for which the athlete is being assessed.

ii. For tasks where concentric force development is deemed to be critical to performance, variables calculated relative to peak force (e.g. index of explosive strength, reactivity coefficient and time to PF) can be analysed using either method. However, if variables are calculated for a specific time period (e.g. impulse at 100 ms, RFD at 100 ms, force at 50 ms), analysis should commence at the start of the concentric phase. If the eccentric and concentric phase is of interest as a functional unit then analysis should commence at the lowest point on the force-time curve.

iii. The practitioner can utilise either the force plate or the linear position transducer to assess PF, plus the additional option of the combined method to measure PP. However the use of the linear position transducer increases within subject variation for both measures decreasing the precision of measurement in a test re-test situation and making definitive conclusions about training outcomes less likely.

iv. Measures of PF, PV and PP generated from the different technologies investigated although highly correlated were significantly different and therefore should not be compared under any circumstances in practice.

v. Very few power-time or force-time measures during a rebound jump squat have sufficient absolute consistency for use in test retest situation. Traditional peak values generally offer greater precision of measurement. However, a number of temporal force and power measures have sufficient relative consistency for applications where determining the rank order of a population is of interest (for example talent identification).

vi. In this research PV and PP and RPD relative to body weight, differentiated fast from slow rugby union players. These variables can therefore be used by the strength and conditioning coach to track training adaptation during resistance training for speed development. As the traditional values of PV and PP provide a more reliable methodology, they may be preferred.

vii. For the rugby union players used in this study, a number of force and power variables differed significantly between playing levels. These included PF, PP, force at 100 ms from minimum force and force and impulse at 200 ms from minimum force. These variables can be used in talent identification and in tracking training interventions in elite rugby union players. Due to the importance of momentum in collision sports tracking absolute values may be of greatest importance.

The cohorts used in these studies were elite senior and elite junior rugby union players, a population for whom the development of strength and power is an important component of athletic development. Cluster training structures have been suggested as an appropriate training prescription for developing muscular power. The prescription of these training structures is appropriate for rugby union players. The practitioner should be cognizant of the following key applications when considering applying cluster structures in resistance training prescription for athletes.

i. Using training structures such as those investigated in this thesis during moderate load ballistic movements, decreases in power and velocity of movement associated with the latter repetitions of a set of jump squats can be reduced by the use of cluster loading configurations. If the training objective is to optimise power and velocity of movement, cluster configurations are an appropriate prescription for the practitioner.
ii. In elite level rugby union players, cluster training structures do not provide a superior stimulus in the development of lower body maximum strength compared to a traditional loading structure. When using a mixed load training approach, if maximum strength is the key training objective a traditional training structure is the more appropriate prescription.
iii. Cluster training does however present a viable training option for the development of lower body power at light to moderate external loads. If the development of explosive power and velocity at light to moderate loads is

regarded as the most important training outcome cluster loading provides an appropriate training stimulus.

iv. It is likely that an integrated approach that uses both loading schemes offers optimal training adaptation or at the very least offers athleteĉs variation that can address training monotony.

9.3 AREAS FOR FUTURE RESEARCH

The studies in this thesis have investigated questions concerned with the testing and training of force, velocity and power in an elite highly trained population. The studies have provided results that have tangible applications for practitioners working with similar populations to the participants in these studies. However, there are a number of areas where future research would provide greater understanding and further advance strength and conditioning practice.

The temporal measures of force and power investigated in this study have received very little previous research attention. In the rebound jump squat that we investigated, the reliability of many of these measures was problematic, particularly in terms of absolute consistency. Future research that quantifies the reliability of these measures during other high velocity movements may be beneficial. For example, we investigated a rebound jump squat methodology that was very simple for the practitioner to implement. However, using a concentric only jump or controlling countermovement depth may improve the reliability of power-time and force-time measures. The population investigated in this study were elite and elite junior rugby union players. In Chapter 6 the importance of force-time and power-time measures in this cohort were assessed. However, success in other sports and other athletic activities may be defined by a different set of temporal measures. Thus the application of the measures investigated to other athletic populations may also warrant investigation.

