UNIVERSITY OF CHICHESTER

An accredited institution of the
UNIVERSITY OF SOUTHAMPTON

DEPARTMENT OF SPORT AND EXERCISE SCIENCES

Establishing the optimum resistance training load for maximal gains in mechanical power output

by

Jason Paul Lake

Thesis for the Doctor of Philosophy

This thesis has been completed as a requirement for a higher degree of the University of Southampton

August 2010

PAGINATED BLANK PAGES ARE SCANNED AS FOUND IN ORIGINAL THESIS

NO INFORMATION MISSING

UNIVERSITY OF CHICHESTER

An accredited institution of the University of Southampton

ABSTRACT

DEPARTMENT OF SPORT AND EXERCISE SCIENCES

Doctor of Philosophy

ESTABLISHING THE OPTIMUM RESISTANCE TRAINING LOAD FOR MAXIMUM GAINS IN MECHANICAL POWER OUTPUT

By Jason Paul Lake

The development of powerful muscle function is fundamental to the strength and conditioning process. Optimal load resistance training uses the load that maximises power output to more efficiently achieve this. However, research has shown that factors including measurement method and training status can significantly influence the optimal load. The five experimental studies of this thesis investigated these factors. First, the way in which the positive lifting phase is identified was examined to establish the underpinnings of ballistic resistance exercise preference over traditional alternatives. The results of this study showed that the positive lifting phase of ballistic resistance exercise did not consider the deceleration phase and when this was applied to traditional resistance exercise a greater portion of the positive lifting phase was spent accelerating the barbell. This finding suggested that the assumption of ballistic resistance exercise superiority is theoretically unfounded whilst potentially posing a greater risk of injury. The next three studies established the reliability and suitability of different methods used to measure resistance exercise power output. The second study revealed that the most practically applicable, theoretically sound and reliable method of obtaining power output used the barbell kinematics approach where the acceleration of the barbell was considered but body mass excluded. This may have important implications for field-based methods that are underpinned by this approach. The results of the third and fourth study reinforced the findings of study two. The third study considered whether neglecting horizontal barbell power caused the barbell kinematics approach to underestimate resistance exercise power output, and established that the horizontal contribution did not exceed 2%. The effect of bilateral asymmetries on barbell power output was examined in the fourth study and demonstrated that although ground kinetic side differences reached 21% they were not transmitted to left and right barbell end power outputs, with left and right bar end differences remaining below 4%. The barbell kinematics approach was then used in the fifth study, to show that stronger, more experienced individuals generated greater mean (17 to 35%) and peak (20 to 45%) power outputs and maximised mean and peak power with loads that were considerably less (3 to 15% of 1RM less) than their weaker, less experienced counterparts. Training status did not significantly affect power and optimal load reliability. To summarise, measurement methods should not be used interchangeably. The barbell kinematics approach is recommended to obtain resistance exercise power output but the optimal load should be prescribed on an individual athlete basis and routinely monitored for maximum accuracy.

Table of contents

List of figures

List of tables

Declaration of authorship

I, Jason Paul Lake declare that the thesis entitled Establishing the Optimum Resistance Training Load for Maximal Gains in Mechanical Power Output, and the work presented in the thesis are both my own and have been generated by me as the result of my own original research. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University;
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- Where I have consulted the published work of others, this is always clearly attributed;
- Where I have quoted from others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- None of this work has been published before submission.

Signed: ....

Date: 17/1/11

Acknowledgements

As with any study, this one could not have happened without the participants to whom I owe a debt of gratitude for their willingness to participate and their patience with me during the data collection, especially those who were called on more than once.

Special thanks needs to be given to the following people:

This project would not have been possible without the supervision of both Mike Lauder and Neal Smith. I must especially thank them for their help at the beginning in nurturing the original concept of this thesis. Although I often got the distinct impression that their nodded agreement was to stop me talking, their feedback was invaluable.

I have to thank both Russ Peters and Kathleen Anne Shorter. Between them but in different ways they spurred me on, allowed me to vent frustrations and generally supported my efforts during varying stages of my data collection and data processing.

Thank you.

I must also thank Adrian for his constant willingness to help and support me. Thank you.

Last but by no means least, my special thanks must go to my beautiful family, my wife Alison, and children George and Megan for whom I seem to have spent most of the last three years as somewhat of a recluse in the "nerd cave".

A very special thank you.

Definitions and abbreviations used

Acceleration: The rate of change of velocity with respect to time (metres per second per second [$m \cdot s^{-2}$]).

Ballistic resistance exercise: Resistance exercise where the load, whether barbell or barbell and body system, is projected by either throwing or jumping with a barbell.

Centre of mass: The point at which the mass of a system (participant, participant/barbell) is concentrated.

Coefficient of Variation: A ratio of the standard deviation of the difference between two measures and the mean of the difference between two measures. Used as an estimate of typical measurement error (See Batterham and George, 2000).

Correlation: The statistical relationship between two variables, varying between -1 and 1.

Displacement: A vector quantity describing the magnitude and direction of movement (metre [m]).

Dynamic resistance exercise: The traditional form of resistance exercise where the load, whether barbell or barbell and body system, is not projected.

Force: The capacity to perform physical work, the push or pull effect exerted on a body; reported in newtons (N) or normalised relative to an individuals body mass (newtons per kg of body mass [$N \cdot kg^{-1}$]).

Force platform: A device that is designed to record the equal and opposite force typically exerted against the ground during human movement in accordance with Newtons third law of motion.

Ground reaction force: The parameter that is equal and opposite to a force that is exerted against the ground; reported in newtons (N) or normalised relative to body mass (newtons per kg of body mass [$N \cdot kg^{-1}$]).

Hang power clean: A variation of the power clean that begins by lowering the bar from arms length at standing to approximately the mid-thigh (See Kawamori *et al.*, 2005).

Intraclass correlation: A statistical measurement quantifying the strength and direction of resemblance between two or more variables (See Batterham and George, 2000).

Jump squat: Jumping with a loaded barbell positioned as if performing a regular squat (See Stone *et al.*, 2003).

Limits of agreement: A method that compares the mean difference between and mean of two measures obtained from two different measurement methodologies to establish the degree of agreement between them (See Bland and Altman, 1986 and 2007).

Mass: The physical quantity of an object (kilogram [kg]).

Maximal muscle function: See definition of "maximum strength" below.

Maximum/maximal strength: An individual's ability to exert maximal force during dynamic movement; typically presented as the one repetition maximum: 1 RM.

Mean: A measure of central tendency, the average of a set of numbers.

Mechanical power output: The rate of work performed during resistance exercise; reported in watts (W) or normalised relative to body mass (watts per unit of body mass [$W \cdot kg^{-1}$]).

One repetition maximum: The resistance exercise load with which only one repetition can be performed using good technique; reported in kilograms (kg) or normalised relative to body mass (kg per kg of body mass [$kg \cdot kg \cdot bm^{-1}$]).

Optimal load: The load, typically presented relative to maximum strength (see above), with which the highest positive lifting phase mean or peak mechanical power output is achieved; considered optimal for the development of powerful muscle function (see below).

Powerful muscle function: The ability to generate large mechanical power outputs.

Power clean: Variation of the Olympic weightlifting clean where a barbell is lifted from the ground to the anterior deltoids primarily by lower limb movement (See Garhammer, 1980).

Reliability: The statistical quantification of the reproducibility of a measurement methodology during repeated measures (See Batterham and George, 2000).

Sampling Frequency: The amount of data samples recorded per second; usually in hertz (Hz).

Velocity: Vector quantity describing the rate and direction of displacement (metres per second [$m \cdot s^{-1}$]).

Weight: The product of an individuals body mass and the acceleration due to gravity (9.81 $m \cdot s^{-2}$).

Work: The product of a mass's displacement, calculated by multiplying the force exerted to an object by its displacement: force × displacement (joule [J]).

Chapter 1 - Introduction

Many aspects of sporting performance rely on powerful muscle function, that is, the ability to generate large mechanical power outputs (Cronin and Sleivert, 2005; Dugan *et al.*, 2004; Kawamori and Haff, 2004). Mechanical power output refers to the rate at which mechanical work is performed (Dugan *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008). Mechanical work quantifies the displacement of a mass:

Work = Force × Distance (Equation 1-1)

(Dugan *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008)

Mechanical power output can be calculated by multiplying the force exerted during movement by its velocity:

Power = Force × Velocity (Equation 1-2)

(Dugan *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008)

The development of powerful muscle function is a critical component of athlete preparation (Baker, 2001a; Kaneko *et al.*, 1983; Kawamori *et al.*, 2005; Stone *et al.*, 2003). However, a degree of uncertainty remains about what, if any is the most efficient training method for its improvement. Research has shown that powerful muscle function can be improved with resistance exercise by increasing the strength of skeletal muscle (the force component) or the speed at which strength can be expressed (the velocity component) (Stone *et al.*, 2003).

Optimal load resistance training has been shown to be a time efficient method of significantly improving both the force and velocity components of mechanical power output (Kaneko *et al.*, 1983; Lyttle *et al.*, 1996; Newton *et al.*, 2006b; Wilson *et al.*, 1993).

The optimal load refers to the resistance exercise load with which mechanical power output is maximised and it can be identified by studying the load-power relationship; the load component typically referring to a percentage of a baseline measure of maximal strength such as the one repetition maximum (1RM) (Kawamori and Haff, 2004). A graphical representation of a typical load-power relationship can be seen in Figure 1.

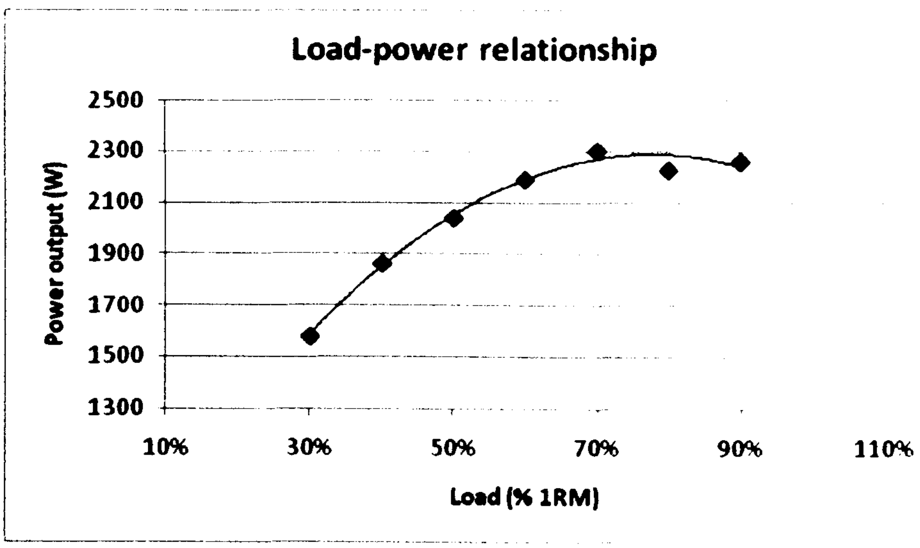

Figure 1-1. Load-power relationship of ballistic exercise performance, indicating an optimal load of 70% 1RM. Data adapted from hang power clean load-power relationship data published by Kawamori *et al.* (2005).

The prescription of the optimal load has historically relied on research that has shown that the optimal load occurs at around 30% of resistance exercise 1RM (Kaneko *et al.*, 1983; Wilson *et al.*, 1993; Lyttle *et al.*, 1996). However, recent research has shown that the optimal load can vary on an individual athlete basis because of many factors, which in turn may compromise the accuracy of training load prescription (Baker *et al.*, 2001a,b; Izquierdo *et al.*, 2001; Kawamori *et al.*, 2005; Siegel *et al.*, 2002; Stone *et al.*, 2003).

The training status of an individual has been shown to cause significant deviations from the classic 30% 1RM optimal load (Baker, 2002; Kawamori *et al.*, 2005; Stone *et al.*, 2003) and appears to be effected by both gender (Jandacka and Vaverka, 2008; Thomas *et al.*, 2007) and age (Izquierdo *et al.*, 2002). Further, study of the load-power relationship has shown that intra-individual performance variance can often exceed 30% of the mean value (Baker, 2002; Kawamori *et al.*, 2005; Stone *et al.*, 2003). This suggests that the optimal load should be prescribed on an individual basis. However, the repeatability of human performance during resistance exercise has not being considered. This could further compound the consequences of intra-individual performance variance and have important implications for any protocol of individualised load-power testing. Therefore it is vitally important that research is undertaken to help gain a greater understanding about the way in which the training status and repeatability factors affect the load-power relationship.

The way in which resistance exercise mechanical power output is measured appears to significantly influence the load-power relationship and in turn the optimal load (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008). The accurate measurement of resistance exercise mechanical power output relies on valid and reliable methods to measure the force that is exerted during resistance exercise and the resultant velocity of the mass of interest (Li *et al.*, 2008). However, there is evidence to suggest that many researchers mismatch (Li *et al.*, 2008) the force and velocity components used to calculate mechanical power output by deriving system centre of mass force and velocity from barbell kinematics (Cormie *et al.*, 2007b; Hori *et al.*, 2007; Winchester *et al.*, 2005). Further, the application of the basic theories that underpin the measurement of resistance exercise mechanical power output varies within the research literature (Baker *et al.*, 2001a, b; Baker, 2002; Bosco *et al.*, 1995; Burnett *et al.*, 2004; Cormie *et al.*, 2007b; Cronin *et al.*, 2004; Driss *et al.*, 2001; Dugan *et al.*, 2004; Frost *et al.*, 2008a, b; Garhammer, 1980, 1993; Haff *et al.*, 1997; Harris *et al.*, 2007; Hori *et al.*, 2007; Izquierdo *et al.*, 1999, 2001, 2002, 2004; Jandacka and Vaverka, 2008; Jennings *et al.*, 2005; Kaneko *et al.*, 1983; Kawamori *et al.*, 2005; Kilduff *et al.*, 2007; Li *et al.*, 2008; Lyttle *et al.*, 1996; McBride *et al.*, 2002; Moir *et al.*, 2005; Newell *et al.*, 2005; Newton *et al.*, 1996; Patterson *et al.*, 2009; Rahmani *et al.*, 2000, 2001; Shim *et al.*, 2001; Siegel *et al.*, 2002; Sleivert and Taingahue, 2004; Thomas *et al.*, 2007; Wilson *et al.*, 1993; Winchester *et al.*, 2005). This not only significantly inflates measures of resistance exercise mechanical power output but also has been shown to affect the load-power relationship (Cormie *et al.*, 2007b; Li *et al.*, 2008). Therefore it is vitally important that research is undertaken to help gain an understanding about how measurement methodology affects the resultant measures of resistance exercise mechanical power output.

Aims

With the above in mind, this thesis assesses the different methods that are used to measure resistance exercise mechanical power output, their effect and the effect that training status has on the load-power relationship:

- Field based methods of measuring barbell displacement tend to be limited to measuring the displacement of one end of the barbell. Recent research (Flanagan and Salem, 2007; Newton *et al.*, 2006a) has highlighted discrepancies in movement symmetry during lower-body resistance exercise. This thesis studies the effect that movement asymmetry has on barbell symmetry. It is hypothesised that movement asymmetry that occurs because of side dominance will significantly affect the symmetry of barbell displacement.

- Field based methods of measuring barbell displacement tend to be limited to the vertical plane only. This thesis examines the contribution that horizontal barbell displacement makes to total resistance exercise mechanical power output. It is hypothesised that a failure to consider this horizontal contribution will result in the significant underestimation of total resistance exercise mechanical power output.

- There is evidence to suggest that the way in which force and velocity are measured can significantly affect resistance exercise mechanical power output (Cormie *et al*, 2007b; Dugan *et al.*, 2004; Hori *et al.*, 2007). This thesis compares the different methods that are commonly used to measure resistance exercise mechanical power output. It is hypothesised that the method used will significantly affect the calculation of resistance exercise mechanical power output and the force and velocity components that underpin it.

- Little is known about the effect that training status, defined for the purpose of this thesis as the level of training experience and/or maximal strength, has on the load-power relationship. This thesis studies the load-power relationship of participants with varied resistance training experience and maximal strength. It is hypothesised that training status will significantly affect the load-power relationship, and as such the load with which mean and peak power is maximised, in addition to affecting mean and peak power and optimal load test-retest reliability.

Chapter 2 - Literature review

The development of a concept of an optimal resistance training load to improve powerful muscle function

In 1964 Richard Berger published the results of his study into the effects that manipulating resistance exercise load could have on powerful muscle function (in this case vertical jump ability). He showed that explosive jump squatting with moderate loads improved powerful muscle function more effectively than both unloaded jump squat and heavy back squat exercise, indicating the potential of eliciting specific training responses by manipulating resistance exercise load.

Kaneko *et al.* (1983) took this a stage further when they studied the effects that load specific elbow flexion exercise had on movement velocity, maximal strength and powerful muscle function. Their results supported their hypothesised load specific training effects; the training group that focused on movement velocity during their training showed the greatest improvements in movement velocity, the heavy resistance training group the greatest improvements in maximal strength, and the group that trained with 30% of their isometric maximum the greatest improvements in powerful muscle function. It was this 30% of isometric maximum training load that was later termed the optimal load (Wilson *et al.*, 1993). Perhaps what is more important, Kaneko *et al.* (1983) found that the movement velocity and maximal strength improvements reported in the optimal load training group closely matched those shown by the other groups, highlighting the potential of optimal load resistance training as an effort and time efficient method of improving both powerful muscle function and maximal strength (Kaneko *et al.*, 1983).

Repeat studies by many research groups also found that 30% of an individual's maximum strength was the optimal load whether exercise 1 RM (Lyttle *et al.*, 1996; McBride *et al.*, 2002) or the isometric maximum value (Wilson *et al.*, 1993) was the reference baseline measure of maximum strength.

Both Wilson *et al.* (1993) and McBride *et al.* (2002) studied the effect of squat jump training with this load, while Lyttle *et al.* (1996) studied the effect of both bench throw and squat jump training with this load. Their findings supported the contentions of Kaneko *et al.* (1983) that optimal load training developed both powerful muscle function and maximal strength. Their results also showed that optimal load training could be applied to both upper and lower-body resistance exercise with similar effects on powerful muscle function and maximal strength (Lyttle *et al.*, 1996; Wilson *et al.*, 1993).

Practical applications of optimal load training

More recent research has continued to support the contention that optimal load training is both an effort and time efficient method of training both powerful muscle function and maximal strength (Cormie *et al.*, 2007d; Harris *et al.*, 2008; Newton *et al.*, 2006b).

A recent study by Newton *et al.* (2006b) implemented optimal load training in a novel way by comparing the effects that heavy resistance exercise and optimal load training had on sports specific tests of powerful muscle function during the first seven weeks and last four weeks of the competitive female volleyball season. Although measures of vertical jump peak force remained relatively consistent following heavy resistance training, measures of powerful muscle function, including peak and average vertical jump power decreased. During the final stages of the active season participants undertook four weeks of optimal load training. They found that the measures of vertical jump peak force increased significantly from midseason. They also found that several measures of powerful muscle function improved significantly or remained consistent because of the optimal load training.

Harris *et al.* (2008) compared the effects of seven weeks of either heavy (80% 1RM) or optimal load jump squat training had on the sprint times of elite rugby league athletes. They found that there was no clear difference between the heavy and optimal load related improvements in 10 and 30 m sprint times. Improvements in maximal squat strength were also found, although the heavy load training improvements were slightly greater than those demonstrated by the optimal load training group. Their results were similar to those reported by Newton *et al.* (2006b), optimal load training helped maintain powerful muscle function to a greater extent than the heavy load training during the seven week training period. These findings further support the contention that a less physical and time demanding method of resistance training can maintain, and in many cases improve both powerful muscle function and maximal strength.

In an interesting twist to the application of optimal load training, Cormie *et al.* (2007d) have recently presented the results of the training effects of optimal load only and combined optimal and heavy load training. They found that in recreationally trained participants both optimal and combined optimal and heavy load training, significantly improved loaded jump squat height and power. Interestingly they found that the effects of the combined optimal and heavy load training tended to extend to the loaded jump squat heights and power in jump squats with heavier loads, loaded jump squat peak force and maximal strength. This is an exciting development in this field however; they urged caution in the interpretation of their results because of the relatively short duration of the training period and the training status of their participants.

Optimal load resistance training is an exciting concept because it appears to offer a time and energy efficient way of improving both powerful muscle function and maximal strength. However, there are some who have suggested that, although attractive, this method may be limited because optimal load power outputs tend not to differ significantly from the surrounding loads on the load-power relationship (Flanagan, 2008 (*in Chiu, 2008*); Harris *et al.*, 2008). This has led to the suggestion that the optimal load refers to a range of loads within the load-power relationship rather than one specific load (Harris *et al.*, 2007).

The exact mechanisms underpinning the specific adaptations associated with optimal load training remain largely unknown. However, it appears that by monitoring resistance exercise power output the relative intensity of resistance exercise can be controlled.

The concept of an optimal load for the development of powerful muscle function is an attractive one. However, in practical terms it relies on the accurate prescription of the appropriate resistance training load. There is a growing body of evidence to suggest that there are several factors that can influence the accurate prescription of the optimal load (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Frost *et al.*, 2008b; Jandacka and Vaverka, 2008; Izquierdo *et al.*, 2002). The primary factors are the way in which resistance exercise mechanical power output is measured (Cormie *et al.*, 2007a; Dugan *et al.*, 2004) and the resistance training experience/maximal strength of the individual (Baker, 2001; Izquierdo *et al.*, 2002; Kawamori *et al.*, 2005; Stone *et al.*, 2003), and as such a review of the effect that these factors can have on the determination of the optimal load will form the basis of the remainder of this chapter.

The measurement of resistance exercise mechanical power output - It's influence on the optimal load

The calculation of resistance exercise mechanical power output relies on accurate measures of the force and velocity component (Li *et al.*, 2008). The way in which these measures are measured has become increasingly popular and at the time of writing there were four key papers that had experimentally reviewed this issue (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008). Li *et al.* (2008) reported that one of three methods tended to be used to measure resistance exercise mechanical power output. These were based on either (1) position-time data, whereby the velocity of the barbell is multiplied by a force component derived from either the constant bar weight (Baker *et al.*, 2001a,b; Jennings *et al.*, 2005), the bar weight considering it's acceleration (Hori *et al.*, 2007; Izquierdo *et al.*, 2002), or the system centre of mass (bar and body) weight considering it's acceleration (Harris *et al.*, 2007); (2) force-time data, whereby the force component is directly measured using a force platform and is multiplied by the velocity of the system centre of mass, which is derived using the impulse-momentum relationship (Kawamori *et al.*, 2005; Li *et al.*, 2008); or (3) a combination of barbell displacement derived velocity, which is multiplied by ground reaction force (Cormie *et al.*, 2007b; Winchester *et al.*, 2005).

It is widely considered that the first position-time method makes little theoretical sense as it does not consider the acceleration of the bar to derive the force component of the power calculation only that of gravity, so will consistently underestimate the force required to accelerate it and thus the mechanical power output achieved (Cormie *et al.*, 2007b; Hori *et al.*, 2007). This is a concern as it is a popular alternative field test to "gold standard" laboratory equivalents (Jennings *et al.*, 2005). Despite the criticism it has received, early optimal load research was based on this method of calculating resistance exercise mechanical power output (Lyttle *et al.*, 1996; Wilson *et al.*, 1993). Further, a review of the results recently presented by Cormie *et al.* (2007b) indicates that although this method significantly underestimates peak force, the differences between this and the second position-time method are non-significant.

The other methods of measuring resistance exercise mechanical power output remain widely accepted despite their focus on different elements of resistance exercise performance and their reliance on assumptions of resistance exercise performance (Dugan *et al.*, 2004). A brief review of these assumptions follows.

The second position-time method considers only the movement velocity of the barbell when only the bar's mass is included in the calculation of the mechanical power output, or rate at which the mass of the bar is displaced through a given range of motion using a specific technique is measured (Hori *et al.*, 2007). However, when body mass is included in the calculations, the integrity of the method relies on how robust the assumption is that the bar's velocity represents that of system's centre of mass. While there are researchers that support this assumption (Cormie *et al.*, 2007a, b; Harris *et al.*, 2007), there are others that have questioned its validity (Hori *et al.*, 2007; Li *et al.*, 2008). It should be remembered that including body mass in the calculation of resistance exercise mechanical power output when using barbell position-time data tends to only be used during the jump squat exercise because it is thought that the bar and body move as one. Li *et al.* (2008) have suggested that the movement velocity of contributing body segments differ significantly from the movement velocity of the barbell so that any calculation of system mechanical power output made from the movement velocity of the bar will overestimate mechanical power. The potential for discrepancies will be discussed later in this section. However, it is important that researchers and practitioners who use barbell position-time data to calculate the force and velocity components necessary for the calculation of resistance exercise mechanical power output are aware that only barbell power, that is, the power output generated against the barbell, should be derived using this method. That this reminder is necessary is worrying as it signals that the way in which methods of measuring resistance exercise mechanical power output are selected may be limited to the simplicity of the movement without consideration for its theoretical underpinnings. Simplicity can be a valuable commodity in a method destined for use in the field (Carlock *et al.*, 2004; Falvo *et al.*, 2006). It is for this reason that this area warrants further research.

Another assumption of the position-time methods is that the displacement of the bar and/or body occurs primarily in the vertical plane with little displacement occurring in the horizontal plane (Cormie *et al.*, 2007b). Research by Garhammer (1980; 1993) into the barbell kinematics of Olympic weightlifting suggests that this may not be the case. Case study data presented by Garhammer (1993) showed that during the snatch and the clean horizontal barbell displacement may have contributed by as much as 10% to the total power output. However, there has since been a paucity of research in this area with a paper by Cormie *et al.* (2007a) being the only exception. When the contribution of horizontal barbell power output was considered during 30% 1RM jump squat performance the total barbell power output increased by less than 1%, but when considered during the 90% 1RM jump squat performance an increase of ~40% peak power output was found. The contribution that horizontal barbell displacement makes to the total (the sum of vertical and horizontal) barbell mechanical power output is not clear. This is another area that requires further research as many field based methods of measuring resistance exercise mechanical power output are limited to measurement of vertical barbell displacement only. Considering that the identification of the optimal load is based on the study of progressive loading surprisingly little is known about its effect on any horizontal contribution.

The use of a force platform enables researchers to directly measure the force exerted against the system (bar and body) centre of mass during resistance exercise. If this performance begins with the system mass on the platform (Kawamori *et al.*, 2005; Hori *et al.*, 2007), the platform has been calibrated correctly and instrumentation protocols followed, system centre of mass kinematics can be derived with confidence from the ground reaction force using a forward dynamics approach that is based on Newtonian mechanics (Driss *et al.*, 2001; Dugan *et al.*, 2004; Harman, 1991; Hori *et al.*, 2007; Kawamori *et al.*, 2005; Li *et al.*, 2008).

However some (Cormie *et al.*, 2007b; Dugan *et al.*, 2004) have questioned the validity of this method, suggesting that it underestimates resistance exercise mechanical power output. This is worrying because not only are the sound theoretical concepts underpinning this method been brought into question but the understanding of what is been measured appears, at best, to be questionable. With this in mind it bears repeating that when the force platform method is used the force component is measured directly, while the velocity component is derived from the pattern and magnitude of force over known periods of time (Harman, 1991; Kawamori *et al.*, 2005; Hori *et al.*, 2007). Any underestimation of resistance exercise mechanical power output from this method can only realistically be viewed because of an underestimation of the velocity component of the power calculation (Li *et al.*, 2008). However, there appears to be confusion within the literature (Cormie *et al.*, 2007b, Dugan *et al.*, 2004), although it is clearly illustrated by the data presented by Hori *et al.* (2007) in which the centre of mass movement velocity was significantly less than that of the barbell. For example, during loaded jump squat performance the peak barbell velocity was 2.23 (± 0.16) $m{\cdot}s^{-1}$ compared to the peak centre of mass velocity, which was 1.99 (± 0.12) $m{\cdot}s^{-1}$. More dramatic differences were found during hang power clean (Olympic weight variation) performance, where peak barbell velocity was 2.16 (± 0.25) $m{\cdot}s^{-1}$ compared to the peak centre of mass velocity, which was 1.48 (± 0.20) $m{\cdot}s^{-1}$. Including body mass in the calculation of jump squat peak power resulted in an overestimation of 374%, while the hang power clean equivalent was 244%. This was recently supported by Li *et al.* (2008) who took the typical analysis a stage further by comparing the movement velocities of anatomical landmarks to that of the barbell during jump squat performance, and in so doing demonstrated that the barbell velocity appeared to overestimate the velocity of the anatomical landmarks.

A further criticism of the methodology underpinning the force platform method has been how data are manipulated to derive centre of mass velocity data; it has been suggested that by dividing the net force to obtain centre of mass acceleration and then integrating this with respect to time to obtain centre of mass velocity may compromise the integrity of the data (Dugan *et al.*, 2004). This may be a valid point however it tends to ignore the manipulation that kinematic data must undergo for the calculation of the force component. The findings of Li *et al.* (2008) and Hori *et al.* (2007) are important as they indicate a critical factor that appears to be overlooked, in that the methods measure different elements of resistance exercise performance. However, there is a paucity of research evidence regarding the effect that progressive loading may have on the different elements of resistance exercise and how it effects measures of mechanical power output from these two methods; it is an area that needs further research.

A third method has been proposed that uses techniques that enable the direct measurement of both the force-by means of a force platform- and velocity by means of barbell motion analysis-component. However doubts already expressed in the previous section about methodological integrity resurface. The force component is directly measured by means of a force platform and is multiplied by the velocity of the barbell, which is directly measured by means of motion analysis (Cormie *et al.*, 2007b). It may appear an attractive method of measuring resistance exercise mechanical power output as it minimises the degree of manipulation that data must undergo. However, it reinforces the assertion that the criticism of the force platform method extends only to the use of calculations that are based on Newtonian mechanics to derive the system centre of mass velocity, which in turn is replaced by a method that appears to actually overestimate the velocity component (Li *et al.*, 2008).

Another factor that should be considered is what effect the type of resistance exercise may have on the validity of this method? If barbell velocity is not a true reflection of the system centre of mass during the jump squat exercise, how much does the pattern and magnitude of barbell velocity deviate from that of the system centre of mass during variations of the Olympics weight lifts? Cormie *et al.* (2007b) have argued that because the barbell pattern of displacement differs to that of the lifter during lifts like the power snatch or power clean, the displacement of the lifter's centre of mass need not be considered. Data published by Garhammer (1993) presents a strong case to the contrary, however. He found through in-depth motion analysis that a lifter's centre of mass may be displaced up to 0.46 m during snatch lift performance and that this could contribute around 15% to the total power output. Further, the end of the positive lifting phase of Olympic weight lift variations tends to be marked by the achievement of maximum vertical barbell velocity (Garhammer, 1980). However, this is achieved during a period in which the barbell's displacement is reliant on the momentum generated by the pull phase impulse. To this end it is reasonable to assume that any overestimation of system centre of mass velocity during jump squat performance will be further exacerbated during the performance of Olympic weight lift variations. However, investigation into this statement is beyond the scope of this thesis.

Training status: Its effect on powerful muscle function and the optimal load

Research findings have consistently highlighted the effect that an individual's training status can have on the load-power relationship and as such, optimal load (Baker, 2001; Izquierdo *et al.*, 2002; Kawamori *et al.*, 2005; Stone *et al.*, 2003). For the purposes of this thesis the term "training status" encompasses many of the physical aspects that appear to contribute to inconsistencies in optimal load related research. Simplistically training status refers to an individual's current level of maximal strength and/or powerful muscle function. This in turn may be affected by the demands of everyday tasks whether they be those of elite sports training or day to day living (Baker, 2001; Izquierdo *et al.*, 2002; Kawamori *et al.*, 2005; Stone *et al.*, 2003), current training demands (Baker, 2001), age (Izquierdo *et al.*, 1999; Joszi *et al.*, 1999; Lynch *et al.*, 1999) and gender (Jandacka and Vaverka, 2008; Joszi *et al.*, 1999; Thomas *et al.*, 2007).

According to one recent study, hang power clean (a variation of part of a competitive weight lift) optimal load was recorded at a relative intensity of 70% of the mean participant 1RM (Kawamori *et al.*, 2005). Taking their analysis a stage further however the authors found that training status, characterised in this case by maximal strength (1 RM), appeared to cause an optimal load variation of ~10%, with weaker participants achieving their optimal load with 80% rather than the 70% 1RM of their stronger counterparts (Kawamori *et al.*, 2005). This can be seen in Table 2-1.

Table 2-1. Percentage differences between the hang power clean peak and mean power outputs of different standard athletes.

Load (%1RM)	Peak Power Output (W)		Differences	Mean Power Output (W)		Differences
	Strong	Weak		Strong	Weak	
30	2873	3114	8.39%	1578	1138	27.88%
40	3587	3245	9.53%	1863	1442	22.60%
50	3774	3571	5.38%	2040	1546	24.22%
60	3983	3835	3.72%	2193	***1651***	24.72%
70	***4281***	3868	9.65%	***2303***	1618	29.74%
80	4070	***3982***	2.16%	2229	1623	27.19%
90	4193	3633	13.36%	2262	1559	31.08%
Mean	**3823**	**3606**	**7.46%**	**2067**	**1511**	**26.78%**
SD	**482**	**325**	**3.90%**	**264**	**178**	**3.08%**
Range	**1408**	**868**	**11.20%**	**725**	**513**	**8.48%**

*Data are adapted from data presented by Kawamori *et al.* (2005); Differences are presented as both absolute to show the direction of the difference, rectified to show the actual difference and are presented relative to the stronger participants. Group optimal loads are presented in bold italics.

Baker has consistently reported deviations from a generalised optimal load because of training status (Baker *et al.*, 2001a, b; Baker, 2002). He has reported that the optimal load of stronger athletes tends to be ~20% of their 1RM less than that of their less strong counterparts during jump squat performance, and that the training status differences were characterised by maximal strength, which was, in turn, a consequence of the athletes standard (Baker, 2001, 2002). In a study by Stone *et al.* (2003) differences of ~30% of the participant back squat exercise 1RM were found between the optimal loads of jump squat performances of stronger and less strong participants; stronger participant optimal load occurring at ~40% rather than the less strong participant at 10% squat 1RM. Some of the results presented by Stone *et al.* (2003) can be seen in Table 2-2.

These findings show that training status, classified by maximal strength, can significantly affect the load-power relationship and as such the optimal load. This suggests that the prescription of the optimal load should be performed on an individual basis.

Table 2-2. Percentage differences between the static start and countermovement jump squat peak power outputs of different standard athletes.

Load (%1RM)	CMJ (W) Strong	CMJ (W) Weak	Difference	SJ (W) Strong	SJ (W) Weak	Difference
10	5079	***3785***	25.48%	5464	***3482***	36.27%
20	5321	3751	29.51%	5517	3474	37.03%
30	5331	3650	31.53%	5502	3431	37.64%
40	***5391***	3296	38.86%	***5635***	3356	40.44%
50	5206	3129	39.90%	5377	3246	39.63%
60	5303	3167	40.28%	5243	3103	40.82%
70	4887	3256	33.37%	5042	2908	42.32%
80	4567	3364	26.34%	4845	2714	43.98%
90	4106	3025	26.33%	4605	2484	46.06%
100	3349	2033	39.30%	3664	1971	46.21%
Mean	**4854**	**3246**	**33.09%**	**5089**	**3017**	**41.04%**
SD	**668**	**502**	**6.10%**	**599**	**500**	**3.57%**
Range	**2042**	**1752**	**14.80%**	**1971**	**1511**	**9.94%**

*Data are adapted from data presented by Stone *et al.* (2003); CMJ= countermovement squat jump, SJ= static start squat jump. Differences are presented relative to the stronger participants. Group optimal loads are presented in bold italics.

The relationship between maximal strength, powerful muscle function and resistance exercise optimal load is well known (Baker, 2001; Izquierdo *et al.*, 2002; Kawamori *et al.*, 2005; Stone *et al.*, 2003), and as such factors that influence maximal strength should be considered in any discussion regarding the development of powerful muscle function. This moves the focus of this review from the effect that athlete standard can have on maximal muscle function and the subsequent differences in optimal load to that of age and gender.

It is well known that the ageing process can affect maximal, and as such, powerful muscle function (Frontera *et al.*, 1988; Hakkinen *et al.*, 1998; Joszi *et al.*, 1999; Lanza *et al.*, 2003; Petrella *et al.*, 2007). However, there is a paucity of research regarding the effect that age related declines in powerful muscle function may have on the optimal load. Results presented by Izquierdo *et al.* (1999) showed that there were differences between the optimal load of middle aged and older men of 40% 1RM when resistance exercise type was considered. Their results showed that age had little influence on the upper-body optimal load (bench press) but produced a difference of 10% 1RM in lower-body (squat) optimal load. Results from a training study by the same research group (Izquierdo *et al.*, 2001), supported the findings regarding ages effect on the upper and lower-body optimal load. When the training demands and differences in resistance exercise type of these studies were considered, optimal load inconsistencies of up to 40% 1RM were found; the optimal load demonstrating power training related shifts of up to 15%, which were exacerbated by the different resistance exercise types. This can be seen in Table 2-3.

Table 2-3. An example of the effect that age can have on the upper and lower-body resistance exercise optimal load.

