The validation of muscle power output measures in lower and upper body resistance exercises

BY

GUNNAR SCHOELER

MRC/ UCT RESEARCH UNIT FOR EXERCISE SCIENCE AND SPORTS MEDICINE,

DEPARTMENT OF HUMAN BIOLOGY

Submitted in partial fulfilment of the
requirements for the degree of
MSc in Exercise Science

University of Cape Town

Supervisors: A/Prof M. Lambert

Cape Town, Western Cape
06th April 2009

DECLARATION

THESIS TITLE:
The validation of muscle power output measures in lower and upper body resistance exercises

I, Gunnar Schoeler, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgments indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.
I empower the university to reproduce for the purpose of research either the whole or any portion of the contents in any matter whatsoever.

SIGNATURE: ______________________________

DATE: ____________________________________

ACKNOWLEDGEMENTS

Several people have contributed to completing this study. I would therefore like to take the opportunity to express my appreciation to each one of them. First of all I would like to thank my subjects for their time and commitment in completing the assessments. Further I would like to say ‘thank you’ to my supervisors Dr. A/Prof Mike Lambert and Dr. Wayne Viljoen for their inspiration, motivation, time and support throughout. In addition, I would like to express my appreciation for getting the chance to experience the innovative environment at the MRC/UCT Research Unit for Exercise Science and Sports Medicine, Cape Town. Special thanks also go Dennis Naudé from “IDEAS Solution and Monitoring” for his professional advice and excellent service. In addition, my parents have, as always, been a great source of wisdom and support for which I will always be thankful. And lastly, I would like to thank the most important person in my life, my wife Lotte, for her continuous support and understanding but most of all for her love and friendship.

TABLE OF CONTENTS

THESIS ABSTRACT

Background: Power output during resistance exercise is measured using a variety of different methods. The reliability and comparability of results obtained from different methods of assessment has been the source of debate for the last decade. *Aim:* To investigate the reliability and comparability of measurements of force, velocity and power measured simultaneously during upper and lower body resistance exercises for the following three methods: a) power derived from ground reaction force, i.e. using a force plate (FP), b) power derived from the displacement of the bar, i.e. displacement tracking laser (L) and c) power as a combination of force derived from ground reaction force (FP) and velocity derived from the displacement of the bar (L) (FPL). *Methods:* 15 Males with a history of resistance training of at least one year participated in the study. Data were acquired simultaneously for each method (FP, L and FPL) during the squat jump and bench throw exercises performed with the unloaded bar and at loads of 20, 30, 40, 50, 60, 70 and 80% 1RM. *Results:* All methods of assessment showed good levels or reliability for each variable (i.e. measures of force, velocity and power), but these were generally higher for peak compared to mean values. Measures of reliability ranged from 0.90 to 1.00 for the intraclass correlation coefficient, from 1.3 to 7.9% for the relative typical error of measurement and from 0.93 to 0.99 for the test-retest correlation coefficient. Measures of power output were significantly different between the three methods in the power-load relationship at lighter loads in both the squat jump and bench throw exercises. Power outputs derived from FPL were generally highest during squat jumps, whereas power outputs derived from FP were consistently higher during bench throws compared to respective measures for the other methods of assessment. The correlation coefficients for measures of power were moderate to high between all three methods (r = 0.79 - 0.99). *Conclusion:* Power output assessed simultaneously with different data acquisition technologies and methods of calculating power are not directly comparable. Based on the moderate to high correlation coefficients it would be useful to evaluate prediction equations (e.g. regression analysis) which correct for the anomalies between methods in future research.

LIST OF FIGURES

LIST OF TABLES

Chapter 1

LITERATURE REVIEW

1.1 INTRODUCTION AND SCOPE OF THE THESIS

The ability to express high explosive strength in sporting movements is a prerequisite for successful athletic performance (6; 39; 74). Explosive strength or “power” is a consequence of the generation of force and velocity during muscle function (19). Improving dynamic muscle strength and speed of contraction by integrating various resistance exercises to athletic training has a long history (39). Accordingly, many different strength training strategies have evolved and have been adopted in a wide range of sports (67; 113). Strength and conditioning training has therefore become a specialization within athletic training (116). Unconditioned athletes benefit from almost any type of structured resistance training (36; 83). However, in well-trained athletes it becomes more complex to design strength training programs that induce muscle adaptations with a significant transfer to performance (29). For these athletes, it is important to identify training methods that stimulate aspects of force and velocity specific to the sporting tasks encountered during competition (11).