Our investigation of cluster training configurations involved two studies. In the first the mechanical responses in terms of force, velocity and power, to various cluster configurations were investigated. While understanding of mechanical stimuli are important for the practitioner to be aware of the nature of the training stimulus, other stimuli need to be investigated in order to further understand the way in which cluster configurations change the training stress during resistance training. Therefore, future research should investigate acute metabolic and hormonal responses to cluster training to ascertain how these are different to a traditional training paradigm. The body of literature would also benefit from investigation of acute mechanical responses when using other external loads to those investigated in this study and during other movement patterns such as Olympic style lifts.

The second cluster loading study (Chapter 8) investigated strength/force, velocity and power adaptations to cluster training structures implemented during the pre-season preparation of elite level rugby union players. It is clearly important that research is conducted in elite level populations, however the limitations and difficulty of elite level research particularly in team sports are well documented (147). Chapter 8 had some of these limitations; it was conducted over a short training period, with a small sample size, in a population undertaking a number of training components. Therefore, larger training studies, which have a longer training duration, and in other athletic populations, are needed to add to the understanding of training adaptations following cluster training.

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APPENDIX A: Subject Information Sheet and Informed Consent Chapters 3, 4, 5 & 6

Information Letter to Participants / Informed Consent form
for the study
Reliability of force-time and power-time variables during the loaded jump squat and their relationship to functional performance tasks.

Thank you for volunteering to participate in my research. This study has been approved by the Edith Cowan University Ethics Committee. This documentation is designed to provide you with information on the purpose and nature of the study. Please do not hesitate to ask if you would like further information. Also remember you are entitled to withdraw yourself from the research at any time without penalty.

Purpose of the Study
This research has two aims;
(i) Investigate the reliability of a variety of strength and power measures during the loaded jump squat
(ii) Investigate the relationship between selected force-time and power-time variables of the jump squat and the relationship to 5, 10 and 30 metre sprint times.

Research Outline
As part of your pre-season strength and conditioning program you perform loaded jump squats, vertical jumps and sprint testing for diagnostic and tracking purposes. If you agree to take part in this research, data generated during this testing program will be further analysed to establish the repeatability of a number of measures of athletic performance and their interrelationships.

Measurements of Athletic Performance
The tasks from which data will be analysed include:

40 kg Jump Squat
Following a standardised warm-up, you will perform three jump squats with an external load of 40kg. You will start this jump squat standing at a self-selected foot width with an Olympic bar placed on their your upper back. You will then perform a countermovement to a self-selected depth and immediately ñjump for maximum heightò. You will be asked to keep the depth of countermovement consistent between jumps. This is identical to the technique typically used in testing and training at the club.

Vertical Jump Height
You will be asked to perform three unloaded countermovement jumps with one minuteôs rest between trials. Jump height will be directly measured during the jumps using a displacement transducer attached to an unloaded lightweight synthetic bar.

Sprint Speed

You will be asked to perform three 30m sprints with approximately four minutes between sprints. You will be asked to start in a two-point crouched position with the left toe 30cm back from the starting line and the right toe approximately in line with the heel of the left foot. Sprint times will be collected on an indoor rubber-based artificial training surface (indoor training centre).

Requirements

You will not be asked to perform any tasks outside of the scheduled testing and training program required as part of your normal strength and conditioning program.

Risk and Ethical Considerations

As with any aspect of your strength and conditioning program, there is a risk of delayed onset muscle soreness and a small risk of muscular injury. The risk of such issues is decreased by thorough preparation, including being familiar with the exercise techniques involved in the study and the implementation of an incremental warm-up.