	Squat Optimal Loads (%1RM)			Bench Press Optimal Loads (%1RM)		
Time	**Week 0**	**Week 8**	**Week 16**	**Week 0**	**Week 8**	**Week 16**
MA	60	70	60	30	45	30
OA	70	60	60	30	30	30
Difference	**-14.29%**	**16.67%**	**0.00%**	**0.00%**	**50.00%**	**0.00%**

*Data adapted from Izquierdo *et al.* (2001). 0= baseline measures; 8= after 8 weeks of heavy resistance training; 16= after 16 weeks of heavy resistance training; **MA**= middle aged (46 yrs) men; **OA**= older aged (64 yrs) men; Difference= absolute difference relative to the middle aged men.

It is generally accepted that gender can affect both maximal and powerful muscle function (Doldo *et al.*, 2006; Garhammer, 1991; Joszi *et al.*, 1999; Martel *et al.*, 2006). However, there is a paucity of research regarding the effect that gender can have on the optimal load. A recent paper by Thomas *et al.* (2007) presented data that showed differences in both the magnitude and pattern of the load-power relationship of male and female athletes during both upper and lower-body resistance exercise. Differences of ~10% 1RM were reported between male and female lower-body resistance exercise optimal load but not for upper-body resistance exercise. Jandacka and Vaverka (2008) showed that there were gender related differences of around 15% in both upper and lower-body resistance exercise optimal load.

Research by Joszi *et al.* (1999) may offer insight into the underlying mechanisms of a gender effect on the optimal load. Studying the effects of resistance training on the powerful muscle function of both young and elderly males and females Joszi *et al.* (1999) reported similar rates of improvement in male and female upper-body powerful muscle function but rates of improvement in lower-body powerful muscle function that were less in females when compared to their male counterparts.

One should consider that on the most basic level the mechanisms underlying the effect that training status, age and gender can have on the optimal load appear to be a consequence of differences of maximal strength and the physical demands of life. With this in mind there is currently a need for study into exactly how these factors influence resistance exercise optimal load so that the strength and conditioning or health care professional may better be able to monitor resistance training intensity. This adds further support to the contention that the optimal load should be prescribed on an individual basis.

In summary, there is a large body of research evidence to support the contention that the optimal load is a more efficient way of developing powerful function, but that it should be prescribed on an individual basis because of the way in which training status, age and gender appear to influence the load-power relationship. However, to achieve this researchers and practitioners need to understand the theories that underpin the methods that are currently popular for the measurement of resistance exercise mechanical power output as this is an area that has been shown to significantly affect the load-power relationship.

Chapter 3 - The way in which the positive lifting phase is determined affects lower-body resistance exercise force, velocity and power output

Introduction

The development of powerful muscle function, the ability to generate large mechanical power outputs, is a critical component of the strength and conditioning process for many athletes (Kawamori and Haff, 2004). Resistance exercise plays an integral part in this process improving the force and velocity components that underpin the calculation of power output (Li *et al.*, 2008).

Research evidence has shown that the barbell acceleration-time relationship is sensitive to whether the barbell is displaced in the dynamic manner associated with traditional resistance exercise or in the ballistic manner of resistance exercise throws and jumps (Newton *et al.*, 1996; Frost *et al.*, 2008b).

It has been suggested that ballistic resistance exercise is a more effective method of developing powerful muscle function than traditional resistance exercise because a significantly greater portion of the positive lifting phase is spent accelerating the barbell (Newton *et al.*, 1996). Newton *et al.* (1996) found that during ballistic upper-body resistance exercise 96% of the positive lifting phase was spent accelerating the barbell compared to 60% during traditional upper-body resistance exercise. This finding appears to have been widely applied to lower-body resistance exercise (Cormie *et al.*, 2007b, c, d; Frost *et al.*, 2008a, b; Wilson *et al.*, 1993), although data have yet to be published to support this assumption.

Recent research findings have suggested that the sensitivity of the barbell acceleration-time relationship may be influenced by the way in which the positive lifting phase is determined (Frost *et al.*, 2008b). This is important because performance measures like average force, average velocity and average power output are determined from the duration of the positive lifting phase. Because the way in which the positive lifting phase of resistance exercise is determined underpins the calculation of key performance measures it provides a logical point to begin addressing the aims of this thesis because of the affect that this could have on the load-power relationship.

Traditionally, the positive lifting phase of traditional and ballistic resistance exercise has been determined as the period between the beginning of positive barbell displacement and peak barbell displacement (Frost *et al.*, 2008b). However, Frost *et al.* (2008b) argued that the traditional approach to the determination of the positive lifting phase of traditional resistance exercise includes periods of deceleration that occur as the momentum of the barbell is arrested towards the end of its range of motion. The results of their study agreed with Newton *et al.* (1996) in terms of the differences that were found between the key measures of traditional and ballistic resistance exercise; the inclusion of the deceleration phase led to a significant underestimation of the key performance measures of traditional resistance exercise. However, the exclusion of this deceleration phase significantly reduced these differences, suggesting that the theoretical and practical superiority of ballistic resistance exercise may be inflated (Frost *et al.*, 2008b). An example of this is presented in (Figure 3-1) where the entire duration represents the traditional method, including the deceleration phase, which is indicated by decreasing barbell velocity, and the alternative method proposed by Frost *et al.* (2008b), where only the acceleration phase (period until peak barbell velocity) is used to determine the positive lifting phase.

It remains that differences between the kinetic (force and power) and kinematic (displacement and velocity) measures of traditional and ballistic lower-body resistance exercise have not been considered although a considerable amount of training related research attention has focused on the lower body. Therefore the primary aim of this study was to compare key kinetic and kinematic measures (see above) of traditional (back squat) and ballistic (jump squat) lower-body resistance exercise. A secondary aim of this study was to examine whether the way in which the positive lifting phase was determined would influence the kinetic and kinematic differences that are associated with traditional and ballistic resistance exercise comparisons. Research evidence (Newton *et al.*, 1996; Frost *et al.*, 2008b) underpinned the hypothesis that key kinematic and kinetic measures would be significantly greater during ballistic performance but that this would be a consequence of the way in which the positive phase was determined. The results of this study will be used to inform exercise selection for subsequent experiments that will address the primary aims of this thesis.

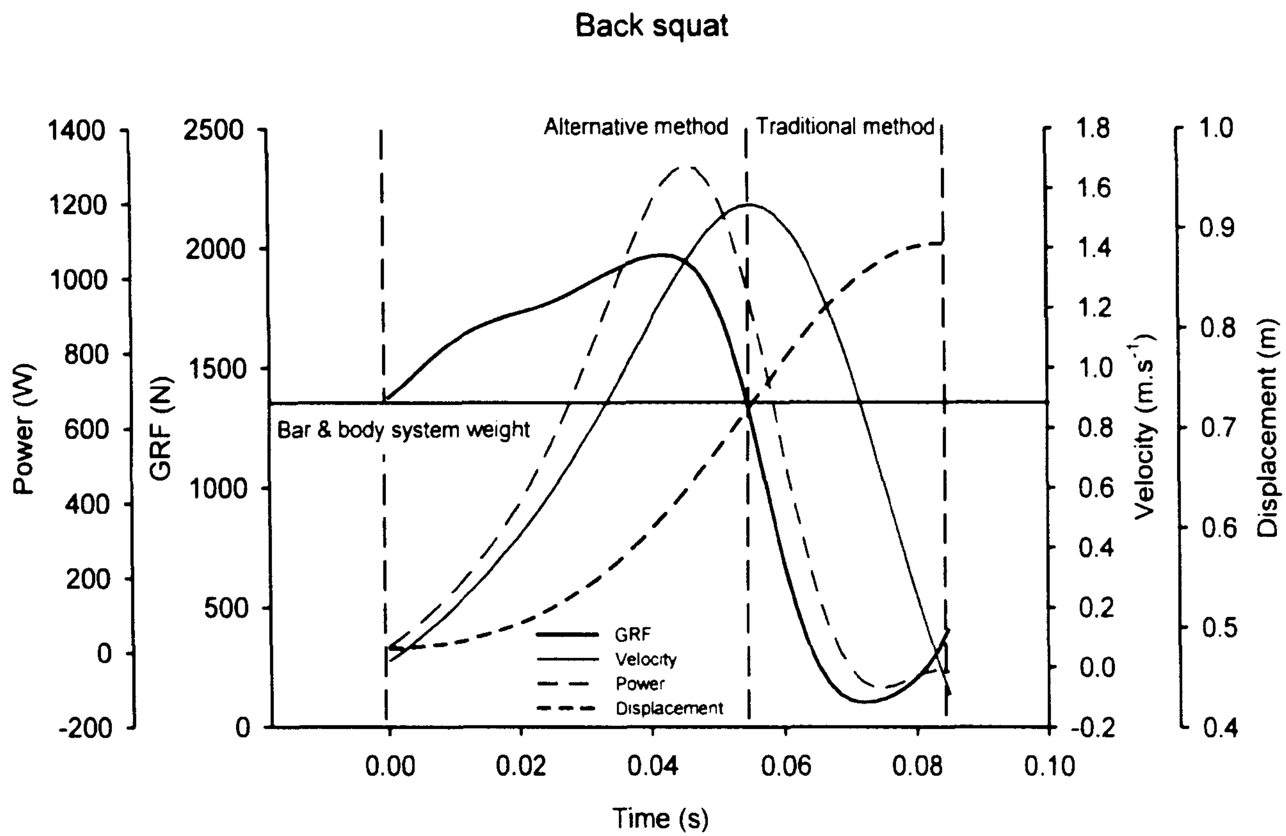

Figure 3-1. A graphical illustration of the different ways in which the positive lifting phase of lower-body resistance exercise can be determined. The traditional method begins at the onset of positive barbell displacement and ends when maximal barbell displacement is achieved; according to Frost et al. (2008), this includes a period of what they refer to as "negative work". The alternative method begins at the same point but only considers the period of positive impulse (net GRF above 0 N - what Frost *et al.*, 2008 refer to as "positive work") so that meaningful comparison can be made between the work performed to displace the load of interest during traditional and ballistic resistance exercise.

Methods

Participants

Ten moderately resistance trained males volunteered. Their mean (± SD) physical characteristics were mass: 79.7 (± 13.6) kg; back squat 1RM of 133.3 (± 22.1) kg; and 2.9 (± 1.5) year's resistance exercise experience. University of Chichester ethics approval was obtained before data collection and following a thorough explanation of the experimental aims and procedures all participants completed a health history questionnaire and provided written informed consent.

Test Procedures

All participants attended two laboratory based testing sessions. The first session established maximum strength in a modified back squat (1 RM) at least 48 hours but no more than one week before the power testing session and followed a procedure that was similar to that outlined and used by Izquierdo *et al.* (2002).

Measurement of back squat performance began after a loaded barbell (Eleiko Weightlifting Training Bar, Sweden) positioned across the subject's posterior deltoids immediately below the C7 vertebrae was taken from free standing squat stands (Scorpion Gym Equipment, Nottingham, UK). The participant squatted until the barbell lightly touched supports that were set to enable a range of motion that approximated 45% of the participant's leg length (Flanagan and Salem, 2007) and stood upright to complete the lift. Participants were instructed to perform the negative descent phase of the lift under control and perform the positive lifting phase as explosively as possible whilst maintaining foot contact with the ground. Following maximal strength testing participants were familiarised with the jump squat exercise, which was performed in the same way as the back squat but with the aim of jumping from the bottom position for maximum height. For the purposes of this exercise the modified back squat was used to represent traditional lower-body resistance exercise and the jump squat its ballistic equivalent.

During the second testing session each participant performed three sets of three repetitions with 45% 1RM in each exercise. This load was selected because it represented a compromise between the typical back squat (Izquierdo *et al.*, 2002; Siegel *et al.*, 2002) and jump squat (Harris *et al.*, 2007) optimal loads. The exercise order was allocated with half of the participants performing the traditional exercise first and the other half performing the ballistic exercise first. A minimum of one minute and a maximum of three minutes recovery were given between each set and five minutes rest was observed between the different exercises (Reiser *et al.*, 1996).

Measurements

The vertical ground reaction forces (GRF) of traditional and ballistic exercise performance were recorded from both feet individually by two 0.4 by 0.6 m Kistler 9851 force platforms (Alton, UK) at a sampling frequency of 500 Hz. Two type 9865E 8-channel charge amplifiers amplified the analogue GRF signals before they were digitally converted. Two cameras (Basler A602fc-2, Germany) were positioned approximately 5 m from the centre of the area of interest around the right hand side of the participant with an inter-camera angle of about 120 degrees. They filmed a retro-reflective spherical marker that was affixed to and represented the right end of the barbell at 100 Hz after first recording a 17-point calibration frame, which was 1.261 by 1.083 by 0.901 m in the X, Y, and Z plane respectively (Peak Performance Technologies Inc., Englewood, CO). The marker was digitised for all successful trials at 100 Hz using Peak Motus 9.2 software. Exercise GRF and barbell kinematic data collection was synchronised using a Peak event and video control unit (Peak Performance Technologies Inc., Englewood, CO).
Digitising began 10 frames immediately before the conclusion of the negative descent phase and ended 10 frames after maximum barbell displacement. This enabled the calculation of three-dimensional spatial co-ordinates of the barbell end using the direct linear transformation procedure.

Data analysis

The barbell displacement-time data was differentiated to determine first velocity and then acceleration using the Peak Motus software and then filtered using a digital low pass fourth order Butterworth filter with a cut off frequency of 6 Hz, which was selected after performing residual analysis (Winter, 1990). Barbell force was then calculated considering both gravitational and barbell acceleration:

$$\text{Barbell force} = (\text{barbell mass} \times g) + (\text{barbell mass} \times \text{barbell acceleration})$$

Hori *et al.* (2007)

Barbell power output was then calculated by multiplying barbell force by the barbell velocity. Vertical GRF from both feet were summed to provide a single GRF measure. From this positive lifting phase average GRF, average barbell velocity and average barbell power, and peak barbell displacement were calculated. The average values were determined from the positive lifting phase of the two lifts. For the traditional exercise this was determined using the traditional approach whereby the positive lifting phase was deemed to begin at the onset of positive barbell displacement - which corresponded with system centre of mass acceleration determined from the GRF-time curve - and peak barbell displacement, and using the method proposed by Frost *et al.* (2008b), whereby the positive lifting phase began at the beginning of positive barbell displacement/onset of system centre of mass acceleration and ended at the point at which the net GRF changed from positive to negative/end of system centre of mass acceleration (Figure 3-1). The ballistic exercise positive lifting phase was determined using the traditional method. The repetition with the highest mean power output from each of the three sets of three repetitions was selected and averaged for analysis (Baker *et al.*, 2001b).

The durations of the different positive lifting phases were also calculated and from these the time to peak barbell velocity was determined as a percentage of the positive lifting phase duration.

Statistical Analysis

All data were presented as mean (± SD) unless otherwise stated. Differences between the traditional and ballistic exercise performance measures, and the influence that the way in which the positive lifting phase of these exercises was determined had on the dependent variables, was examined using one-way analysis of variance with post hoc analysis performed using the Holm-Sidak procedure where appropriate. The dependent variables of interest were mean GRF, mean barbell velocity, mean barbell power, peak barbell displacement, the positive lifting phase duration, and time to peak velocity. Effect sizes (d) for the variables of interest calculated using the different methods of determining the positive lifting phase were calculated using the methods described by Rhea (2004):

Pre-Post d = (post test mean – pre-test mean) / pre-test SD

All statistical calculations were performed using SPSS version 16.0 for Windows (SPSS, Inc., Chicago, IL) and an alpha value of $p \leq 0.05$ was used to determine statistical significance.

Results

The mean (± SD) traditional and ballistic exercise performance data are presented in Table 3-1, which illustrates the way in which the positive lifting phase was determined had on key performance. The results revealed that when both the acceleration and deceleration phase were included in the determination of the positive lifting phase of the traditional exercise performance the mean GRF (35%, $p = 0.001$; $d = -1.9$) and time to peak velocity (45%, $p < 0.0001$; $d = -1.3$) was significantly less than the equivalent ballistic exercise values. However, its influence did not extend to mean velocity (13%, $p = 0.882$; $d = -0.3$), mean power (66%, $p = 0.090$; $d = -1.7$), peak displacement (27%, $p = 0.082$; $d = -1$) and positive lifting phase duration (36%, $p = 0.365$; $d = -1.6$). When the deceleration phase was excluded from the determination of the traditional exercise positive lifting phase the results revealed that the differences between the traditional and ballistic exercise mean GRF (4%, $p = 0.894$; $d = -0.3$) and time to peak velocity (9.5%, $p = 0.285$; $d = 0.7$) were significantly reduced. Further, a significant shift in the time to peak velocity was found when the acceleration phase only method was used with a significantly greater portion of the traditional exercise positive lifting phase spent accelerating the barbell (100% compared to 82%, $p<0.001$; $d = 7.3$) (Figure 3-1). The exclusion of the deceleration phase during the back squat reduced the effect size from $d = -1.7$ to -0.3.

Table 3-1. Mean (± SD) traditional and ballistic exercise performance data.

Positive work phase	Mean GRF (N)	Mean velocity ($m \cdot s^{-1}$)	Mean power (W)	Peak displacement (m)	Duration (s)	Time to peak velocity (% duration)
BS a	1331.06	0.90	529.42	0.84	0.13‡	61.30
	± 238.37	± 0.35	± 206.90	± 0.20	± 0.08	± 16.20
BS b	1716.51	0.87	759.46	0.84	0.07	99.96‡
	± 260.64	± 0.34	± 406.52	± 0.20	± 0.01	± 0.13
JS	1789.24†	1.00	886.53	1.03	0.09	81.84†
	± 262.37	± 0.33	± 401.66	± 0.16	± 0.01	± 2.50

* BS a = positive lifting phase determined using traditional acceleration and deceleration approach; BS b = positive lifting phase determined using the alternative acceleration only approach (Frost *et al.*, 2008a); † = significantly greater than BS a (p<0.001); ‡ = significantly greater than JS (p<0.001).

Discussion

Research evidence (Frost *et al.*, 2008a; Newton *et al.*, 1996) has suggested that ballistic upper-body resistance exercise, where the barbell is thrown, may be superior for the development of powerful function compared to traditional, non-ballistic resistance exercise because it typically enables the generation of significantly larger mean force, mean velocity and mean power output across the positive lifting phase. However, differences between these measures generated during both traditional and ballistic lower-body resistance exercise have not, until now been considered. Further, the way in which the positive lifting phase is determined was recently shown to significantly influence traditional-ballistic differences (Frost *et al.*, 2008b). This study set out to compare key kinetic and kinematic measures - including mean positive lifting phase force, velocity and power - of traditional and ballistic lower-body resistance exercise and to examine whether the way in which the positive lifting phase is determined would influence differences between traditional and ballistic exercise.

The results of this study demonstrated that differences between key performance measures of traditional and ballistic lower-body resistance exercise were sensitive to the way in which the positive lifting phase was determined. Therefore the hypothesis that key kinematic and kinetic measures would be significantly greater during ballistic performance but that this would be a consequence of the way in which the positive phase was determined, was accepted.

The inclusion of the deceleration phase resulted in differences between the traditional and ballistic exercise mean force, velocity and power that were similar to those reported in the literature for upper-body resistance exercise (Frost *et al.*, 2008b; Newton *et al.*, 1996). However, differences caused by the inclusion of the deceleration phase varied. Its exclusion resulted in a significant increase in mean force (from 1331 to 1717 N), but the shorter positive phase duration resulted in a slightly greater difference between the traditional and ballistic exercises in mean velocity (13 to 18%). A consequence of this was that the reduction in mean power differences (66 to 21%) was less than anticipated and less than those recently reported by Frost *et al.* (2008b) for upper-body resistance exercise. However, differences were still considerable causing a decrease in the effect size from large (d = -1.7) to trivial (d= -0.3) (Rhea, 2004). Further, excluding the deceleration phase during the traditional resistance exercise from the determination of the positive lifting phase, using the methods outlined by Frost *et al.* (2008b) led to some surprising results.

Regarding the mean force effect, the results of this study were in good agreement with the literature (Frost *et al.*, 2008b; Newton *et al.*, 1996). The exclusion of the deceleration phase resulted in a considerable reduction in the differences between the traditional and ballistic exercises, from 35% (d = -1.9, large) to ~4% (d= -0.3, trivial). However, the exclusion of the deceleration phase did not reduce differences between the traditional and ballistic exercises absolutely. The reader is reminded that a critical part of ballistic resistance exercise performance is the control of the load as it is returned to the start position. Ideally the use of some sort of braking device is advised (Frost *et al.*, 2008b; Hori *et al.*, 2008), however this may not always be available. While the consequences of not using a braking device during ballistic lower-body resistance exercise may not be as potentially problematic as those associated with ballistic upper-body resistance exercise, it remains that without a braking device athletes may be exposed to considerable impact forces during loaded jump squat landing (Hori *et al.*, 2008). Remembering that the difference between the traditional and ballistic exercise power output effect size was reduced from large to trivial by simply excluding the deceleration phase during the determination of the positive lifting phase, it is reasonable to question the blanket prescription of the jump squat over the back squat for the majority of lower-body power development.

This contention is further supported by an unexpected finding from this study. The results showed that during jump squat performance an average of 18% (± 2.5%) of the positive lifting phase was spent decelerating the barbell (Figure 3-3 [shows deceleration for 22% of duration]). This is in stark contrast to previous findings regarding ballistic upper-body resistance exercise (Frost *et al.*, 2008b; Newton *et al.*, 1996). A graphical illustration of the delay between the end of the acceleration phase and peak barbell displacement can be seen in Figure 3-3, and it appears that the momentum generated during the acceleration phase results in a considerably greater carry over in terms of barbell displacement compared to the upper-body resistance exercise equivalent. Researchers have described the way in which they have determined the positive lifting phase of ballistic upper-body resistance exercise as beginning at the first instance of positive barbell displacement until either peak barbell displacement or the completion of the acceleration phase (Frost *et al.*, 2008b; Newton *et al.*, 1996). In a second paper by Frost *et al.* (2010), the endpoint of the positive lifting phase of ballistic resistance exercise was defined as the point at which either the barbell left the hands or peak barbell displacement was achieved, suggesting that there would be little difference between the two.

While this may be the case during ballistic upper-body resistance exercise it does not apply to the lower-body equivalent and suggests that the superiority of ballistic resistance exercise over its traditional equivalent is questionable and carries with it additional injury potential.

The generation of an extra 4% of force resulted in 17% more power output during the ballistic exercise. However this appeared to be a consequence of the greater barbell displacement, occurring outside of the actual acceleration phase. The other important point to remind oneself about is the mechanical consequence of the high impact landing that the athlete may be exposed to if a mechanical braking system is not available.

Hori *et al.* (2008) compared the effects of weighted jump squat training with and without a braking mechanism designed to reduce landing impact forces. Subjects undertook an eight week jump squat training program, half with and half without the braking mechanism, to establish whether reducing the impact stretch shortening cycle would inhibit power training gains. They reported increases in jump power and maximum strength that were considerably greater for the braking training group, whilst significantly reducing landing impact kinetics. Their findings indicated that in moderately trained individuals the eccentric contraction that occurs during the SSC of jump landing does not enhance power and maximal strength. The authors suggested that training responses remain velocity specific and their results indicate that there may not be any power or maximal strength training advantage to be gained from jump squat training.

Therefore, considering the results presented by Hori *et al.* (2008) and the results of this study, it is reasonable to suggest that back squat training with sub-maximal, optimal loads may be as developmentally beneficial but less mechanically demanding than weighted jump squat training.

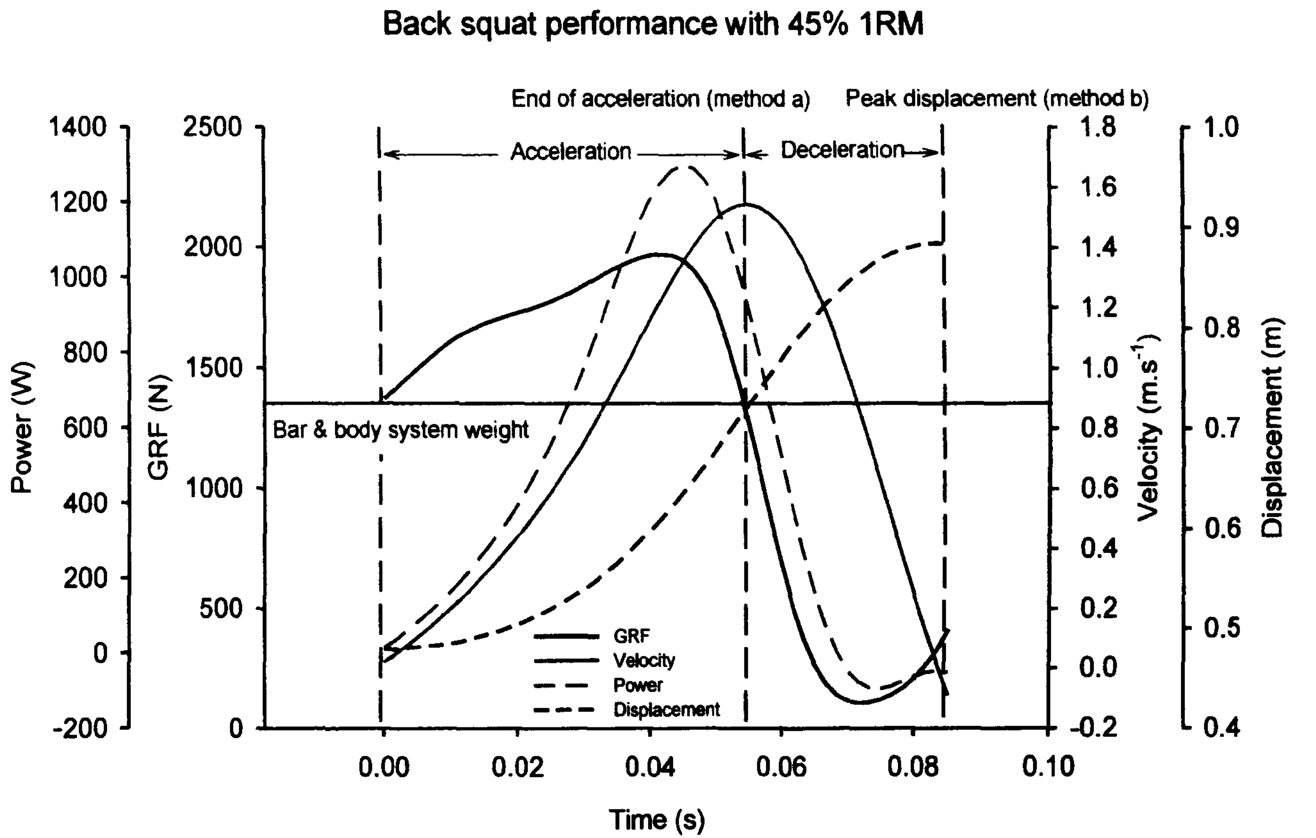

Figure 3-2. A representative illustration of the acceleration (light grey) and deceleration (dark grey) that occurred during traditional back squat performance.

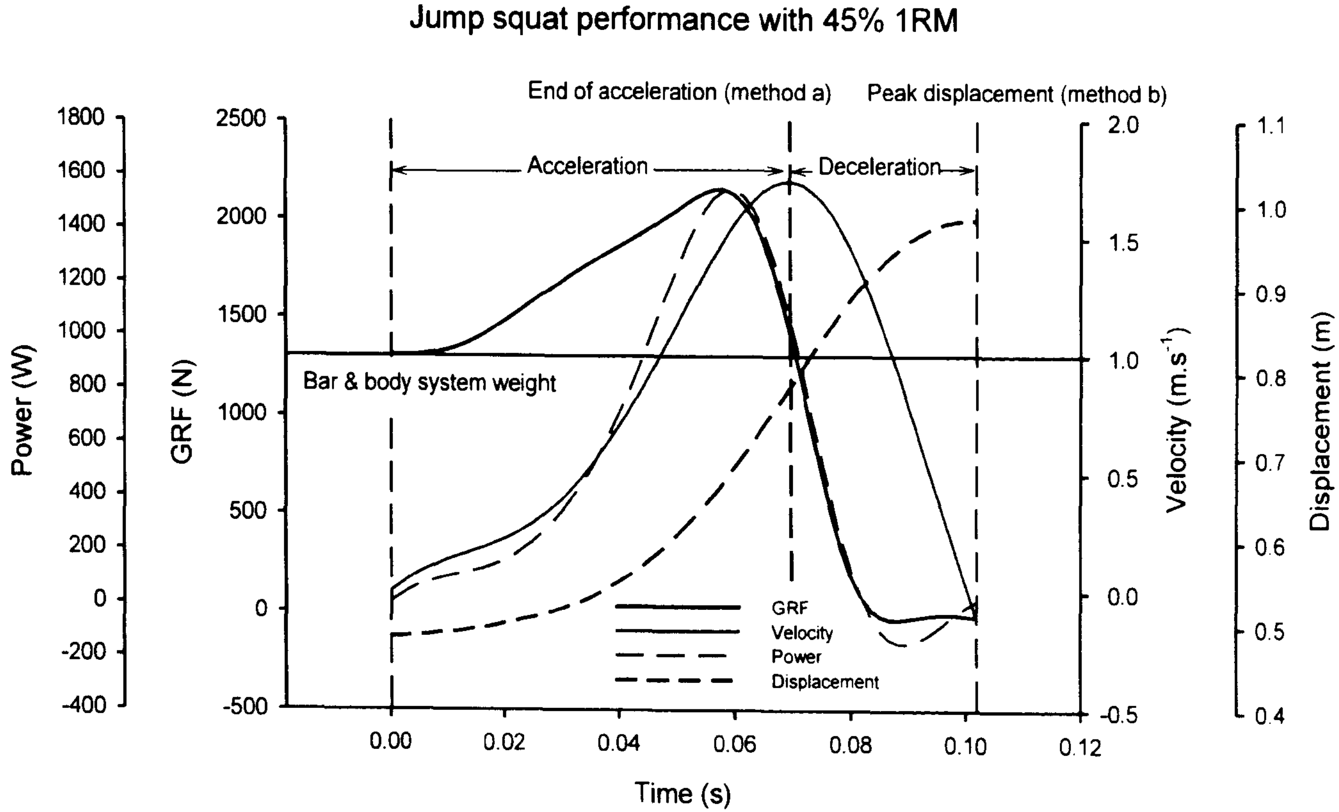

Figure 3-3. A representative illustration of the acceleration (light grey) and deceleration (dark grey) that occurred during ballistic jump squat performance.

Of practical relevance was the observation that the acceleration phase of traditional back squat performance was easily identifiable from the velocity-time curve. Figure 3-2 shows that the velocity-time curve in relation to the GRF-time curve, clearly indicating that the end of the acceleration phase (determined from the GRF-time curve) corresponded with peak barbell velocity. This suggests that access to a typically laboratory based force platform is not necessary to establish the acceleration phase of tradition resistance exercise if one has access to motion analysis equipment that can provide sample by sample feedback.

Although the results of this study demonstrated that the assumed superiority of ballistic resistance exercise over non-ballistic resistance exercise for the development of power may have been over emphasised, the methodology used was not without its limitations and should be both acknowledged and considered when interpreting the results.
While the performance of both exercises to a fixed bottom position facilitated controlled descent and a consistent range of motion, it interrupted typical performance technique, and although subjects were fully familiarised with these exercise variations it is possible that they may have restricted use of the stretch-shortening cycle, possibly compromising maximal performance. However, it was felt that this potential limitation would have equal affect on both exercises and may explain the relatively low power outputs that were reported. The reader is also reminded that this study only considered one load: 45% 1RM, and that while the rationale was sound, further research is needed to explore the affect that the way in which the positive lifting phase of traditional and ballistic lower-body resistance exercise is determined has on the expression of power at different loads and the development of powerful muscle function.

To summarise, it would appear that the theoretical superiority of ballistic resistance exercise for the development of powerful muscle function may have been inflated by proponents of its use without consideration for its potentially harmful mechanical consequences. It is therefore suggested that strength and conditioning professionals and sports scientists should reconsider their use of ballistic resistance exercise and instead consider using traditional resistance exercises to both develop and study powerful muscle function. They should also review their theoretical understanding of the way in which the positive lifting phase of resistance exercise is determined and consider the methods outlined by Frost *et al.* (2010). With regard to the aims of this thesis, the results of this study have informed the selection of traditional resistance exercise to study the factors that affect the measurement of resistance exercise power in general and the determination of the optimal load specifically.

Chapter 4 - Reliability and validity of methods commonly used to measure power output during non-ballistic lower-body resistance exercise

Introduction

The results presented in Chapter 3 demonstrated that the way in which the positive lifting phase of resistance exercise is determined can significantly affect mechanical power output. However, the reliability and validity of the method used to measure power output had not been established.

The accurate measurement of resistance exercise mechanical power output relies on the ability to obtain valid and reliable measures of the force and velocity components that underpin it (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008). These measures are typically obtained from one of three general methodologies that are based on barbell displacement, resistance exercise ground reaction force (GRF), or a combination of barbell displacement and resistance exercise GRF (Cormie *et al.*, 2007b; Hori *et al.*, 2007; Li *et al.*, 2008), and are summarised in Table 4-1.

The simplest and perhaps most common barbell displacement based method obtains the force component from the product of the barbell mass and the acceleration of gravity (Baker, 2001a; Wilson *et al.*, 1993). If instantaneous barbell displacement is known the process can be taken a stage further using inverse dynamics that are based on Newton's second law (Hori *et al.*, 2007). This was the method that was used in Chapter 3. Both methods have been used to obtain estimates of both barbell and barbell and body system centre of mass force. The velocity component is obtained from the rate of barbell displacement (Hori *et al.*, 2007; Li *et al.*, 2008). The GRF method relies on a force component that is measured directly from a force platform and a velocity component that is derived using a forward dynamics approach that is based on the impulse-momentum relationship that does not consider barbell kinematics (Dugan *et al.*, 2004; Kawamori *et al.*, 2005). The combined method relies on a force component that is measured directly from a force platform and a velocity component that is obtained directly from the barbell (Cormie *et al.*, 2007b; Hori *et al.*, 2007; Li *et al.*, 2008; Winchester *et al.*, 2005).

Table 4-1. The different methods used to calculate back squat mechanical power output.

Method 1	**Vertical Bar Force** (bar mass × g) × **Vertical Bar Velocity**	Coelho *et al.* (2003), Jandacka & Vaverka (2008), Jennings *et al.* (2005). Similar approach used by Baker (2001), Izquierdo *et al.* (2002), Wilson *et al.* (1993)
Method 2	**Vertical Bar Force** (bar mass × g) + (bar mass × bar acceleration) × **Vertical Bar Velocity**	Bosco *et al.* (1995), Cronin *et al.* (2000), Dugan *et al.* (2004), Hori *et al.* (2007), Li *et al.* (2008), Mastropaolo (1992), Sleivert & Taingahue (2004), Stone *et al.* (2003)
Method 3	**Vertical Ground Reaction Force** × **Vertical Centre of Mass Velocity** $\left(\int_0^t a\ \mathrm{dt} = \left(\frac{1}{m}\right)\int_0^t (GRF - BW)\mathrm{dt}\right)$	Driss *et al.* (2001), Haff *et al.* (1997), Kawamori *et al.* (2005), Kilduff *et al.* (2007), Li *et al.* (2008), McBride *et al.* (1999), Moir *et al.* (2005), Patterson *et al.* (2009), Rahmani *et al.* (2001)
Method 4	**Vertical Ground Reaction Force** × **Vertical Bar Velocity**	Burnett *et al.* (2004), Cormie *et al.* (2007b,c), McBride *et al.* (2002), Winchester *et al.* (2005)
Method 5	**Vertical System Force** (system mass × g) + (system mass × bar acceleration) × **Vertical Bar Velocity**	Harris *et al.* (2007), Hori *et al.* (2007), Newell *et al.* (2005)

It has been suggested that the way in which resistance exercise mechanical power output is measured can significantly influence the load-power relationship, which may have important implications for the identification of the optimal load (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Li *et al.*, 2008). Further, what may be the most appropriate method to measure resistance exercise power remains a contentious and ongoing issue.

A review of the literature, suggests that the three general methodologies obtain the necessary force and velocity components from different aspects of resistance exercise performance, namely the barbell kinematics and system centre of mass kinetics (Cormie *et al.*, 2007b; Hori *et al.*, 2007; Li *et al.*, 2008). It appears that this may underpin any effect that methodology may have on mechanical power output and the load-power relationship.

The barbell methods offer a potentially robust way of measuring resistance exercise power, relying on the movement of a known mass (Hori *et al.*, 2007; Li *et al.*, 2008). However, the application of the simplest method (Method 1, Table 4-1) does not consider the acceleration of the barbell, which has been shown to result in the underestimation of the force component (Cormie *et al.*, 2007b), which in turn is reflected in any subsequent measure of power. The consideration of barbell acceleration (Method 2, Table 4-1) provides a more accurate representation of the force component and any subsequent measures of barbell power (Hori *et al.*, 2007). Both barbell methods (Methods 1 and 2, Table 4-1) track the movement of a known mass and lend themselves well to field based applications (Hori *et al.*, 2007). This method has and continues to be combined with the weight of the bar/body system (Harris *et al.*, 2007; Wilson *et al.*, 1993) and provides a relatively robust way of estimating system force (Chiu *et al.*, 2004), but appears to overestimate the velocity component (Li *et al.*, 2008). It is for this reason that these measures should only be related to the mass of the barbell (Dugan *et al.*, 2004).