A key matter for coaches and athletes is to achieve optimal training adaptations within a given time frame to ensure adequate contest preparation (116). Sports scientists and coaches are therefore challenged to develop evidence-based training strategies that can improve sport specific muscle performance in an efficient and predictable way (64). Consequently, the assessment of force, velocity and power output during dynamic muscle function has become a common procedure in exercise science research. Such assessments enable performance capacities of the neuromuscular system under different conditions to be evaluated, monitored and compared (37). Such tests evaluate the power generation capacities of an athlete for a specific exercise movement under different loading conditions. In particular, the power-load relationship associated with resistance exercises has been explored in many studies (53). For example, such investigations have focused on:

- muscle power adaptations to different training strategies (53; 80; 80);
- relationship of power output to other qualities of strength (38);

- relationship between power output and sporting performance (16), and
- comparisons of power output capacities of athletes from different sporting backgrounds (67; 69).

Various practical applications have been derived from respective research findings (82). Accordingly, many practitioners assess power output to obtain integrative information about the performance qualities of an individual as required in athlete profiling (16; 86), talent evaluation (23) and/or training prescription as well as monitoring of subsequent (long term) adaptations (7; 67). The competitive nature of many sports requires progressive development of athletic performance.

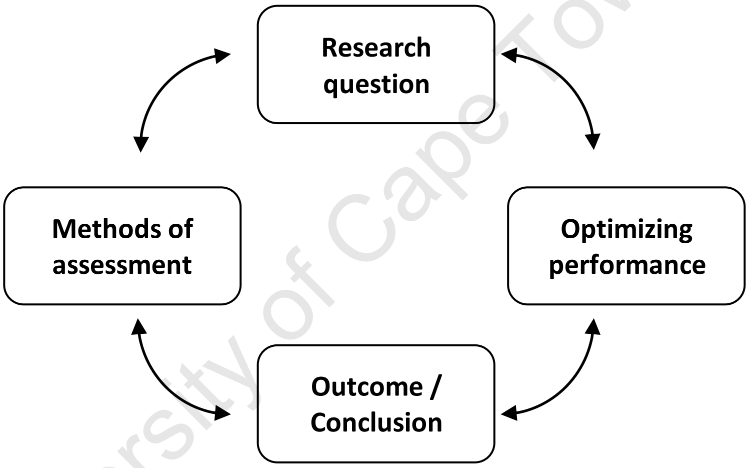


Figure 1: inter relationship between performance, research question, assessment and research outcome

As high power output capacities are considered to be a key factor for successful sports participation scientists are motivated to advance research related to the generation of power output during muscle function. Consequently, researchers have developed a variety of customized equipment to accommodate power testing (2; 48). In particular, over the last decade the equipment designed to measure power output has become more sophisticated. Based on the outcomes of respective research many recommendations have been suggested to improve athletic performance (42). The inter-relationship between performance, research question, assessments and outcome is shown in Figure 1. Within this inter-relationship the methods of assessment form a significant link between the research question and consequent recommendations to coaches and athletes. In other words, the outcome of a study designed to answer questions about performance is dependent on the reliability and accuracy of the testing methods used. As there are no standardized procedures for the assessment of muscle power, knowledge about reliability and accuracy of the different testing methods are imperative (2; 3; 48).

Researchers have criticized the lack of standard procedures consistently over the last decade. More specifically, scientists argue that the diversity of assessment procedures and testing equipment may be a key reason for the contradictive study outcomes associated with some areas of power output research (41; 44). The following concerns have been repeatedly emphasized:

- Reliability of equipment and performance tests (37)
- Differences in calculating and presenting power output (44)
- Comparability of measurements from different assessments (32)
- Insufficient reporting on exact data acquisition procedures (2)

As a result, there is no consensus about which training loads are most beneficial to advance functional power output and offer the most effective transference to performance (76). In particular, there has been extensive debate on the diversity of technical equipment used to assess power output in dynamic muscle function.

Surprisingly, despite the fundamental criticism related to certain methodological aspects of power output assessments, most of the concerns are based on theoretical arguments (44). Only recently, investigators have assessed power output derived from independent measurements obtained simultaneously during resistance exercises (32; 44; 63). At present, research comparing measures of power of different assessments is limited. For example, there are two investigations in lower body movements at a single absolute load of 40 kg (63) and two relative loads of 30% and 90% of maximum strength (32). Both research groups reported significant differences in power output measurements derived from independent methods.

Uncertainty about the reliability and comparability of measures acquired with different methods clearly diminishes the value of subsequent information and reduces its application to research and practice. In particular, for the assessment of power output in elite athletes it is important to ensure that even small, though meaningful changes in muscle power performance can be detected (31). From a practical perspective measurements conducted at different venues or with different types of equipment often have to be compared (41). Therefore, further research is needed to clarify the methodological concerns outlined above (2; 3; 32; 41).