The findings of this study will be submitted for publication; however your anonymity will be protected at all times. All information that can be identified with each individual will be kept confidential by the principal researcher at all times.

Queries and Questions

If you have any further queries regarding the research project you can contact either the principal researcher, Keir Hansen (keir@wrfc.co.uk or keirhans@gmail.com, Ph +44-7702-776109) or Associate Professor Dr John Cronin (john.cronin@aut.ac.nz, +64-9-912999 x7523).

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:
Kim Gifkins (Research Ethics Officer)
Building 1, Block 'B', Level 3, Room 333,
Edith Cowan University, 100 Joondalup Drive,
JOONDALUP WA 6027
Phone: (+61 8) 6304 2170
Email: research.ethics@ecu.edu.au
Website: http://www.ecu.edu.au/GPPS/ethics

Thank you for agreeing to participate in this research.

Keir Hansen

Declaration

I have been informed that jump squat, vertical jump and sprint data collected as part of my pre-season training program will be analysed for this research project. I understand that this analysis will not only help improve the assessment of human muscular power performance, but also help my coaches in my strength diagnosis and prescription of my power training.

I ____________declare that I have been provided with, read and understood a copy of the information letter, explaining this research project, its purposes and requirements.

I have been given the opportunity to ask any questions and have had these questions answered to my satisfaction.

I am aware that if I have additional questions I can contact either the principle researcher (Keir Hansen) or Associate Professor John Cronin

I understand that the information provided will be used only for the purposes of this research, be kept confidential, and that my identity will not be disclosed without my consent.

Given this, I freely agree to participate in this research project and understand that I am free to withdraw from further participation at any time, without explanation or penalty.

Signed:_______________________

Date:_________________________

APPENDIX B: Subject Information Sheet and Informed Consent Chapter 7

Information Letter to Participants / Informed Consent form
for the study
The effect of set structure on selected force-time and power-time variables during a training bout in the jump squat.

Thank you for volunteering to participate in my research. This study has been approved by the Edith Cowan University Ethics Committee. This documentation is designed to provide you with information for you on the purpose and nature of the study. Please do not hesitate to ask if you would like further information. Also remember you are entitled to withdraw yourself from the research at any time without penalty.

Purpose of the Study

The purpose of this project is to investigate the effect of the structure of a strength training session (in terms of sets, repetitions and rest) on force and power parameters when training using the loaded jump squat. Of particular interest is the effect of breaking a training bout into small work blocks termed ñclustersò on force and power variables. We are trying to ascertain how training set structure affects force-time and power-time measures compared to traditional training measures such as peak force and peak power during training. We are also interested to investigate if cluster loading patterns provide a more appropriate method of training force-time and power-time variables than traditional loading patterns.

Research Outline

You will be asked to report for testing on four occasions at least 72 hours apart but within a period of two weeks. Some of these sessions may be performed within your normal strength training program, but some may require additional training sessions. Any additional session will not exceed 30 minutes in duration (including warm-up, cool down and recovery). In each session you will be asked to perform four sets of six repetitions of a jump squat loaded at 40 kg using the technique described below. This technique is identical to the technique we normally use in testing and training at the club. Each session will involve the sets being structured with different amounts of rest between ñclustersò of repetitions. These sessions will be performed in a randomised order. The training structures are as follows:

(i) Traditional loading: 4 x 6 repetitions with 3 minutes between sets.
(ii) Cluster 1: 4 x 6 x singles (1 repetition) with 15 seconds rest between repetitions and two minutes between sets.
(iii) Cluster 2: 4 x 3 x doubles (2 repetitions) with 30 seconds rest between pairs and 2 minutes between sets.
(iv) Cluster 3: 4 x 2 x triples (3 repetitions) with 75 seconds rest between triples and two minutes between sets.