Recent research suggests that these concerns may extend to the method that combines the direct measurement of both the force and velocity component (Li *et al.*, 2008). Both of these measures of system centre of mass power rely on barbell velocity, which does not appear to be an accurate reflection of the system centre of mass velocity (Li *et al.*, 2008). By deriving the velocity of the system centre of mass from a directly measured force component one can be confident of the theory that underpins it but at the cost of not been able to monitor the movement of the barbell (Dugan *et al.*, 2004), which is often an important aspect of the analysis of resistance exercise performance (Cormie *et al.*, 2007b; Winchester *et al.*, 2005). In addition to this, the direct measurement of the force component tends to be restricted to the laboratory environment, which may limit its practical application.

Therefore, it is important that the selection of a measurement methodology is based on an understanding of the theory that underpins the method as well as its practical limitations. The aims of this study were to assess the within-session reliability of, and degree of agreement between the different methods that are commonly used to calculate resistance exercise mechanical power output. The results of this study will examine the reliability and validity of the method used to calculate power output in Chapter 3, and inform the selection of a theoretical and practical "gold standard" method for measuring resistance exercise mechanical power output with the aim of standardising data collection methods in this area.

Methods

Participants

Twenty physically active males who had between 2 and 4 years resistance training experience volunteered. Their mean (± SD) physical characteristics were age: 24.8 (± 6.3) years; mass: 85.9 (± 13.5) kg; back squat 1RM: 163.1 (± 40.4) kg; and back squat 1RM relative to body mass (1RM/body mass): 1.9 (± 0.4) kg per kg of body mass ($kg \cdot kg \cdot bm^{-1}$). University of Chichester ethics approval was obtained before data collection and following a thorough explanation of the experimental aims and procedures all subjects completed a health history questionnaire and provided written informed consent.

Test Procedures

Participant modified back squat 1 RM was established during the first visit to the laboratory, following a procedure that was similar to that outlined and used by Izquierdo *et al.* (2002). Measurement of back squat performance began after a loaded barbell (Eleiko Weightlifting Training Bar, Sweden) positioned across the subject's posterior deltoids immediately below the C7 vertebrae was taken from free standing squat stands (Scorpion Gym Equipment, Nottingham, UK). The participant squatted until the barbell lightly touched supports that were set to enable a range of motion that approximated 45% of the participant's leg length (Flanagan and Salem, 2007) and stood upright to complete the lift.

Two to seven days later a second testing session was attended, beginning with a standardised warm up that included 5 minutes of easy stationary cycling, light (<50% 1RM) squatting and stretching. Participants then performed single back squats with 15, 30, 45, 60, 75 and 90% of their 1RM in that order. Two attempts were performed with each load with a minimum of one minute and a maximum of three minutes rest provided between each lift (Reiser *et al.*, 1996). Participants were instructed to perform the negative descent phase of the back squat under control and perform the positive lifting phase as explosively as possible whilst maintaining foot contact with the ground in an attempt to maximise power output. Data from the two trials were used for the within session reliability analysis and the average of the two trials was used for the validity analysis.

Measurements

A schematic of the experimental setup is presented in Figure 4-1. The three dimensional GRF of back squat performance were recorded from both feet separately by two 0.4 by 0.6m Kistler 9851 force platforms (Alton, UK) at a sampling frequency of 500 Hz. The analogue GRF signals were amplified by two type 9865E 8-channel charge amplifiers before they were digitally converted.

Two video cameras (Basler Vision Technologies, Germany) were positioned approximately five metres from the centre of the force platforms around the right hand side of the participant with an inter-camera angle of about 120 degrees. They filmed back squat performance at 100 Hz with a shutter speed of 1/1000s (Gourgoulis *et al.*, 2000) after first recording a 17 point calibration frame, which was 1.261 by 1.083 by 0.901 m in the X, Y, and Z plane respectively (Peak Performance Technologies Inc., Englewood, CO). Spotlights positioned on rigid tripods immediately behind each camera illuminated a retro-reflective marker that was positioned on the right end of the barbell during back squat performance to assist subsequent digitisation. Back squat GRF and movement footage data collection was synchronised using a Peak event and video control unit (Peak Performance Technologies Inc., Englewood, CO).

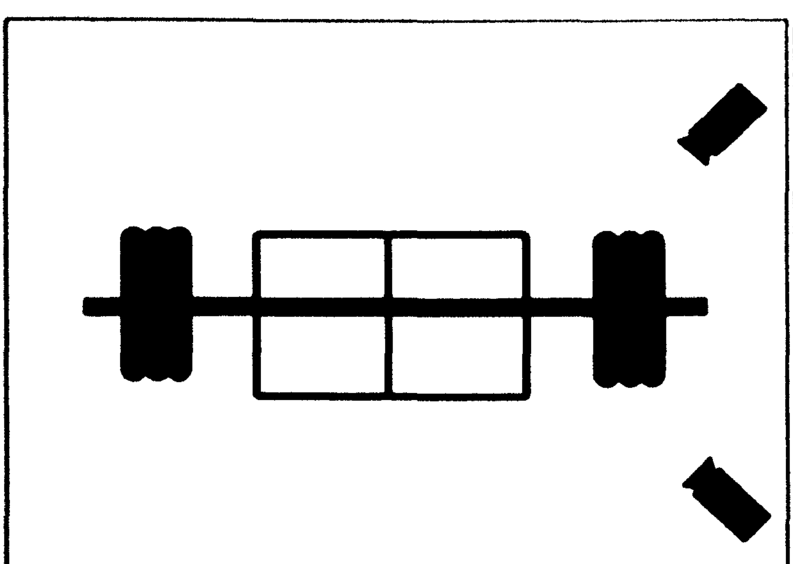

Figure 4-1. Schematic of the force platform and camera position.

The barbell marker was automatically digitised for all successful trials at 100 Hz using Peak Motus 9.2 software. Digitising began approximately 10 frames immediately before the achievement of the back squat bottom position and ended approximately 10 frames after the lift. This enabled the calculation of three dimensional spatial co-ordinates of the barbell end using the direct linear transformation procedure. Following digitisation the raw co-ordinate data was smoothed using a digital low pass fourth order Butterworth filter with a cut off frequency of 6 Hz, which was selected after performing residual analysis (Winter, 1990).

Data analysis

The different methods that were used to obtain force and velocity are presented in Table 4-1. Four different methods (F1, 2, 3 and 4, Table 4-1) were used to obtain measures of peak and mean force and two methods (V1 and 2, Table 4-1) were used to obtain measures of peak and mean velocity. The different method peak and mean positive lifting phase power outputs were then calculated according to the methods (P1, 2, 3, 4 and 5) presented in Table 4-1 using the Kinecalc function in the Peak Motus 9.2 software. These were then plotted against load to obtain the optimal load, which for this study was operationally defined as the load (% 1RM) that generated the highest peak and mean positive lifting phase power output (Kawamori and Haff, 2004). This process was repeated for each participant and for each of the five methods and mean and peak optimal loads and power outputs were tabulated for later analysis.

Statistical analysis

The centrality and spread of the data were presented as means (± SD). Systematic bias between the test-retest and method comparison data was studied with paired *t*-tests. These were performed and 95% confidence limits obtained using SPSS version 16.0 (SPSS, Inc., Chicago, IL). An alpha level of $p \leq 0.05$ was used to determine statistical significance. Because the assumption of homoscedasticity was violated, data were log-transformed and mean differences presented as a percentage using the approach described and used by Hopkins (2000).

For the method comparison aspect of the analysis the percentage differences were calculated relative to the criterion method, which would be presented first in tabulated results. Comparisons were made between the method two and one, three and two, three and four and three and five peak and mean positive lifting phase power outputs. Thus, method two was the criterion barbell method and method 3 the criterion system centre of mass method. These comparisons were made because the criterion methods two and three represent the correct application of Newtonian mechanics for the power that is generated against the barbell (Bosco *et al.*, 1995; Cronin *et al.*, 2000; Hori *et al.*, 2007; Li *et al.*, 2008; Mastropaolo, 1992; Sleivert and Taingahue, 2004; Stone *et al.*, 2003) and system centre of mass respectively (Driss *et al.*, 2001; Haff *et al.*, 1997; Hori *et al.*, 2007; Kawamori *et al.*, 2005; Kilduff *et al.*, 2007; Li *et al.*, 2008; McBride *et al.*, 1999; Moir *et al.*, 2005; Patterson *et al.*, 2009; Rahmani *et al.*, 2001), while method one (Baker, 2001; Coelho *et al.*, 2003; Izquierdo *et al.*, 2002; Jandacka and Vaverka, 2008; Jennings *et al.*, 2005; Wilson *et al.*, 1993), four (Burnett *et al.*, 2004; Cormie *et al.*, 2007b, c; McBride *et al.*, 2002; Winchester *et al.*, 2005) and five (Harris *et al.*, 2007; Newell *et al.*, 2005) represent the common and theoretically unsound methods that are often used in their place.

Absolute reliability was studied using percentage coefficient of variation (CV) and relative reliability using the Intraclass correlation (ICC). These, along with their 95% confidence limits were derived from a spreadsheet (downloaded from newstats.org/xrely.xls). The degree of agreement between the different methods was studied using 95% limits of agreement (LOA) (Bland and Altman, 1986, 2007). To do this the total error (standard deviation of the log-transformed method differences) was multiplied by 1.96. Data were then back transformed to enable the presentation of 95% LOA as a percentage of the mean criteria method value (Batterham and George, 2000).

Results

Reliability

The mean (±SD) test-retest peak and mean power outputs obtained by the different methods are presented in Table 4-2. The results of the test-retest analysis are presented in Table 4-3.

Table 4-2. Mean (± SD) test-retest peak and mean power outputs (W) for the different methods at their respective mean and peak positive lifting phase optimal loads.

	Method 1		Method 2		Method 3		Method 4		Method 5	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Peak	1400.66 (352.67)	1329.11 (312.03)	1626.21 (445.91)	1569.70 (396.72)	2156.79 (561.23)	2185.27 (587.62)	2845.49 (643.37)	2792.75 (649.32)	2723.53 (607.76)	2694.55 (652.25)
Mean	615.41 (181.20)	594.86 (152.69)	731.64 (211.87)	716.72 (190.78)	1142.04 (398.27)	1162.64 (407.13)	1377.34 (279.86)	1419.74 (358.68)	1304.07 (270.06)	1339.09 (335.16)

Except for the method one peak power output (mean difference: -4.8%, $p < 0.05$) the test-retest results did not demonstrate evidence of systematic bias. However, the method two peak power output test-retest difference did approach statistical significance (mean difference: -3%, $p = 0.08$).

Table 4-3. Mean and peak positive lifting phase power output test-retest reliability results.

	Peak Power					Mean Power				
	Method 1	Method 2	Method 3	Method 4	Method 5	Method 1	Method 2	Method 3	Method 4	Method 5
Mean % Difference	-4.8†	-3.0‡	1.1	-1.9	-1.4	-2.5	-1.6	1.4	2.0	1.8
Lower 95% CL	-7.9	-6.4	-2.7	-4.6	-3.7	-8.8	-7.7	-5.2	-2.5	-3.0
Upper 95% CL	-1.5	0.4	5.0	0.8	0.9	4.1	5.0	8.4	6.7	6.8
CV	6.3	6.6	7.2	5.1	4.4	12.9	12.5	13.1	8.6	9.2
Lower 95% CL	5.0	5.2	5.7	4.0	3.5	10.1	9.8	10.3	6.8	7.3
Upper 95% CL	8.8	9.1	10.0	7.1	6.1	18.0	17.6	18.4	12.0	12.8
ICC	0.93	0.94	0.94	0.96	0.97	0.81	0.82	0.91	0.89	0.87
Lower 95% CL	0.86	0.87	0.87	0.91	0.94	0.64	0.65	0.81	0.77	0.73
Upper 95% CL	0.97	0.97	0.97	0.98	0.99	0.91	0.91	0.96	0.95	0.94

•CV = % coefficient of variation; CL = confidence limit; ICC = Intraclass correlation. † = trial one significantly greater than trial two at $p < 0.05$; ‡ trial one greater than trial two $p = 0.08$.

The results of the test-retest reliability were mixed (Table 4-3). In general peak power typical error (% CV) was low, ranging from 4.4 to 7.2%, while the test-retest correlations were high (r = 0.93 to 0.97). Conversely, mean power typical error (% CV) was much higher, ranging from 8.6 to 13.1%, and the test-retest correlations lower (r = 0.81 to 0.91).

Method comparison

Representative load-power curves for each of the five different methods are presented in Figure 4-2.

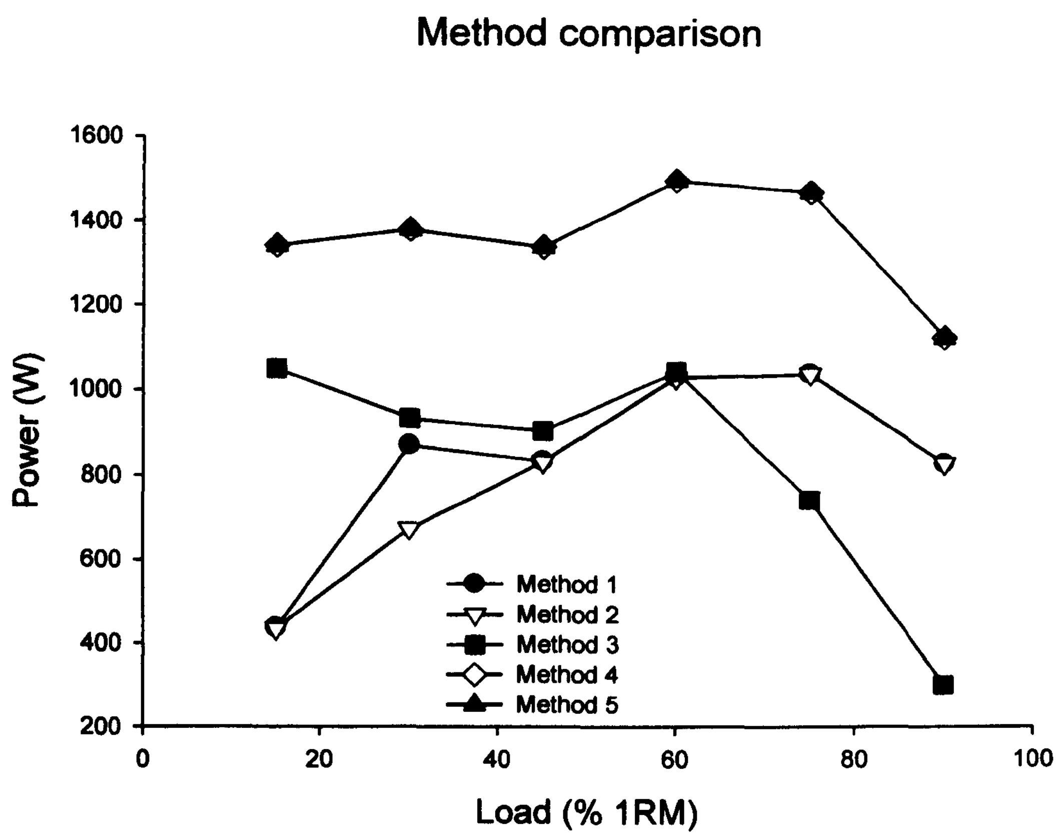

Figure 4-2. Representative load- power relationships for each of the five different methods examined in this study.

The results of the peak and mean power method comparison are presented in Table 4-4 and Table 4-5. There was a significant systematic bias between each comparison ($p \leq 0.025$) and this difference was relatively stable across the peak and mean power outputs.

The results of the limits of agreement analysis showed that with the exception of the method one and two comparison (peak power: 8%; mean power: 8.3%) agreement was low for both peak and mean power output (Table 4-4 and Table 4-5).

Table 4-4. Peak power method comparison mean % differences, 95% confidence limits (CL), and 95% limits of agreement (LOA).

Method	Mean % Difference	Lower 95% CL	Upper 95% CL	95% LOA
2 vs 1	16.7	14.9	18.4	8.3
3 vs 2	35.3	25.8	44.9	50.5
3 vs 4	-23.6	-31.9	-15.2	43.2
3 vs 5	-20.4	-28.4	-12.4	41.0

Table 4-5. Mean power method comparison mean % differences, 95% confidence limits (CL), and 95% limits of agreement (LOA).

Method	Mean % Difference	Lower 95% CL	Upper 95% CL	95% LOA
2 vs 1	19.6	17.9	21.4	8.0
3 vs 2	54.4	38.3	70.6	95.5
3 vs 4	-20.6	-36.4	-4.9	92.1
3 vs 5	-16.1	-31.3	-0.9	88.1

The effect that measurement methodology had on peak and mean power optimal load is presented in Table 4-6 and Table 4-7. The method two peak power optimal load was significantly less (3.7%) than the method one equivalent (p = 0.008). Further, the method two peak (-30.1%, $p < 0.0001$) and mean (38.6%, $p < 0.0001$) optimal loads were significantly less than the method three equivalents.

Table 4-6. Peak power optimal load method comparison mean % differences, 95% confidence limits (CL), and 95% limits of agreement (LOA).

Method	Mean % Difference	Lower 95% CL	Upper 95% CL	95% LOA
2 vs 1	-3.7	-6.2	-1.2	11.7
2 vs 3	-30.1	-43.3	-16.9	73.9
3 vs 4	-4.0	-19.5	11.5	90.7
3 vs 5	-4.8	-17.6	8.1	71.7

The results of the limits of agreement analysis showed relatively good agreement between the method one and two peak power optimal loads (11.7%), and good agreement between the method one and two mean power optimal loads (7%).

Table 4-7. Mean power optimal load method comparison mean % differences, 95% confidence limits (CL), and 95% limits of agreement (LOA).

Method	Mean % Difference	Lower 95% CL	Upper 95% CL	95% LOA
2 vs 1	-1.1	-2.6	0.4	7.0
2 vs 3	-38.6	-55.9	-21.3	104.2
3 vs 4	13.2	-9.1	35.4	145.4
3 vs 5	9.6	-13.4	32.6	152.7

Discussion

The first aim of this study was to establish the test-retest reliability of back squat power output across different methods.

To achieve this reliability was broken down into the two subcategories of absolute and relative reliability (Atkinson and Nevill, 1998). Absolute reliability was examined by quantifying the typical measurement error using the coefficient of variation (CV), while relative reliability was examined using intraclass correlations (Hopkins, 2000). The method comparison was achieved using 95% limits of agreement (Bland and Altman, 1986). However, that test-retest reliability is often examined using the limits of agreement approach should be acknowledged (Atkinson and Nevill, 1998). The rationale for not using this approach in the present study can be attributed to the way in which the strength and conditioning literature typically approaches this issue. With power measurement, and with only one exception (Jennings *et al.*, 2005), test-retest reliability has tended to be examined using the approach adopted by the present study. However, in the majority of cases relative reliability, as the intraclass correlation is the only measure that is used to quantify test-retest reliability. Indeed, this is an approach that has been actively encouraged by the *Journal of Strength and Conditioning Research.*

The acceptability of test-retest measurement error should be based on criteria that in turn should be based on expected outcome goals (Atkinson and Nevill, 1998). Regarding the present study, the process of creating a set of acceptability criteria for test-retest reliability and method agreement was based on the typical behaviour of the load-power relationship during back squat performance, particularly for its response to changes in power output from the optimal load.

However, research concerning the load-power relationship of lower-body power has tended to focus on ballistic resistance exercises like the jump squat (Baker *et al.*, 2001b; Cormie *et al.*, 2007b, c; Jennings *et al.*, 2005; Li *et al.*, 2008; Patterson *et al.*, 2009; Sleivert and Taingahue, 2004; Stone *et al.*, 2003; Thomas *et al.*, 2007) and variations of the Olympic weight lifts (Haff *et al.*, 1997; Kawamori *et al.*, 2005; Kawamori *et al.*, 2006; Kilduff *et al.*, 2007).

To date, four studies have presented data (actual or graphical) that were sufficient to enable the calculation of the effect that changes from the mean power optimal load had on the load-power relationship (Izquierdo *et al.*, 1999, 2001, 2004; Siegel *et al.*, 2002). When the different categories of participant population that were examined in these studies were considered a total of eight sets of mean load-power relationship data were available. These studies used method one to obtain their measures of power.

Fairing slightly less well, at the time of writing there were only two studies that had presented data (actual or graphical) that were sufficient to enable the calculation of the effect that changes from the peak power optimal load had on the load-power relationship (Cormie *et al.,* 2007b, c). However, one of these studies (Cormie *et al.,* 2007b) used methods one, three, four and five to obtain their measures of peak power output. With this in mind there were a total of five sets of peak load-power relationship data available for analysis.

With the aforementioned data, percentage difference changes in peak and mean power output were calculated from one and two load changes either side of the optimal load. The results of this are presented as percentage differences in Table 4-8 and Table 4-9.

Table 4-8. Typical back squat peak power responses to changes in load either side of the optimal load.

Author	Method	Load increase (% 1RM)	OL (% 1RM)	% Δ in MP from 1 load decrement	% Δ in MP from 2 load decrements	% Δ in MP from 1 load increment	% Δ in MP from 2 load increments
Cormie *et al.* (2007b)	1	10	80	0.8	3.2	3.7	-
Cormie *et al.* (2007b)	3	10	80	0.4	4.6	2.3	-
Cormie *et al.* (2007b)	4	10	70	0.6	5.8	0.4	6.5
Cormie *et al.* (2007b)	5	10	30	-	-	8.8	14.3
Cormie *et al.* (2007c)	4	10	70	0.6	5.8	0.4	6.5

* % Δ in PP = percentage change in peak power output because 1 or 2 load decrements or increments from the optimal load.

Reliability

Regarding reliability, the reference data sets that were obtained from the literature, although limited, provided criteria for the assessment of test-retest differences. When the results of the test-retest differences were compared to the effect that changes from the optimal load had on the peak load-power relationship the results demonstrated that, in general, the different methods lacked the sensitivity necessary to detect changes in power output that occurred because of one load change either side of the optimal load. However, the results showed that methods four and five were able to detect changes in peak power. Further, they were the only methods able to detect changes in peak power that occurred from two load changes either side of the optimal load.

Table 4-9. Typical back squat mean power responses to changes in load either side of the optimal load.

Author	Population	Load increase (%1RM)	OL (% 1RM)	% Δ in MP from 1 load decrement	% Δ in MP from 2 load decrements	% Δ in MP from 1 load increment	% Δ in MP from 2 load increments
Izquierdo *et al.* (1999)	YM	10-15	60	6.1	-	3.1	18.4
Izquierdo *et al.* (1999)	OM	10-15	70	2.5	10	-	-
Izquierdo *et al.* (2001)	YM	10-15	60	4.3	-	2.1	25.5
Izquierdo *et al.* (2001)	OM	10-15	70	10.7	16.7	-	-
Izquierdo *et al.* (2004)	W	10-15	30	20.2	-	1.6	6.9
Izquierdo *et al.* (2004)	RC	10-15	30	5	-	10	32
Izquierdo *et al.* (2004)	C	10-15	45	8.9	24.4	8.9	11.1
Siegel *et al.* (2002)	R	10	60	5.3	12	0	2.7

*YM = young man (~40 years); OM = older man (~65 years); W = competitive weightlifters; RC = competitive road cyclists; C = untrained controls; R = recreationally trained.; % Δ in MP = percentage change in peak power output because of 1 or 2 load decrements or increments from the optimal load.

Conversely, the results demonstrated that the sensitivity of method one would only detect changes in the mean load-power relationship that occurred because of two load changes either side of the optimal load (Table 4-8 and Table 4-9). To put these findings into context (Atkinson and Nevill, 1998), the results demonstrated that changes in the load-power relationship would have to exceed a magnitude dictated by the typical error to be considered meaningful. In the case of the criteria data (Table 4-8 and Table 4-9) that the results of this study were compared to, the results show that this did not happen.

The lack of back squat load-power relationship research has also had an impact on the availability of test-retest reliability data in the literature. Regarding absolute reliability for peak power output, Rahmani *et al.* (2000) presented an average coefficient of variation of 5.6%. Regarding absolute reliability for mean power output, Bosco *et al.* (1995) presented a coefficient of variation of 5%, while Izquierdo *et al.* (2002) reported a coefficient of variation of 7%. With this in mind it appears that based on the effects that change from the optimal load has on both the peak and mean load-power relationship (Table 4-8 and Table 4-9), the methods that have been used in published studies (Bosco *et al.*, 1995; Izquierdo *et al.*, 2002; Rahmani *et al.*, 2000) and were examined in the present study, are not sensitive enough to detect changes in the load-power relationship where load progressions of between 10 to 15% 1RM are used.

With regard to relative reliability, the results of this study were in good agreement with previous studies in terms of peak (Cormie *et al.*, 2007a, b: 0.86 to 0.98; Rahmani *et al.*, 2000: 0.57 to 0.91) and mean (Bosco *et al.*, 1995: 0.84; Izquierdo *et al.*, 2001: 0.8 to 0.99), and were better than some *r* values reported for mean power output (Izquierdo *et al.*, 2002: 0.75). Although this finding is important for a methods ability to differentiate between individual participants it should be remembered that the test-retest should not, as often happens within the literature, be relied on as a single method of quantifying measurement error.

The above findings have implications for the theory that there is an optimal load for the development of powerful muscle function. Harris *et al.* (2007) recently suggested that the optimal load occurs across a "bandwidth" of loads rather than at one point in the load-power relationship. This theory was also recently discussed in a review paper by Chiu (2008). However, this does not detract from the methodological limitations that the results of this study have highlighted regarding the inability of most methods to detect changes in the load-power relationship. Further, the findings regarding load induced changes in the load-power relationship should be considered when method agreement is been assessed.

Did the different method peak and mean power outputs agree?

The second aim of this study was to establish the degree of agreement between five methods that are commonly used to obtain measures of lower-body resistance exercise power. To achieve this both peak and mean power output were examined. Further, methods that focussed on both the barbell and system centre of mass were differentiated. As with most method comparison studies criterion methods were chosen to represent a barbell and system centre of mass "gold standard". For the barbell, the method two was chosen because it relied on the kinematics of a known mass. This method has been criticised by some (Cormie *et al.*, 2007b, and c) because it underestimates the force component of the power calculation. However, it remains that by avoiding guesswork this relatively simple method enables one to obtain an accurate measure of barbell power. Of greater controversy is the way in which system centre of mass power is obtained (Li *et al.*, 2008). Method three was selected as the system centre of mass "gold standard" because it enables the direct measurement of the force component from which the velocity component can then be obtained (Hori *et al.*, 2007). Similar to the barbell method however, this method has been criticised for underestimating the velocity component (Cormie *et al.*, 2007b). However, this suggests that critics may not fully understand the theoretical underpinnings of the calculations (Li *et al.*, 2008). A thorough understanding of the fundamentals of these calculations is imperative so that researchers can inform the process of bridging the gap between research and practical application.

Regarding the power output method comparison the results showed that although there was a considerable, but not significant systematic bias between the method one and two peak and mean power outputs (16.7 and 19.6% respectively), the degree of agreement between was very high (8.3 and 8% respectively). Putting this into context, the agreement would not be less than 8.3% for 95% of comparisons made between method one and two.

However further comparisons did not yield similar results. The systematic bias between the method two and three, method three and four, and method three and five peak and mean power outputs was considerable. Importantly the results showed that agreement was very poor (Table 4-5 and Table 4-6).

This unequivocally demonstrated that there was a clear difference between barbell and system centre of mass methods that are used to obtain power, and that the different methods of obtaining system centre of mass power should not be used interchangeably. These findings agree with previously published method comparison research (Cormie *et al.*, 2007b; Hori *et al.*, 2007; Li *et al.*, 2008). However, a unique difference lies in the way in which these findings were interpreted. Regarding the system centre of mass, Li *et al.* (2008) were quite categorical in their attitude to the different methods that are used to obtain measures of resistance exercise power output, stating that the different methods tend to mismatch methodological components and tend to require more, typically laboratory based, equipment (Cormie *et al.*, 2007b). The results of the current study reinforced the author's agreement with their statement, and it was this belief that contributed to the interpretation of the test-retest reliability data. For example, method four produced the lowest typical error but was based on a mismatch of measurement methods that were believed to be theoretically unsound and therefore the author discommended the use of this method. However, the requirement for the equipment on which it relies somewhat nullified its low typical error. Although portable force platforms are available (Frost *et al.*, 2008a), they remain largely restricted to the laboratory setting (Hori *et al.*, 2007).

Did the different method peak and mean optimal loads agree?

Regarding the optimal load method comparison the results largely reflected the power output method comparison. Systematic bias between the method one and two peak (-3.7%) and mean (-1.1%) power optimal load was low and while agreement between the method one and two peak power optimal load was not as high as perhaps was expected (95% limits of agreement: 11.7%), the agreement between the method one and two mean power optimal load was (95% limits of agreement: 7%).

Agreement between the method two and three, method three and four and method three and five peak and mean power optimal loads was very poor, with 95% limits of agreement ranging from 71.7% to 90.7% for the peak power optimal loads and 104.2% to 152.7% for the mean power optimal loads. This should serve to reinforce the need to avoid using the method three, four and five approaches interchangeably. However, the keen of eye should have noticed that there was very little bias between the method three and four (-4%) and method three and five (-4.8%) peak power optimal loads. To the authors knowledge this is the first study that has used the 95% limits of agreement approach to examine the degree of agreement between different methods that are used to obtain measures of resistance exercise power output. Where previous studies have used less stringent statistical methods to quantify method agreement (Cormie *et al.*, 2007b; Hori *et al.*, 2007; Li *et al.*, 2008) it has likely led method agreement been based on either systematic bias or test-retest correlation alone. Perhaps of greater importance is that although there was a relatively small degree of systematic bias between these methods the shape of their load-power relationships differed considerably.

Although the results of this study made clear distinctions between the different methods that are commonly used to measure resistance exercise power, aspects of the measurement methodology should be clarified. The application of the results was intended, ultimately, for field use, but was obtained using laboratory based equipment. The rationale for this was that a large array of field based systems have been compared to laboratory based systems (Burnett *et al.*, 2004; Chiu *et al.*, 2004; Cronin *et al.*, 2004; Hori *et al.*, 2007; Li *et al.*, 2008; Newell *et al.*, 2005; Newton, 1997; Thompson and Bemben, 1999), and so the use of a laboratory based system enabled centralised and controlled measurement that could be synchronised with the theoretically sound criteria system centre of mass power measurement technique that uses a force platform. As such it was felt that laboratory use was justified and the application of the results of this study to field based methods valid.

To summarise, the results of this study clearly demonstrated test-retest reliability that may compromise the researcher's ability to detect changes in the load-power relationship. This reliability should be established before load-power testing is performed so that the researcher can establish a magnitude that load induced changes in the load-power relationship must exceed if they are to be considered meaningful. With the possible exception of method one and two, the different methods that are used to obtain power output should not be used interchangeably as they tend to differ considerably. These differences were found to influence the shape of the load-power relationship and in turn, the point at which mean and peak power was maximised- the optimal load. The method four and five measures of system centre of mass power were considerably greater than those of the theoretically sound method three measures. However, because the method three reliability was relatively poor it is suggested that the method two barbell kinematics approach should be used to obtain measures of back squat mean and peak power output and to determine the optimal load for the development of powerful muscle function. While the barbell kinematics based method two is recommended to be the preferred method for determining power output and the optimal load, the force and velocity components underpinning it related only to movement in the vertical plane. Further consideration of the factors that may influence vertical barbell kinematics is needed to refine the measurement of resistance exercise mechanical power output in general and the optimal load specifically and will be considered in Chapter 5 and Chapter 6.

Chapter 5 - An examination of the relative contribution of horizontal barbell displacement to total barbell power output during upper and lower-body resistance exercise

Introduction

Resistance exercise power output is commonly measured to monitor both resistance training intensity and improvements in powerful muscle function (Cormie *et al.*, 2007b; Hori *et al.*, 2007). The validity and reliability of using barbell kinematics to obtain the force and velocity components that are necessary to calculate resistance exercise power output was established in Chapter 4. This is a relatively simple but theoretically sound method that is not limited to a laboratory environment and as such has lent itself to the development of field test alternatives (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Garhammer, 1993; Hori *et al.*, 2007; Shim *et al.*, 2001; Siegel *et al.*, 2002; Stone *et al.*, 2003). However, it was noted in Chapter 4 that field measures tend to be restricted to movement that occurs in the vertical plane and as such cannot consider the horizontal displacement of the barbell, which may lead to a considerable underestimation of total barbell power output.

Using video analysis techniques, Garhammer (1993) showed that during the "pull" phase of the clean the relative contribution of barbell horizontal power to total barbell power was between 10 and 16% depending on which phase of the lift was considered. Using two linear position transducers Cormie *et al.* (2007b) showed that in some cases of ballistic jump squat performance the inclusion of horizontal power can reduce total barbell power in traditional and ballistic lower-body resistance exercise. This may have been a consequence of the considerable horizontal displacement that occurs during squatting movements (Garhammer, 1993); each direction representing a positive and negative movement according to whichever reference system has been used. When considerable amounts of horizontal work are performed in different directions so that positive horizontal work describes movement of the bar away from the body and negative horizontal work bar movement towards the body, any additional work may be cancelled out if the negative work is not rectified.

In a second study, Cormie *et al.* (2007a) showed that during ballistic lower-body resistance exercise the relative contribution of barbell horizontal power to total barbell power was about 1% with a light load (30% 1RM), increasing to about 40% with a heavy load (90% 1RM). Their results supported the work of Garhammer (1980, 1993), indicating that the contribution of horizontal barbell power to total barbell power could be considerable. Their results also suggested that resistance exercise load influenced the magnitude of the horizontal barbell power contribution to total barbell power. The latter finding warrants further study because it shows that incremental loading can influence the amount of horizontal work that is performed during resistance exercise so that as load increases the ability of vertical barbell power to reflect total barbell power may decrease. Further, it is not known how this horizontal work differs during different types of resistance exercise.

Therefore, as a first step towards refining the barbell kinematics approach (method two, Table 4-1) that was validated and recommended in Chapter 4, the aim of this study was to determine whether horizontal barbell power output during upper (bench press) and lower-body (back squat) resistance exercise made a significant contribution to method two vertical barbell power. A secondary aim was to establish whether horizontal contributions were affected by incremental loading. Based on recent research evidence (Cormie *et al.*, 2007a) it was hypothesised that the barbell kinematics approach would underestimate power output during exercise performance with heavy loads.

Methods

Participants

Eight moderately resistance trained males volunteered to participate in this investigation. Their mean (± *SD*) physical characteristics were age: 25.4 (± 4.9) years, mass: 83.3 (± 10.7) kg, height: 1.80 (± 0.3) m, back squat 1RM: 116.6 (± 19.4) kg, back squat 1RM relative to body mass (1RM/body mass): 1.5 (± 0.3) kg per kg of body mass ($kg{\cdot}kg{\cdot}bm^{-1}$), bench press 1RM: 82.2 (± 13.6) kg, bench press 1RM relative to BM: 1.1 (± 0.2) $kg{\cdot}kg{\cdot}bm^{-1}$. University of Chichester ethics approval was obtained before data collection and following a thorough explanation of the experimental aims and procedures all participants completed a health history questionnaire and provided written informed consent. Criteria for participant inclusion in this study included that the participant have a minimum of one years experience with both the back squat and bench press exercise and were able to perform both exercises with good technique.

Test Procedures

Each participant attended two testing sessions that were separated by no more than seven days. The first testing session was used to determine both bench press and back squat 1RM and the second to record the kinematic data of power testing with 30, 60 and 90% of the 1RM.

1RM Testing

The bench press and back squat 1RM testing followed a procedure that was similar to that outlined and used by Stone *et al.* (2003) for the jump squat exercise.

During back squat performance the barbell (Eleiko Weightlifting Training Bar, Sweden) positioned across the subject's posterior deltoids immediately below the C7 vertebrae (Hori *et al.*, 2007; Stone *et al.*, 2003) was taken from free standing squat stands (Scorpion Gym Equipment, Nottingham, UK). The participant squatted until the upper surface of the thigh was parallel with the ground returning to the start position to complete the lift (Siegel *et al.*, 2002; Stone *et al.*, 2003). The parallel position depth was gauged visually during the 1RM testing session and the bottom position recorded. Using this information a bungee cord was positioned across a free standing wooden "door frame" to enforce consistent depth (Siegel *et al.*, 2002). Any squats that did not meet the depth criteria were excluded from the analysis. During bench press performance the barbell was taken from the same squat stands in a shoulder width grip. The participant then lowered the barbell until it touched the chest in line with the nipples, extending the shoulders and elbows to return to the start position to complete the lift. Any bench press performance that did not see the barbell lightly touch the chest was excluded from the analysis.

Participants were instructed to perform the eccentric phase of the bench press and back squat under control and perform the positive lifting phase as explosively as possible whilst maintaining contact with the bench during the bench press and with the ground during the back squat.

Horizontal contribution testing

Each subject performed two single lifts with 30, 60 and 90% of their 1RM with a minimum of one minute and a maximum of three minutes recovery between each lift (Reiser *et al.*, 1996) and the lift with the greatest peak vertical barbell power was selected for later analysis (Kawamori *et al.*, 2005). The 30, 60 and 90% 1RM loads were selected to represent relatively light, moderate and heavy resistance exercise intensities. Verbal encouragement was given during all resistance exercise performances (Izquierdo *et al.*, 2002).

Measurements

Three cameras (Basler A602fc-2, Germany) were positioned on rigid tripods approximately 5 m from the centre of the area of interest around the right hand side of the participant. They filmed a retro-reflective spherical marker that was affixed to and represented the right end of the barbell at 100 Hz with a shutter speed of 1/1000s (Gourgoulis *et al.*, 2000) after first recording a 17-point calibration frame, which was 1.261 by 1.083 by 0.901 m in the X, Y, and Z plane respectively (Peak Performance Technologies Inc., Englewood, CO). This was digitised for all successful trials at 100 Hz using Peak Motus 9.2 software and enabled the calculation of three-dimensional spatial coordinates of the barbell end using the direct linear transformation procedure.