1.1.1 Scope of the thesis

The key objective of the present study is to investigate measures of power output derived simultaneously from different technical equipment namely: force plate, bar displacement sensor and the combination of force plate and bar displacement sensor. These three methods are frequently used in research to assess muscle power (32). The comparison between measures of power derived from these methods might therefore be relevant to resolving some of the methodological concerns mentioned above. Novel aspects of the study are:

a) to investigate the effect of methodological differences over a broader power - load spectrum
b) to study power outputs derived simultaneously from different methods in lower and upper body resistance exercises

To meet these objectives the thesis was divided into four phases as follows:

Phase One:
Review of the literature to expand on the background of the debate and explore the technical considerations and underlying principles of different methodologies;

Phase Two:

Modify the existing equipment to enable force, velocity and power output data to be measured simultaneously with three different techniques;

Phase Three:

Simultaneous data collection of force, velocity and power output during the bench throw and squat jump over a range of loads; The brief pause (1-2 seconds) after the eccentric phase allowed the movement of the subject to be controlled accurately (i.e. during the concentric phase) - we felt this control was important as the focus of the study was on the measurement of force, velocity and power generation during the concentric phase.

Phase Four:

Data analysis, interpretation and discussion on the practical application of the data;

In particular, this study attempts to answer the questions:

For data acquired simultaneously during the squat jump and bench throw exercises with three different methods of assessment, i.e. force plate, bar displacement sensor, and a combination of force plate and bar displacement sensor:

1) How reliable are measurements of force, velocity and power for each method? [1]
2) Are there significant differences in the power-load relationship derived from these three methods for the squat jump and bench throw exercises?

The context of these questions is shown in Figure 2.

---

[1] Indicators of reliability for variables within each technique are examined by calculating limits of agreement, interclass correlation coefficient, test-retest correlation and typical error of measurement.

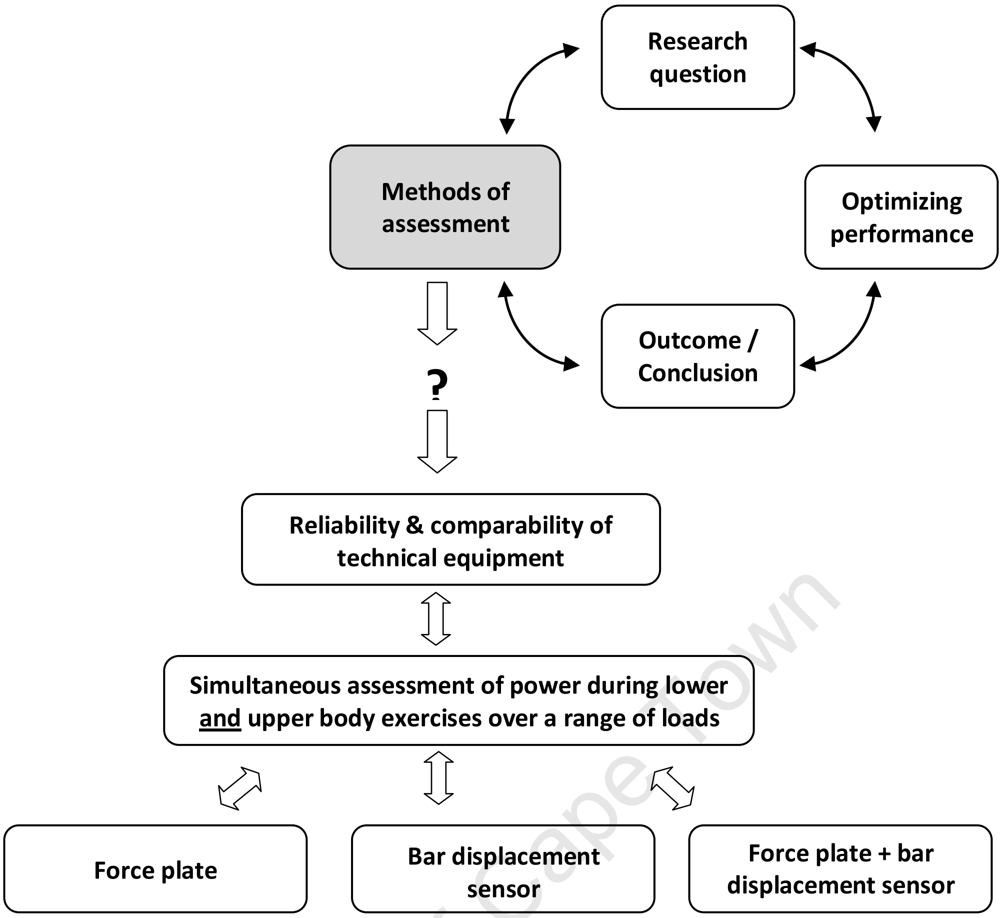


Figure 2: Research question on reliability and comparability of technical equipment in context with the interrelation of research and performance

1.1.2 General procedures for assessments of muscle power

The following section aims to provide a general overview of procedures for assessments of muscle power as a base for further discussions.