Measurements of Athletic Performance

The only task from which data will be analysed include is the loaded jump squat with a 40kg external load. Following a standardised warm-up, you will perform four sets of six jump squats with an external load of 40kg using one of the aforementioned set structures. This involves standing at a self selected foot width with an Olympic bar placed on your upper back. You will then perform a countermovement to a self selected depth and immediately ñjump for maximum heightò. You will be asked to keep the depth of countermovement consistent between jumps. This is identical to the technique typically used in testing and training at the club. Additional to force and power measures, heart rate data will be collected during each training bout, so you will be asked to wear a heart rate strap during data collection.

Requirements

You will be asked to perform four training sessions of no more than 30 minutes. The details of these sessions are outlined above. Some of these sessions may be performed within your normal strength training program, but some may require additional training sessions. Any additional training sessions will be scheduled to ensure no impact on your other training commitments.

Risk and Ethical Considerations

As with any aspect of your strength and conditioning program, there is a risk of delayed onset muscle soreness and a small risk of muscular injury. The risk of such issues is decreased by thorough preparation, including being familiarised with the exercise techniques involved in the study and the implementation of an incremental warm-up.

The findings or this study will be submitted for publication; however your anonymity will be protected at all times. All information that can be identified with each individual will be kept confidential by the principal researcher at all times.

Queries and Questions

If you have any further queries regarding the research project you can contact either the principal researcher, Keir Hansen ((keir@wrfc.co.uk or keirhans@gmail.com, Ph +44-7702-776109) or Associate Professor Dr John Cronin (john.cronin@aut.ac.nz, +64-9-912999 x7523).

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JOONDALUP WA 6027
Phone: (+61 8) 6304 2170
Email: research.ethics@ecu.edu.au
Website: http://www.ecu.edu.au/GPPS/ethics

Thank you for agreeing to participate in this research.

Keir Hansen

Declaration

I have been informed of the procedures involved in this study. I understand that this analysis will not only help improve understanding training structures for developing human muscular power performance, but also help my coaches in understand which training structures are most appropriate for my athletic development.

I ____________declare that I have been provided with, read and understood a copy of the information letter, explaining this research project, its purposes and requirements.
I have been given the opportunity to ask any questions and have had these questions answered to my satisfaction.

I am aware that if I have additional questions I can contact either the principle researcher (Keir Hansen) or Associate Professor John Cronin

I understand that the information provided will be used only for the purposes of this research, be kept confidential, and that my identity will not be disclosed without my consent.

Given this, I freely agree to participate in this research project and understand that I am free to withdraw from further participation at any time, without explanation or penalty.

Signed:______________________

Date:________________________

APPENDIX C: Subject Information Sheet and Informed Consent Chapter 8

Information Letter to Participants / Informed Consent form
for the study
The effect of set structure during eight weeks of high-velocity resistance training on force-time and power-time variables in a loaded jump squat.

Thank you for volunteering to participate in my research. This study has been approved by the Edith Cowan University Ethics Committee. This documentation is designed to provide you with information for you on the purpose and nature of the study. Please do not hesitate to ask if you would like further information. Also remember you are entitled to withdraw yourself from the research at any time without penalty.

Purpose of the Study

Inter-rep rest or ñclusterò loading is a term used to describe training structures where, sets (during strength and power training) are broken into small ñclustersò of repetitions with short rest periods in between. The purpose of this project is to compare the effect of cluster arrangements during lower limb resistance training over 8 weeks on force-time and power-time variables, and functional performance (sprinting). We are trying to ascertain whether cluster loading patterns provide a more appropriate method of training rate dependant force and power variables than traditional loading patterns. Of particular interest is the effect of different set structures on force-time and power-time measures following the implementation of a training program using ballistic resistance training.

Research Outline

Over pre-season you will be undertaking a comprehensive strength training program including two sessions a week specifically targeting the development of lower body strength and power. This training program will be preceded by a testing program profiling your lower body strength, power and speed, and these qualities will be re-assessed at the end of your 8 week pre-season program. Table 1 outlines the structure of the testing and training program. Should you agree to participate in this research, you will be allocated to either a control group using a traditional structure in training or a cluster group using cluster loading in training.