Data analysis

The raw horizontal and vertical barbell displacement data were smoothed using a digital low pass fourth order Butterworth filter with a cut off frequency of 6 Hz, which was selected after performing residual analysis (Winter, 1990), and was then differentiated to determine first velocity and then acceleration using the Peak Motus software. Horizontal and vertical barbell force was then calculated by multiplying the acceleration of the barbell by its mass (considering the acceleration of gravity for vertical barbell force). Horizontal and vertical barbell power was then calculated by multiplying barbell force by its velocity (Hori *et al.*, 2007), and summed to determine total barbell power. Before this however, horizontal power was rectified so that the contribution of both the positive anterior and negative posterior work could be considered. Peak and mean measures of horizontal, vertical and total barbell power were taken from the positive lifting phase, which was determined using the method outlined and used in Chapter 3.

Statistical analysis

All data were presented as mean (± SD) unless otherwise stated. Two-way repeated measures analysis of variance were used to establish whether including horizontal barbell power significantly affected total barbell power, and to establish load × movement plane interactions. Mean and peak barbell bench press and back squat power were the dependent variables and load (30, 60 and 90% 1RM: within) and movement plane (vertical and horizontal and vertical total: between) the independent variables. Further, two-way repeated measures analysis of variance were used to establish whether there were differences between the horizontal contribution to bench press and back squat total barbell power, and to establish the effect of load. Mean and Peak horizontal contributions were the dependent variables and load (30, 60 and 90% 1RM: within) and exercise (bench press and back squat: between) the independent variables. Significant differences were explored using one-way analysis of variance and planned comparisons. Effect sizes (*d*) between vertical and total barbell power output were calculated using the methods outlined in Chapter 3. All statistical analysis was performed using SPSS version 16.0 for Windows (SPSS, Inc., Chicago, IL). For all analyses statistical significance was set at alpha $p \leq 0.05$.

Results

The mean (± SD) peak and mean bench press and back squat vertical, horizontal, and total barbell power, and the relative contribution of horizontal power to total power are presented in Table 5-1, Table 5-2, Table 5-3 and Table 5-4.

Table 5-1. Mean (± SD) peak and mean vertical (Y), horizontal (X) and total (T) power during bench press performance with 30, 60 and 90% 1RM.

		Peak			**Mean**		
		30%	**60%**	**90%**	**30%**	**60%**	**90%**
Power (W)	**Y**	637.34 (168.21)	531.18 (108.23)	438.91 (49.99)	240.30 (43.69)	298.01 (50.39)	240.73 (60.12)
	X	4.78 (3.60)	6.90 (6.71)	7.69 (4.80)	1.98 (1.45)	1.98 (1.98)	1.79 (1.12)
	T	642.142 (166.78)	538.07 (112.56)	446.60 (47.59)	242.29 (43.42)	299.99 (42.34)	242.52 (59.56)

Table 5-2. Mean (± SD) peak and mean vertical (Y), horizontal (X) and total (T) power during back squat performance with 30, 60 and 90% 1RM.

		Peak			**Mean**		
		30%	**60%**	**90%**	**30%**	**60%**	**90%**
Power (W)	**Y**	802.64 (95.38)	1079.17 (175.09)	1262.16 (318.06)	373.96 (51.83)	555.02 (107.64)	1079.17 (175.09)
	X	18.37 (5.55)	17.03 (8.15)	22.64 (23.56)	7.31 (1.83)	5.72 (2.25)	17.03 (8.15)
	T	821.01 (96.32)	1096.19 (169.35)	1284.80 (323.02)	381.27 (51.88)	560.75 (107.11)	1096.19 (173.73)

Bench press (peak: $p = 0.746$, $d = 0.008$; mean: $p = 0.789$, $d = 0.005$) and back squat (peak: $p = 0.900$, $d = 0.001$; mean: $p = 0.907$; $d = 0.001$) barbell power was not significantly affected by the inclusion of the horizontal contribution. Further, there were no load × movement plane interactions ($p \geq 0.899$, $d \leq 0.006$).

There were no significant differences between the horizontal contribution to peak total barbell power during back squat and bench press performance ($p = 0.061$, $d = 0.245$), although the back squat contribution (1.7-2.3%) tended to be greater than the bench press equivalent (0.9-1.8%). Load did not affect the peak horizontal contribution to total barbell power ($p = 0.956$, $d = 0.003$).

The horizontal contribution to mean total barbell power was not significantly affected by relative load ($p = 0.205$, $d = 0.124$), but was significantly affected by exercise type ($p = 0.010$, $d = 0.439$). However, this only applied to the 30% 1RM condition where the back squat mean horizontal contribution was significantly greater than the bench press mean horizontal contribution (2% compared to 0.9%, $p = 0.008$, $d = 1.419$) (Table 5-3).

Table 5-3. Mean (± range) peak contribution of horizontal barbell power to total barbell power during bench press and back squat positive lifting phase performance with 30, 60 and 90% 1RM.

	30%	**60%**	**90%**
Bench Press	0.86% (-1.34 to 1.35%)	1.27% (-0.35 to 2.88%)	1.83% (0.22 to 3.44%)
Back Squat	2.28%† (1.31 to 3.26%)	1.70% (0.26 to 3.14%)	2.29% (-0.33 to 4.91%)

† = back squat greater than bench press horizontal contribution ($p = 0.008$, $d = 1.419$).

Table 5-4. Mean (± range) mean contribution of horizontal barbell power to total barbell power during bench press and back squat positive lifting phase performance with 30, 60 and 90% 1RM.

	30%	**60%**	**90%**
Bench Press	0.87% (-0.21 to 3.03%)	0.63% (-0.22 to 1.48%)	0.83% (0.03 to 1.63%)
Back Squat	1.95% (1.16 to 2.75%)	1.08% (0.16 to 2.01%)	1.11% (-0.62 to 2.84%)

Discussion

This is the first study to determine the contribution of horizontal barbell power during the bench press and back squat, and the first to examine the effect that relative exercise intensity and exercise type has on the horizontal contribution. The results showed that the vertical only displacement method did not significantly underestimate total barbell power during both upper and lower-body resistance exercise, with the horizontal contribution of both exercises failing to exceed 2.3% of the total barbell power, which led to the rejection of the first hypothesis.

The horizontal contribution was considerably less than the values reported by Garhammer (1993) for the clean exercise (10-16%) and the values reported by Cormie *et al.* (2007a) for the jump squat exercise with 90% 1RM (about 40%). However, it was similar to the values reported by Cormie *et al.* (2007a) for the jump squat exercise with 30% 1RM (about 1%). The differences found between the values reported by Garhammer (1993) and the results of the present investigation may be explained by the specific trajectory that the barbell must follow around the body during the clean, particularly during the period where the barbell is displaced around the knees in preparation for the beginning of the second pull. With regard to the differences found between the horizontal contribution of the 90% 1RM back squat condition studied in the present investigation and the 90% 1RM jump squat condition studied by Cormie *et al.* (2007a), this may be explained by the traditional rather than ballistic nature of the back squat. It may also be because during jump squat performance any horizontal barbell displacement occurs over a greater range of motion because of the nature of the exercise. However, this does not explain the differences (about 40%) between the 30 and 90% 1RM jump squat conditions reported by Cormie *et al.* (2007a).

The results of the present investigation show that the contribution of horizontal power during traditional upper and lower-body resistance exercise was not affected by incremental loading. This is an important finding because it supports the efficacy of bench press and back squat load-power testing that rely on vertical displacement only methods to obtain measures of power. A significant affect would have indicated that as load increases changes in resistance exercise power might be masked according to the affect that relative exercise intensity has on the horizontal contribution. This led to the rejection of the second hypothesis. The significant loading affect reported by Cormie *et al.* (2007a) suggested that this may be the case for ballistic lower-body resistance exercise, which is a concern because a lot of ballistic resistance exercise load-power related research has relied on measures of vertical displacement only power (Baker, 2002; Baker *et al.*, 2001 a; 2001b; Harris *et al.*, 2007; Izquierdo *et al.*, 2002; Jennings *et al.*, 2005; Sleivert and Taingahue, 2004; Stone *et al.*, 2003; Thomas *et al.*, 2007; Winchester *et al.*, 2005). With this in mind, further research into the affect that load has on the horizontal contribution of ballistic lower-body resistance exercise maybe warranted.

With regard to the differences that were found between the bench press and back squat horizontal contributions, this was not surprising when one considers the greater ranges of motion and lever arms that are associated with the back squat, although it should be remembered that the back squat horizontal contribution did not exceed 2.3% of total barbell power. To date there is a paucity of research that has considered the horizontal contribution of ballistic upper-body resistance exercise. Considering the findings regarding discrepancies between traditional and ballistic lower-body resistance exercise horizontal contributions, research into the affect that the inclusion of horizontal power may have on ballistic lower-body resistance exercise may be warranted.

To summarise, the findings of the present study showed that the exclusion of horizontal power output did not lead to a significant underestimation of mean or peak measures of traditional upper and lower-body resistance exercise power output. Further, the contribution of horizontal barbell power was not affected by relative exercise intensity. This is important because it increases the efficacy of the barbell vertical displacement based approach (method two) that was validated and recommended in Chapter 4, further refining its suitability to measure resistance exercise power. However, comparison of this study's findings to results reported by Cormie *et al.* (2007a) suggest that this may not be the case during ballistic lower-body resistance exercise. With this in mind, research into the affect that load has on ballistic lower-body resistance exercise may be warranted.

Chapter 6 - Does side dominance affect the symmetry of barbell end kinematics during lower-body resistance exercise?

Introduction

There has been a recent increase in the research focus on movement symmetry during bilateral resistance exercise (Flanagan and Salem, 2007; Newton *et al.*, 2006a; Song *et al.*, 2003). The study of independently measured left and right side ground reaction forces (GRF) has shown that during controlled bilateral resistance exercise healthy individuals tend to favour a side that may not correspond with the side they perceive to be dominant by as much as 10% (Flanagan and Salem, 2007; Newton *et al.*, 2006a). Some researchers have suggested that this may be an underlying cause of injury (Flanagan and Salem, 2007); while others have suggested that it may be a consequence of past injury or leg length discrepancy (Newton *et al.*, 2006a).

Lauder and Lake (2008) recently demonstrated that during power snatch performance asymmetric intervention significantly influenced bar end trajectory. However, little is known about whether side dominance, determined from independently measured GRF, influences the symmetry of left and right bar end kinematics.

This is an important but apparently overlooked aspect of powerful muscle function measurement methodology that could have important implications for strength and conditioning professionals. The accurate measurement of resistance exercise mechanical power output is critical for monitoring both resistance training intensity (Baker, 2001; Cormie *et al.*, 2007b; Kawamori *et al.*, 2005; Lyttle *et al.*, 1996; McBride *et al.*, 2002; Wilson *et al.*, 1993) and the effects of resistance training (Falvo *et al.*, 2006; Izquierdo *et al.*, 2002; Kaneko *et al.*, 1983).

A method that derives the velocity and force components necessary to calculate resistance exercise power output from vertical barbell end displacement was validated in Chapter 4 (method two, Table 4-1), and is an approach that is commonly used for the strength and conditioning process and to study human performance (Cormie *et al.*, 2007b; Dugan *et al.*, 2004; Fletcher *et al.*, 1958; Garhammer, 1993; Hori *et al.*, 2007; Li *et al.*, 2008; Nelson and Burdett, 1978). Therefore, if side dominance influences barbell end symmetry it could compromise the validity of mechanical power outputs obtained using the barbell kinematics based method two, which in turn could compromise the validity of the strength and conditioning process and the study of human performance.

Taking the refinement of method two (Table 4-1) a stage further therefore, the aim of this study was to test the hypothesis that ground kinetic asymmetries would significantly affect the symmetry of method two power output. A secondary aim of this study was to test the hypothesis that progressive loading would intensify this effect.

Methods

Participants

Ten physically active males with a minimum of one year's back squat experience volunteered to participate in this study. Their mean (± *SD*) physical characteristics were age: 28.8 (± 8.5) years, mass: 80.6 (± 10.7) kg, height: 1.80 (± 0.04) m, squat one repetition maximum (1RM): 122.3 (± 36.7) kg and relative (1RM/body mass) squat 1RM: 1.5 (± 0.4) kg per kg of body mass ($kg \cdot kg \cdot bm^{-1}$). University of Chichester ethics approval was obtained before data collection and all participants completed a health history questionnaire and provided written informed consent.

Test Procedures

All subjects participated in two testing sessions that were separated by approximately seven days: the first session, during which the back squat 1RM was established using a procedure that was similar to that outlined and used by Stone *et al.* (2003), and a second session, during which asymmetry testing was performed.

During both testing sessions the measurement of back squat performance began after a loaded barbell (Eleiko Weightlifting Training Bar, Sweden) positioned across the subject's posterior deltoids immediately below the C7 vertebrae (Hori *et al.*, 2007; Stone *et al.*, 2003) was taken from free standing squat stands (Scorpion Gym Equipment, Nottingham, UK). The participant squatted until the upper surface of the thigh was parallel with the ground and stood upright to the start position to complete the lift (Siegel *et al.*, 2002; Stone *et al.*, 2003). The parallel position depth was gauged visually during the 1RM testing session and the bottom position recorded. Using this information a bungee cord was positioned across a free standing frame to enforce consistent depth (Siegel *et al.*, 2002). Any squats that did not meet the depth criteria were excluded from the analysis. Participants were instructed to perform the eccentric phase of the back squat under control and perform the positive lifting phase as explosively as possible whilst maintaining foot contact with the ground.

During asymmetry testing each participant performed two maximal effort single back squats with 30, 60 and 90% 1RM with a minimum of one minute and a maximum of three minutes recovery between each lift (Reiser *et al.*, 1996). The 30, 60 and 90% 1RM loads were selected to encompass a light, moderate and heavy spectrum of relative exercise intensity. Verbal encouragement was given during all performances (Izquierdo *et al.*, 2002).

Measurements

The vertical GRF of back squat performance was recorded from both feet individually by two 0.4 by 0.6 m Kistler 9851 force platforms (Alton, UK) at a sampling frequency of 500 Hz. The analogue GRF signals were amplified by two type 9865E 8-channel charge amplifiers before they were digitally converted.

Three digital cameras (Basler A602fc-2, Germany) were positioned on rigid tripods around and approximately 5 m from the centre of the area of interest (Figure 6-1). Each camera filmed back squat performance at 100 Hz with a shutter speed of 1/1000s (Gourgoulis *et al.*, 2000) after first recording a 17 point calibration frame, which was 1.261 by 1.083 by 0.901 m in the X, Y, and Z plane respectively (Peak Performance Technologies Inc., Englewood, CO). The GRF and bar end kinematics were synchronised using a Vicon MX control unit (Peak Performance Technologies Inc., Englewood, CO).
Retro-reflective markers that were positioned on both ends of the bar were digitised at 100 Hz using Peak Motus 9.2 software from approximately 10 frames before the conclusion of the eccentric phase to approximately 10 frames after the positive lifting phase. Following digitisation the raw co-ordinate data were smoothed using a digital low pass fourth order Butterworth filter with a cut off frequency of 6 Hz, which was selected after performing residual analysis (Winter, 1990), and differentiated with respect to time to obtain bar end velocity and acceleration.

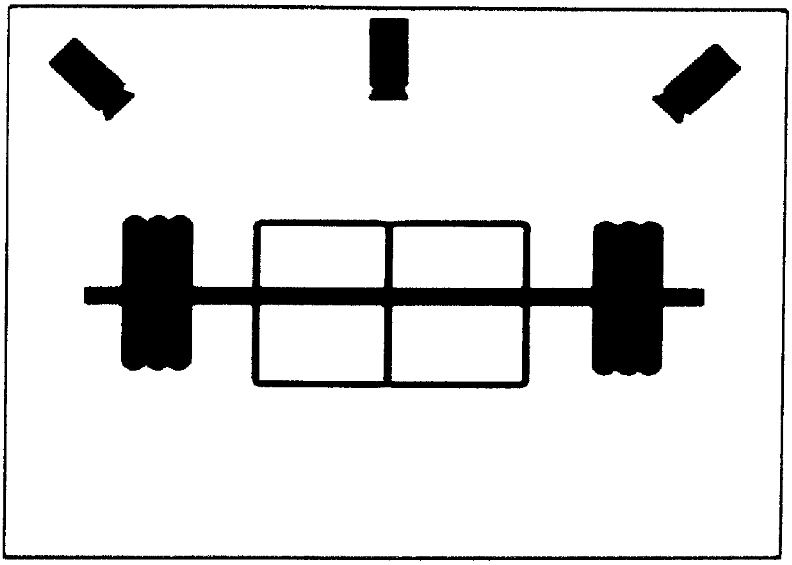

Figure 6-1. A schematic of the experimental set-up that shows the position of the three cameras and two force platforms relative to the position of the bar during back squat performance.

Mechanical power output was calculated from the kinematics of both ends of the barbell using method two, which is described in Chapter 4 (Table 4-1).

Measures of GRF and bar end power were then averaged across the duration of the positive lifting phase for further analysis. This approach has recently been used by Flanagan and Salem (2007), who suggested that peak performance data may not accurately represent the behaviour of measures of interest over a selected period of time. The positive lifting phase was determined using the method outlined and used in Chapter 3, whereby only positive work was considered, and both GRF and power output were normalised relative to body mass, GRF presented as newtons per kg of body mass ($N \cdot kg^{-1}$) and power output as watts per kg of body mass ($W \cdot kg^{-1}$).

Side dominance was determined using three different methods: perceived handedness (left-right side dominance: LRSD) (Flanagan and Salem, 2007; Newton *et al.*, 2006a); left and right side positive lifting phase GRF dominance (force side dominance: FSD) (Flanagan and Salem, 2007; Newton *et al.*, 2006a); and left and right positive lifting phase bar end power output dominance (barbell side dominance: BSD). Differences between the left and right and dominant (D) and non-dominant (ND) side average positive lifting phase GRF (AGRF) and average positive lifting phase bar end power outputs (ABP) were then calculated as percentage differences using standard procedures.

Statistical Analysis

The absolute and relative measurement reliability of the AGRF and ABP was assessed using the coefficient of variation (CV) and intraclass correlation coefficients (ICCs) respectively on within session test-retest data obtained from back squat performances with 30, 60 and 90% 1RM. To test the hypotheses that ground kinetic asymmetries would significantly influence bar end symmetry and that progressive loading would intensify this effect a two-way (side × load) analysis of variance was used to examine mean differences in the AGRF and ABP. In addition to this, Pearson product-moment correlations between the D and ND side differences for each of the different methods and loads were calculated to provide a descriptive view of the relationships between ground kinetic asymmetries and bar end power symmetry. Dominant-non dominant side effect sizes (*d*) were calculated using the method described in Chapter 3, but adapted thusly:

> Dominant - Non-dominant d = (dominant side mean value – non-dominant side mean value) / non-dominant side SD

All statistical calculations were performed using SPSS version 16.0 for Windows (SPSS, Inc., Chicago, IL) and an alpha value of $p \leq 0.05$ was used to determine statistical significance.

Results

The results of the test-retest analysis are presented in Table 6-1 and demonstrate a high degree of both relative and absolute reliability for AGRF and ABP at different relative intensities.

Table 6-1. Mean within session test-retest % differences, coefficients of variation (CV) and Intraclass correlations (ICC) for the measures of AGRF and ABP at 30, 60 and 90% 1RM.

Load	Measure	AGRF	ABP
	% Diff	-0.12	1.88
30%	% CV	1.30	6.50
	ICC	0.99	0.95
	% Diff	-0.01	-0.59
60%	% CV	0.90	6.50
	ICC	0.99	0.94
	% Diff	-0.01	-1.77
90%	% CV	1.20	8.30
	ICC	0.99	0.91

*AGRF = average ground reaction force; ABP = average bar power.

The mean (± *SD*) D and ND side positive lifting phase AGRF and ABP are presented in Table 6-2 and the mean percentage differences between the D and ND side AGRF and ABP are presented in

Table 6-3. There were no significant differences between the D and ND side FSD ($p = 0.11$, $d = 0.1$), LRSD ($p = 0.47$, $d = 0.01$), BSD ($p = 0.91$, $d = 0$) AGRF and D and ND side FSD ($p = 0.89$, $d = 0$), LRSD ($p = 0.98$, $d = 0$) and BSD ($p = 0.67$, $d = 0$) ABP. Further, 60 and 90% 1RM AGRF and ABP were significantly greater than 30% AGRF and ABP ($p < 0.0001$, $d = 0.34$ to 0.36) (Table 6-2).

The relationships between D and ND AGRF and ABP differences are presented in Table 6-4. At 30% 1RM there was a strong but non-significant negative relationship (FSD: $r = -0.63$, $p > 0.05$; LRSD: $r = -0.59$, $p > 0.05$; BSD: $r = -0.60$, $p > 0.05$) between the AGRF and ABP D and ND side differences, with increases in these differences resulting in no change or a reduction in the ABP D and ND side differences. The relationship between the AGRF and ABP D and ND side differences were negligible for all methods at 60% 1RM and for FSD and BSD differences at 90% 1RM (see Table 6-4). However, at 90% 1RM the LRSD D and ND side AGRF and ABP differences were significantly related ($r = 0.66$, $r^2 = 0.43$, $p < 0.05$).

Table 6-2. Mean (± SD) D and ND side AGRF and ABP during back squat positive lifting phase.

	AGRF ($N \cdot kg^{-1}$)						ABP ($W \cdot kg^{-1}$)					
	FSD		LRSD		BSD		FSD		LRSD		BSD	
	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND
30%	0.77 (0.19)	0.67 (0.14)	0.74 (0.21)	0.69 (0.13)	0.70 (0.13)	0.74 (0.22)	4.93 (1.18)	4.93 (1.17)	4.90 (1.18)	4.96 (1.16)	4.99 (1.15)	4.88 (1.19)
60%	0.92 (0.20)	0.87 (0.08)	0.89 (0.20)	0.90 (0.09)	0.85 (0.12)	0.91 (0.18)	7.59 (1.63)	7.56 (1.66)	7.63 (1.64)	7.52 (1.66)	7.68 (1.66)	7.47 (1.63)
90%	1.09 (0.28)	1.00 (0.20)	1.08 (0.22)	1.01 (0.27)	1.09 (0.24)	1.00 (0.25)	7.76 (2.36)	7.60 (2.33)	7.67 (2.36)	7.69 (2.34)	7.81 (2.40)	7.54 (2.29)

*FSD = force side dominance; LRSD = left-right side dominance; BSD = bar power side dominance; AGRF = average ground reaction force; ABP = average bar power; D = dominant side; ND = non-dominant side.

Table 6-3. Mean (± 95% confidence limits: CL) percentage differences between the D and ND side AGRF and ABP during the back squat positive lifting phase.

Measure	Load (% 1RM)	Mean	Lower 95% CL	Upper 95% CL
FSD AGRF	30	20.74	4.92	36.56
	60	13.78	2.84	24.71
	90	13.49	5.16	21.81
FSD ABP	30	-0.13	-2.41	2.14
	60	0.37	-2.18	2.92
	90	2.25	-0.36	4.85
LRSD AGRF	30	5.63	-16.21	27.46
	60	-2.52	-17.49	12.45
	90	8.20	-3.39	19.79
LRSD ABP	30	-1.38	-3.40	0.64
	60	1.58	-0.69	3.85
	90	0.01	-3.10	3.11
BSD AGRF	30	-3.79	-25.85	18.27
	60	-6.21	-20.22	7.79
	90	9.29	-1.82	20.40
BSD ABP	30	2.47	1.16	3.78
	60	2.69	1.13	4.26
	90	3.45	1.75	5.15

*CI = 95% confidence interval; FSD = force side dominance; LRSD = left-right side dominance; BSD = bar power side dominance; AGRF = average ground reaction force; ABP = average bar power.

Table 6-4. Pearson product moment correlations between the AGRF and ABP dominant and non-dominant side differences.

	30%	60%	90%
FSD	-0.63	0.09	0.02
LRSD	-0.59	0.03	0.66†
BSD	-0.60	0.02	0.29

*FSD = force side dominance; LRSD = left-right side dominance; BSD = bar power side dominance; † = significantly correlated ($p < 0.05$).

Discussion

The results of this study demonstrated that asymmetries in ground kinetics did not influence the symmetry of the barbell end power output, leading to the rejection of the first hypothesis. Statistically significant differences of between 13.5 and 20.7% were found between the dominant and non-dominant side AGRF when side dominance was determined according to the dominant left and right AGRF (FSD); differences that were considerably greater than those previously reported (~6%: Flanagan and Salem, 2007; Newton *et al.*, 2006a). The results indicated that the increased technical demands of heavier back squat performance (60 and 90% 1RM) reduced the relative dominant and non-dominant side AGRF differences. Although not statistically significant the relative consistency of the loading effect observed during the 60 and 90% 1RM conditions suggested that the assessment of ground kinetic asymmetry during bilateral resistance exercise must consider the potential effects of progressive loading.

Interestingly when side dominance was determined according to perceived handedness (LRSD) differences between the dominant and non-dominant AGRF were consistent with the findings of Newton *et al.* (2006a) both for magnitude and a lack of statistical significance. However, the differences observed in this study were not consistent across the different loading conditions (30%: 5.6%; 60%: -2.5%; 90% 8.2%), suggesting that although the load affect was not statistically significant, perceived handedness may not be the most reliable way to determine side dominance for the assessment of movement symmetry during bilateral lower-body resistance exercise. Of course the way in which side dominance is determined will depend largely on the facilities available, but it appears that the effective assessment of ground kinetic asymmetries requires the ability to independently measure left and ride side GRF. The strong positive relationship that was found between the dominant and non-dominant LRSD AGRF and ABP differences at 90% 1RM was interesting but of little practical relevance in an applied perspective when the inconsistent nature of the other relationships was considered.

However, this may have been a consequence of the large variability that was observed in this study. Further study into this aspect of the study using a single-subject design may be justified and may provide insight into the predictive ability of bar end asymmetries on ground kinetic asymmetries. The differences that were observed between the dominant left and right side AGRF (FSD) and the side that was perceived to be dominant (LRSD) did not influence the symmetry of bar end power outputs (FSD: -0.1 to 2.2%; LRSD: -1.4 to 1.6%;

Table 6-3). The greatest mean difference that was observed between the left and right side ABP (BSD) during this study was 3.4% (1.7 to 5.1% 95% confidence interval). From an applied perspective such a difference is not a concern but is a surprise given the large ground kinetic asymmetries that were observed.

A graphical example of good ground kinetic and good bar end symmetry is presented in Figure 6-2, whilst an example of poor ground kinetic symmetry and good bar end symmetry is presented in

Figure 6-3. Figure 6-2 illustrates a positive lifting phase ground kinetic asymmetry that did not exceed 2% and bar end kinematic asymmetry that remained under 0.6%, although bar end asymmetries did reach 8.4% in some subjects with mode values of ~5%.

Figure 6-3 illustrates a positive lifting phase ground kinetic asymmetry that averaged ~7% but reached 18% at its peak. This difference was typical of the FSD GRF differences. However, so too is the bar end symmetry that again did not exceed 0.6%.

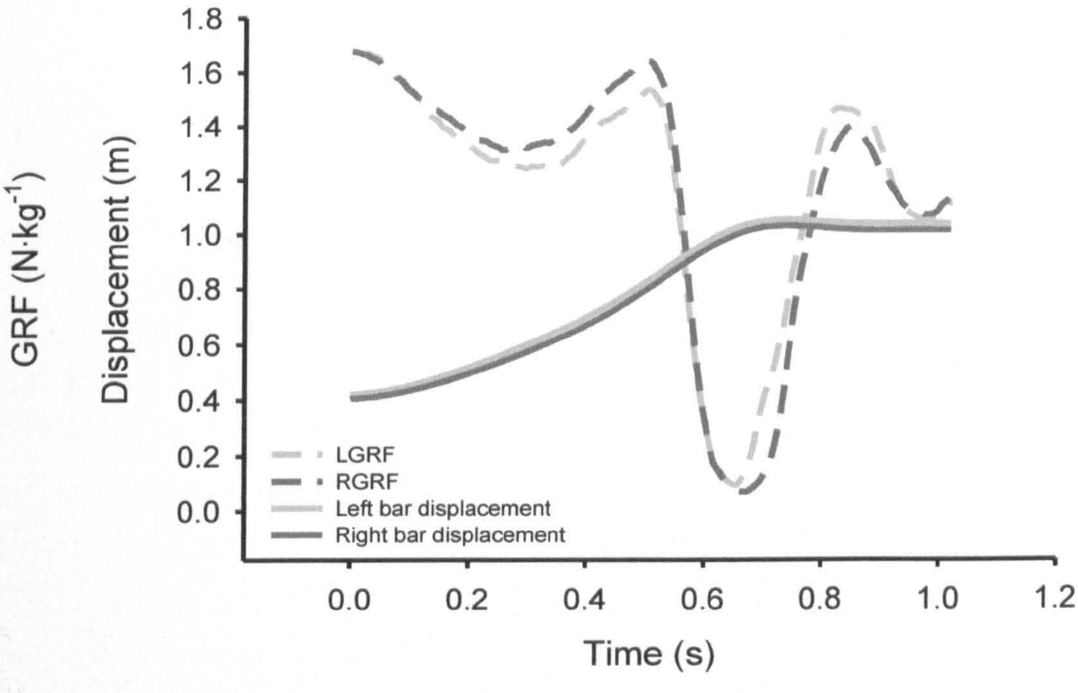

Figure 6-2. An example of good GRF and bar end kinematic symmetry during back squat performance.

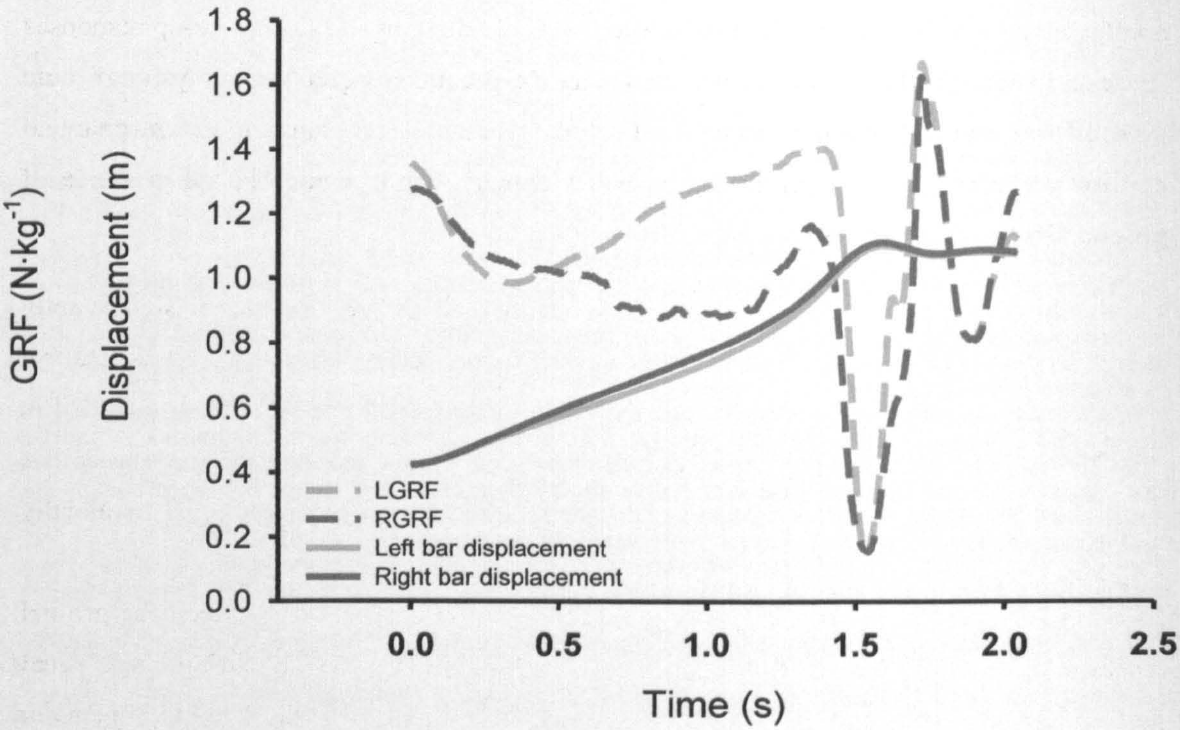

Figure 6-3. An example of poor GRF symmetry and its lack of effect on bar end kinematic symmetry during back squat performance.

These findings are unique to this study because the effect that ground kinetic side dominance has on the symmetry of bar end power outputs had not previously been investigated. They are important because a) they demonstrate that ground kinetic asymmetries do not affect the symmetry of barbell end power output during back squat performance, b) they increase the efficacy of the vertical displacement based approach for (method two) of measuring back squat power output that was validated and recommended in Chapter 4, and c) they indicate that the body must compensate in some way to avoid the quite considerable ground kinetic asymmetries effecting the symmetry of the barbell, which may go some way to support the contentions of Newton *et al.* (2006a) regarding injury potential.

Although this study is the first to examine the affect of ground kinetic asymmetries on the symmetry of power outputs measured from both ends of the barbell, high between-subject variance may have compromised the clarity of the results. In addition to this, the consistency of within-subject symmetry was not assessed. It is felt that this could be an important part of any future work because knowledge of within-subject consistency would underpin any training based interventions. Therefore, further research in this area should employ a single subject methodology to examine individual, in addition to group responses (Bates, 1996). Further work could also include electromyographic analysis of core musculature and 3D motion analysis of trunk mechanics to examine the mechanical demands of maintaining symmetrical barbell kinematics and kinetics in the presence of ground kinetic asymmetries.

To summarise, ground kinetic asymmetries and progressive loading do not significantly affect the symmetry of barbell end power output during back squat performance, supporting the efficacy of method two (Table 4-1) that was validated and recommended in Chapter 4. This has important implications for strength and conditioning professionals because this method tends to be more accessible, less technically complex and financially cheaper compared to alternative and typically laboratory based methods.
Apparently healthy individuals demonstrate considerable differences between the ground reaction forces that are generated between the left and right side during back squat performance. These may be a cause for concern and the focus of correctional treatments or training programs. However, they do not affect the symmetry of the barbell and as such the measures of resistance exercise power that is often obtained from bar end kinematics. Further, progressive loading does not significantly influence ground kinetic or bar end kinematic side differences. Ground kinetic side differences should be assessed from independently measured left and right side ground reaction forces and the symmetry of barbell end power from independently measured left and right barbell end kinematics.

Regarding the initial aims of this thesis, a measurement methodology that derives resistance exercise mechanical power output from the vertical displacement of the barbell has been recommended and validated. Further, the factors that might affect it - horizontal barbell displacement and barbell end asymmetries - have been examined and the results of Chapter 5 and Chapter 6 have reinforced method validity. Therefore, the final experimental chapter will establish the affect that training status – maximal strength and resistance training experience - has on power output and the optimal load in general and power output and the optimal load reliability specifically.

Chapter 7 - Does training status affect the optimal load and its test-retest reliability?

Introduction

In Chapter 2 a review of the literature established that optimal load training is used to more efficiently develop powerful muscle function (Cormie *et al.*, 2007d; Harris *et al.*, 2008; Kaneko *et al.*, 1983; Kawamori and Haff, 2004; Newton *et al.*, 2006; Wilson *et al.*, 1993), whereby *efficiency* referred to the ability of optimal load training to generate performance gains equivalent to or better than traditional heavy resistance training while exposing the athlete to considerably less training related intensity. The concept involves resistance training with the load that maximises mechanical power output, which is determined by studying the load-power relationship (Dugan *et al.*, 2004; Li *et al.*, 2008).

The methodological factors that affect the measurement of power output have been examined. Chapter 3 established that the positive lifting phase of resistance exercise should be determined from the acceleration only approach rather than the traditional peak displacement acceleration and deceleration approach that was historically used. The reliability and validity of the different methods (Table 4-1) that are commonly used to measure resistance exercise power output was established in Chapter 4 and a barbell kinematics based method recommended (method 2). The validity of this method was further examined and reinforced in Chapters 5 and 6.

However, research has shown that training status, characterised in this thesis by both maximal strength (Baker, 2001, Stone *et al.*, 2003) and training experience (Rhea, 2004), and related factors, such as age (Izquierdo *et al.*, 1999) and gender (Jandacka and Vaverka, 2008; Thomas *et al.*, 2007) can affect the load-power relationship, and as a consequence, the optimal load.

For example, Stone *et al.* (2003) found that stronger participants maximised jump squat peak power output with 40% of their 1RM compared to less strong participants, who maximised peak power output with 10% of their 1RM. Conversely, Harris *et al.* (2007) found that stronger athletes maximised peak power output with around 7% less of their 1RM than less strong athletes. Kawamori *et al.* (2005) reported similar findings during hang power clean performance, where stronger participants maximised mean and peak power output with 10% less of their 1RM less than the less strong participants (70 compared to 80% 1RM). Stone *et al.* (2003) explained that their optimal load differences may have occurred because of the relationship between maximal strength and the rate of force development, and because greater resistance training experience may have meant a greater exposure to power training; this may have influenced their ability to express powerful muscle function. The findings presented by Kawamori *et al.* (2005) may be explained by the research of Winchester *et al.* (2005), who posited that not only was greater resistance training experience associated with greater maximal strength but also greater technical efficiency, particularly in variations of the Olympic weight lifts.