The measurement of force, velocity and power is sometimes termed “dynamometry” (73). Dynamometry can be defined as the measurement of energy used in doing mechanical work. In the present context this term refers to the assessment of kinematic and kinetic energy during various muscle actions (37). The assessment of isokinetic and isometric muscle function offers limited information to athletic performance, as most sporting movements incorporate phases of acceleration and deceleration (40). Isoinertial (constant gravitational load) testing of muscle function simulates dynamic sporting movements more closely than assessments of isometric or isokinetic muscle actions (41). The following discussion therefore, refers to dynamic, isoinertial dynamometry.

Even though research designs vary, the general structure of testing procedures is similar (2), and can be summarised as follows (please also refer to Figure 3a).

For most studies athletes are asked to maintain similar pre-test conditions for training intensity and nutrition. During the first testing session the athletes have the opportunity to familiarize themselves with the testing process, in particular with the correct movement technique of the exercise investigated (36; 53). Next, the maximum dynamic strength of each athlete in the exercise concerned is assessed (32; 34; 39; 40). This is defined as the maximum load at which an athlete can perform only one repetition of the exercise with good form and technique, i.e. one repetition maximum (1RM) (19). After adequate rest, each athlete performs the exercise at predefined percentages of the 1RM, ensuring that the relative loading intensity is similar for all athletes (34). Each trial should be performed with maximum voluntary effort to obtain a realistic indication of the maximal power output capacity at the time of testing (92; 98).

Force and velocity during the movement are gathered with specific equipment to derive power. Data can be analyzed and presented for the power generation during a single movement, resulting in a power-time curve. The power-load curve represents the changes in maximum power output over the range of loads tested. Depending on the aim of a study, this assessment can be repeated to track possible alterations in the power-time and/or power-load relationship.

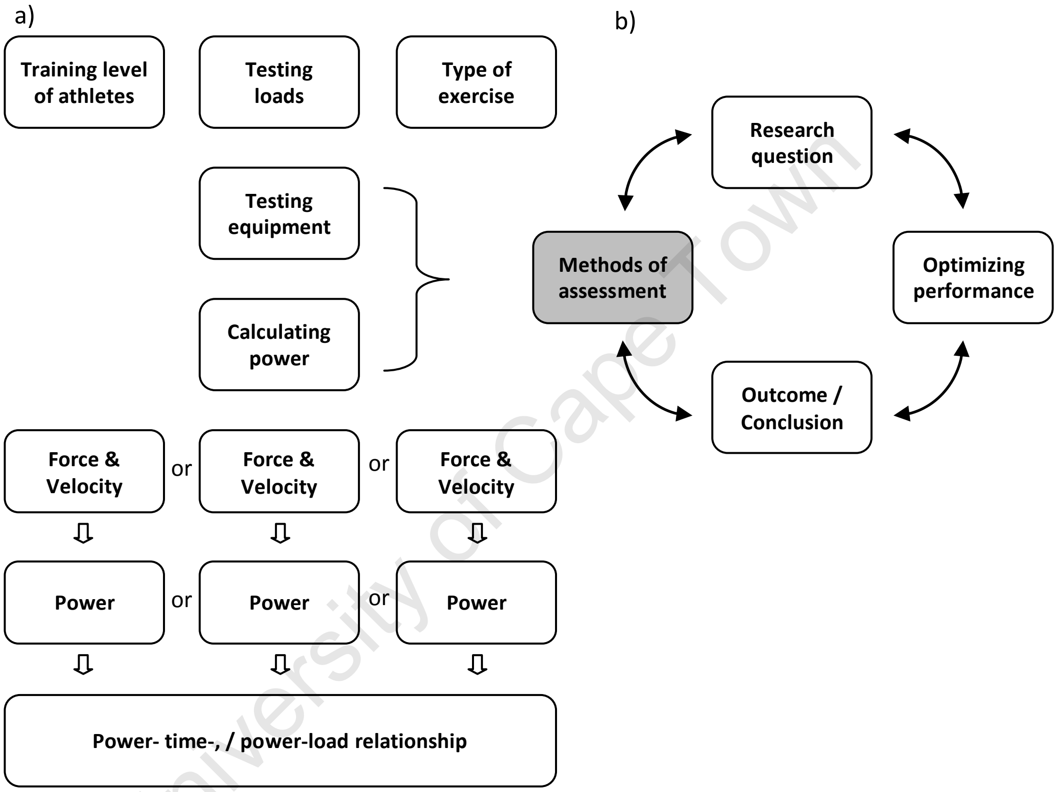


Figure 3: Basic procedure of muscle power assessments and different methods to derive force and velocity (a) in context with the inter relation of research and performance (b) emphasizing the importance of accurate testing equipment and calculations methods

This illustrates that a sound understanding of the respective testing equipment used in a study is important for accurate interpretation of the outcome measures.