Table 1: Structure of testing and training over the next 10 weeks.

Week 1	Test session 1: Jump Squat Testing, Speed Testing Test session 2: 1RM Testing
Weeks 2-9	Training: 2 x lower limb strength-power training sessions (including jump squats).
Week 10	Test session 1: Jump Squat Testing, Speed Testing Test session 2: 1RM Testing

Measurements of Athletic Performance

The tasks from which data will be analysed include:

Jump Squat

Following a standardised warm-up, you will asked to perform three jump squats each, at body weight, then at a variety of external loads between 0kgs and 60kgs using a technique identical to that typically used in training and testing at the club. This involves standing at a self selected foot width with an Olympic bar placed on your upper back. You will then perform a countermovement to a self selected depth and immediately ñjump for maximum heightò. You will be asked to keep the depth of countermovement consistent between jumps.

Sprint Speed

You will be asked to perform three 30m sprints with approximately four minutes between sprints. You will be asked to start in a two point crouched position with the left toe 30cm back from the starting line and the right toe approximately in line with the heel of the left foot. Sprint times will be collected on an indoor rubber based artificial training surface (indoor training centre).

Back Squat 1RM

Prior to testing you will perform a series of warm-up sets of the back squat with loads gradually increasing from 70% to 85% of your estimated 1RM. At the completion of this warm-up, you will be required to complete a series of single repetitions increasing the external load on the bar at increments of 5kg until a lift can no longer be completed. Starting weight will be determined based on previous test data. Depth will be visually regulated by the tester with you descending to a depth whereby a line between the greater trochanter (hip) and the lateral malleolus (knee) is parallel with the floor prior to ascent for the lift to be acceptable.

Requirements

This research will not require you to undertake any testing or training which you donôt typically undertake as part of your pre-season preparation. The volume and intensity (sets, reps, load and total rest) will not be adjusted if you are allocated to the cluster loading group. Only the structures of your training will be modified. You will still take part in team training, skill, and conditioning sessions as you normal. You will be asked to continue with your normal nutritional and recovery strategies during the course of the study.

Risk and Ethical Considerations

As with any aspect of your strength and conditioning program, there is a risk of delayed onset muscle soreness and a small risk of muscular injury. The risk of such issues is decreased by thorough preparation, including being familiarised with the exercise techniques involved in the study and the implementation of an incremental warm-up.

The findings or this study will be submitted for publication; however your anonymity will be protected at all times. All information that can be identified with each individual will be kept confidential by the principal researcher at all times.

Queries and Questions

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Thank you for agreeing to participate in this research.

Keir Hansen

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I have been informed of the procedures involved in this study. I understand that this analysis will not only help improve understanding training structures for developing human muscular power performance, but also help my coaches in understand which training structures are most appropriate for my athletic development.

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I understand that the information provided will be used only for the purposes of this research, be kept confidential, and that my identity will not be disclosed without my consent.

Given this, I freely agree to participate in this research project and understand that I am free to withdraw from further participation at any time, without explanation or penalty.

Signed:_______________________

Date:_________________________

APPENDIX D: Statement of Contribution of Others

Statement of Contribution of Others for Thesis Submitted for the Degree of Doctor of Philosophy, by Keir Hansen, School of Exercise, Biomedical and Health Sciences, August 2011.

The following publications are included in this thesis.