Further, training status, categorised by maximal strength, appears to underpin the affect that age and gender can have on power output and the optimal load. Izquierdo *et al.* (2002) reported considerable differences between the loads that maximised power output in athletes from different sports, but in earlier research (Izquierdo *et al.*, 1999) showed that younger men (40 years) generated significantly higher power outputs than their older (65 years) counterparts. They also maximised power output at different relative exercise intensities (60 compared to 70% 1RM for back squat and 45 compared to 30% 1RM for bench press). Jandacka and Vaverka (2008) found similar effects for gender with men tending to generate much higher power outputs at lower relative exercise intensities during both bench press and back squat performance.

This suggests that training status may control the ability to express powerful muscle function, and is a concern because coaches are often responsible for athletes of differing standards. A review of the literature suggests that a blanket application of traditional optimal load training theory may be inappropriate and that the load that maximises power output should be identified on an individual basis (Flanagan, 2008 (*in Chiu, 2008*); Harris *et al.*, 2007). To date however, research has not specifically addressed the effect that training status may have on mechanical power output and the optimal load of back squat performance.

The ability of a performance test to consistently reproduce accurate measures is a factor that is critical to the practical relevance and usefulness of that test (Atkinson and Nevill, 1998). However, with only one exception (Harris *et al.*, 2007) optimal load reliability has not been established. Harris *et al.* (2007) studied power outputs across a range of loads (10 to 100% 1RM) during jump squat performance in well-trained athletes, reporting a typical error for mean and peak power optimal load test-retest reliability of around 6%. A question that remains unanswered however is whether training experience affects test-retest reliability. If training status affects test-retest reliability it could have important implications for the way in which practitioners approach load-power testing with subjects of differing training status.

Therefore, the aim of this study was to establish whether training status affected the load with which mean and peak power was maximised, its intra - and inter - session reliability and whether training status affected optimal load reliability. It was hypothesised that stronger individuals would generate greater mean and peak power outputs and that these would be maximised at loads that differed from less strong individuals. It was also hypothesised that because greater exposure to resistance exercise should, at least theoretically improve resistance exercise efficiency, stronger, more experienced individuals would demonstrate greater test-retest reliability than their weaker, less experienced counterparts.

Methods

Participants

Thirty-one male subjects of mixed resistance training experience volunteered to participate in this study. Subjects were grouped according to training experience, using the method outlined by Rhea (2004) - where those with less than one year's resistance training experience were classed as untrained, those with between one and five years experience were classed as recreationally trained, and those with more than five years experience were classed as trained - and back squat maximal strength (1RM), using the methods outlined and used by Stone *et al.* (2003) – where the strongest and five weakest (according to back squat relative 1RM) participants were grouped for later comparison. The mean (± SD) physical characteristics are presented in Table 7-1. University of Chichester ethics approval was obtained before data collection and following a thorough explanation of the experimental aims and procedures all subjects completed a health history questionnaire and provided written informed consent.

Table 7-1. Mean (± SD) physical characteristics of the different subgroups.

	Untrained (n = 12)	Recreationally (n = 10)	Trained (n = 9)	Weak (n = 5)	Strong (n = 5)
Mass (kg)	75.46 (12.67)	80.18 (15.00)	90.58 (13.51)	79.66 (18.21)	84.32 (12.17)
Back squat 1RM (kg)	115.83 (26.61)	138.00 (17.98)	192.50 (42.68)	109.00 (38.14)	205.00 (55.00)
Back squat 1RM ($kg \cdot kg \cdot bm^{-1}$)	1.53 (0.22)	1.74 (0.19)	2.14 (0.45)	1.34 (0.21)	2.41 (0.42)
Back squat ROM (m)	0.38 (0.02)	0.38 (0.02)	0.38 (0.01)	0.38 (0.04)	0.38 (0.02)

*$kg \cdot kg \cdot bm^{-1}$ = kg per kg of body mass; ROM = back squat positive lifting phase range of motion; Untrained, recreationally trained and trained refers to guidelines presented by Rhea (2004); Weak and strong refers to methods described and used by Stone *et al.* (2003).

Test procedures

All subjects attended the laboratory on six separate occasions with a minimum of four days and a maximum of seven days between sessions. The first three sessions were used to familiarise all subjects with the modified back squat that was used to assess lower-body maximal strength and powerful muscle function (see Chapter 3). The first (introduction) session was used to establish exercise range of motion, which was set at 45% of participant leg length (Flanagan and Salem, 2007). Leg length was measured between the lateral malleolus and greater trochanter three times using a steel tape measure and the mean of the three measures used for subsequent calculations. Following a standardised five-minute bicycle ergometer warm-up, all subjects were given instruction on the technique requirements for back squat performance and asked to perform between three and five sets of five to eight repetitions with loads that felt light to moderately challenging to ensure that these could be met following the criteria described by Flanagan and Salem (2007). In some cases, subjects who had no resistance exercise experience required additional coaching but did not exceed a total of ten sets during the first session. Particular emphasis was put on the following elements of technique: keep chest up and out, weight on heels and "sit back", flexing at the hips and knees until the barbell lightly touched safety supports positioned to mark the exercise range of motion, and keeping the weight on the heels, drive the hips forward during the ascent. The bicycle ergometer warm-up and light squatting was performed at the beginning of all sessions, both familiarisation and testing. During the second and third (familiarisation) sessions, all subjects were asked to perform five to eight progressively heavier sets of three to eight repetitions. Load was increased until it felt challenging to perform three repetitions, which decreased as load increased. During this and the third session particular emphasis was placed on controlling the descent until the barbell lightly touched the safety supports, at which point subjects were asked to perform the ascent as explosively as possible. During the third familiarisation session, subjects performed progressively heavier sets until a "heavy but not maximum" load was reached. This was used to inform load selection during the fourth (maximal strength testing) session, which occurred four to seven days later and used a protocol similar to that outlined and used by Frost *et al.* (2008a) for bench press performance. During the fourth (maximal strength) session participants were instructed to perform one set of four repetitions with 60% of their estimated (from third familiarisation session loads) 1RM, one set of three repetitions with 70% of their estimated 1RM, one set of two repetitions with 80% of their estimated 1RM, and one single lift with 90% of their estimated 1RM. Participants then performed progressively heavier (increases between 5 and 10 kg) single lifts until a maximum was achieved. This was signalled by a failure to successfully perform a lift with good technique during two attempts with a given load. Rest periods of one to three minutes were given between the warm up sets and up to five minutes between the maximum attempts (Reiser *et al.*, 1996).

During the two final sessions load-power relationship testing was performed using the protocol outlined in Chapter 4. Briefly, following the warm up procedure explained above participants performed two maximal effort single lifts with 15, 30, 45, 60, 75 and 90% of the 1RM recorded during the fourth session, with a minimum of one minute and a maximum of three minutes rest between all lifts (Reiser *et al.*, 1996).

During all back squat testing the barbell (Eleiko Weightlifting Training Bar, Sweden) was positioned across the subject's posterior deltoids, immediately below the C7 vertebrae, and taken from freestanding squat stands (Scorpion Gym Equipment, Nottingham, UK). Subjects were not allowed to "bounce" the barbell off the safety supports and were instructed to maintain foot-floor contact throughout the ascent. Further, all subjects were asked to refrain from all lower-body resistance exercise for the duration of the study and to not participate in exercise or sporting performance 48 hours before each session.

Measurements and data analysis

The displacement of the right bar end was recorded and processed, and peak and mean power output calculated, using the experimental set-up, equipment and calculations outlined and used in Chapter 3. One repetition maximums and mean and peak power outputs were normalised relative to participant body mass (kg per kg of body mass: $kg \cdot kg \cdot bm^{-1}$ and Watts per kg body mass: $W \cdot kg^{-1}$ respectively). Peak and mean relative power output optimal loads were determined using the process outlined and used in Chapter 4. Briefly, the load-power curves (both mean and peak power) of each participant were studied and the load with which the positive lifting phase mean and peak power output was maximised determined. This was done for both lifts during the first load-power testing session (fifth session, four to seven days after session four), which were labelled A1 and A2 respectively, and the first lift of the second load-power testing session (sixth session, four to seven days after session five), which was labelled B1.

Statistical analysis

All statistical data were presented as means (± SD) unless otherwise stated. Differences in maximal strength were examined in two different ways. Where the Rhea (2004) method was used to define training status a one-way analysis of variance was used to establish differences between the untrained, recreationally trained and trained subgroups. Where the Stone *et al.* (2003) method was used to define training status paired *t*-tests were used to establish differences between "strong" and "weak" participants (defined above).

A two-factor mixed factorial analysis of variance was used to establish whether there were any significant differences between the dependent variables of mean and peak relative power output and mean and peak optimal load. The independent variables were participant training status (between subjects factor, independently testing the two different methods: Rhea and Stone) and testing session (the within subject factor: session A1 and A2 and session B1), and provided a general indication of the effect of training status and test-retest bias. Training status by session interactions were used to quantify the effects of training status on test-retest bias. Post hoc analysis was performed using the Holm-Sidak procedure where appropriate to establish where significant differences lay.

Random test-retest error was examined using the percentage coefficient of variation (CV). The CV was calculated by dividing the standard deviation of each participant's test-retest data by the test-retest mean and multiplying this by 100 (Cronin *et al.,* 2004). The effect that training status had on random error (CV) was examined in two different ways; where the Rhea (2004) method was used, one-way analysis of variance was used to establish differences between the untrained, recreationally trained and trained CV for mean and peak power and mean and peak power optimal load. Where the Stone *et al.* (2003) method was used paired t-tests were used to establish differences between "strong" and "weak" participant random error. All statistical procedures were performed using SPSS for Windows version 16.0 (Chicago, Il.) and an alpha value of $p \leq 0.05$ was set to establish significant differences. Effect sizes (*d*) were calculated using the methods described and used in Chapter 3.

Results

Maximal strength

The results showed that trained participants were significantly stronger than untrained (29%, $p < 0.0001$, $d = 2.85$) and recreationally trained (19%, $p = 0.002$, $d = 2.09$) participants. Recreationally trained participants were 12% stronger than the untrained participants, although this difference did not reach statistical significance ($p = 0.267$, $d = 1$). Further, the five strongest participants were significantly stronger than the five weakest participants (44%, $p = 0.014$, $d = 5$). There was a strong relationship between training experience and maximal strength ($r = 0.66$, $p < 0.0001$), but not between training experience and test-retest reliability ($p = 0.44$ to 0.70) and maximal strength and test-retest reliability ($p = 0.07$ to 0.89).

Status effect on mean and peak power and optimal load

Mean (± SD) power output and optimal load data are presented in Table 7-2. Load-power curves are presented in Figure 7-1. Training status had a moderate to very large effect on mean and peak power (Table 7-2, Figure 7-2, and Figure 7-3). It did not significantly affect the load-power relationship, but moderate differences were found between weak and strong (Stone) mean power optimal loads, and moderate to large differences were found between untrained, recreationally trained and trained (Rhea) mean power optimal loads (Figure 7-1).

Table 7-2. Mean (± SD) peak and mean positive lifting phase power output ($W \cdot kg^{-1}$) and optimal load (% 1RM) data from the different testing sessions.

	PP A1	PP A2	PP B1	POL A1	POL A2	POL B1	MP A1	MP A2	MP B1	MOL A1	MO L A2	MOL B1
Rhea	16.25	15.63	16.89	77.50	71.25	83.75	6.60	6.65	7.05	80.00	76.25	78.75
(u)	4.53	4.64	5.26	12.52	11.31	7.72	2.05	2.23	2.65	11.68	11.89	9.32
Rhea	18.27	17.43	18.31	82.50	82.50	81.67	6.96	6.83	7.24	78.00	82.50	78.33
(r)	4.32	4.65	5.28	10.61	14.58	10.90	1.37	1.60	1.96	9.49	7.91	14.58
Rhea	21.69	21.88	22.65	81.67	65.00	73.33	8.11	8.38	8.67	75.00	66.67	66.67
(t)	6.27	6.62	4.66	10.90	22.50	19.04	2.11	2.22	2.41	16.77	22.64	16.96
Stone	14.93	13.40	13.97	78.00	75.00	81.00	6.47	6.52	5.74	78.00	81.00	72.00
(w)	5.31	5.47	4.50	12.55	15.00	13.42	2.76	3.35	1.70	12.55	8.22	12.55
Stone	26.13	25.02	25.85	84.00	75.00	69.00	9.51	9.44	9.76	75.00	69.00	72.00
(s)	5.79	6.00	4.28	8.22	25.98	22.7	2.01	2.02	1.94	10.61	22.75	24.65

* PP = peak power; MP = mean power; POL = peak optimal load; MOL = mean optimal load; u = untrained; r = recreationally trained; t = trained; w = weak; s = strong.

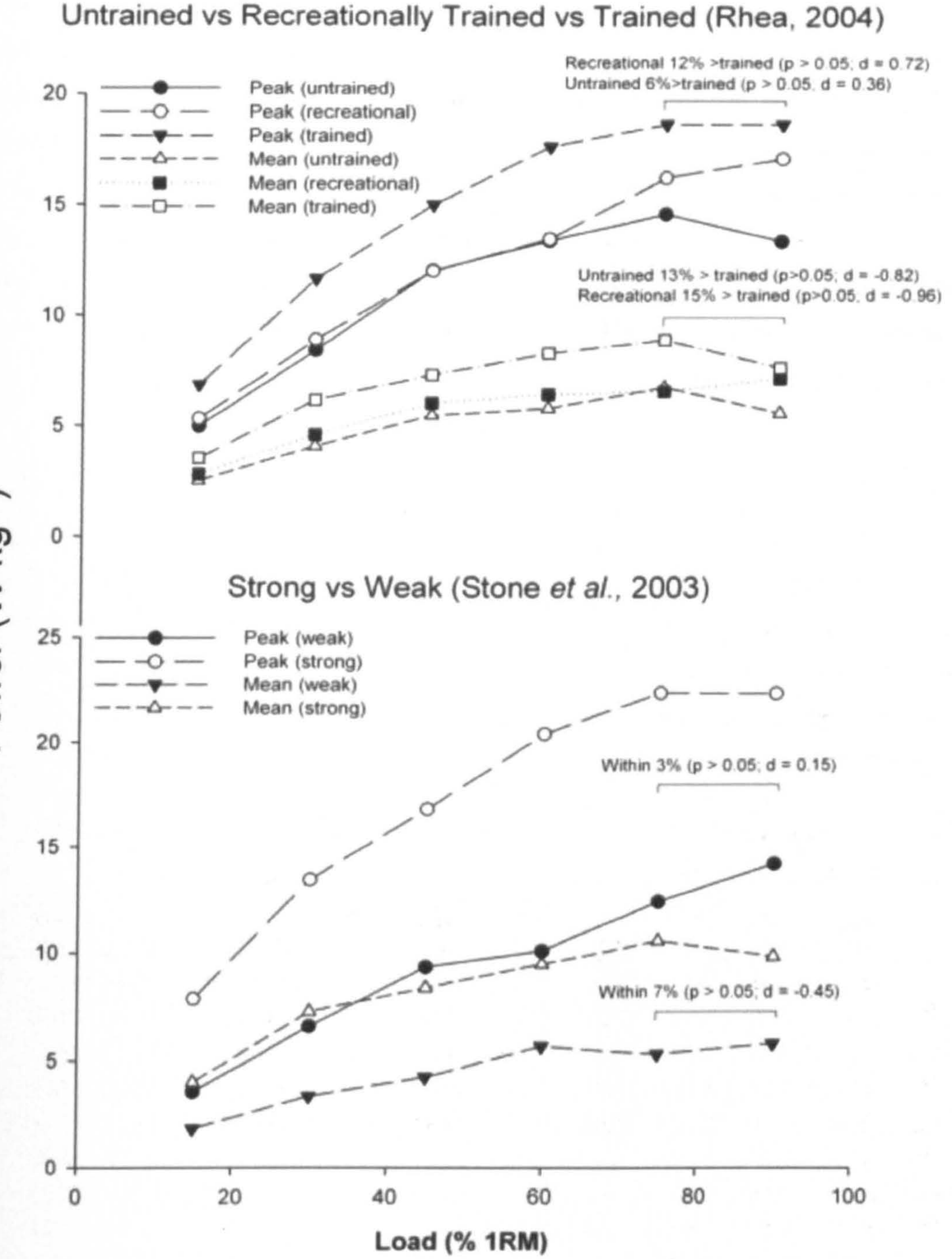

Figure 7-1. The effect of training status on the load-mean and peak power relationship.

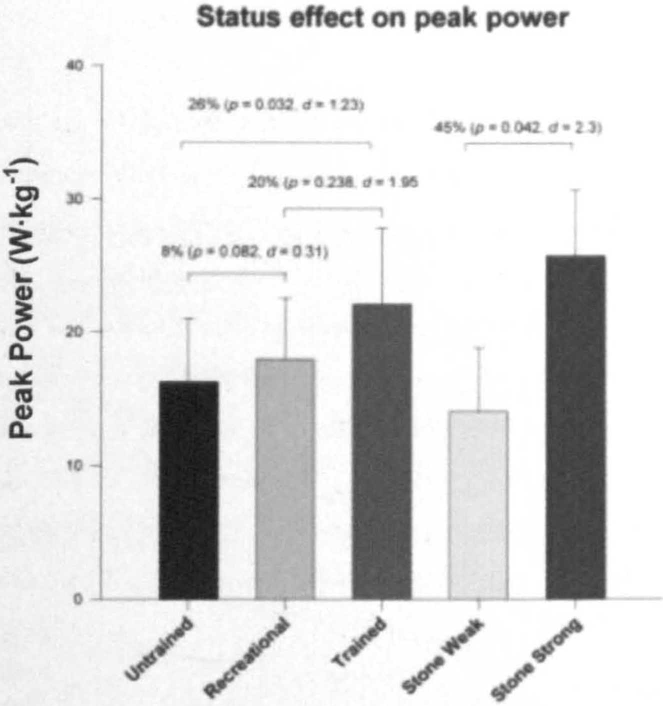

Figure 7-2. Training status effect on positive lifting phase peak power.

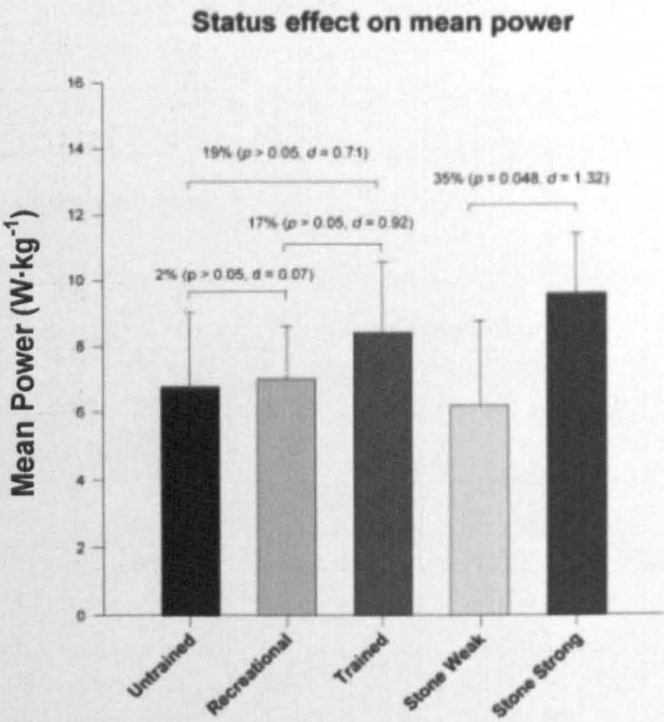

Figure 7-3. Training status effect on positive lifting phase mean power.

Reliability

Mean power optimal load test-retest differences did not exceed 4% ($p > 0.05$, Figure 7-5), however, moderate to large differences were found for the between session peak power optimal loads (Figure 7-4). In addition, training status did not influence mean or peak power optimal load test-retest bias (training status by session interaction: $p > 0.05$).

Except for mean power optimal load comparisons, within session reliability tended to be better than between session reliability, and mean and peak power reliability better than mean and peak power optimal load reliability (Table 7-3). Training status did not influence random test-retest error ($p > 0.05$; Table 7-3). However, Table 7-3 shows that greater training experience (Rhea, 2004) did not necessarily result in greater test-retest reliability; stronger subjects tended to produce more reliable measures of mean and peak power output, but not mean and peak power optimal loads.

Table 7-3. Mean and peak power and optimal load test-retest coefficients of variation (± 95% confidence limits).

	Rhea			Stone		Pooled
	Untrained	Recreational	Trained	Weak	Strong	
PP A1-A2	6.3 (2.6)	5.1 (3.1)	6.6 (4.3)	8.2 (4.9)	4.4 (6.0)	6.0 (1.8)
PP A1-B1	11.1 (4.5)	5.0 (3.1)	11.0 (9.5)	5.6 (5.4)	6.8 (3.1)	9.2 (3.3)
POL A1-A2	10.6 (5.0)	5.9 (4.9)	17.5 (13.5)	8.3 (6.7)	17.3 (22.0)	10.9 (4.6)
POL A1-B1	12.5 (5.3)	12.0 (5.2)	14.0 (13.8)	13.9 (12.4)	22.4 (18.7)	12.7 (4.5)
MP A1-A2	7.7 (3.2)	6.1 (3.2)	5.2 (2.4)	6.8 (6.6)	5.4 (2.6)	6.5 (1.8)
MP A1-B1	16.2 (9.1)	7.2 (4.1)	9.5 (8.8)	11.4 (7.2)	6.3 (2.5)	11.6 (4.7)
MOL A1-A2	12.9 (7.2)	9.3 (4.0)	14.8 (10.2)	8.2 (11.0)	14.6 (16.9)	12.2 (4.1)
MOL A1-B1	7.7 (3.9)	10.6 (3.8)	20.3 (9.9)	5.7 (6.9)	17.1 (15.5)	12.1 (3.7)

*PP = peak power; MP = mean power; POL = peak optimal load; MOL = mean optimal load.

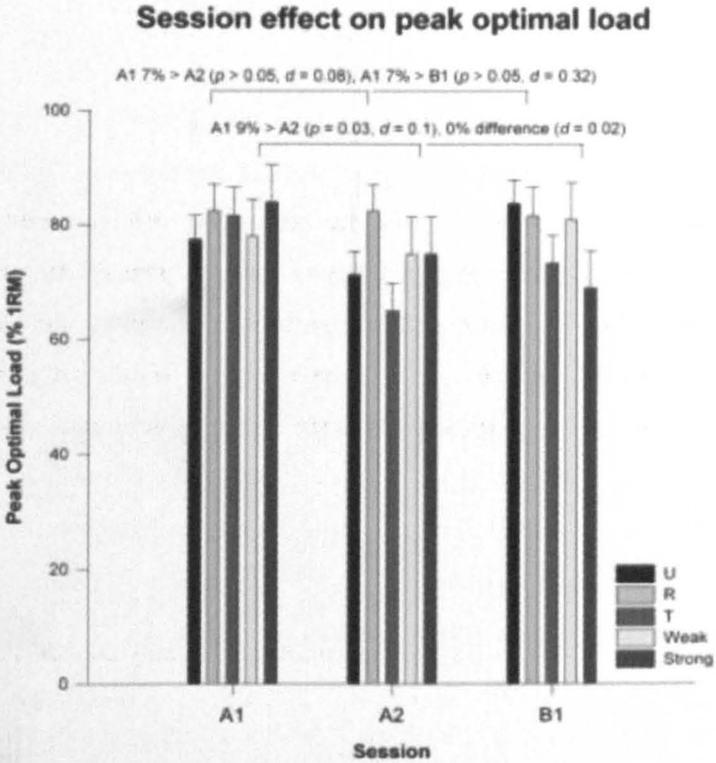

Figure 7-4. Mean (± SD) test-retest differences for peak optimal load.

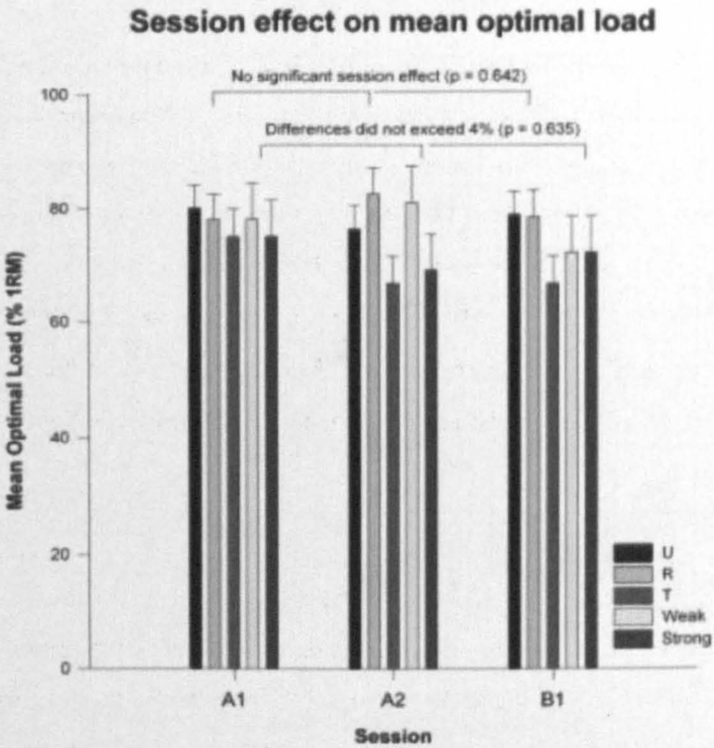

Figure 7-5. Mean (± SD) test-retest differences for mean optimal load.

Discussion

The aim of this study was to establish whether training status affected the load with which mean and peak power was maximised and whether training status affected optimal load reliability. It was hypothesised that stronger individuals would generate greater mean and peak power outputs and that these would be maximised at loads that differed from less strong individuals. It was also hypothesised that training status would underpin test-retest reliability.

Maximal strength

The trained participants were 29% stronger than the untrained participants and 19% stronger than the recreationally trained participants; recreationally trained participants were 12% stronger than untrained participants. The five strongest individuals were 44% stronger than the five weakest individuals. These findings were expected but although the training experience based differences agreed with previous research for back squat performance (Izquierdo *et al.*, 1999, 2002; Jandacka and Vaverka, 2008), the strength based differences were almost double those of similar comparisons (Izquierdo *et al.*, 1999, 2002; Jandacka and Vaverka, 2008). For example, Izquierdo *et al.* (2002) compared the back squat strength and power of athletes from different sporting backgrounds. However, comparison of the strongest athletes (weightlifters) to their non-resistance trained control group yielded a 24.5% difference in back squat 1RM. The strongest participants in the present study were considerably stronger than the weightlifters studied in the Izquierdo *et al.* (2002) study (1RM of 1.5 compared to 2 $kg \cdot kg \cdot bm^{-1}$ in the Izquierdo *et al.*, 2002 study and 1.3 compared to 2.4 $kg \cdot kg \cdot bm^{-1}$ in the present study). However, similar differences (39%) were reported by Stone *et al.* (2003) between the five strongest and weakest participant static start and countermovement jump squat 1RM.

Mean and peak power output

Regarding the first hypothesis that stronger individuals would generate greater mean and peak power outputs, trained participants generated peak power outputs that were 26% greater than untrained participants and 20% greater than recreationally trained participants, while recreationally trained participants generated peak power outputs that were 8% greater than untrained participants. Further, trained participants generated mean power outputs that were 19% greater than the untrained participant equivalent and 17% greater than the recreationally trained equivalent. However, differences between the recreationally trained and untrained participant mean power outputs did not exceed 2%. The training experience related differences agreed with some previous research findings (Izquierdo *et al.*, 1999; Jandacka and Vaverka, 2008) but not others (Izquierdo *et al.*, 2002; Stone *et al.*, 2003). For example, in contrast to the differences in maximal strength, Izquierdo *et al.* (2002) reported a 46% difference in mean power output between trained weightlifters and untrained control participants, while Stone *et al.* (2003) reported differences of around 34% between strong and weak participant peak power outputs. The mean power outputs generated by the stronger participants in the present study were between 14 and 22% less than those generated by the weightlifters in the study by Izquierdo *et al.* (2002). In spite of these differences the findings of the present study supported the hypothesis that stronger participants would generate greater power outputs during back squat performance.

Status effect on mean and peak power optimal load

Regarding the hypothesis that the load with which mean and peak power output was maximised would be affected by training status, recreationally trained participant peak optimal loads occurred with 12% 1RM less than the trained participants, while untrained participant peak optimal load occurred with 6% 1RM more. This was considerably less than the status based peak power optimal load differences reported by Stone *et al.* (2003) (30% 1RM) but in good agreement with back squat related research (Izquierdo *et al.*, 1999; Jandacka and Vaverka, 2008). The status effect on mean power optimal load was more dramatic, with recreationally trained mean optimal load occurring with 15% 1RM less than the trained participant equivalent, and untrained participant mean optimal loads tending to occur with 13% 1RM less than the trained participant equivalents. A review of the literature indicated that there are conflicting opinions about the mechanisms underpinning these differences. Research has shown that greater experience with an exercise can result in a more efficient expression of explosive force production (Kawamori *et al.*, 2005; Winchester *et al.*, 2005). While this opinion is not universally supported (Harris *et al.*, 2007) it appears to have underpinned the pattern of optimal load differences in the present study.

Interestingly, strong and weak peak optimal loads occurred within 3% 1RM of one another, while their mean optimal loads were within 7% 1RM of one another. This was a surprise as recent research findings indicated that greater differences would occur (Kawamori *et al.*, 2005; Stone *et al.*, 2003). However, further analysis showed that there was a large degree of test-retest variance. There were no differences during some testing sessions (A2 for peak optimal load and B1 for mean optimal load) but differences of up to 17.4% 1RM in others (B1 for peak optimal load and A2 for mean optimal load). In the majority of cases these differences were accompanied by large standard deviations (up to 9.5% in some cases), which may go some way to explain the lack of statistically significant differences. Importantly, in all but one (untrained versus trained peak optimal load) effect sizes were moderate to large (d = -0.96 to 0.72). The lack of within and between session consistency and the evidence of a moderate to large effect is a concern that strength and conditioning practitioners should consider as it has the potential to undermine single testing session based training load prescription. Therefore, the second hypothesis was supported.

Test-retest reliability of mean and peak power output and optimal load

Although there was no significant status by test-retest interaction, within and between session variance was high and may have had an impact on the present findings (Figure 7-4 and Figure 7-5). Mean power optimal load test-retest differences did not exceed 4%. However, it was the weaker, less experienced participants who demonstrated the better test-retest random error, while their mean power output test-retest random error tended to be noticeably, though not significantly, less.

In some cases (A1 versus A2) the peak optimal load test-retest percentage differences reached 9%. Typical loading strategies use loading increments of 10 to 15% of the 1RM, which means that although these differences were not statistically significant, they warrant consideration in the process of training optimal training load prescription.

Peak power output test-retest random error did not appear to vary noticeably across the different statuses. However, A1 versus B1 random error tended to be greater than A1 versus A2 random error for all variables of interest. Initially this may indicate a lack of familiarisation with the testing protocol. It was anticipated that the less experienced participants might demonstrate less test-retest reliability. However, it was felt that the four-week familiarisation protocol that was used in this study would be sufficient to overcome this problem. This appears to have been supported by the finding that trained (resistance training experience $\geq$ 5 years) participants' demonstrated random error that was similar to and in some cases greater than that of the weaker, less experienced participants.

Perhaps the most interesting finding was that stronger, more experienced participant mean, but particularly peak power optimal load test-retest random error tended to be considerably greater than the weaker, less experienced equivalents. This finding was not anticipated and led to the rejection of perhaps the most important, practically relevant hypothesis of the present study. That mean and peak optimal load test-retest reliability was poor in general, but more so for stronger, more experienced participants challenges the concept of an optimal resistance training load for the more efficient development of powerful muscle function. However, that research (Wilson *et al.,* 1993; Lyttle *et al.,* 1996; Cormie *et al.,* 2007d; Harris *et al.,* 2008; Winchester *et al.,* 2008) has demonstrated, first hand, the potential worth of the concept confuses the issue further. These findings, combined with existing posits (Flanagan, 2008 (*cited in Chiu, 2008*) and research evidence (Harris *et al.,* 2007), take the theory of an optimal range of loads rather than a specific load for the efficient development of powerful muscle function a stage further. They also reinforce the need to prescribe the optimal load on an individual athlete basis and should, where possible, be constantly monitored.

To summarise, stronger individuals do generate greater mean and peak power outputs during back squat performance than their weaker, less experienced counterparts. Further, the load at which mean and peak power is maximised appears to be influenced by training status. Although the load-power relationship demonstrated questionable reliability lesser experienced individuals did not generate less reliable load-power relationships. Indeed, in the present study, the results indicated that in many cases stronger, more experienced individuals generated less reliable load-power relationships. The results of this study reinforce the need to not only prescribe the optimal load on an individual athlete basis but that it appears to require session to session monitoring to ensure its accuracy. Further, it is important that strength and conditioning professionals consider the affects of training status when implementing research based resistance training practices.

Chapter 8 - General discussion, conclusions and implications for further research

A review of the scientific literature showed that there were several factors that appeared to influence the load-power relationship, which in turn could affect the load with which mean and peak power- the optimal load- is maximised. Of the greatest concern were the methodological factors, including the way in which the positive lifting phase is determined, the way in which resistance exercise mechanical power output is measured, and individual training status.

There has been a preference for the use of ballistic resistance exercises for the development of powerful muscle function because it was believed that a greater portion of the positive lifting phase was spent accelerating the load, which in turn was thought to stimulate a greater training effect (Baker, 2001, 2002; Frost *et al.*, 2008a and b; Newton *et al.*, 2006b). Frost *et al.* (2008b) recently showed that this was not the case for upper-body resistance exercise when only the positive work considered in ballistic resistance exercise was used to determine the positive lifting lifting phase of traditional non-ballistic resistance exercise. However, the affect that this has on equivalent lower-body resistance exercise had not been established.

The calculation of resistance exercise mechanical power output relies on the accurate measurement of the force and velocity components that underpin it. There are currently limitations to the way in which the theory underpinning the calculation of resistance exercise power is interpreted and applied in real world settings. Measures of barbell power output can be derived from barbell displacement data and lend themselves well to cost effective field applications. However, this method has been criticised because it is believed that it may not provide an accurate reflection of the barbell and body system power output (Cormie *et al.*, 2007b). It has been suggested that because many of the methods that are used to measure barbell power rely on the vertical displacement of the barbell they may underestimate true power output because they do not consider the horizontal contribution (Garhammer, 1980, 1993; Cormie *et al.*, 2007a and b). Further, recent research has suggested that significant side dominance is often demonstrated in bilateral lower-body resistance exercise (Flanagan and Salem, 2007; Newton *et al.*, 2006a). This may influence the symmetry of the barbell and if this is the case, the integrity of methods that use barbell end displacement to measure resistance exercise mechanical power output.

Another factor that has been shown to influence the load-power relationship is training status (defined by both maximal strength and resistance training experience), whereby stronger, more experienced athletes maximise mean and/or peak power output at points on the load-power curve that are different to those of their weaker, less experienced counterparts (Kawamori *et al.*, 2005; Stone *et al.*, 2003). However, the effect that training status had on test-retest reliability had not been established. Therefore, this thesis examined the methodological concerns described above.

To have confidence in the way in which mechanical power output is measured, it was necessary to compare key kinetic and kinematic measures of traditional (back squat) and ballistic (jump squat) lower-body resistance exercise. Whether the way in which the positive lifting phase was determined would influence the kinetic and kinematic differences that are associated with traditional and ballistic resistance exercise comparisons was also examined. It was hypothesised that key kinematic and kinetic measures would be significantly greater during ballistic performance but that this would be a consequence of the way in which the positive lifting phase was determined. The results of the study led to the rejection of the hypothesis. Neglecting the deceleration phase that was performed during the positive lifting phase of traditional back squat exercise caused a considerable decrease in the differences in mean power output that were achieved during both traditional back and ballistic jump squat performance. Further, neglect of the deceleration phase led to the finding that the barbell was accelerated for a significantly greater portion of the positive lifting phase during back squat performance compared to the ballistic jump squat equivalent. Of practical relevance was the finding that the end of the positive work phase of traditional back squat performance was marked by the peak barbell velocity. From these findings it was suggested that the deceleration phase be ignored when determining the positive lifting phase of resistance exercise as it makes no contribution to barbell power output but can affect mean positive lifting phase values and is easily identifiable from the velocity-time graph as the period beginning with the transition from negative to positive barbell velocity until peak barbell velocity is reached.

Once the theoretical underpinnings of positive lifting phase identification had been considered, it was necessary to assess the reliability of and degree of agreement between the different methods that are commonly used to calculate resistance exercise mechanical power output and the force and velocity components that underpin them; This was the focus of Chapter 4. Repeat performances of lower-body resistance exercise were recorded during one testing session. Mechanical power output was measured by five different methods that were based on three general approaches that are based on barbell displacement, system ground reaction forces and a combination of barbell displacement and system ground reaction forces. From conflicting evidence in current literature it was hypothesised that the method used would significantly affect resistance exercise mean and peak mechanical power output. The results clearly demonstrated poor test-retest reliability that may compromise the researcher's ability to detect changes in the load-power relationship. It was suggested that method reliability should be established before load-power testing is performed so that the researcher can establish a magnitude that load induced changes in the load-power relationship must exceed if they are to be considered meaningful. Further, with the possible exception of method one and two (barbell kinematics based methods, see Table 4-1), the different methods that are commonly used to obtain measures of resistance exercise power should not be used interchangeably as they tend to differ considerably. Differences were found to influence the shape of the load-power relationship and in turn, the point at which maximal mean and peak power output was achieved - the optimal load. The method four (GRF × bar velocity) and five (system force derived from bar kinematics × bar velocity) measures of system centre of mass power were considerably greater than those of the theoretically sound method three measures. This was because both method four (GRF × bar velocity) and five (system force derived from bar kinematics × bar velocity) relied on the assumption that barbell velocity provided an accurate representation of the system centre of mass velocity, which comparison with the GRF based method three refuted. However, because the method three (GRF based method, see Table 4-1) reliability was poor it was suggested that the barbell kinematics based method two should be used to obtain measures of mean and peak power output and the optimal load to achieve the remaining aims of this thesis. However, it was important to be aware of the potential limitations of method two, which derived measures of barbell power from the vertical displacement of one end of the barbell. Research evidence (Cormie *et al.*, 2007a) showed that method two's failure to consider horizontal barbell displacement could lead to an underestimation of powerful muscle function, thus compromising method validity.