To expand on this further the following review is divided into four parts:

Part One:

Outline of the general relationship between force, velocity and power during muscle function, with some references to the alteration of this relationship during various resistance exercises;

Part Two:

Discussion of the different underlying physical principles and calculation methods used to measure power output;

Part Three:

Description of the key concepts and technical details of dynamometers;

Part Four:

Summary of the methodological concerns associated with equipment to assess power output reported in the literature;

1.2 PART ONE - BASIC RELATIONSHIP BETWEEN FORCE, VELOCITY AND POWER

There is some debate as to which terminology describes muscle function most accurately (49). However, for the purpose of this review the terms “eccentric action” (i.e. muscle lengthening under tension), “isometric action” (i.e. no movement of the respective body part) and “concentric action” (i.e. muscle shortening and force generation) are used to describe muscle function. The following section describes the interplay of force, velocity and power generation of muscle during resistance exercise movements.

“The force-velocity relationship characterizes the capability of the neuromuscular system to function under various loading conditions.” (40). In other words, the force-velocity curve represents the results from several trials of an exercise performed with different loads (1). Maximum force achieved at zero velocity, i.e. in the isometric state is higher than the maximum force for the concentric action (Figure 4,a) (17). The higher the shortening velocity of a muscle, the less force the muscle can produce. This is primarily due to the reduced time available for the actin-myosin cross-bridges to form connections at fast shortening velocities (19). Consequently, maximum

velocity may occur in the unloaded condition (Figure 4,b) (28). Applying forces greater then maximal isometric force results in a lengthening of the muscle. Forces produced during this phase can exceed maximal isometric force by up to 100% (106). This can be partly explained by the greater amount of force needed to detach the cross-bridges under lengthening conditions (28). The force-velocity relationship can best be described by a double hyperbolic curve (Figure 4) (54; 57).

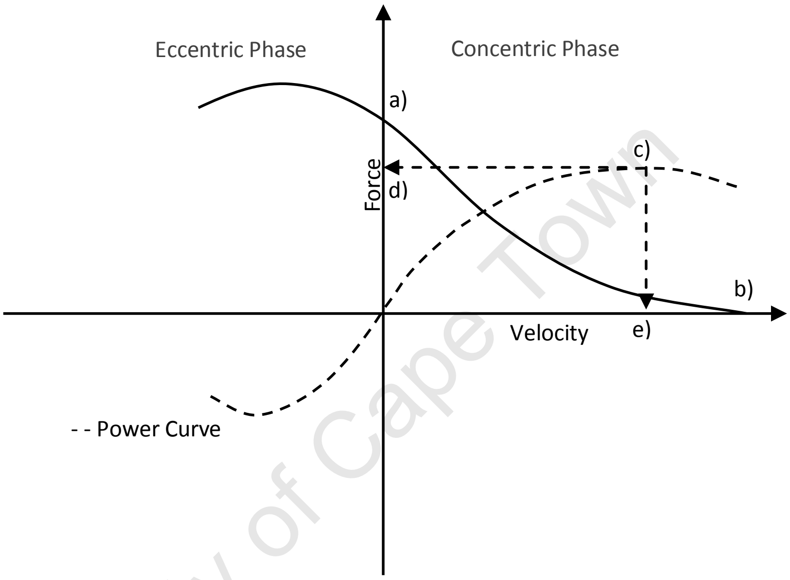


Figure 4: General force-, velocity-, power curve during muscle function under various loading conditions; a = maximum force, b = maximum velocity, c = maximum power and d = loading condition coincided with maximum power, e = velocity generation coincided with maximum power output

Power output (P) is a function of the force and velocity generation during any muscle action. The following equations describe the physical relationship of force (F in N), velocity (v in $m.s^{-1}$) and power (in W):

$P = F * v$ ………………………………………………………………………. (i)

Whereby force (F) represents the acceleration (a in $m.s^{-2}$*) of a respective mass (mass in kg):*

$F = a * mass$………………………………………………………………...……. (ii)

and velocity (v) indicates the displacement (d in m) over time (t in s):

$v = d / t$ …………………………………………………………………………. (iii)

And work (U in Nm^{-1} *or J) is the product of force and displacement of the object the force is applied on:*

$U = F * d$ ……………………………………………………………………….. (v)

Moreover, power can be defined as the amount of work performed per unit of time:

$P = U * t$ ………………………………………………………………………. (vi)

Therefore mechanical power can be described as follows:

$P = ((m * a) * d) / t = (F * d) / t = U / t$ ………………………………………….. (vi)

or expressed in units:

$$P = kg * m.s^{-2} * m.s^{-1} = \frac{kg * m.s^{-2} * m}{s} = N * m.s^{-1} = \frac{N * m}{s} = W$$

As shown from the above equations power output varies according to the movement velocity that can be generated at various loads (Figure 4). Maximum concentric force (Figure 4,a) and maximum velocity (Figure 4,b) clearly represent two extreme points of the force velocity spectrum. Maximum power output (Figure 4,c), however, is achieved at a compromised level of maximal force (Figure 4,d) and maximal velocity (Figure 4,e) (98). In other words, the contribution of force and velocity to the movement is optimal (though not maximal) to generate maximum power output (71; 89). The corresponding load (Figure 4,d) is often referred to as “optimal load” or P_{max} (power maximum) load (34; 110).

The relationship between force, velocity and power varies according to factors such as type of exercise and the specific training level of the athlete (39; 98). The following sections outline these factors in more detail.

1.2.1 Exercise modality

A variety of exercise modes have been investigated (41; 66; 72; 98; 112). In the upper body, for example, concentric only flat bench press (70; 98), traditional bench press (98) pure concentric bench throws (8; 13; 39), incline rebound bench throws (13) and flat rebound bench throws (12; 13; 39; 85) have been assessed. In the lower body exercises examined have ranged from pure concentric squat jump movements (14; 26; 44; 46; 59; 80) over traditional squats (98; 112; 117), double leg press (103) to weighted countermovement jumps (20; 27; 40; 100). All these movements are derivatives of the traditional bench press or squat exercises, yet have distinctive movement qualities and power-load relationships (39; 98). The term “traditional exercises” has been used extensively in the literature and refers to the following (40; 50; 56; 71; 89; 98): The main characteristic of traditional exercises is the pronounced deceleration phase towards the end of the concentric movement (85). For example, Eliot et al. (47) found that during a traditional bench press with a load of 81% 1RM, deceleration of the bar occurs for 52% of the concentric phase. Velocity of the movement for the respective load is therefore sub maximal (102).

In ballistic exercises the athlete accelerates continuously throughout the concentric movement, where after the bar gets released (e.g. bench throw) or the athlete takes off the ground (e.g. squat jump) (58; 72).

At near-maximum loads the movement profiles of traditional and ballistic exercises become similar (40), because the load gets too heavy to be progressively accelerated throughout the movement (96). Thus, calculating relative loads for the ballistic version of an exercises based on the 1RM for the traditional exercise version is a common approach (13; 14; 38). For example, in a description about methods of testing muscle power, one paragraph might explain the maximal strength testing for the squat and another paragraph might deal with the power testing during jump squats at different loads relative to the squat 1RM (12; 36).

Both, traditional and ballistic exercises can be performed with or without a brief pause between the eccentric and concentric movement phase. Exercises with a brief break after the eccentric phase are often called “pure concentric” movements. In exercises with a quick transition from the eccentric to the concentric phase, the effects of the stretch shortening cycle (SSC) can be measured (84; 111). Briefly, the stretch shortening cycle involves an active lengthening phase followed immediately by an active shortening phase (28). Such muscle actions demonstrate a substantial augmentation of muscle performance during the concentric phase of the movement. Several underlying mechanisms have been suggested and can be summarised as follows: a) release of potential/elastic energy stored in the musculotendinous system during the active pre stretch, b) relatively increased muscle activation at the onset of concentric contraction in stretch shortening cycle muscle actions allowing for greater force production c) myoelectric potentiation, i.e. increased neuromuscular activity, d) optimized muscle-tendon interaction improves length tension relationship and shifts storage of elastic energy to the serial elastic sections other than the contractile components (for further information please refer to reference 108). Many dynamic muscle functions incorporate the stretch shortening cycle. The potentiating effect of the stretch shortening cycle on the concentric muscle performance results from the synergistic interaction of the mechanisms highlighted above (28; 39).

Explosive execution of a movement refers to the intention to move the object as quickly as possible. This is often associated with exercises performed at light to moderate loads and high movement velocities (87). However, under relatively heavy loading conditions the athlete can still intend to move the object as quickly as possible, but this does not result in high movement velocities. Maximum force application from the very start of the movement independent of movement velocity might be a clearer description of explosive muscle actions (13; 21; 97).

Due to the pronounced deceleration at the end of the concentric phase, power generation in traditional exercises is sub maximal (32; 41; 84; 93; 100; 108; 111). Power is maximized at relatively heavy loads (80; 81). Ballistic exercises allow for continuous acceleration throughout the concentric phase, resulting in higher power outputs than may occur during traditional exercises. The load that maximizes power output (i.e. P_{max}) in ballistic exercises shifts towards lighter loads (39; 41). Exercises combining countermovement, explosive and ballistic qualities generate the highest power outputs (84; 98; 100). Research suggests that these exercises most closely evoke neuromuscular responses which are similar to those responses occurring during jumping, running, throwing and tackling movements (6; 14; 35; 41; 44; 48).