Chapter publication reference	Author %
Chapter 2 (Section 2.3)	
Hansen, K.T. & Cronin, J.B. (2009). Training loads for the development of lower body muscular power during squatting movements. *Strength and Conditioning Journal,* 31 (3), 18-33.	KH 90% (literature searching, data analysis & manuscript preparation), JC 10% (manuscript review & critique)
Chapter 3	
Hansen, K.T., Cronin, J.B. & Newton, M.J. (2011). Three methods of calculating force-time variables in the rebound jump squat. *Journal of Strength and Conditioning Research,* 25 (3), 867-871.	KH 85% (research design, data collection & analysis, manuscript preparation & review), JC 10% (research design, manuscript review), MN 5% (research design, manuscript review).
Chapter 4	
Hansen, K.T., Cronin, J.B. & Newton, M.J. (2011). The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes. *Journal of Strength and Conditioning Research,* 25 (5), 1447-1456.	KH 85% (research design, data collection & analysis, manuscript preparation & review), JC 10% (research design, manuscript review), MN 5% (research design, manuscript review).
Chapter 5	
Hansen, K.T., Cronin, J.B. & Newton, M.J. (2011). The reliability of linear position transducer, force plate and combined measurement of explosive power-time variables during a loaded jump squat in elite athletes. *Sports Biomechanics,* 10 (1), 46-58.	KH 85% (research design, data collection & analysis, manuscript preparation & review), JC 10% (research design, manuscript review), MN 5% (research design, manuscript review).
Chapter 6	
Hansen, K.T., Cronin, J.B., Pickering, S.L. & Douglas, L. (In Press). Do force-time and power-time measures in a loaded jump squat differentiate between speed performance and playing level in	KH 80% (research design, data collection & analysis, manuscript preparation & review), JC 10% (research design, manuscript review),

elite and elite junior rugby union players? *Journal of Strength and Conditioning Research.*	SP 5% (data collection, manuscript review), LD 5% (data collection, manuscript review)
Chapter 7 Hansen, K.T., Cronin, J.B. & Newton, M.J. (In Press). The effect of cluster loading on force, velocity and power during ballistic jump squat training. *International Journal of Sports Physiology and Performance.*	KH 85% (research design, data collection & analysis, manuscript preparation & review), JC 10% (research design, manuscript review), MN 5% (research design, manuscript review).
Chapter 8 Hansen, K.T., Cronin, J.B., Pickering, S.L. & Newton, M.J. (2011). Does cluster loading enhance lower body power development in pre-season preparation of elite rugby union players? *Journal of Strength and Conditioning Research.* 25 (8), 2118-2126.	KH 80% (research design, data collection & analysis, manuscript preparation & review), JC 10% (research design, manuscript review), MN 5% (research design, manuscript review), SP 5% (data collection, manuscript review)

I, *Keir Hansen*, contributed to the above listed publications at the stated level.

Signed: Date: 21.7.2011

I, as a co-Author, endorse that the level of contribution to the listed publications by the candidate and co-authors as indicated above is appropriate.

Professor John B. Cronin John Cronin Date: 21.7.2011

Dr Michael J. Newton Date: 21.7.2011

Stuart L. Pickering Stuart Pickering Date: 21.7.2011

Lee Douglas Lee Douglas Date: 21.7.2011

APPENDIX E: Abstracts for Published Experimental Papers, Chapters 3-8

Chapter 3: Three methods of calculating force-time variables in the rebound jump squat.

The force-time qualities of the lower limb of athletes have been assessed using a variety of exercises and methodologies. The purpose of this study was to investigate the differences between three methods previously used to calculate various force-time measures during a rebound jump squat. Twenty five professional rugby players performed three jump squats, each of which was analysed using three different methods of calculation for a number of force-time variables. Method one analysed the force-time curve from minimum force to maximum force, method two analysed the concentric portion of the force-time curve only and method three analysed both the eccentric and concentric components of the force-time curve. Significant differences were found ($p<0.001$) between all three methods of analysis (% difference 1.1% - 364.3%) for all of the force-time variables calculated. However, a number of variables had very high ($r = 0.76$ ï 0.86) or practically perfect ($r = 0.93$ - 1.00) correlation coefficients between analysis methods showing similar rank order of the population regardless of the analysis methods utilised. The results suggested that force-time variables which assess rate of force development relative to peak force produce significantly different values, but these values are highly correlated whether the concentric phase is included in the analysis or the eccentric and concentric phase are included in the analysis. However, when time-dependent variables are investigated the starting point of calculation results in the measurement of functionally independent physical qualities.