Whilst a preferred measurement methodology had been selected, potential limitations remained. Chapter 5 set out to refine this method by establishing whether the power that was generated in the vertical plane underestimated total barbell power output because it did not consider horizontal barbell displacement. Total barbell power output was calculated as the sum of vertical and rectified horizontal (anterior-posterior) power output. The results presented by Cormie *et al.* (2007a) led to the hypothesis that a failure to consider horizontal barbell displacement would result in a significant underestimation of upper and lower-body resistance exercise total mechanical power output and that this would be affected by progressive loading. The results of Chapter 5 did not support the hypothesis. Total barbell power output did not significantly differ from vertical barbell power output during both upper and lower-body resistance exercise, vertical only power output did not underestimate total bar power, and this was not affected by progressive loading. These findings have important implications for strength and conditioning professionals and for research into powerful muscle function because they increased the efficacy of the vertical barbell displacement based method two provided an accurate representation of total barbell power output.

Historically bilateral resistance exercise has been assumed to be symmetrical. Research evidence (Flanagan and Salem, 2007, Newton *et al.*, 2006a) recently challenged this, demonstrating that healthy individuals tended to favour a dominant side by as much as 10%. However, it was not known if ground kinetic side differences were transmitted to the barbell. If this was the case it could influence barbell symmetry, which would in turn compromise the validity of method two. Chapter 6 aimed to establish the consequences of ground kinetic side dominance on the symmetry of barbell end power output, further refining the barbell displacement based method recommended in Chapter 4. Side dominance was determined in three ways: perceived handedness- whether participants were left or right handed, left or right side dominance- determined from independently measured ground reaction forces, and left and right side bar end dominance according to left and right bar end power output. It was hypothesised that side dominance would significantly affect the symmetry of power outputs recorded from both ends of the barbell. The results of this experiment did not support this hypothesis. Although non-significant differences of up to 21% were found between the forces that were generated by the dominant and non-dominant sides, differences between the power outputs recorded from both ends of the barbell did not exceed 4%. Further, progressive loading did not affect side dominance or the symmetry of power outputs recorded from both ends of the barbell. These findings reinforce the validity of using the displacement from one end of the barbell to calculate resistance exercise mechanical power output because they show that data recorded from either end of the barbell does not differ significantly, thus refining the use of the barbell kinematics based method two during back squat performance.

The final factor under consideration for the accurate measurement of resistance exercise power in general, and the identification of optimal load specifically was training status, which was considered in Chapter 7. In addition, the load with which mean and peak power was maximised, its intra- and inter-session reliability and whether training status affected optimal load reliability. It was hypothesised that stronger individuals would generate greater mean and peak power outputs and that these would be maximised at loads that differed from less strong individuals. It was also hypothesised that training status would underpin test-retest reliability, with stronger, more experienced individuals demonstrating greater test-retest reliability. The results of this study showed that stronger individuals did generate greater mean and peak power outputs during back squat performance compared to their weaker, less experienced counterparts. Further, the load at which mean and peak power was maximised was influenced by training status. However, the load-power relationship demonstrated questionable reliability but this was not expressed in the way that was expected. Indeed, the results indicated that in many cases stronger, more experienced individuals generated less reliable load-power relationships. The results of this study reinforced the need to not only prescribe the optimal load on an individual athlete basis but that the optimal load may require session to session monitoring to ensure the desired training stimulus.

Regarding the methodological concerns surrounding the concept of an optimal resistance training load for the more efficient development of powerful muscle function the results of this thesis have confirmed:

- The way in which the positive lifting phase is determined caused a considerable but non-significant difference in mean power output, increasing when the deceleration phase was neglected.
- The way in which the positive lifting phase is determined significantly affects the amount of the positive lifting phase during which the barbell is accelerated.
- The different methods that are commonly used to measure resistance exercise mechanical power output rely on distinctly different elements of resistance exercise performance - namely barbell kinematics and system kinetics. Their respective values differ significantly, and as such should not be used interchangeably.
- Using a combination of theoretical soundness, practical applicability and reliability, results from this thesis led to the recommendation that a barbell kinematics method

that enables the force – considering barbell acceleration - and velocity parameters necessary to calculate mechanical power output to be derived from barbell displacement should be used for both field and laboratory based measurement. In addition to the factors mention above, this method enables the measurement of powerful muscle function during traditional resistance exercise without interfering with performance.

- The exclusion of horizontal barbell power did not result in a significant underestimation of total barbell power output during back squat and bench press performance.
- Horizontal barbell power is not affected by progressive loading during back squat or bench press performance.
- Movement asymmetry recorded from independent force platforms did not affect the symmetry of mechanical power output recorded from both ends of the barbell during back squat performance.
- Side dominance is not affected by progressive loading during back squat performance.
- Stronger, more experienced individuals generate significantly greater mean and peak power outputs compared to their weaker, less experienced counterparts.
- Training status did not significantly influence mean and peak power output test-retest reliability, but reliability was poorer for the stronger, more experienced individuals.
- Training status did not significantly influence mean and peak power optimal load test-retest reliability, but reliability was poorer for the stronger, more experienced individuals.
- The optimal load should be prescribed on an individual basis.
- The optimal load varies considerably both within and between sessions.

A number of research questions, some of which have arisen from the results of this thesis remain unanswered. This thesis has addressed the primary aims regarding the way in which resistance exercise mechanical power output is measured and the factors that affect this. However, there needs to be further research into several of the methodological factors that may influence the load-power relationship in general and the optimal load specifically. Therefore, the following program of experimental research is suggested for further study:

- The study of a greater range of loads is required to gain an understanding of method sensitivity and whether this affects power output, the load-power relationship and ultimately the optimal load. It is noteworthy that a variety of different methods has been used to measure and monitor resistance exercise power output during optimal load training studies. Therefore, controlled experiments are required to establish whether the method used to determine and monitor the optimal load influence optimal load training outcomes?

- It is possible that perceived limitations to the optimal load training outcomes of the traditional back squat may lie with the way in which the positive lifting phase was determined to identify exercise power outputs. Do the optimal load training outcomes of the traditional back squat and ballistic jump squat differ when the back squat optimal load is determined from the positive only work phase? Positive findings might encourage back squat intervention over the ballistic jump squat, which in turn could reduce the increased injury risk associated with ballistic jump squat performance (Hori *et al.*, 2008). This is important because it avoids compromising the potentially more efficient method of developing powerful muscle function with an increased potential for injury from landing impacts. Therefore, controlled experiments are required to establish the effectiveness of optimal load back squat training.

- In addition to the above, it is possible that resistance exercise interventions such as resistance bands and chains could both alter the acceleration-time curve and reduce the duration of the deceleration phase associated with ballistic resistance exercise (Baker and Newton, 2005). This could make greater acceleratory demands during traditional resistance exercise performance, which may lead to improved powerful muscle function. Establishing the effects of resistance band and chain interventions on traditional resistance exercise would provide strength and conditioning professionals with methods that could be used as alternatives or in tandem with traditional resistance exercise to stimulate training adaptations and avoid training "staleness".

- The efficacy of optimal load training with variations of the Olympic weight lifts has not been established. This type of resistance exercise would appear to lend itself to optimal load resistance training because of its explosive, whole body nature that revolves around an explosive triple extension of the lower-body (Kawamori and Haff, 2004). Controlled training studies are required to determine whether this type of resistance exercise offers an efficient method of developing powerful muscle function, and whether it has any advantages over traditional resistance exercise optimal load training.

- An area of research that remains to be fully explored is the duration of rest interval between repetitions and sets during resistance exercise. Lawton *et al.* (2006) established that when a set of six repetitions was broken down in sets of one, two and three during upper-body resistance exercise power output was considerably greater when compared to a set of six continuous repetitions. However, similar strategies have not been applied to lower-body resistance exercise. This method has demonstrated that it has the potential to improve the efficiency of resistance exercise for the development of powerful muscle function. Therefore, controlled experiments are required to establish whether the manipulation of inter-repetition rest intervals can improve the efficiency of lower-body optimal load training.

- The findings regarding ground kinetic side dominance during traditional back squat performance warrant further research attention. Specifically it would be in the coach and athlete's interest to establish the factors that underpin ground kinetic side dominance and intervention strategies that might reduce the condition. By ignoring the problem do athletes run the risk of exacerbating the condition, which might in time lead to injury? Research into the latter question would not be possible without compromising the well being of subjects. However, it would be enlightening to establish the effectiveness of interventions that aim to reduce side dominance. Further, the development of a field-based method that would enable coaches who do not have access to multiple force platforms with a way of identifying and monitoring side dominance is required.

Appendix A – Summary raw data

Summary Raw Data – Chapter 3

condition	mean grf	mean v	mean p	peak disp	duration	t2pv
1	2057.80	0.63	622.18	0.97	0.09	100
1	2089.57	1.30	1326.24	0.70	0.08	100
1	1771.12	0.75	650.06	0.92	0.06	100
1	1341.04	0.97	715.40	0.36	0.06	100
1	1353.51	0.55	346.55	0.81	0.06	100
1	1771.88	0.59	492.31	1.00	0.08	100
1	1821.05	0.85	705.92	1.02	0.06	100
1	1793.82	1.59	1645.87	0.76	0.06	100
1	1692.74	0.67	619.01	0.89	0.06	100
1	1472.57	0.76	471.10	0.96	0.07	100
2	1783.72	0.66	537.03	0.97	0.11	74
2	1677.88	1.39	871.98	0.70	0.10	73
2	1329.66	0.75	493.14	0.92	0.09	63
2	1076.53	0.99	488.04	0.36	0.10	63
2	1076.41	0.57	279.20	0.81	0.09	64
2	1405.72	0.64	397.55	1.00	0.11	66
2	1286.12	0.87	490.93	1.02	0.36	17
2	1300.36	1.63	917.24	0.76	0.10	63
2	1244.41	0.74	455.40	0.89	0.09	67
2	1129.77	0.78	363.66	0.96	0.10	65
3	2123.92	0.67	682.78	1.07	0.10	84
3	2127.42	1.35	1398.86	0.97	0.11	86
3	1849.55	0.82	753.58	1.08	0.09	80
3	1375.64	1.20	927.55	0.64	0.10	82
3	1403.02	0.70	456.54	0.96	0.09	78
3	1931.59	0.90	715.25	1.24	0.09	82
3	1863.27	0.90	733.07	1.18	0.09	83

Legend:

1 = positive only back squat work
2 = Back squat acceleration and deceleration phase

3 = jump squat work

grf = ground reaction force

v = velocity

p = power

disp = displacement

t2pv = time to peak velocity

3	1866.98	1.73	1791.60	1.05	0.09	84
3	1751.76	0.79	749.65	1.02	0.08	81
3	1599.27	0.97	656.39	1.12	0.08	78

Summary Raw Data – Chapter 4

Participant	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5
1	1509.9	2437.5	2707.5	2577.0	1344.7
2	1054.8	1567.8	1850.2	1828.0	964.1
3	1400.3	2495.7	2430.7	2452.9	1191.1
4	1501.7	2101.2	2433.2	2244.7	1310.9
5	1578.9	2176.6	3144.9	3180.5	1344.5
6	660.6	998.7	1185.7	1175.0	620.7
7	1469.6	2001.4	2424.6	2330.3	1264.0
8	984.8	1083.0	1476.0	1414.7	859.6
9	1174.8	1694.4	2045.4	2018.6	1065.8
10	1599.8	1537.9	2646.0	2564.5	1322.5
11	1260.6	1763.5	2066.7	2090.2	1147.9
12	1130.1	1264.8	1411.4	1317.5	1072.7
13	1315.7	1816.7	2420.4	2325.5	1231.4
14	1848.4	2124.0	2980.5	2882.1	1690.3
15	1586.9	2507.8	3116.0	3159.1	1352.3
16	1673.3	2476.5	3194.5	3153.0	1439.7
17	2670.8	3514.2	3945.1	3845.8	2208.1
18	2111.1	2521.3	3414.1	3367.0	1804.6
19	1855.5	1856.7	2927.6	2703.3	1568.5
20	1342.3	1524.5	2584.8	2511.9	1181.8

Legend:
Peak = peak power
Mean = mean power
1 = method 1
2 = method 2
3 = method 3
4 = method 4
5 = method 5

Participant	Mean 1	Mean 2	Mean 3	Mean 4	Mean 5
1	759.4	1452.5	1292.7	1243.7	638.2
2	515.9	827.2	1103.8	1101.0	449.7
3	575.3	1360.9	1185.7	1166.9	473.5
4	627.8	1183.6	868.3	807.3	518.8
5	702.8	1024.7	1531.0	1426.7	582.8
6	304.1	541.7	619.5	591.3	262.2
7	693.0	1127.3	1201.0	1113.1	569.1
8	370.8	571.4	732.2	693.2	307.7
9	462.7	846.6	1046.6	1023.0	386.7
10	717.9	536.8	1295.5	1224.6	545.6
11	583.6	960.3	1085.8	1043.6	498.5
12	554.5	809.1	773.6	787.1	486.0
13	679.5	1088.9	1248.9	1211.2	602.0
14	948.5	1082.4	1564.7	1477.6	813.3
15	700.5	1324.6	1528.4	1424.8	583.3
16	692.7	1281.2	1490.2	1379.7	580.6
17	1244.0	1956.2	2026.0	1977.5	989.1
18	849.7	1160.8	1490.8	1399.4	717.3
19	624.6	881.4	1241.8	1155.3	515.3
20	654.5	594.7	1338.8	1234.1	527.2

Summary Raw Data - Chapter 5

Side	Method	Load	AGRF	ABP
d	fsd	30	0.756	4.657
d	fsd	30	0.705	5.254
d	fsd	30	0.806	7.273
d	fsd	30	1.293	3.140
d	fsd	30	0.653	4.905
d	fsd	30	0.802	5.937
d	fsd	30	0.677	5.643
d	fsd	30	0.738	4.123
d	fsd	30	0.656	4.567
d	fsd	30	0.584	3.810
nd	fsd	30	0.523	4.849
nd	fsd	30	0.674	5.177
nd	fsd	30	0.899	7.316
nd	fsd	30	0.615	3.309
nd	fsd	30	0.642	4.764
nd	fsd	30	0.755	5.965
nd	fsd	30	0.897	5.660
nd	fsd	30	0.634	3.922
nd	fsd	30	0.514	4.464
nd	fsd	30	0.553	3.903
d	fsd	60	0.967	7.477
d	fsd	60	1.011	8.164
d	fsd	60	0.631	10.746
d	fsd	60	1.321	5.165
d	fsd	60	0.820	7.000
d	fsd	60	1.066	9.234
d	fsd	60	0.672	8.087
d	fsd	60	0.917	7.022
d	fsd	60	0.933	7.441
d	fsd	60	0.892	5.545
nd	fsd	60	0.936	7.055
nd	fsd	60	0.825	7.863
nd	fsd	60	0.825	10.863
nd	fsd	60	0.819	5.202
nd	fsd	60	0.777	7.127
nd	fsd	60	1.045	9.367
nd	fsd	60	0.841	7.773
nd	fsd	60	0.869	6.899
nd	fsd	60	0.902	7.939
nd	fsd	60	0.884	5.553
d	fsd	90	1.187	8.125
d	fsd	90	1.172	9.857
d	fsd	90	0.807	9.234

Legend:
d = dominant side
nd = non-dominant side
fsd = force side dominance
lrsd = left/right side dominance
bsd = bar side dominance
Load = 30, 60 or 90% 1RM
AGRF = average ground reaction force
(body weights)
ABP = average barbell power
($W.kg^{-1}$)

d	fsd	90	1.406	2.487
d	fsd	90	1.017	8.130
d	fsd	90	1.389	9.183
d	fsd	90	0.473	8.253
d	fsd	90	1.133	7.830
d	fsd	90	1.161	9.767
d	fsd	90	1.164	4.735
nd	fsd	90	1.142	7.857
nd	fsd	90	1.103	9.681
nd	fsd	90	0.661	8.753
nd	fsd	90	0.996	2.373
nd	fsd	90	0.944	7.888
nd	fsd	90	1.283	8.416
nd	fsd	90	0.646	8.397
nd	fsd	90	1.101	7.711
nd	fsd	90	1.112	10.135
nd	fsd	90	0.985	4.762
d	lrsd	30	0.756	4.657
d	lrsd	30	0.674	5.177
d	lrsd	30	0.806	7.273
d	lrsd	30	1.293	3.140
d	lrsd	30	0.642	4.764
d	lrsd	30	0.755	5.965
d	lrsd	30	0.677	5.643
d	lrsd	30	0.738	4.123
d	lrsd	30	0.514	4.464
d	lrsd	30	0.584	3.810
nd	lrsd	30	0.523	4.849
nd	lrsd	30	0.705	5.254
nd	lrsd	30	0.899	7.316
nd	lrsd	30	0.615	3.309
nd	lrsd	30	0.653	4.905
nd	lrsd	30	0.802	5.937
nd	lrsd	30	0.897	5.660
nd	lrsd	30	0.634	3.922
nd	lrsd	30	0.656	4.567
nd	lrsd	30	0.553	3.903
d	lrsd	60	0.967	7.477
d	lrsd	60	0.825	7.863
d	lrsd	60	0.631	10.746
d	lrsd	60	1.321	5.165
d	lrsd	60	0.777	7.127
d	lrsd	60	1.045	9.367
d	lrsd	60	0.672	8.087
d	lrsd	60	0.917	7.022
d	lrsd	60	0.902	7.939
d	lrsd	60	0.884	5.553

nd	lrsd	60	0.936	7.055
nd	lrsd	60	1.011	8.164
nd	lrsd	60	0.825	10.863
nd	lrsd	60	0.819	5.202
nd	lrsd	60	0.820	7.000
nd	lrsd	60	1.066	9.234
nd	lrsd	60	0.841	7.773
nd	lrsd	60	0.869	6.899
nd	lrsd	60	0.933	7.441
nd	lrsd	60	0.892	5.545
d	lrsd	90	1.142	7.857
d	lrsd	90	1.172	9.857
d	lrsd	90	0.807	9.234
d	lrsd	90	1.406	2.487
d	lrsd	90	0.944	7.888
d	lrsd	90	1.283	8.416
d	lrsd	90	0.646	8.397
d	lrsd	90	1.101	7.711
d	lrsd	90	1.112	10.135
d	lrsd	90	1.164	4.735
nd	lrsd	90	1.187	8.125
nd	lrsd	90	1.103	9.681
nd	lrsd	90	0.661	8.753
nd	lrsd	90	0.996	2.373
nd	lrsd	90	1.017	8.130
nd	lrsd	90	1.389	9.183
nd	lrsd	90	0.473	8.253
nd	lrsd	90	1.133	7.830
nd	lrsd	90	1.161	9.767
nd	lrsd	90	0.985	4.762
d	bsd	30	0.523	4.849
d	bsd	30	0.705	5.254
d	bsd	30	0.899	7.316
d	bsd	30	0.615	3.309
d	bsd	30	0.653	4.905
d	bsd	30	0.755	5.965
d	bsd	30	0.897	5.660
d	bsd	30	0.738	4.123
d	bsd	30	0.656	4.567
d	bsd	30	0.553	3.903
nd	bsd	30	0.756	4.657
nd	bsd	30	0.674	5.177
nd	bsd	30	0.806	7.273
nd	bsd	30	1.293	3.140
nd	bsd	30	0.642	4.764
nd	bsd	30	0.802	5.937
nd	bsd	30	0.677	5.643

nd	bsd	30	0.634	3.922
nd	bsd	30	0.514	4.464
nd	bsd	30	0.584	3.810
d	bsd	60	0.967	7.477
d	bsd	60	0.705	8.164
d	bsd	60	0.825	10.863
d	bsd	60	0.819	5.202
d	bsd	60	0.777	7.127
d	bsd	60	1.045	9.367
d	bsd	60	0.672	8.087
d	bsd	60	0.917	7.022
d	bsd	60	0.902	7.939
d	bsd	60	0.884	5.553
nd	bsd	60	0.936	7.055
nd	bsd	60	0.825	7.863
nd	bsd	60	0.631	10.746
nd	bsd	60	1.321	5.165
nd	bsd	60	0.820	7.000
nd	bsd	60	1.066	9.234
nd	bsd	60	0.841	7.773
nd	bsd	60	0.869	6.899
nd	bsd	60	0.933	7.441
nd	bsd	60	0.892	5.545
d	bsd	90	1.187	8.125
d	bsd	90	1.172	9.857
d	bsd	90	0.807	9.234
d	bsd	90	1.406	2.487
d	bsd	90	1.017	8.130
d	bsd	90	1.389	9.183
d	bsd	90	0.646	8.397
d	bsd	90	1.133	7.830
d	bsd	90	1.112	10.135
d	bsd	90	0.985	4.762
nd	bsd	90	1.142	7.857
nd	bsd	90	1.103	9.681
nd	bsd	90	0.661	8.753
nd	bsd	90	0.996	2.373
nd	bsd	90	0.944	7.888
nd	bsd	90	1.283	8.416
nd	bsd	90	0.473	8.253
nd	bsd	90	1.101	7.711
nd	bsd	90	1.161	9.767
nd	bsd	90	1.164	4.735

Summary Raw Data – Chapter 6

Exercise	Load	Plane	PP	MP
b	30	y	616.7	240.0
b	30	y	1004.0	316.7
b	30	y	419.4	167.7
b	30	y	603.9	204.3
b	30	y	537.6	243.4
b	30	y	702.2	270.8
b	30	y	491.4	208.6
b	30	y	723.5	270.9
b	30	x	1.8	0.6
b	30	x	1.2	0.6
b	30	x	11.9	4.0
b	30	x	3.3	1.5
b	30	x	5.7	2.1
b	30	x	4.9	2.3
b	30	x	1.0	0.4
b	30	x	8.4	4.5
b	30	t	617.1	240.6
b	30	t	1004.4	317.2
b	30	t	423.7	171.8
b	30	t	605.0	205.8
b	30	t	543.3	245.5
b	30	t	706.8	273.1
b	30	t	492.0	209.0
b	30	t	728.7	275.3
b	60	y	647.5	332.7
b	60	y	524.3	381.3
b	60	y	420.0	224.6
b	60	y	495.1	299.9
b	60	y	382.5	269.7
b	60	y	541.6	260.1
b	60	y	499.3	261.2
b	60	y	739.1	354.6
b	60	x	1.3	0.6
b	60	x	0.7	0.1
b	60	x	-	-
b	60	x	5.0	1.8
b	60	x	12.9	2.9
b	60	x	6.3	1.9
b	60	x	1.8	0.2
b	60	x	20.3	6.2
b	60	t	648.5	333.2
b	60	t	524.4	381.4
b	60	t	685.7	312.0

Legend:
b = bench press
s = back squat
y = vertical plane
x = horizontal plane
t = x and y combined
PP = peak power
MP = mean power

b	60	t	497.1	301.7
b	60	t	383.2	272.7
b	60	t	543.6	262.0
b	60	t	501.1	261.4
b	60	t	754.7	360.8
b	90	y	445.9	161.3
b	90	y	497.6	334.4
b	90	y	402.9	223.6
b	90	y	495.8	264.5
b	90	y	488.4	328.3
b	90	y	413.9	175.4
b	90	y	346.5	225.9
b	90	y	420.2	212.4
b	90	x	17.1	2.8
b	90	x	4.3	0.4
b	90	x	8.9	3.9
b	90	x	2.8	1.1
b	90	x	3.9	1.1
b	90	x	3.6	0.8
b	90	x	12.9	1.7
b	90	x	8.1	2.6
b	90	t	451.4	164.1
b	90	t	497.8	334.8
b	90	t	407.7	227.5
b	90	t	496.0	265.6
b	90	t	489.5	329.5
b	90	t	415.6	176.1
b	90	t	351.3	227.6
b	90	t	425.0	214.9
s	30	y	835.0	400.1
s	30	y	725.3	403.0
s	30	y	625.2	302.7
s	30	y	916.8	388.9
s	30	y	801.8	304.8
s	30	y	910.1	466.7
s	30	y	873.0	385.2
s	30	y	733.9	340.3
s	30	x	23.9	10.6
s	30	x	15.9	7.4
s	30	x	16.1	6.2
s	30	x	26.5	8.6
s	30	x	22.7	7.6
s	30	x	15.1	6.2
s	30	x	8.0	3.9
s	30	x	18.7	7.8
s	30	t	839.7	410.8
s	30	t	737.6	410.5

s	30	t	638.5	308.9
s	30	t	928.1	397.5
s	30	t	809.8	312.4
s	30	t	925.0	472.9
s	30	t	878.5	389.1
s	30	t	749.1	348.1
s	60	y	1177.2	565.9
s	60	y	1157.8	561.6
s	60	y	879.1	482.4
s	60	y	1293.6	673.0
s	60	y	824.3	395.8
s	60	y	1288.2	755.6
s	60	y	1116.7	537.3
s	60	y	896.4	468.7
s	60	x	7.4	2.8
s	60	x	19.6	7.9
s	60	x	23.6	6.8
s	60	x	13.1	4.8
s	60	x	30.0	9.2
s	60	x	15.3	6.6
s	60	x	4.2	2.3
s	60	x	23.0	5.3
s	60	t	1181.5	568.7
s	60	t	1173.8	569.6
s	60	t	895.2	489.2
s	60	t	1303.5	677.8
s	60	t	835.7	405.0
s	60	t	1301.0	762.2
s	60	t	1120.4	539.6
s	60	t	910.1	474.0
s	90	y	1613.2	652.0
s	90	y	1373.9	612.4
s	90	y	787.2	387.8
s	90	y	1383.9	738.9
s	90	y	941.6	370.4
s	90	y	1741.5	883.5
s	90	y	1307.9	629.1
s	90	y	948.1	419.9
s	90	x	73.6	10.2
s	90	x	5.4	2.9
s	90	x	9.2	1.9
s	90	x	14.0	4.1
s	90	x	39.6	4.4
s	90	x	103.6	33.6
s	90	x	13.2	5.1
s	90	x	3.6	0.8
s	90	t	1623.7	662.2

s	90	t	1376.2	615.3
s	90	t	793.6	389.7
s	90	t	1390.6	743.1
s	90	t	942.4	374.8
s	90	t	1843.4	917.1
s	90	t	1313.5	634.1
s	90	t	950.4	420.7

Summary Raw Data – Chapter 7

Participant	a	b	c	d	e	f
1	8.34	7.72	8.79	2.95	3.18	3.68
2	22.29	22.12	20.13	10.41	12.04	8.13
3	11.55	10.2	11.41	5.05	5.04	4.82
4	19.15	16.21	18.03	8.15	7.19	7.57
5	21.92	21.07	18.9	7.49	8.6	7.07
6	17.2	14.75	24.69	5.83	6.27	13.91
7	15.93	18.04	17.36	7.3	7.02	7.47
8	18.08	18.81	22.9	6.82	6.97	7.6
9	10.87	11.39	13.5	3.65	4.74	5.55
10	18.46	14.88	13.03	8.07	6.52	5.29
11	16.66	14.16	16.83	6.75	6.76	6.57
12	15.83	12.8	12.69	7.2	5.57	5.49
13	17.42	17.85	19.02	6.21	5.61	6.3
14	17.55	17.19	17.82	5.95	6.13	6.87
15	12.38	13.61	23.5	6.71	5.76	12.05
16	12.04	11.87	11.05	6.03	5.08	4.97
17	19.14	20.48	22.85	7.43	7.12	8.54
18	26.75	25.86	26	9.02	8.24	9.9
19	16.75	16.79	15.15	6.82	6.58	6.06
20	21.65	21.67	24.51	8.11	9.3	10.04
21	10.4	9.34	10.31	4.81	4.46	4.75
22	21.51	19.44	22.45	8.89	9.18	9.15
23	18.19	19.18		5.81	6.45	
24	17.72	17.74	19.17	7.58	8.23	8.46
25	25.09	26.19	29.4	11.52	12.56	12.61
26	33.91	33.78	29.76	11.72	10.42	10.28
27	27.2	21.55	24.93	7.72	7.77	7.55
28	18.92	16.59	17	7.69	7.16	7.09
29	21.77	17.78	22.12	6.14	5.84	6.23
30	19.48	20.22	18.6	7.91	7.78	7.44
31	18.76	29.45	19.33	5.96	9.89	6.3

Legend:
a = relative peak power session a1
b = relative peak power session a2
c = relative peak power session b1
d = relative mean power session a1
e = relative mean power session a2
f = relative mean power session b1

Participant	a	b	c	d	e	f
1	75	90	75	75	75	75
2	60	60	90	60	90	60
3	75	60	90	90	90	75

Legend:
a = peak optimal load session a1
b = peak optimal load

4	75	60	90	75	60	90
5	90	90	90	90	90	90
6	60	75	90	75	75	90
7	90	75	75	90	60	75
8	75	75	90	75	75	75
9	60	60	75	60	90	75
10	90	75	75	90	75	75
11	90	90	90	75	75	60
12	90	75	60	90	75	90
13	75	75	90	75	90	90
14	90	90	75	75	90	60
15	90	75	90	90	75	60
16	90	75	75	90	75	75
17	90	60	90	90	60	90
18	90	90	75	75	75	90
19	75	90	90	75	90	90
20	75	90	90	75	90	90
21	60	45	75	60	75	60
22	90	90	90	90	75	75
23	90	90		90	90	
24	75	90	90	75	90	90
25	75	30	30	60	30	30
26	90	90	75	90	75	75
27	90	75	75	75	75	75
28	90	75	90	90	75	75
29	90	60	75	45	60	60
30	60	60	60	90	90	60
31	75	30	75	60	30	75

session a2
c = peak opitmal load
session b1
d = mean optimal load
session a1
e = mean optimal load
session a2
f = mean optimal load
session b1

Appendix B – Statistical Output

Chapter 3 – SPSS Output

Descriptive Statistics

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
meanGRF	back squat acc only	10	1716.5100	260.64549	82.42334	1530.0555	1902.9645	1341.04	2089.57
	back squat acc+dec	10	1331.0580	238.36978	75.37914	1160.5385	1501.5775	1076.41	1783.72
	jump squat	10	1789.2420	262.36645	82.96756	1601.5563	1976.9277	1375.64	2127.42
	Total	30	1612.2700	319.21153	58.27978	1493.0745	1731.4655	1076.41	2127.42
meanVEL	back squat acc only	10	.8660	.33639	.10638	.6254	1.1066	.55	1.59
	back squat acc+dec	10	.9020	.34618	.10947	.6544	1.1496	.57	1.63
	jump squat	10	1.0030	.33193	.10497	.7656	1.2404	.67	1.73
	Total	30	.9237	.33164	.06055	.7998	1.0475	.55	1.73
meanPOW	back squat acc only	10	759.4640	406.51988	128.55287	468.6572	1050.2708	346.55	1645.87
	back squat acc+dec	10	529.4170	206.90167	65.42805	381.4085	677.4255	279.20	917.24
	jump squat	10	886.5270	401.66112	127.01640	599.1959	1173.8581	456.54	1791.60
	Total	30	725.1360	370.45635	67.63577	586.8053	863.4667	279.20	1791.60
peakDIS	back squat acc only	10	.8390	.19874	.06285	.6968	.9812	.36	1.02
	back squat acc+dec	10	.8390	.19874	.06285	.6968	.9812	.36	1.02
	jump squat	10	1.0330	.16323	.05162	.9162	1.1498	.64	1.24
	Total	30	.9037	.20356	.03717	.8277	.9797	.36	1.24
DURATION	back squat acc only	10	.0680	.01135	.00359	.0599	.0761	.06	.09
	back squat acc+dec	10	.1250	.08290	.02621	.0657	.1843	.09	.36
	jump squat	10	.0920	.00919	.00291	.0854	.0986	.08	.11
	Total	30	.0950	.05257	.00960	.0754	.1146	.06	.36
time_to_PEAK_VEL	back squat acc only	10	65.7000	9.94485	3.14484	58.5859	72.8141	48.00	79.00
	back squat acc+dec	10	40.3000	11.97265	3.78609	31.7353	48.8647	10.00	51.00
	jump squat	10	72.6000	3.53396	1.11754	70.0720	75.1280	68.00	79.00
	Total	30	59.5333	16.69138	3.04742	53.3007	65.7660	10.00	79.00

Results of the One Way ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
meanGRF	Between Groups	1212652.553	2	606326.277	9.396	.001
	Within Groups	1742331.391	27	64530.792		
	Total	2954983.944	29			
meanVEL	Between Groups	.101	2	.050	.441	.648
	Within Groups	3.089	27	.114		
	Total	3.189	29			
meanPOW	Between Groups	655313.934	2	327656.967	2.661	.088
	Within Groups	3324585.340	27	123132.790		
	Total	3979899.274	29			
peakDIS	Between Groups	.251	2	.125	3.563	.042
	Within Groups	.951	27	.035		
	Total	1.202	29			
DURATION	Between Groups	.016	2	.008	3.468	.046
	Within Groups	.064	27	.002		
	Total	.080	29			
time_to_PEAK_VEL	Between Groups	5786.867	2	2893.433	34.076	.000
	Within Groups	2292.600	27	84.911		
	Total	8079.467	29			

Results of the Post Hoc Analysis

						95% Confidence Interval	
Dependent Variable	(I) exercise	(J) exercise	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
meanGRF	back squat acc only	back squat acc+dec	385.45200*	113.60527	.006	96.3193	674.5847
		jump squat	-72.73200	113.60527	.894	-361.8647	216.4007
	back squat acc+dec	back squat acc only	-385.45200*	113.60527	.006	-674.5847	-96.3193
		jump squat	-458.18400*	113.60527	.001	-747.3167	-169.0513
	jump squat	back squat acc only	72.73200	113.60527	.894	-216.4007	361.8647
		back squat acc+dec	458.18400*	113.60527	.001	169.0513	747.3167
meanVEL	back squat acc only	back squat acc+dec	-.03600	.15126	.994	-.4210	.3490
		jump squat	-.13700	.15126	.754	-.5220	.2480
	back squat acc+dec	back squat acc only	.03600	.15126	.994	-.3490	.4210
		jump squat	-.10100	.15126	.882	-.4860	.2840
	jump squat	back squat acc only	.13700	.15126	.754	-.2480	.5220
		back squat acc+dec	.10100	.15126	.882	-.2840	.4860

meanPOW	back squat acc only	back squat acc+dec	230.04700	156.92851	.395	-169.3461	629.4401
		jump squat	-127.06300	156.92851	.810	-526.4561	272.3301
	back squat acc+dec	back squat acc only	-230.04700	156.92851	.395	-629.4401	169.3461
		jump squat	-357.11000	156.92851	.090	-756.5031	42.2831
	jump squat	back squat acc only	127.06300	156.92851	.810	-272.3301	526.4561
		back squat acc+dec	357.11000	156.92851	.090	-42.2831	756.5031
peakDIS	back squat acc only	back squat acc+dec	.00000	.08392	1.000	-.2136	.2136
		jump squat	-.19400	.08392	.084	-.4076	.0196
	back squat acc+dec	back squat acc only	.00000	.08392	1.000	-.2136	.2136
		jump squat	-.19400	.08392	.084	-.4076	.0196
	jump squat	back squat acc only	.19400	.08392	.084	-.0196	.4076
		back squat acc+dec	.19400	.08392	.084	-.0196	.4076
DURATION	back squat acc only	back squat acc+dec	-.05700*	.02173	.042	-.1123	-.0017
		jump squat	-.02400	.02173	.626	-.0793	.0313
	back squat acc+dec	back squat acc only	.05700*	.02173	.042	.0017	.1123
		jump squat	.03300	.02173	.365	-.0223	.0883
	jump squat	back squat acc only	.02400	.02173	.626	-.0313	.0793
		back squat acc+dec	-.03300	.02173	.365	-.0883	.0223
time_to_PEAK_VEL	back squat acc only	back squat acc+dec	25.40000*	4.12095	.000	14.9119	35.8881
		jump squat	-6.90000	4.12095	.285	-17.3881	3.5881
	back squat acc+dec	back squat acc only	-25.40000*	4.12095	.000	-35.8881	-14.9119
		jump squat	-32.30000*	4.12095	.000	-42.7881	-21.8119
	jump squat	back squat acc only	6.90000	4.12095	.285	-3.5881	17.3881
		back squat acc+dec	32.30000*	4.12095	.000	21.8119	42.7881

*. The mean difference is significant at the 0.05 level.

Chapter 4 - SPSS Output

Reliability t tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pp1b	1415.3750	12	349.25127	100.82016
	pp1a	1507.4350	12	399.16664	115.22948
Pair 2	pp2b	1688.1083	12	445.73113	128.67149
	pp2a	1774.2917	12	502.70553	145.11859
Pair 3	pp3b	2280.0917	12	557.94154	161.06385
	pp3a	2291.8250	12	529.73452	152.92118
Pair 4	pp4b	3071.7833	12	697.23018	201.27302
	pp4a	3104.7333	12	690.43856	199.31244
Pair 5	pp5b	2949.2500	12	675.98877	195.14115
	pp5a	2974.5667	12	636.02323	183.60409
Pair 6	mp1b	633.6000	12	148.69209	42.92371
	mp1a	653.7417	12	189.48644	54.70002
Pair 7	mp2b	749.6917	12	194.58409	56.17159
	mp2a	778.0333	12	222.47883	64.22411
Pair 8	mp3b	1133.5500	12	376.79774	108.77214
	mp3a	1145.6750	12	342.81910	98.96335
Pair 9	mp4b	1471.7917	12	353.11680	101.93604
	mp4a	1454.6833	12	297.42437	85.85902
Pair 10	mp5b	1388.8250	12	323.54231	93.39862
	mp5a	1364.8583	12	288.88281	83.39328

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	pp1b - pp1a	-92.06000	128.28993	37.03411	-173.57153	-10.54847	-2.486	11	.030
Pair 2	pp2b - pp2a	-86.18333	142.87983	41.24586	-176.96485	4.59818	-2.090	11	.061
Pair 3	pp3b - pp3a	-11.73333	245.53804	70.88073	-167.74076	144.27410	-.166	11	.872
Pair 4	pp4b - pp4a	-32.95000	235.82535	68.07691	-182.78628	116.88628	-.484	11	.638
Pair 5	pp5b - pp5a	-25.31667	120.79473	34.87044	-102.06598	51.43264	-.726	11	.483
Pair 6	mp1b - mp1a	-20.14167	68.28074	19.71095	-63.52518	23.24184	-1.022	11	.329
Pair 7	mp2b - mp2a	-28.34167	65.76344	18.98427	-70.12576	13.44243	-1.493	11	.164
Pair 8	mp3b - mp3a	-12.12500	171.48214	49.50263	-121.07956	96.82956	-.245	11	.811
Pair 9	mp4b - mp4a	17.10833	103.05447	29.74926	-48.36936	82.58602	.575	11	.577
Pair 10	mp5b - mp5a	23.96667	78.76262	22.73681	-26.07671	74.01005	1.054	11	.314

Method Comparison t tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pp2	1597.9550	20	416.40123	93.11015
	pp1	1364.8822	20	327.70290	73.27660
Pair 2	pp3	2171.0250	20	564.64213	126.25782
	pp2	1597.9550	20	416.40123	93.11015
Pair 3	pp3	2171.0250	20	564.64213	126.25782
	pp4	2819.1175	20	638.83716	142.84833
Pair 4	pp3	2171.0250	20	564.64213	126.25782
	pp5	2709.0375	20	625.73649	139.91893
Pair 5	mp2	724.1750	20	193.33821	43.23174
	mp1	605.1300	20	159.82138	35.73715
Pair 6	mp3	1152.3375	20	391.52536	87.54773
	mp2	724.1750	20	193.33821	43.23174
Pair 7	mp3	1152.3375	20	391.52536	87.54773
	mp4	1398.5378	20	310.80694	69.49854
Pair 8	mp3	1152.3375	20	391.52536	87.54773
	mp5	1321.5775	20	292.47700	65.39985

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	pp2 - pp1	233.07275	105.79137	23.65567	183.56087	282.58463	9.853	19	.000
Pair 2	pp3 - pp2	573.07000	408.38470	91.31760	381.94008	764.19992	6.276	19	.000
Pair 3	pp3 - pp4	-648.09250	417.73995	93.40949	-843.60081	-452.58419	-6.938	19	.000
Pair 4	pp3 - pp5	-538.01250	390.67293	87.35712	-720.85306	-355.17194	-6.159	19	.000
Pair 5	mp2 - mp1	119.04500	42.17477	9.43056	99.30660	138.78340	12.623	19	.000
Pair 6	mp3 - mp2	428.16250	320.75910	71.72392	278.04262	578.28238	5.970	19	.000
Pair 7	mp3 - mp4	-246.20025	325.72196	72.83364	-398.64282	-93.75768	-3.380	19	.003
Pair 8	mp3 - mp5	-169.24000	311.11840	69.56819	-314.84789	-23.63211	-2.433	19	.025

Chapter 5 – SPSS Output

Results of the Two Way RM ANOVA for Bench Press Peak Power

Within-Subjects Factors

Measure:MEASURE_1

loads	Dependent Variable
1	bench_pp_30
2	bench_pp_60
3	bench_pp_90

Between-Subjects Factors

		Value Label	N
plane_code	0	vertical	8
	1	total	8

Descriptive Statistics

	plane_code	Mean	Std. Deviation	N
bench_pp_30	vertical	637.340	179.8216	8
	total	640.139	179.2603	8
	Total	638.739	173.4593	16
bench_pp_60	vertical	531.177	115.7021	8
	total	567.284	120.3297	8
	Total	549.230	115.5504	16
bench_pp_90	vertical	438.905	53.4401	8
	total	441.775	51.7773	8
	Total	440.340	50.8528	16

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
loads	Sphericity Assumed	315898.581	2	157949.291	11.405	.000	.449	22.810	.987
	Greenhouse-Geisser	315898.581	1.751	180403.514	11.405	.000	.449	19.971	.977
	Huynh-Feldt	315898.581	2.000	157949.291	11.405	.000	.449	22.810	.987
	Lower-bound	315898.581	1.000	315898.581	11.405	.005	.449	11.405	.881
loads * plane_code	Sphericity Assumed	2952.140	2	1476.070	.107	.899	.008	.213	.065
	Greenhouse-Geisser	2952.140	1.751	1685.909	.107	.875	.008	.187	.064
	Huynh-Feldt	2952.140	2.000	1476.070	.107	.899	.008	.213	.065
	Lower-bound	2952.140	1.000	2952.140	.107	.749	.008	.107	.061
Error(loads)	Sphericity Assumed	387767.183	28	13848.828					
	Greenhouse-Geisser	387767.183	24.515	15817.591					

	Huynh-Feldt	387767.183	28.000	13848.828					
	Lower-bound	387767.183	14.000	27697.656					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1.414E7	1	1.414E7	665.797	.000	.979	665.797	1.000
plane_code	2327.036	1	2327.036	.110	.746	.008	.110	.061
Error	297343.895	14	21238.850					

a. Computed using alpha = .05

Results of the Two Way RM ANOVA for Bench Press Mean Power

Within-Subjects Factors

Measure:MEASURE_1

loads	Dependent Variable
1	bench_mp_30
2	bench_mp_60
3	bench_mp_90

Between-Subjects Factors

		Value Label	N
plane_code	0	vertical	8
	1	total	8

Descriptive Statistics

	plane_code	Mean	Std. Deviation	N
bench_mp_30	vertical	240.302	46.7115	8
	total	242.286	46.4172	8
	Total	241.294	44.9973	16
bench_mp_60	vertical	298.009	53.8663	8
	total	310.661	45.2620	8
	Total	304.335	48.5056	16
bench_mp_90	vertical	240.730	64.2722	8
	total	242.524	63.6753	8
	Total	241.627	61.8121	16

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
loads	Sphericity Assumed	42168.171	2	21084.085	10.765	.000	.435	21.530	.982
	Greenhouse-Geisser	42168.171	1.516	27807.978	10.765	.001	.435	16.324	.950
	Huynh-Feldt	42168.171	1.783	23645.620	10.765	.001	.435	19.197	.971
	Lower-bound	42168.171	1.000	42168.171	10.765	.005	.435	10.765	.862
loads * plane_code	Sphericity Assumed	308.988	2	154.494	.079	.924	.006	.158	.061
	Greenhouse-Geisser	308.988	1.516	203.764	.079	.876	.006	.120	.060
	Huynh-Feldt	308.988	1.783	173.264	.079	.906	.006	.141	.060
	Lower-bound	308.988	1.000	308.988	.079	.783	.006	.079	.058
Error(loads)	Sphericity Assumed	54840.870	28	1958.603					
	Greenhouse-Geisser	54840.870	21.230	2583.217					
	Huynh-Feldt	54840.870	24.967	2196.556					
	Lower-bound	54840.870	14.000	3917.205					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	3305446.384	1	3305446.384	685.934	.000	.980	685.934	1.000
plane_code	359.918	1	359.918	.075	.789	.005	.075	.057
Error	67464.598	14	4818.900					

a. Computed using alpha = .05

Results of the Two Way RM ANOVA for Back Squat Peak Power

Within-Subjects Factors

Measure:MEASURE_1

loads	Dependent Variable
1	squat_pp_30
2	squat_pp_60
3	squat_pp_90

Between-Subjects Factors

		Value Label	N
plane_code	0	vertical	8
	1	total	8

Descriptive Statistics

	plane_code	Mean	Std. Deviation	N
squat_pp_30	vertical	802.636	101.9623	8
	total	813.283	100.7320	8
	Total	807.960	98.0667	16
squat_pp_60	vertical	1079.168	187.1778	8
	total	1090.137	185.7247	8
	Total	1084.653	180.2194	16
squat_pp_90	vertical	1262.160	340.0195	8
	total	1279.214	362.0162	8
	Total	1270.687	339.3962	16

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
loads	Sphericity Assumed	1734845.868	2	867422.934	37.299	.000	.727	74.598	1.000
	Greenhouse-Geisser	1734845.868	1.221	1421243.453	37.299	.000	.727	45.529	1.000
	Huynh-Feldt	1734845.868	1.372	1264667.351	37.299	.000	.727	51.166	1.000
	Lower-bound	1734845.868	1.000	1734845.868	37.299	.000	.727	37.299	1.000
loads * plane_code	Sphericity Assumed	104.239	2	52.119	.002	.998	.000	.004	.050
	Greenhouse-Geisser	104.239	1.221	85.396	.002	.980	.000	.003	.050
	Huynh-Feldt	104.239	1.372	75.988	.002	.987	.000	.003	.050
	Lower-bound	104.239	1.000	104.239	.002	.963	.000	.002	.050
Error(loads)	Sphericity Assumed	651165.803	28	23255.922					
	Greenhouse-Geisser	651165.803	17.089	38104.049					

	Huynh-Feldt	651165.803	19.205	33906.188					
	Lower-bound	651165.803	14.000	46511.843					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	5.337E7	1	5.337E7	437.948	.000	.969	437.948	1.000
plane_code	1993.709	1	1993.709	.016	.900	.001	.016	.052
Error	1706024.454	14	121858.890					

a. Computed using alpha = .05

Results of the Two Way RM ANOVA for Back Squat Mean Power

Within-Subjects Factors

Measure:MEASURE_1

loads	Dependent Variable
1	squat_mp_30
2	squat_mp_60
3	squat_mp_90

Between-Subjects Factors

		Value Label	N
plane_code	0	vertical	8
	1	total	8

Descriptive Statistics

	plane_code	Mean	Std. Deviation	N
squat_mp_30	vertical	373.964	55.4033	8
	total	381.271	55.4654	8
	Total	377.617	53.6874	16
squat_mp_60	vertical	555.024	115.0691	8
	total	560.746	114.5013	8
	Total	557.885	110.9327	16
squat_mp_90	vertical	586.755	182.1206	8
	total	594.630	190.1678	8
	Total	590.693	179.9204	16

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Loads	Sphericity Assumed	421193.199	2	210596.599	42.452	.000	.752	84.904	1.000

	Greenhouse-Geisser	421193.199	1.193	353003.536	42.452	.000	.752	50.652	1.000
	Huynh-Feldt	421193.199	1.335	315618.661	42.452	.000	.752	56.652	1.000
	Lower-bound	421193.199	1.000	421193.199	42.452	.000	.752	42.452	1.000
loads * plane_code	Sphericity Assumed	9.962	2	4.981	.001	.999	.000	.002	.050
	Greenhouse-Geisser	9.962	1.193	8.349	.001	.987	.000	.001	.050
	Huynh-Feldt	9.962	1.335	7.465	.001	.992	.000	.001	.050
	Lower-bound	9.962	1.000	9.962	.001	.975	.000	.001	.050
Error(loads)	Sphericity Assumed	138902.904	28	4960.818					
	Greenhouse-Geisser	138902.904	16.704	8315.359					
	Huynh-Feldt	138902.904	18.683	7434.720					
	Lower-bound	138902.904	14.000	9921.636					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1.242E7	1	1.242E7	303.047	.000	.956	303.047	1.000
plane_code	582.654	1	582.654	.014	.907	.001	.014	.051
Error	573900.711	14	40992.908					

a. Computed using alpha = .05

Results of the Two Way RM ANOVA for Peak Horizontal Contribution Effect

Within-Subjects Factors

Measure:MEASURE_1

loads	Dependent Variable
1	peak_cont_30
2	peak_cont_60
3	peak_cont_90

Between-Subjects Factors

		Value Label	N
exercise_code	.0	bench	7
	1.0	squat	8

Descriptive Statistics

	exercise_code	Mean	Std. Deviation	N
peak_cont_30	bench	.0040	.00394	7
	squat	.0135	.00593	8
	Total	.0091	.00692	15
peak_cont_60	bench	.0051	.00700	7
	squat	.0106	.00539	8
	Total	.0080	.00660	15
peak_cont_90	bench	.0063	.00581	7
	squat	.0105	.01826	8
	Total	.0085	.01363	15

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
loads	Sphericity Assumed	.000	2	.000	.045	.956	.003	.090	.056
	Greenhouse-Geisser	.000	1.177	.000	.045	.871	.003	.053	.055
	Huynh-Feldt	.000	1.324	.000	.045	.895	.003	.059	.055
	Lower-bound	.000	1.000	.000	.045	.836	.003	.045	.054
loads * exercise_code	Sphericity Assumed	.000	2	.000	.366	.697	.027	.733	.103
	Greenhouse-Geisser	.000	1.177	.000	.366	.588	.027	.431	.090
	Huynh-Feldt	.000	1.324	.000	.366	.612	.027	.485	.092
	Lower-bound	.000	1.000	.000	.366	.555	.027	.366	.087
Error(loads)	Sphericity Assumed	.002	26	.000					
	Greenhouse-Geisser	.002	15.297	.000					
	Huynh-Feldt	.002	17.208	.000					

	Lower-bound	.002	13.000	.000					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	.003	1	.003	28.765	.000	.689	28.765	.999
exercise_code	.000	1	.000	4.220	.061	.245	4.220	.477
Error	.001	13	.000					

a. Computed using alpha = .05

Results of the Two Way RM ANOVA for Mean Horizontal Contribution Effect

Within-Subjects Factors

Measure:MEASURE_1

loads	Dependent Variable
1	mean_cont_30
2	mean_cont_60
3	mean_cont_90

Between-Subjects Factors

		Value Label	N
exercise_code	.0	bench	7
	1.0	squat	7

Descriptive Statistics

	exercise_code	Mean	Std. Deviation	N
mean_cont_30	bench	.0066	.00515	7
	squat	.0194	.00589	7
	Total	.0130	.00849	14
mean_cont_60	bench	.0063	.00616	7
	squat	.0104	.00643	7
	Total	.0084	.00640	14
mean_cont_90	bench	.0071	.00557	7
	squat	.0120	.01176	7
	Total	.0095	.00920	14

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
loads	Sphericity Assumed	.000	2	.000	1.693	.205	.124	3.385	.320

	Greenhouse-Geisser	.000	1.295	.000	1.693	.216	.124	2.192	.254
	Huynh-Feldt	.000	1.507	.000	1.693	.214	.124	2.551	.275
	Lower-bound	.000	1.000	.000	1.693	.218	.124	1.693	.224
loads * exercise_code	Sphericity Assumed	.000	2	.000	1.664	.210	.122	3.329	.316
	Greenhouse-Geisser	.000	1.295	.000	1.664	.220	.122	2.156	.251
	Huynh-Feldt	.000	1.507	.000	1.664	.218	.122	2.508	.271
	Lower-bound	.000	1.000	.000	1.664	.221	.122	1.664	.221
Error(loads)	Sphericity Assumed	.001	24	.000					
	Greenhouse-Geisser	.001	15.541	.000					
	Huynh-Feldt	.001	18.083	.000					
	Lower-bound	.001	12.000	.000					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	.004	1	.004	75.804	.000	.863	75.804	1.000
exercise_code	.001	1	.001	9.387	.010	.439	9.387	.803
Error	.001	12	.000					

a. Computed using alpha = .05

Results of the One Way ANOVA for Exercise Effects on Mean Horizontal Contribution

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
mean_cont_30	bench	8	.0087	.00761	.00269	.0024	.0151	.00	.02
	squat	8	.0195	.00546	.00193	.0149	.0240	.01	.03
	Total	16	.0141	.00847	.00212	.0096	.0186	.00	.03
mean_cont_60	bench	7	.0063	.00616	.00233	.0006	.0120	.00	.02
	squat	7	.0104	.00643	.00243	.0045	.0163	.00	.02
	Total	14	.0084	.00640	.00171	.0047	.0121	.00	.02
mean_cont_90	bench	8	.0083	.00628	.00222	.0031	.0136	.00	.02
	squat	8	.0111	.01117	.00395	.0018	.0204	.00	.04
	Total	16	.0097	.00887	.00222	.0050	.0144	.00	.04

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
mean_cont_30	Between Groups	.000	1	.000	10.547	.006

	Within Groups	.001	14	.000		
	Total	.001	15			
mean_cont_60	Between Groups	.000	1	.000	1.459	.250
	Within Groups	.000	12	.000		
	Total	.001	13			
mean_cont_90	Between Groups	.000	1	.000	.376	.550
	Within Groups	.001	14	.000		
	Total	.001	15			

Results of the Paired t test for Exercise Effect on Mean Horizontal Contribution at 30% 1RM

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	bench_mean_cont_30	.0087	8	.00761	.00269
	squat_mean_cont_30	.0195	8	.00546	.00193

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	bench_mean_cont_30 - squat_mean_cont_30	-.01075	.00831	.00294	-.01770	-.00381	-3.661	7	.008

Chapter 6 - SPSS Output

Results of the Two Way ANOVA

Between-Subjects Factors

		Value Label	N
Side	.000	D	30
	1.000	ND	30
Load	.000	30.000	20
	1.000	60.000	20
	2.000	90.000	20

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	FSD AGRF	1.164[a]	5	.233	6.320	.000	.369	31.600	.994
	FSD ABP	97.115[c]	5	19.423	6.074	.000	.360	30.370	.992
	LRSD AGRF	1.097[d]	5	.219	5.758	.000	.348	28.789	.988
	LRSD ABP	97.068[e]	5	19.414	6.069	.000	.360	30.347	.991
	BSD AGRF	1.119[f]	5	.224	5.890	.000	.353	29.452	.990
	BSD ABP	97.619[g]	5	19.524	6.123	.000	.362	30.617	.992
Intercept	FSD AGRF	47.192	1	47.192	1280.861	.000	.960	1280.861	1.000
	FSD ABP	2716.666	1	2716.666	849.561	.000	.940	849.561	1.000
	LRSD AGRF	47.192	1	47.192	1238.787	.000	.958	1238.787	1.000
	LRSD ABP	2716.666	1	2716.666	849.326	.000	.940	849.326	1.000
	BSD AGRF	46.651	1	46.651	1228.157	.000	.958	1228.157	1.000
	BSD ABP	2716.666	1	2716.666	852.046	.000	.940	852.046	1.000
Side	FSD AGRF	.097	1	.097	2.621	.111	.046	2.621	.356
	FSD ABP	.057	1	.057	.018	.894	.000	.018	.052
	LRSD AGRF	.020	1	.020	.530	.470	.010	.530	.110
	LRSD ABP	.003	1	.003	.001	.976	.000	.001	.050
	BSD AGRF	.001	1	.001	.015	.905	.000	.015	.052
	BSD ABP	.570	1	.570	.179	.674	.003	.179	.070
Load	FSD AGRF	1.061	2	.531	14.401	.000	.348	28.801	.998
	FSD ABP	96.980	2	48.490	15.164	.000	.360	30.328	.999

	LRSD AGRF	1.061	2	.531	13.928	.000	.340	27.855	.998
	LRSD ABP	96.980	2	48.490	15.160	.000	.360	30.319	.999
	BSD AGRF	1.058	2	.529	13.923	.000	.340	27.845	.998
	BSD ABP	96.980	2	48.490	15.208	.000	.360	30.416	.999
Side * Load	FSD AGRF	.007	2	.003	.089	.915	.003	.178	.063
	FSD ABP	.078	2	.039	.012	.988	.000	.024	.052
	LRSD AGRF	.015	2	.008	.201	.818	.007	.403	.080
	LRSD ABP	.085	2	.042	.013	.987	.000	.027	.052
	BSD AGRF	.060	2	.030	.796	.456	.029	1.592	.179
	BSD ABP	.069	2	.034	.011	.989	.000	.022	.052
Error	FSD AGRF	1.990	54	.037					
	FSD ABP	172.677	54	3.198					
	LRSD AGRF	2.057	54	.038					
	LRSD ABP	172.725	54	3.199					
	BSD AGRF	2.051	54	.038					
	BSD ABP	172.174	54	3.188					
Total	FSD AGRF	50.346	60						
	FSD ABP	2986.459	60						
	LRSD AGRF	50.346	60						
	LRSD ABP	2986.459	60						
	BSD AGRF	49.821	60						
	BSD ABP	2986.459	60						
Corrected Total	FSD AGRF	3.154	59						
	FSD ABP	269.793	59						
	LRSD AGRF	3.154	59						
	LRSD ABP	269.793	59						
	BSD AGRF	3.170	59						
	BSD ABP	269.793	59						

a. R Squared = .369 (Adjusted R Squared = .311)

b. Computed using alpha = .05

c. R Squared = .360 (Adjusted R Squared = .301)

d. R Squared = .348 (Adjusted R Squared = .287)

e. R Squared = .360 (Adjusted R Squared = .301)

f. R Squared = .353 (Adjusted R Squared = .293)

g. R Squared = .362 (Adjusted R Squared = .303)

Results of the Post Hoc Analysis - Side

Estimates

Dependent Variable	Side	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
FSD AGRF	D	.927	.035	.857	.997
	ND	.847	.035	.776	.917
FSD ABP	D	6.760	.326	6.105	7.414
	ND	6.698	.326	6.043	7.353
LRSD AGRF	D	.905	.036	.834	.977
	ND	.869	.036	.797	.940
LRSD ABP	D	6.736	.327	6.081	7.391
	ND	6.722	.327	6.067	7.376
BSD AGRF	D	.879	.036	.807	.950
	ND	.885	.036	.813	.956
BSD ABP	D	6.826	.326	6.173	7.480
	ND	6.631	.326	5.978	7.285

Pairwise Comparisons

Dependent Variable	(I) Side	(J) Side	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
FSD AGRF	D	ND	.080	.050	.111	-.019	.180
	ND	D	-.080	.050	.111	-.180	.019
FSD ABP	D	ND	.062	.462	.894	-.864	.987
	ND	D	-.062	.462	.894	-.987	.864
LRSD AGRF	D	ND	.037	.050	.470	-.064	.138
	ND	D	-.037	.050	.470	-.138	.064
LRSD ABP	D	ND	.014	.462	.976	-.912	.940
	ND	D	-.014	.462	.976	-.940	.912
BSD AGRF	D	ND	-.006	.050	.905	-.107	.095
	ND	D	.006	.050	.905	-.095	.107
BSD ABP	D	ND	.195	.461	.674	-.729	1.119
	ND	D	-.195	.461	.674	-1.119	.729

Based on estimated marginal means

a. Adjustment for multiple comparisons: Sidak.

Results of the Post Hoc Analysis - Load

Estimates

Dependent Variable	Load	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
FSD AGRF	30.000	.719	.043	.633	.805
	60.000	.898	.043	.812	.984
	90.000	1.044	.043	.958	1.130
FSD ABP	30.000	4.932	.400	4.130	5.734
	60.000	7.576	.400	6.774	8.378
	90.000	7.679	.400	6.877	8.480
LRSD AGRF	30.000	.719	.044	.631	.806
	60.000	.898	.044	.810	.985
	90.000	1.044	.044	.957	1.132
LRSD ABP	30.000	4.932	.400	4.130	5.734
	60.000	7.576	.400	6.774	8.378
	90.000	7.679	.400	6.877	8.480
BSD AGRF	30.000	.719	.044	.632	.806
	60.000	.882	.044	.795	.970
	90.000	1.044	.044	.957	1.131
BSD ABP	30.000	4.932	.399	4.131	5.732
	60.000	7.576	.399	6.776	8.377
	90.000	7.679	.399	6.878	8.479

Pairwise Comparisons

Dependent Variable	(I) Load	(J) Load	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
FSD AGRF	30.000	60.000	-.179*	.061	.014	-.328	-.029
		90.000	-.325*	.061	.000	-.475	-.176
	60.000	30.000	.179*	.061	.014	.029	.328
		90.000	-.146	.061	.057	-.296	.003
	90.000	30.000	.325*	.061	.000	.176	.475
		60.000	.146	.061	.057	-.003	.296
FSD ABP	30.000	60.000	-2.644*	.565	.000	-4.038	-1.251
		90.000	-2.747*	.565	.000	-4.140	-1.353
	60.000	30.000	2.644*	.565	.000	1.251	4.038
		90.000	-.103	.565	.997	-1.496	1.291
	90.000	30.000	2.747*	.565	.000	1.353	4.140
		60.000	.103	.565	.997	-1.291	1.496
LRSD AGRF	30.000	60.000	-.179*	.062	.016	-.331	-.027
		90.000	-.325*	.062	.000	-.477	-.173
	60.000	30.000	.179*	.062	.016	.027	.331
		90.000	-.146	.062	.062	-.299	.006
	90.000	30.000	.325*	.062	.000	.173	.477
		60.000	.146	.062	.062	-.006	.299
LRSD ABP	30.000	60.000	-2.644*	.566	.000	-4.038	-1.251
		90.000	-2.747*	.566	.000	-4.140	-1.353
	60.000	30.000	2.644*	.566	.000	1.251	4.038
		90.000	-.103	.566	.997	-1.496	1.291
	90.000	30.000	2.747*	.566	.000	1.353	4.140

		60.000	.103	.566	.997	-1.291	1.496
BSD AGRF	30.000	60.000	-.163*	.062	.031	-.315	-.012
		90.000	-.325*	.062	.000	-.477	-.173
	60.000	30.000	.163*	.062	.031	.012	.315
		90.000	-.162*	.062	.033	-.314	-.010
	90.000	30.000	.325*	.062	.000	.173	.477
		60.000	.162*	.062	.033	.010	.314
BSD ABP	30.000	60.000	-2.644*	.565	.000	-4.036	-1.253
		90.000	-2.747*	.565	.000	-4.138	-1.355
	60.000	30.000	2.644*	.565	.000	1.253	4.036
		90.000	-.103	.565	.997	-1.494	1.289
	90.000	30.000	2.747*	.565	.000	1.355	4.138
		60.000	.103	.565	.997	-1.289	1.494

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Sidak.

Side by Load Interaction

4. Side * Load

Dependent Variable	Side	Load	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
FSD AGRF	D	30.000	.767	.061	.645	.889
		60.000	.923	.061	.801	1.045
		90.000	1.091	.061	.969	1.213
	ND	30.000	.671	.061	.549	.792
		60.000	.872	.061	.751	.994
		90.000	.997	.061	.876	1.119
FSD ABP	D	30.000	4.931	.565	3.797	6.065
		60.000	7.588	.565	6.454	8.722
		90.000	7.760	.565	6.626	8.894
	ND	30.000	4.933	.565	3.799	6.067
		60.000	7.564	.565	6.430	8.698
		90.000	7.597	.565	6.464	8.731
LRSD AGRF	D	30.000	.744	.062	.620	.868
		60.000	.894	.062	.770	1.018
		90.000	1.078	.062	.954	1.201
	ND	30.000	.694	.062	.570	.817
		60.000	.901	.062	.778	1.025
		90.000	1.010	.062	.887	1.134
LRSD ABP	D	30.000	4.902	.566	3.768	6.035
		60.000	7.635	.566	6.501	8.768
		90.000	7.672	.566	6.538	8.805
	ND	30.000	4.962	.566	3.828	6.096
		60.000	7.518	.566	6.384	8.651
		90.000	7.686	.566	6.552	8.820
BSD AGRF	D	30.000	.699	.062	.576	.823
		60.000	.851	.062	.728	.975

		90.000	1.085	.062	.962	1.209
	ND	30.000	.738	.062	.615	.862
		60.000	.913	.062	.790	1.037
		90.000	1.003	.062	.879	1.126
BSD ABP	D	30.000	4.985	.565	3.853	6.117
		60.000	7.680	.565	6.548	8.812
		90.000	7.814	.565	6.682	8.946
	ND	30.000	4.879	.565	3.747	6.011
		60.000	7.472	.565	6.340	8.604
		90.000	7.543	.565	6.411	8.675

Chapter 7 SPSS Output

Maximal Strength

Results of the maximal strength comparison One-Way ANOVA – Rhea

Descriptives

rhea_1rm

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
untrained	12	1.5283	.21477	.06200	1.3919	1.6648	1.08	1.77
recreational	10	1.7450	.19074	.06032	1.6085	1.8815	1.50	2.02
trained	9	2.1422	.44916	.14972	1.7970	2.4875	1.58	3.08
Total	31	1.7765	.38304	.06880	1.6360	1.9170	1.08	3.08

ANOVA

rhea_1rm

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.953	2	.976	11.164	.000
Within Groups	2.449	28	.087		
Total	4.402	30			

Multiple Comparisons

rhea_1rm
Bonferroni

(I) rhea_status	(J) rhea_status	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
untrained	recreational	-.21667	.12662	.294	-.5391	.1058
	trained	-.61389*	.13040	.000	-.9460	-.2818
recreational	untrained	.21667	.12662	.294	-.1058	.5391
	trained	-.39722*	.13588	.020	-.7432	-.0512
trained	untrained	.61389*	.13040	.000	.2818	.9460
	recreational	.39722*	.13588	.020	.0512	.7432

*. The mean difference is significant at the 0.05 level.

Results of the maximal strength comparison paired t tests, Stone

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	stone_weak	1.4640	5	.22233	.09943
	stone_strong	2.3180	5	.51388	.229

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	stone_weak - stone_strong	-.85400	.52956	.23682	-1.51153	-.19647	-3.606	4	.023

Results of the Mixed-Factor Two-Way ANOVA, Peak Power, Rhea

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	ppa
2	ppb
3	ppc

Between-Subjects Factors

		N
rhea_standard	.00	12
	1.00	9
	2.00	9

Descriptive Statistics

	rhea_standard	Mean	Std. Deviation	N
ppa	.00	16.2475	4.53228	12
	1.00	18.2800	4.58074	9
	2.00	21.6922	6.27329	9
	Total	18.4907	5.45099	30
ppb	.00	15.6283	4.64169	12
	1.00	17.2333	4.88564	9
	2.00	21.8789	6.62082	9
	Total	17.9850	5.83340	30
ppc	.00	16.8867	5.26288	12
	1.00	18.3089	5.28229	9
	2.00	22.6456	4.66066	9
	Total	19.0410	5.50587	30

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	15.742	2	7.871	1.345	.269	.047	2.690	.278
	Greenhouse-Geisser	15.742	1.789	8.798	1.345	.269	.047	2.407	.263
	Huynh-Feldt	15.742	2.000	7.871	1.345	.269	.047	2.690	.278
	Lower-bound	15.742	1.000	15.742	1.345	.256	.047	1.345	.201
session * rhea_standard	Sphericity Assumed	4.118	4	1.030	.176	.950	.013	.704	.084
	Greenhouse-Geisser	4.118	3.579	1.151	.176	.937	.013	.630	.083
	Huynh-Feldt	4.118	4.000	1.030	.176	.950	.013	.704	.084
	Lower-bound	4.118	2.000	2.059	.176	.840	.013	.352	.075

Error(session)	Sphericity Assumed	316.019	54	5.852					
	Greenhouse-Geisser	316.019	48.312	6.541					
	Huynh-Feldt	316.019	54.000	5.852					
	Lower-bound	316.019	27.000	11.704					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	31084.264	1	31084.264	448.104	.000	.943	448.104	1.000
rhea_standard	534.558	2	267.279	3.853	.034	.222	7.706	.648
Error	1872.946	27	69.368					

a. Computed using alpha = .05

Pairwise Comparisons

Measure:MEASURE_1

(I) rhea_standard	(J) rhea_standard	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
.00	1.00	-1.687	2.120	1.000	-7.099	3.726
	2.00	-5.818*	2.120	.032	-11.230	-.406
1.00	.00	1.687	2.120	1.000	-3.726	7.099
	2.00	-4.131	2.267	.238	-9.917	1.654
2.00	.00	5.818*	2.120	.032	.406	11.230
	1.00	4.131	2.267	.238	-1.654	9.917

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Results of the Mixed-Factor Two-Way ANOVA, Mean Power, Rhea

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	mpa
2	mpb
3	mpc

Between-Subjects Factors

		N
rhea_standard	.00	12
	1.00	9
	2.00	9

Descriptive Statistics

	rhea_standard	Mean	Std. Deviation	N
mpa	.00	6.5983	2.05480	12
	1.00	7.0844	1.39095	9
	2.00	8.1056	2.11462	9
	Total	7.1963	1.94350	30
mpb	.00	6.6475	2.22616	12
	1.00	6.8700	1.68995	9
	2.00	8.3789	2.22129	9
	Total	7.2337	2.14919	30
mpc	.00	7.0500	2.64918	12
	1.00	7.2367	1.95857	9
	2.00	8.6678	2.40880	9
	Total	7.5913	2.41677	30

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	2.717	2	1.359	.755	.475	.027	1.510	.172
	Greenhouse-Geisser	2.717	1.399	1.942	.755	.433	.027	1.057	.150
	Huynh-Feldt	2.717	1.562	1.740	.755	.446	.027	1.179	.156
	Lower-bound	2.717	1.000	2.717	.755	.392	.027	.755	.134
session * rhea_standard	Sphericity Assumed	.654	4	.163	.091	.985	.007	.363	.067
	Greenhouse-Geisser	.654	2.799	.234	.091	.958	.007	.254	.065
	Huynh-Feldt	.654	3.124	.209	.091	.968	.007	.284	.065
	Lower-bound	.654	2.000	.327	.091	.913	.007	.182	.062
Error(session)	Sphericity Assumed	97.155	54	1.799					
	Greenhouse-Geisser	97.155	37.784	2.571					
	Huynh-Feldt	97.155	42.168	2.304					
	Lower-bound	97.155	27.000	3.598					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	4844.486	1	4844.486	481.453	.000	.947	481.453	1.000

rhea_standard	43.385	2	21.692	2.156	.135	.138	4.312	.402
Error	271.680	27	10.062					

a. Computed using alpha = .05

Results of the Mixed-Factor Two-Way ANOVA, Peak Power, Stone

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	ppa
2	ppb
3	ppc

Between-Subjects Factors

		N
stone_standard	.00	5
	1.00	5

Descriptive Statistics

	stone_standard	Mean	Std. Deviation	N
ppa	.00	14.9340	5.31095	5
	1.00	26.1340	5.78505	5
	Total	20.5340	7.89016	10
ppb	.00	13.4000	5.46531	5
	1.00	25.0240	5.99690	5
	Total	19.2120	8.17260	10
ppc	.00	13.9700	4.50415	5
	1.00	25.8520	4.28316	5
	Total	19.9110	7.50915	10

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	8.748	2	4.374	1.548	.243	.162	3.096	.280
	Greenhouse-Geisser	8.748	1.871	4.675	1.548	.245	.162	2.897	.270
	Huynh-Feldt	8.748	2.000	4.374	1.548	.243	.162	3.096	.280
	Lower-bound	8.748	1.000	8.748	1.548	.249	.162	1.548	.196
session * stone_standard	Sphericity Assumed	.593	2	.296	.105	.901	.013	.210	.063
	Greenhouse-Geisser	.593	1.871	.317	.105	.889	.013	.196	.063
	Huynh-Feldt	.593	2.000	.296	.105	.901	.013	.210	.063
	Lower-bound	.593	1.000	.593	.105	.754	.013	.105	.059

Error(session)	Sphericity Assumed	45.214	16	2.826					
	Greenhouse-Geisser	45.214	14.971	3.020					
	Huynh-Feldt	45.214	16.000	2.826					
	Lower-bound	45.214	8.000	5.652					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	11863.192	1	11863.192	153.237	.000	.950	153.237	1.000
stone_standard	1003.755	1	1003.755	12.965	.007	.618	12.965	.882
Error	619.339	8	77.417					

a. Computed using alpha = .05

Results of the Status Effect on Peak Power

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	stone_pp_weak	14.1200	5	5.01817	2.24419
	stone_pp_strong	25.6800	5	5.13293	2.29552

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1 stone_pp_weak - stone_pp_strong	-11.56000	8.73172	3.90495	-22.40187	-.71813	-2.960	4	.042

Results of the Mixed-Factor Two-Way ANOVA, Mean Power, Stone

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	mpa
2	mpb
3	mpc

Between-Subjects Factors

	N

stone_standard	.00	5
	1.00	5

Descriptive Statistics

	stone_standard	Mean	Std. Deviation	N
mpa	.00	6.4720	2.76323	5
	1.00	9.5120	2.00582	5
	Total	7.9920	2.78366	10
mpb	.00	6.5180	3.34576	5
	1.00	9.4440	2.02409	5
	Total	7.9810	3.02890	10
mpc	.00	5.7380	1.69952	5
	1.00	9.7600	1.93563	5
	Total	7.7490	2.72807	10