Chapter 4: The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes.

The best method of assessing muscular force qualities during iso-inertial stretch shorten cycle (SSC) lower body movements remains a subject of much debate. This study had two purposes: Firstly, to calculate the inter-day reliability of peak force (PF) measurement and a variety of force-time measures, and, secondly, to compare the reliability of the two most common technologies for measuring force during loaded jump squats, the linear position transducer and the force plate. Twenty-five male elite level rugby union players performed three rebound jump squats with a 40kg external load on two occasions one week apart. Vertical ground reaction forces were directly measured via a force plate and force was differentiated from position data collected using a linear position transducer. From these data a number of force-time variables were calculated for both the force plate and linear position transducer. Intra-class correlation coefficient (ICC), coefficient of variation (CV) and percent change in the mean were used as measures of between-session reliability. Additionally, Pearsonôs product moment correlation coefficients were used to investigate inter-correlations between variables and technologies. Both the force plate and linear position transducer were found to be a reliable means of measuring PF (ICC = 0.88 ï 0.96, CV = 2.3% - 4.8%) and the relationship between the two technologies was very high and high for days one and two respectively (*r* = 0.67 - 0.88). Force-time variables calculated from force plate data tended to have greater relative and absolute consistency (ICC = 0.70 ï 0.96, CV = 5.1% - 51.8%) than those calculated from differentiated linear position transducer data (ICC = 0.18 ï 0.95, CV = 7.7% - 93.6%). Inter-correlations between variables ranged from trivial to practically perfect (*r* = 0.00 ï 1.00). It was concluded that PF can be measured reliably with both force plate and linear position transducer technology and these measurements are related. A number of force-time values can also be reliably calculated via the use of ground reaction force data. Although some of these force-time variables can be reliably calculated using position data, variation of measurement is generally greater when using position data to calculate force.

Chapter 5: The reliability of linear position transducer, force plate and combined measurement of explosive power-time variables during a loaded jump squat in elite athletes.

The purpose of this study was to determine the between day reliability of power-time measures calculated with data collected using the linear position transducer or the force plate independently, or a combination of the two technologies. Twenty five male rugby union players performed three jump squats on two occasions one week apart. Ground reaction forces were measured via a force plate and position data were collected using a linear position transducer. From these data a number of power-time variables were calculated for each method. The force plate, linear position transducer and a combined method were all found to be a reliable means of measuring peak power (ICC = 0.87 ï 0.95, CV = 3.4% - 8.0%). The absolute consistency of power-time measures varied between methods (CV = 8.0 ï 53.4). Relative consistency of power-time measures was generally comparable between methods and measures, and for many variables was at an acceptable level (ICC = 0.77 ï 0.94). Although a number of time dependent power variables can be reliably calculated from data acquired from the three methods investigated, the reliability of a number of these measures is below that which is acceptable for use in research and for practical applications.

Chapter 6: Do force-time and power-time measures in a loaded jump squat differentiate between speed performance and playing level in elite and elite junior rugby union players?

The purpose of this study was to investigate the discriminative ability of rebound jump squat force-time and power-time measures in differentiating speed performance and competition level in elite and elite junior rugby union players. Forty professional rugby union players performed three rebound jump squats with an external load of 40kg from which a number of force-time and power-time variables were acquired and analyzed. Additionally, players performed three sprints over 30 m with timing gates at 5 m, 10 m and 30 m. Significant differences ($p < 0.05$) between the fastest 20 and slowest 20 athletes, and elite ($n = 25$) and elite junior ($n = 15$) players in speed and force-time and power-time variables were determined using independent sample t-tests. The fastest and slowest sprinters over 10 m differed in peak power expressed relative to body weight. Over 30m there were significant differences in peak velocity and relative peak power and rate of power development calculated with a moving average between the fastest 20 and slowest 20 athletes. There was no significant difference in speed over any distance between elite and elite junior rugby union players, however a number of force and power variables including peak force, peak power, force at 100 ms from minimum force, and force and impulse 200 ms from minimum force were significantly ($p < 0.05$) different between playing levels. Whereas only power values expressed relative to body weight were able to differentiate speed performance, both absolute and relative force and power values differentiated playing levels in professional rugby union players. For speed development in rugby union players training strategies should aim to optimise the athleteǒs power to weight ratio and lower body resistance training should focus on movement velocity. For player development to transition elite junior players to elite status, adding lean mass is likely to be most beneficial.

Chapter 7: The effect of cluster loading on force, velocity and power during ballistic jump squat training.

The purpose of this study was to investigate the effect of set structure, in terms of repetition work:rest ratios on force, velocity and power during jump squat training. Twenty elite and elite junior rugby players performed training sessions comprising 4 sets of 6 repetitions of a jump squat using four different set configurations. The first involved a traditional configuration (TT) of 4 x 6 repetitions with 3 minutes rest between sets, the second (CT1) 4 x 6 x singles (1 repetition) with 12 seconds rest between repetitions, the third (CT2) 4 x 3 x doubles (2 repetitions) with 30 seconds rest between pairs, and the third (CT3) 4 x 2 x triples (3 repetitions) with 60 seconds rest between triples. A spreadsheet for the analysis of controlled trials which calculated the p-value, and % difference and Cohens effect size from log-transformed data was used to investigate differences in repetition force, velocity and power profiles between configurations. Peak power was significantly lower ($p < 0.05$) for the TT condition when compared to CT1 and CT3 for repetition 4, and all cluster configurations for repetitions 5 and 6. Peak velocity was significantly lower ($p < 0.05$) for the TT condition compared to CT3 at repetition four, significantly lower compared to CT2 and CT3 at repetition five, and significantly lower compared to all cluster conditions for repetition 6. Providing inter-repetition rest during a traditional set of six repetitions can attenuate decreases in power and velocity of movement through the set.

Chapter 8: Does cluster loading enhance lower body explosive power development in pre-season preparation of elite rugby union players?

The purpose of this study was to ascertain whether cluster training structures led to improved power training adaptations in the pre-season preparation of elite level rugby union players. Eighteen highly trained athletes were divided into two training groups, a traditional training group (TT, N = 9) and a cluster training group (CT, N = 9) prior to undertaking 8 weeks of lower body resistance training. Force-velocity-power profiling in the jump squat movement was undertaken and maximum strength was assessed in the back squat prior to and following the training intervention. Two way analysis of variance and magnitude based inferences were used to assess changes in maximum strength and force, velocity and power values pre- to post-training. Both TT and CT significantly ($p < 0.05$) increased maximum strength post training. There was a possibly negative effect for CT on maximum strength when compared to TT (pre-post change = 14.6% ± 18.0 and 18.3% ± 10.1 respectively). There were no significant differences pre- to post-training for any jump squat force, velocity or power measures. However, magnitude based inferences showed there was a likely positive effect of CT when compared to TT for peak power (pre-post change = 7.5 ± 7.0% and 1.0 ± 6.2% respectively) and peak velocity at 40 kg (pre-post change = 4.7 ± 6.1% and 0.0 ± 5.0% respectively), and for peak velocity at body weight (pre-post change = 3.8 ± 3.4% and 0.5 ± 3.8% respectively). Although both a traditional and cluster training loading pattern improved lower body maximum strength in a highly trained population, the traditional training structure resulted in greater maximum strength adaptation. There was some evidence to support the possible benefit of cluster type loading in training prescription for lower body power development.