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	.377	2	.188	.261	.774	.032	.521	.084
	Greenhouse-Geisser	.377	1.832	.206	.261	.755	.032	.477	.083
	Huynh-Feldt	.377	2.000	.188	.261	.774	.032	.521	.084
	Lower-bound	.377	1.000	.377	.261	.623	.032	.261	.074
session * stone_standard	Sphericity Assumed	1.815	2	.908	1.256	.311	.136	2.512	.234
	Greenhouse-Geisser	1.815	1.832	.991	1.256	.310	.136	2.301	.223
	Huynh-Feldt	1.815	2.000	.908	1.256	.311	.136	2.512	.234
	Lower-bound	1.815	1.000	1.815	1.256	.295	.136	1.256	.168
Error(session)	Sphericity Assumed	11.561	16	.723					
	Greenhouse-Geisser	11.561	14.653	.789					
	Huynh-Feldt	11.561	16.000	.723					
	Lower-bound	11.561	8.000	1.445					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]

Intercept	1875.778	1	1875.778	122.222	.000	.939	122.222	1.000
stone_standard	83.133	1	83.133	5.417	.048	.404	5.417	.534
Error	122.778	8	15.347					

a. Computed using alpha = .05

Results of the Status Effect on Mean Power

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	stone_mp_weak	6.2600	5	2.55402	1.14219
	stone_mp_strong	9.5800	5	1.89130	.84581

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1 stone_mp_weak - stone_mp_strong	-3.32000	3.67927	1.64542	-7.88841	1.24841	-2.018	4	.114

Results of the Mixed-Factor Two-Way ANOVA, Peak Power Optimal Load, Rhea

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	pola
2	polb
3	polc

Between-Subjects Factors

		N
rhea_standard	.00	12
	1.00	9
	2.00	9

Descriptive Statistics

	rhea_standard	Mean	Std. Deviation	N
pola	.00	77.5000	12.52271	12
	1.00	81.6667	10.89725	9
	2.00	81.6667	10.89725	9
	Total	80.0000	11.37147	30
polb	.00	71.2500	11.30668	12
	1.00	81.6667	15.20691	9
	2.00	65.0000	22.50000	9
	Total	72.5000	17.20816	30
polc	.00	83.7500	7.72393	12
	1.00	81.6667	10.89725	9
	2.00	73.3333	19.03943	9
	Total	80.0000	13.26130	30

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	1051.136	2	525.568	4.166	.021	.134	8.332	.711
	Greenhouse-Geisser	1051.136	1.979	531.091	4.166	.021	.134	8.245	.707
	Huynh-Feldt	1051.136	2.000	525.568	4.166	.021	.134	8.332	.711
	Lower-bound	1051.136	1.000	1051.136	4.166	.051	.134	4.166	.503
session * rhea_standard	Sphericity Assumed	1062.500	4	265.625	2.106	.093	.135	8.422	.587
	Greenhouse-Geisser	1062.500	3.958	268.416	2.106	.094	.135	8.334	.584
	Huynh-Feldt	1062.500	4.000	265.625	2.106	.093	.135	8.422	.587
	Lower-bound	1062.500	2.000	531.250	2.106	.141	.135	4.211	.394

Error(session)	Sphericity Assumed	6812.500	54	126.157						
	Greenhouse-Geisser	6812.500	53.438	127.483						
	Huynh-Feldt	6812.500	54.000	126.157						
	Lower-bound	6812.500	27.000	252.315						

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	530734.091	1	530734.091	1661.428	.000	.984	1661.428	1.000
rhea_standard	937.500	2	468.750	1.467	.248	.098	2.935	.286
Error	8625.000	27	319.444					

a. Computed using alpha = .05

Results of the Session Effect on Peak Power Optimal Load

Estimates

Measure:MEASURE_1

session	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	80.278	2.135	75.897	84.658
2	72.639	3.031	66.420	78.858
3	79.583	2.380	74.699	84.468

Pairwise Comparisons

Measure:MEASURE_1

(I) session	(J) session	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	2	7.639*	2.805	.034	.480	14.798
	3	.694	3.062	1.000	-7.121	8.510
2	1	-7.639*	2.805	.034	-14.798	-.480
	3	-6.944	2.908	.073	-14.367	.478
3	1	-.694	3.062	1.000	-8.510	7.121
	2	6.944	2.908	.073	-.478	14.367

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Results of the Mixed-Factor Two-Way ANOVA, Mean Power Optimal Load, Rhea

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	mola
2	molb
3	molc

Between-Subjects Factors

		N
rhea_standard	.00	12
	1.00	9
	2.00	9

Descriptive Statistics

	rhea_standard	Mean	Std. Deviation	N
mola	.00	80.0000	11.67748	12
	1.00	76.6667	9.01388	9
	2.00	75.0000	16.77051	9
	Total	77.5000	12.50862	30
molb	.00	76.2500	11.89442	12
	1.00	81.6667	7.90569	9
	2.00	66.6667	22.63846	9
	Total	75.0000	15.75677	30
molc	.00	78.7500	9.32372	12
	1.00	78.3333	14.57738	9
	2.00	66.6667	16.95582	9
	Total	75.0000	14.20296	30

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	123.864	2	61.932	.447	.642	.016	.894	.119
	Greenhouse-Geisser	123.864	1.948	63.596	.447	.637	.016	.871	.118
	Huynh-Feldt	123.864	2.000	61.932	.447	.642	.016	.894	.119
	Lower-bound	123.864	1.000	123.864	.447	.509	.016	.447	.099
session * rhea_standard	Sphericity Assumed	495.833	4	123.958	.895	.473	.062	3.580	.266
	Greenhouse-Geisser	495.833	3.895	127.290	.895	.471	.062	3.486	.262
	Huynh-Feldt	495.833	4.000	123.958	.895	.473	.062	3.580	.266
	Lower-bound	495.833	2.000	247.917	.895	.420	.062	1.790	.188

Error(session)	Sphericity Assumed	7479.167	54	138.503						
	Greenhouse-Geisser	7479.167	52.587	142.225						
	Huynh-Feldt	7479.167	54.000	138.503						
	Lower-bound	7479.167	27.000	277.006						

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	504436.364	1	504436.364	1695.409	.000	.984	1695.409	1.000
rhea_standard	1579.167	2	789.583	2.654	.089	.164	5.308	.482
Error	8033.333	27	297.531					

a. Computed using alpha = .05

Results of the Mixed-Factor Two-Way ANOVA, Peak Power Optimal Load, Stone

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	pola
2	polb
3	polc

Between-Subjects Factors

		N
stone_standard	.00	5
	1.00	5

Descriptive Statistics

	stone_standard	Mean	Std. Deviation	N
pola	.00	78.0000	12.54990	5
	1.00	84.0000	8.21584	5
	Total	81.0000	10.48809	10
polb	.00	75.0000	15.00000	5
	1.00	75.0000	25.98076	5
	Total	75.0000	20.00000	10
polc	.00	81.0000	13.41641	5
	1.00	69.0000	22.74863	5
	Total	75.0000	18.70829	10

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	240.000	2	120.000	.653	.534	.075	1.306	.140
	Greenhouse-Geisser	240.000	1.841	130.396	.653	.523	.075	1.202	.136
	Huynh-Feldt	240.000	2.000	120.000	.653	.534	.075	1.306	.140
	Lower-bound	240.000	1.000	240.000	.653	.442	.075	.653	.110
session * stone_standard	Sphericity Assumed	420.000	2	210.000	1.143	.344	.125	2.286	.216
	Greenhouse-Geisser	420.000	1.841	228.192	1.143	.341	.125	2.103	.207
	Huynh-Feldt	420.000	2.000	210.000	1.143	.344	.125	2.286	.216
	Lower-bound	420.000	1.000	420.000	1.143	.316	.125	1.143	.157
Error(session)	Sphericity Assumed	2940.000	16	183.750					
	Greenhouse-Geisser	2940.000	14.724	199.668					
	Huynh-Feldt	2940.000	16.000	183.750					

	Lower-bound	2940.000	8.000	367.500					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	177870.000	1	177870.000	327.117	.000	.976	327.117	1.000
stone_standard	30.000	1	30.000	.055	.820	.007	.055	.055
Error	4350.000	8	543.750					

a. Computed using alpha = .05

Results of the Mixed-Factor Two-Way ANOVA, Mean Power Optimal Load, Stone

Within-Subjects Factors

Measure:MEASURE_1

session	Dependent Variable
1	mola
2	molb
3	molc

Between-Subjects Factors

		N
stone_standard	.00	5
	1.00	5

Descriptive Statistics

	stone_standard	Mean	Std. Deviation	N
mola	.00	78.0000	12.54990	5
	1.00	75.0000	10.60660	5
	Total	76.5000	11.06797	10
molb	.00	81.0000	8.21584	5
	1.00	69.0000	22.74863	5
	Total	75.0000	17.32051	10
molc	.00	72.0000	12.54990	5
	1.00	72.0000	24.64752	5
	Total	72.0000	18.43909	10

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
session	Sphericity Assumed	105.000	2	52.500	.467	.635	.055	.933	.113
	Greenhouse-Geisser	105.000	1.846	56.875	.467	.621	.055	.862	.110
	Huynh-Feldt	105.000	2.000	52.500	.467	.635	.055	.933	.113
	Lower-bound	105.000	1.000	105.000	.467	.514	.055	.467	.093
session * stone_standard	Sphericity Assumed	195.000	2	97.500	.867	.439	.098	1.733	.173
	Greenhouse-Geisser	195.000	1.846	105.625	.867	.433	.098	1.600	.167
	Huynh-Feldt	195.000	2.000	97.500	.867	.439	.098	1.733	.173
	Lower-bound	195.000	1.000	195.000	.867	.379	.098	.867	.131
Error(session)	Sphericity Assumed	1800.000	16	112.500					
	Greenhouse-Geisser	1800.000	14.769	121.875					
	Huynh-Feldt	1800.000	16.000	112.500					
	Lower-bound	1800.000	8.000	225.000					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure:MEASURE_1
Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	166507.500	1	166507.500	284.628	.000	.973	284.628	1.000
stone_standard	187.500	1	187.500	.321	.587	.039	.321	.079
Error	4680.000	8	585.000					

a. Computed using alpha = .05

Results of the One-Way ANOVA, Method Effect on Test-Retest Reliability – Rhea

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
r_pp_cv1_2	.00	12	6.3417	4.67400	1.34927	3.3719	9.3114	.50	15.20
	1.00	10	5.0800	5.07714	1.60553	1.4480	8.7120	.10	15.00
	2.00	9	9.3444	10.12906	3.37635	1.5586	17.1303	.10	31.40
	Total	31	6.8065	6.79082	1.21967	4.3156	9.2973	.10	31.40
r_pp_cv1_3	.00	12	10.4500	8.43461	2.43486	5.0909	15.8091	2.70	35.60
	1.00	9	5.9333	4.19881	1.39960	2.7058	9.1608	.40	12.20
	2.00	9	13.6556	12.03725	4.01242	4.4029	22.9082	1.70	37.70
	Total	30	10.0567	9.00998	1.64499	6.6923	13.4210	.40	37.70
r_pol_cv1_2	.00	12	10.5833	8.85190	2.55532	4.9591	16.2076	.00	28.30
	1.00	10	5.8900	7.89056	2.49522	.2454	11.5346	.00	20.20
	2.00	9	22.3444	23.23193	7.74398	4.4868	40.2021	.00	60.60
	Total	31	12.4839	15.37667	2.76173	6.8437	18.1241	.00	60.60
r_pol_cv1_3	.00	12	13.9667	12.09232	3.49075	6.2836	21.6498	.00	28.30
	1.00	9	9.9778	11.74136	3.91379	.9526	19.0030	.00	35.40
	2.00	9	12.7778	19.19842	6.39947	-1.9794	27.5350	.00	60.60
	Total	30	12.4133	14.07310	2.56939	7.1584	17.6683	.00	60.60
r_mp_cv1_2	.00	12	7.6917	5.67746	1.63894	4.0844	11.2990	.10	18.40
	1.00	10	6.1100	5.16386	1.63296	2.4160	9.8040	.10	18.10
	2.00	9	8.4778	10.49092	3.49697	.4137	16.5418	.50	35.10
	Total	31	7.4097	7.07848	1.27133	4.8133	10.0061	.10	35.10
r_mp_cv1_3	.00	12	13.5333	14.45019	4.17141	4.3521	22.7145	1.50	53.50
	1.00	9	5.3444	4.03550	1.34517	2.2425	8.4464	.20	12.90
	2.00	9	10.5556	17.72633	5.90878	-3.0701	24.1812	.30	49.90
	Total	30	10.1833	13.50300	2.46530	5.1412	15.2254	.20	53.50
r_mol_cv1_2	.00	12	12.8917	12.75122	3.68096	4.7899	20.9934	.00	28.30
	1.00	10	9.3100	6.48236	2.04990	4.6728	13.9472	.00	15.70

	2.00	9	18.4444	17.49544	5.83181	4.9963	31.8926	.00	47.10
	Total	31	13.3484	12.92898	2.32211	8.6060	18.0908	.00	47.10
r_mol_cv1_3	.00	12	11.6083	11.79888	3.40604	4.1117	19.1050	.00	28.30
	1.00	9	9.5000	10.08985	3.36328	1.7443	17.2557	.00	28.30
	2.00	9	11.6222	20.92862	6.97621	-4.4649	27.7094	.00	60.60
	Total	30	10.9800	14.23692	2.59929	5.6638	16.2962	.00	60.60

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
r_pp_cv1_2	Between Groups	90.371	2	45.186	.978	.388
	Within Groups	1293.087	28	46.182		
	Total	1383.459	30			
r_pp_cv1_3	Between Groups	271.441	2	135.721	1.759	.191
	Within Groups	2082.772	27	77.140		
	Total	2354.214	29			
r_pol_cv1_2	Between Groups	1353.214	2	676.607	3.300	.052
	Within Groups	5740.048	28	205.002		
	Total	7093.262	30			
r_pol_cv1_3	Between Groups	83.537	2	41.768	.199	.821
	Within Groups	5659.978	27	209.629		
	Total	5743.515	29			
r_mp_cv1_2	Between Groups	28.113	2	14.057	.267	.768
	Within Groups	1475.034	28	52.680		
	Total	1503.147	30			
r_mp_cv1_3	Between Groups	346.651	2	173.325	.947	.400
	Within Groups	4940.951	27	182.998		
	Total	5287.602	29			

r_mol_cv1_2	Between Groups	399.317	2	199.659	1.211	.313
	Within Groups	4615.440	28	164.837		
	Total	5014.757	30			
r_mol_cv1_3	Between Groups	28.163	2	14.082	.065	.937
	Within Groups	5849.845	27	216.661		
	Total	5878.008	29			

Results of the One-Way ANOVA, Method Effect on Test-Retest Reliability – Stone

Descriptives

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
s_pp_cv1_2	.00	5	8.2600	5.56893	2.49050	1.3453	15.1747	.50	15.00
	1.00	5	4.4400	6.80537	3.04345	-4.0100	12.8900	.10	16.40
	Total	10	6.3500	6.19843	1.96012	1.9159	10.7841	.10	16.40
s_pp_cv1_3	.00	5	7.3200	4.27867	1.91348	2.0073	12.6327	.60	12.20
	1.00	5	6.6600	3.91063	1.74889	1.8043	11.5157	.40	10.30
	Total	10	6.9900	3.87999	1.22696	4.2144	9.7656	.40	12.20
s_pol_cv1_2	.00	5	8.3000	7.66257	3.42681	-1.2143	17.8143	.00	15.70
	1.00	5	17.2800	25.06087	11.20756	-13.8372	48.3972	.00	60.60
	Total	10	12.7900	18.10049	5.72388	-.1583	25.7383	.00	60.60
s_pol_cv1_3	.00	5	17.0400	11.86246	5.30505	2.3108	31.7692	.00	28.30
	1.00	5	5.1600	7.06562	3.15984	-3.6131	13.9331	.00	12.90
	Total	10	11.1000	11.13253	3.52042	3.1363	19.0637	.00	28.30
s_mp_cv1_2	.00	5	6.7800	7.61525	3.40564	-2.6756	16.2356	.10	18.10
	1.00	5	5.4200	2.91839	1.30514	1.7963	9.0437	.50	8.30
	Total	10	6.1000	5.48392	1.73417	2.1770	10.0230	.10	18.10

s_mp_cv1_3	.00	5	8.7800	11.03005	4.93279	-4.9156	22.4756	1.00	27.40
	1.00	5	3.6200	5.23421	2.34081	-2.8791	10.1191	.30	12.90
	Total	10	6.2000	8.58163	2.71375	.0611	12.3389	.30	27.40
s_mol_cv1_2	.00	5	8.2400	12.52809	5.60273	-7.3157	23.7957	.00	28.30
	1.00	5	14.5800	19.28956	8.62655	-9.3711	38.5311	.00	47.10
	Total	10	11.4100	15.69377	4.96280	.1834	22.6366	.00	47.10
s_mol_cv1_3	.00	5	13.9600	10.07214	4.50440	1.4538	26.4662	.00	28.30
	1.00	5	2.5800	5.76906	2.58000	-4.5832	9.7432	.00	12.90
	Total	10	8.2700	9.79048	3.09602	1.2663	15.2737	.00	28.30

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
s_pp_cv1_2	Between Groups	36.481	1	36.481	.944	.360
	Within Groups	309.304	8	38.663		
	Total	345.785	9			
s_pp_cv1_3	Between Groups	1.089	1	1.089	.065	.805
	Within Groups	134.400	8	16.800		
	Total	135.489	9			
s_pol_cv1_2	Between Groups	201.601	1	201.601	.587	.466
	Within Groups	2747.048	8	343.381		
	Total	2948.649	9			
s_pol_cv1_3	Between Groups	352.836	1	352.836	3.702	.091
	Within Groups	762.564	8	95.321		
	Total	1115.400	9			
s_mp_cv1_2	Between Groups	4.624	1	4.624	.139	.719
	Within Groups	266.036	8	33.255		
	Total	270.660	9			
s_mp_cv1_3	Between Groups	66.564	1	66.564	.893	.372

	Within Groups	596.236	8	74.530		
	Total	662.800	9			
s_mol_cv1_2	Between Groups	100.489	1	100.489	.380	.555
	Within Groups	2116.160	8	264.520		
	Total	2216.649	9			
s_mol_cv1_3	Between Groups	323.761	1	323.761	4.806	.060
	Within Groups	538.920	8	67.365		
	Total	862.681	9			

References

Atkinson, G., and Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, **26**, 217-238.

Baker, D. (2001). Comparison of upper-body strength and power between professional and college-aged rugby league players. *Journal of Strength and Conditioning Research*, **15**, 30-35.

Baker, D. (2002). Differences in strength and power among junior-high, senior-high, college-aged, and elite professional rugby league players. *Journal of Strength and Conditioning Research*, **16**, 581-585.

Baker, D., Nance, S., and Moore, M. (2001a). The load that maximises the average mechanical power output during explosive bench press throws in highly trained athletes. *Journal of Strength and Conditioning Research*, **15**, 20-24.

Baker, D., Nance, S., and Moore, M. (2001b). The load that maximises the average mechanical power output during jump squats in power-trained athletes. *Journal of Strength and Conditioning Research*, **15**, 92-97.

Baker, D., and Newton, R.U. (2005) Methods to increase the effectiveness of maximal power training for the upper body. *Strength and Conditioning Journal*, **27**, 24-32.

Bates, B. T. (1996). Single-subject methodology: an alternative approach. *Medicine and Science in Sports and Exercise*, **28**, 631-638.

Batterham, A. M., and George, K. P. (2000). Reliability in evidence-based clinical practice: A primer for allied health professionals. *Physical Therapy in Sport*, **4**, 122-128.

Berger, R. A. (1964). Effects of dynamic and static training on vertical jumping ability. *The Research Quarterly*, **34**, 419-424.

Bland, J. M., and Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, **1**, 307-310.

Bland, J. M., and Altman, D. G. (2007). Agreement between methods of measurement with multiple observations per individual. *Journal of Biopharmaceutical Statistics*, **17**, 571-582.

Bosco, C., Belli, A., Astrua, M., Tihanyi, J., Pozzo, R., Kellis, S., Tsarpela, O., Foti, C., Manno, R., and Tranquilli, C. (1995). A dynamometer for evaluation of dynamic muscle work. *European Journal of Applied Physiology*, **70**, 379-386.

Burnett, A., Beard, A., Newton, R. U., and Netto, K. (2004). *A comparison of methods to calculate the optimal load for maximal power output in the power clean*. Paper presented at the International Society of Biomechanics in Sport, Ottawa, Canada.

Carlock, J. M., Smith, S. L., Hartman, M. J., Morris, R. T., Ciroslan, D. A., Pierce, K. C., Newton, R. U., Harman, E. A., Sands, W. A., and Stone, M. H. (2004). The relationship between vertical jump power estimates and weightlifting ability: A field-test approach. *Journal of Strength and Conditioning Research,* **18**, 534-539.

Chiu, L. Z. F. (2008). Does an optimal load exist for power training? *Strength and Conditioning Journal,* **30**, 67-69.

Chiu, L. Z. F., Schilling, B. K., Fry, A. C., and Weiss, L. W. (2004). Measurement of resistance exercise force expression. *Journal of Applied Biomechanics,* **20**, 204-212.

Coelho, C. W., Hamar, D., and De Araujo, C. G. S. (2003). Physiological responses using 2 high-speed resistance training protocols. *Journal of Strength and Conditioning Research,* **17**, 334-337.

Cormie, P., Deane, R., and McBride, J. M. (2007a). Methodological concerns for determining power output in the jump squat. *Journal of Strength and Conditioning Research,* **21**, 424-430.

Cormie, P., McBride, J. M., and McCaulley, G. O. (2007b). Validation of power measurement techniques in dynamic lower body resistance exercises. *Journal of Applied Biomechanics,* **23**, 103-118.

Cormie, P., McCauley, G. O., Triplett, T. N., and McBride, J. M. (2007c). Optimal loading for maximal power ouptut during lower-body resistance exercises. *Medicine and Science in Sports and Exercise,* **39**, 340-349.

Cormie, P., McCaulley, G. O., and McBride, J. M. (2007d). Power versus strength-power jump squat training: Influence on the load-power relationship. *Medicine and Science in Sports and Exercise,* **39**, 996-1003.

Cronin, J., Hing, R. D., and McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research,* **18**, 590-593.

Cronin, J., and Sleivert, T. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine,* **35**, 213-234.

Cronin, J. B., McNair, P. J., and Marshall, R. N. (2000). The role of maximal strength and load on initial power production. *Medicine and Science in Sports and Exercise,* **32**, 1763-1769.

Doldo, N. A., Delmonico, M. J., Bailey, J. A., Hand, B. D., Kostek, M. C., Rabon-Stith, K. M., Menon, K. S., Conway, J. M., Carignan, C. R., and Hurley, B. F. (2006). Muscle-power quality: Does sex or race affect movement velocity in older adults? *Journal of Aging and Physical Activity,* **14**, 411-422.

Driss, T., Vandewalle, H., Qui\vS, v. J., Miller, C., and Monod, H. (2001). Effects of external loading on power output in a squat jump on a force platform: A comparison between strength and power athletes and sedentary individuals. *Journal of Sports Sciences,* **19**, 99-105.

Dugan, E. L., Doyle, T. L. A., Humphries, B., Hasson, C. J., and Newton, R. U. (2004). Determining the optimal load for jump squats: A review of methods and calculations. *Journal of Strength and Conditioning Research,* **18**, 668-674.

Falvo, M. J., Schilling, B. K., and Weiss, L. W. (2006). Techniques and considerations for determining isoinertial upper-body power. *Sports Biomechanics,* **5**, 293-311.

Flanagan, S., and Salem, G. (2007). Bilateral differences in the net joint torques during the squat exercise. *The Journal of Strength and Conditioning Research,* **21**, 1220-1226.

Fletcher, J. G., Lewis, H. E., and Wilkie, D. R. (1958). Photographic methods for estimating external lifting work in man. *Ergonomics,* **2**, 114-115.

Frontera, W. R., Meredith, C. N., O'Reilly, K. P., Knuttgen, H. G., and Evans, W. J. (1988). Strength conditioning in older men: Skeletal muscle hypertrophy and improved function. *Journal of Applied Physiology,* **64**, 1038-1044.

Frost, D., Cronin, J., and Newton, R. (2010). A novel approach to identify the end of the positive lifting phase during ballistic upper-body movements. *Journal of Strength and Conditioning Research*, 282-286.

Frost, D. M., Cronin, J. B., and Newton, R. U. (2008a). A comparison of the kinematics, kinetics and muscle activity between pneumatic and free weight resistance. *European Journal of Applied Physiology,* **104**, 937-956.

Frost, D. M., Cronin, J. B., and Newton, R. U. (2008b). Have we underestimated the kinematic and kinetic benefits of non-ballistic motion? *Sports Biomechanics,* **7**, 372-385.

Garhammer, J. (1980). Power production by olympic weightlifters. *Medicine and Science in Sports and Exercise,* **12**, 54-60.

Garhammer, J. (1991). A comparison of maximal power outputs between elite male and female weightlifters in competition. *Journal of Applied Biomechanics,* **7**, 3-11.

Garhammer, J. (1993). A review of power output studies of olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research,* **7**, 76-89.

Gourgoulis, V., Aggelousis, N., Mavromatis, G., and Garas, A. (2000). Three-dimensional kinematic analysis of the snatch of elite Greek weightlifters. *Journal of Sports Sciences*, **18**, 643-652.

Haff, G. G., Stone, M., O'Bryant, H. S., Harman, E., Dinan, C., Johnson, R., and Han, K. H. (1997). Force-time dependent characteristics of dynamic and isometric muscle actions. *Journal of Strength and Conditioning Research*, **11**, 269-272.

Hakkinen, K., Newton, R. U., Gordon, S. E., McCormick, M., Volek, J. S., Nindl, B. C., Gotshalk, L. A., Campbell, W. W., Evans, W. J., Hakkinen, A., Humphries, B. J., and Kraemer, W. J. (1998). Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *Journal of Gerontoly A: Biological Sciences and Medical Sciences*, **53**, 1341-1349.

Harman, E. (1991). Estimation of human power output from vertical jump. *Journal of Applied Sports Science Research*, **5**, 116-120.

Harris, N. K., Cronin, J. B., and Hopkins, W. G. (2007). Power outputs of a machine squat-jump across a spectrum of loads. *Journal of Strength and Conditioning Research*, **21**, 1260-1264.

Harris, N. K., Cronin, J. B., Hopkins, W. G., and Hansen, K. T. (2008). Squat jump training at maximal power loads vs. Heavy loads: Effect on sprint ability. *Journal of Strength and Conditioning Research*, **22**, 1742-1749.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, **30**, 375-381.

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., and Nosaka, K. (2007). Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *Journal of Strength and Conditioning Research*, **21**, 314-320.

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Andrews, W. A., Chapman, D. W., and Nosaka, K. (2008). Comparison of weighted jump squat training with and without eccentric braking. *Journal of Strength and Conditioning Research*, **22**, 54-65.

Izquierdo, M., Hakkinen, K., Gonzalez-Badillo, J. J., Ibanez, J., and Gorostiaga, E. M. (2002). Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *European Journal of Applied Physiology*, **87**, 264-271.

Izquierdo, M., Hakkinen, K., Ibanez, J., Garrues, A., Anton, A., Zuniga, M., Larrion, J. L., and Gorostiaga, E. M. (2001). Effects of strength training on muscle power and serum hormones in middle-aged and older men. *Journal of Applied Physiology,* **90**, 1497-1507.

Izquierdo, M., Ibanez, J., Hakkinen, K., Kraemer, W. J., Ruesta, M., and Gorostiaga, E. M. (2004). Maximal strength and power, muscle mass, endurance and serum hormones in weightlifters and road cyclists. *Journal of Sports Sciences,* **22**, 465-478.

Izquierdo, M., J., I., Gorostiaga, E., Garrues, M., Zuniga, A., Anton, A., Larrionn, J. L., and Hakkinen, K. (1999). Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiologica Scandinavia,* **167**, 57-68.

Jandacka, D., and Vaverka, F. (2008). A regression model to determine load for maximum power output. *Sports Biomechanics,* **7**, 361-371.

Jennings, C. I. L., Viloen, W., Durandt, J., and Lambert, M. I. (2005). The reliability of the fitrodyne as a measure of muscle power. *Journal of Strength and Conditioning Research,* **19**, 859-863.

Joszi, A. C., Campbell, W. W., Joseph, L., Davey, J. L., and Evans, W. J. (1999). Changes in power with resistance training in older and younger men and women. *Journal of Gerontology: Medical Sciences,* **54a**, 591-596.

Kaneko, M., Fuhimoto, T., Toji, H., and Suei, K. (1983). Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scandinavian Journal of Sports Science,* **5**, 50-55.

Kawamori, N., Crum, A. J., Blumert, P. A., Kulik, J. R., Childers, J. T., Wood, J. A., Stone, M. H., and Haff, G. G. (2005). Influence of different relative intensities on power output during the hang power clean: Identification of the optimal load. *Journal of Strength and Conditioning Research,* **19**, 698-708.

Kawamori, N., and Haff, G. G. (2004). The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research,* **18**, 675-684.

Kawamori, N., Rossi, S. J., Justice, B. D., Haff, E. E., Pistilli, E. E., O'Bryant, H. S., Stone, M. H., and Haff, G. G. (2006). Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *Journal of Strength and Conditioning Research,* **20**, 483-491.

Kilduff, L. P., Bevan, H., Owen, N., Kingsley, M. I. C., Bunce, P., Bennett, M., and Cunningham, D. (2007). Optimal loading for peak power output during the hang power clean in professional rugby players. *International Journal of Physiology and Sports Performance,* **2**, 260-269.

Lanza, I. R., Towse, T. F., Caldwell, G. E., Wigmore, D. M., and Kent-Braun, J. A. (2003). Effects of age on human muscle torque, velocity, and power in two muscle groups. *Journal of Applied Physiology,* **95**, 2361-2369.

Lauder, M., and Lake, J. (2008). Biomechanical comparison of unilateral and bilateral power snatch lifts. *Journal of Strength and Conditioning Research,* **22**, 653-660.

Li, L., Olson, M. W., and Winchester, J. B. (2008). A proposed method for determining peak power in the jump squat. *Journal of Strength and Conditioning Research,* **22**, 326-331.

Lawton, T. W., Cronin, J. B., and Lindsell, R. P. (2006) Effect of interrepetition rest intervals on weight training repetition power output. *Journal of Strength and Conditioning Research,* **20**, 172-176.

Lynch, N. A., Metter, E. J., Lindle, R. S., Fozard, J. L., Tobin, J. D., Roy, T. A., Fleg, J. L., and Hurley, B. F. (1999). Muscle quality. I age-associated differences between arm and leg muscle groups. *J Appl Physiol,* **86**, 188-194.

Lyttle, A. D., Wilson, G. J., and Ostrowski, K. J. (1996). Enhancing performance: Maximal power versus combined weights and plyometrics training. *Journal of Strength and Conditioning Research,* **10**, 173-179.

Martel, G. F., Roth, S. M., Ivey, F. M., Lemmer, J. T., Tracy, B. L., Hurlbut, D. E., Metter, E. J., Hurley, B. F., and Rogers, M. A. (2006). Age and sex affect human muscle fibre adaptations to heavy-resistance strength training. *Experimental Physiology,* **91**, 457-464.

Mastropaolo, J. A. (1992). A test of the maximum-power stimulus theory for strength. *European Journal of Applied Physiology,* **65**, 415-420.

McBride, J. M., Triplett-McBride, T., Davie, A., and Newton, R. U. (1999). A comparison of strength and power characteristics between power lifters, olympic lifters, and sprinters. *Journal of Strength and Conditioning Research,* **13**, 58-66.

McBride, J. M., Triplett-McBride, T., Davie, A., and Newton, R. U. (2002). The effect of heavy vs light load jump squats on the development of strength, power, and speed. *Journal of Strength and Conditioning Research,* **16**, 75-82.

Moir, G., Sanders, R., Button, C., and Glaister, M. (2005). The influence of familiarization on the reliability of force variables measured during unloaded and loaded vertical jumps. *Journal of Strength and Conditioning Research,* **19**, 140-145.

Morrow, J. R., and Hosler, W. W. (1981). Strength comparisons in untrained men and trained women athletes. *Medicine and Science in Sports and Exercise,* **13**, 194-197.

Nelson, R. C., and Burdett, R. G. (1978). Biomechanical analysis of Olympic weightlifting. In: *Biomechanics of sports and kinanthropometry.* (Landry, F., and Orban, W, eds.), Symposia Specialists Inc., Miami, Florida, pp. 169-180.

Newell, P. B., Dugan, E. L., and Kruger, S. E. (2005). Linear position transducer/force platform method for determining power output during free standing jump squats. *Medicine and Science in Sports and Exercise,* **37**, S410.

Newton, R. U. (1997). *Expression and development of maximal muscle function.* (Unpublished doctoral dissertation). Southern Cross University, Lismore, NSW.

Newton, R. U., Gerber, A., Nimphius, S., Shim, J. K., Doan, B. K., Robertson, M., Pearson, D. R., Craig, B. W., Hakkinen, K., and Kraemer, W. J. (2006a). Determination of functional strength imbalance of the lower extremities. *Journal of Strength and Conditioning Research,* **20**, 971-977.

Newton, R. U., Kraemer, W. J., Hakkinen, K., Humphries, B. J., and Murphy, A. J. (1996). Kinematics, kinetics, and muscle activation during explosive upper body movements. *Journal of Applied Biomechanics,* **12**, 31-43.

Newton, R. U., Rogers, R. A., Volek, J. S., Hakkinen, K., and Kraemer, W. J. (2006b). Four weeks of optimal load ballistic resistance training at the end of season attenuates declining jump performance of women volleyball players. *Journal of Strength and Conditioning Research,* **20**, 955-961.

Patterson, C., Raschner, C., and Platzer, H. P. (2009). Power variables and bilateral force differences during unloaded and loaded squat jumps in high performance alpine skiers. *Journal of Strength and Conditioning Research,* **23**, 779-787.

Petrella, J. K., Kim, J. S., Tuggle, C. S., and Bamman, M. M. (2007). Contributions of force and velocity to improved power with progressive resistance training in young and older adults. *European Journal of Applied Physiology,* **99**, 343-351.

Rhamani, A., Dalleau, G., Viale, F., Hautier, C. A., and Lacour, J-R. (2000). Validity and reliability of a kinematic device for measuring the force developed during squatting. *Journal of Applied Biomechanics*, **16**, 26-35.

Rahmani, A., Viale, F., Dalleau, G., and Lacour, J. R. (2001). Force/velocity and power/velocity relationships in squat exercise. *European Journal of Applied Physiology,* **84**, 227-232.

Reiser, R. F., Smith, S. L., and Rattan, R. (1996). Science and technology to enhance weightlifting performance: The olympic program. *Strength and Conditioning Journal*, **18**, 43-51.

Rhea, M. R. (2004). Determining the magnitude of treatment effects in strength training research through the use of the effect size. *Journal of Strength and Conditioning Research*, **18**, 918-920.

Rhea, M. R., Alvar, B. A., Burkett, L. N., and Ball, S. D. (2003). A meta-analysis to determine the dose response for strength development. *Medicine and Science in Sports and Exercise*, **35**, 456-464.

Ronnestad, B. R. (2009). Acute effects of various whole-body vibration frequencies on lower-body power in trained and untrained subjects. *Journal of Strength and Conditioning Research*, **23**, 1309-1315.

Sheppard, J. M., Cormack, S., Taylor, K. L., McGuigan, M. R., and Newton, R. U. (2008). Assessing the force-velocity characteristics of the leg extensors in well-trained athletes: The incremental load power profile. *Journal of Strength and Conditioning Research*, **22**, 1320-1326.

Shim, A. L., Bailey, M. L., and Westings, S. H. (2001). Development of a field test for upper-body power. *Journal of Strength and Conditioning Research*, **15**, 192-197.

Siegel, J. A., Gilders, R. M., Staron, R. S., and Hagerman, F. C. (2002). Human muscle power output during upper and lower-body exercises. *Journal of Strength and Conditioning Research*, **16**, 173-178.

Sleivert, G. G., and Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in team sport athletes. *European Journal of Applied Physiology*, **87**, 264-271.

Song, J. E., Flanagan, S. P., Admon, C., Wang, M. Y., and Salem, C. J. (2003). Lower extremity joint kinetics in older adults are symmetric while performing the squat exercise. *Medicine and Science in Sports and Exercise*, **35**, S347.

Thomas, G. A., Kraemer, W. J., Spiering, B. A., Volek, J. S., Anderson, J. M., and Maresh, C. M. (2007). Maximal power at different percentages of one repetition maximum: Influence of resistance and gender. *Journal of Strength and Conditioning Research*, **21**, 336-342.

Thompson, C. J. and Bemben, M. G. (1999). Reliability and comparability of the accelerometer as a measure of muscular power. *Medicine and Science in Sports and Exercise*, **31**, 897-902.

Wilson, G. J., Newton, R. U., Murphy, A. J., and Humphries, B. J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine and Science in Sports and Exercise,* **25**, 1279-1286.

Winchester, J. B., Erickson, T. M., Blaak, J. B., and McBride, J. M. (2005). Changes in bar path kinematics and kinetics after power clean training. *Journal of Strength and Conditioning Research,* **19**, 177-183.

Winter, D. A. (1990). *Biomechanics and motor control of human movement.* John Wiley & Sons, Inc., Chichester, UK.