1.2.2 Subject characteristics

Typically, the training status of subjects investigated for power output have ranged from untrained women (103), sedentary older men (68; 83), sportspersons of different backgrounds (67; 86; 87; 94; 114), to strength and power specific athletes (4; 6; 12; 13; 51; 53; 100). It may be concluded from these studies that motor abilities such as maximum strength and power production depend not only on the type of exercise, but are also specific to factors such as the individual's gender, current training status and long term resistance training experience (15; 67; 96). It follows, that one has to be cautious to generalize individual findings for universal training recommendations (44). For example, in referring to recommendations for maximum power output training Cronin (41) states: "*The predilection of research to train all subjects at one load (e.g. 30 % one repetition maximum [1RM]) is fundamentally flawed due to inter-individual P_{max} [maximum power] differences, which may be ascribed to factors such as training status (strength level) and the exercise (muscle groups) used.*"

In summary, the first part of the literature shows, that a variety of research questions related to muscle power output have been addressed. Most importantly, the research findings show that the relationship of force, velocity and power output varies under different conditions. Power output seems to be specific to the combination of conditioning level of the athlete, particular movement qualities of the exercise tested and respective muscle groups involved.

The next part of the review introduces the underlying physical principles that have been applied to derive power output.

1.3 PART TWO - PHYSICAL PRINCIPLES ASSOCIATED WITH MEASURING MUSCLE POWER OUTPUT

At this stage it might be important to restate that mechanical power is defined as a mathematical product of force and velocity. Consequently power output cannot be measured directly, but is derived from measures of variables contributing to the calculation of power (page11). Thus, researchers have applied various physical laws to derive power output based on measurements such as acceleration (104), displacement (6; 12; 37) or force (31; 117) acquired during the test of performance. For the sake of clarity the term "object" is used from now on to refer either to the body, body part, barbell or any mass involved in the movement investigated. Also, "system mass" refers to the total sum of masses lifted. For example, in movements that involve the propulsion of the athletes' body and a loaded bar, system mass compromises body mass (of the athlete) and any external load lifted (41; 62; 89). Furthermore, "change in time" (short: Δ time) refers to the predefined time intervals over which force, displacement or acceleration data are sampled throughout the movement. The most common approaches to derive power output by applying various physical principles are outlined in the following sections.

1.3.1 Ground reaction force (GRF)

Some research groups measure ground reaction forces exerted during the a movement by means of a force plate (37; 44). This approach is based on the third Newtonian law that states: *"To every action there is an equal and opposite reaction"* (117). The ground reaction force is considered to act upon the total body centre of mass, thereby accelerating the object upwards (63). Subsequently, the impulse-momentum relationship for linear movements has been applied to derive power (44; 63): Impulse is equal to a change in momentum: the force multiplied by the time-period over which it is applied is equal to the product of the total mass lifted and the change in velocity (63):

Impulse = Δ Momentum ………………………………………………....   (i)
Force * Time = System Mass * ΔVelocity ……………………………..   (ii)

For calculating absolute vertical velocity (velocity$_{tot}$) from ground reaction forces, the force data minus the effect of body weight (or the total weight lifted) is used, because it is ultimately the net vertical force (Force$_{net}$), which leads to changes in vertical velocity (55). In other words, one has to overcome the specific inertia of the object first before movement can occur.

ΔVelocity = (Force$_{net}$ * Time) / System Mass………………………… (iii)
*(Where Force$_{net}$ = GRF - System Mass * gravity)*

Assuming that the initial velocity is zero, absolute vertical velocity is calculated by adding each ΔVelocity value to the absolute velocity (velocity$_{tot}$) at the beginning of the previous time interval, starting at zero e.g.:

Velocity$_{tot1}$ = 0 …………………………………………………………... (iv)
Velocity$_{tot2}$ = Velocity$_{tot1}$ + ΔVelocity$_{1\text{-}2}$ ……………………………..... (v)
Velocity$_{tot3}$ = Velocity$_{tot2}$ + ΔVelocity$_{2\text{-}3}$ ……………………………...... (vi)

Corresponding power output is calculated as follows:

Power = Force * Velocity$_{tot}$ …………………………………….............. (vii)

1.3.2 Displacement

Some research groups track the displacement of the bar over time to derive force, velocity and power data (6; 80; 98). Knowing the system mass and the time period for the respective change in displacement enables the calculation of velocity, acceleration, force and power. The following equations are applicable using this approach:

Velocity = Δ Displacement / Δ Time ……………………………………… (i)

Acceleration is calculated by subtracting the final velocity from the initial velocity and dividing this difference by the time taken for the change in velocity:

Acceleration = ΔVelocity / Δ Time ………………………………………… (ii)

Force is calculated by multiplying system mass and acceleration:

Force = System Mass * Acceleration …………………………............ (iii)

Power is calculated by multiplying force and velocity:

Power = Force * Velocity …………………………………………….….. (iv)

1.3.3 Acceleration

Another way to derive power is to measure acceleration during the movement (44; 63; 95). First, the change in velocity over the respective time interval is derived by multiplying acceleration by the change in time. To initiate an upwards movement gravity has to be overcome first. Therefore, acceleration without the effect of gravity (Acc_{net}) is used to derive change in movement velocity:

$\Delta Velocity = Acc_{net} * Time$ ………………………………………………… (i)

Absolute velocity is the sum of ΔVelocity:

$Velocity_{tot} = \Delta Velocity_{1+2+\ldots i}$ …………………………………………… (ii)

Multiplying system mass by acceleration including the effect of gravity (Acc_{tot}) derives corresponding force data:

$Force = Acc_{tot} * System\ Mass$ …………………………………………... (iii)

Power output is then calculated by multiplying force and velocity data:

$Power = Force * Velocity_{tot}$ ……………………………………………. (iv)

1.3.4 Methods of calculating power output

There are some differences in the way researchers have calculated power output. The following sections outline these differences.

1.3.4.1 Inclusion versus exclusion of body mass for calculating power in lower body movements

For movements involving propulsion of the entire body as in squat exercises, power has been calculated based on the external load only (68; 98), or based on the sum of external load plus body mass (14; 34; 100). Both calculation methods are theoretically valid. However, including body mass results in higher absolute power values (44). More importantly, the effect of inclusion or exclusion of body mass on the power-load relationship is poorly understood. Recently, Cormie et al. reported significant differences in the power-load curve derived from either including or excluding body mass to calculate power during lower body exercises (32). Research findings representing power values based either on external load only (68; 69; 98) or external load plus body mass (34; 41; 63; 117) should therefore be interpreted and compared with caution (2; 41).

1.3.4.2 Average versus peak power output

Contentious opinions exist about whether, peak or average power output, is more valuable and which reference value should be used for practical application and training recommendations (41; 44). From a practical perspective, to assess average power output, one has to determine the start and end points of the respective phase of a movement. This can sometimes be difficult and subjective. Small errors in determining this range might be amplified during subsequent calculations of average power output (63). In comparison, determining the peak value in the power data is much easier and less influenced by subjective decision-making during data analysis. It is technically correct to report power output either as an average or peak value (44). Unfortunately most studies only report either average (10; 13; 15; 22; 67; 84; 99) or peak power output (78; 80; 98; 101; 103; 113). More information would be provided if both average and peak power values would be reported.

1.4 PART THREE - KEY TECHNICAL CONCEPTS IN DYNAMOMETRY

The previous section highlighted the importance of a sound understanding of physical principles and their application for an accurate calculation of power output during muscle function. A comprehensive knowledge of the technical equipment used to derive force, velocity and power data is of equal importance, as subsequent calculations are based on this acquired information. The majority of research groups use customized equipment such as force plates (37; 44), position transducers (37; 70), accelerometers (104) or ultrasound and infrared technology (71). The diversity of dynamometers used in research is partly due to the specific field of interest, availability of resources such as technology, space, labour and financial constraints(37). Being familiar with the first principles of such technical devices is important for obtaining accurate measurements and interpreting subsequent outcomes appropriately (24; 48; 115).

In the following section general concepts and relevant terminology related to equipment used to assess power output are discussed. However, it is beyond the scope of this thesis. to explore all underlying details of technical engineering.

1.4.1 Basic design of dynamometer

As mentioned earlier, dynamometry refers to the assessment of kinematic and kinetic energy during muscle function (65). Therefore, such energy signals need to be translated into a digital format for further computing. This is generally referred to as “data acquisition” (24; 77). Despite the variety of dynamometers used in research, the equipment used to acquire data share a basic design structure (24), which is outlined in the following section and summarized in Figure 6.

Transducer
A “transducer” is a sensor which detects energy in one form and reports it in another form (18). In the present context the kinematic or kinetic energy signal received during resistance exercise movements is proportionally converted into a voltage or current signal. In technical terms this process is called “analog conversion” (i.e. mechanical to electrical) (18; 77).

Amplifier
The acquired analog signal is by nature small and needs to be enlarged by an amplifier to facilitate further processing (24).

Analog-to-digital converter
The amplified analog signal is converted into a digital format by means of an analog-to-digital converter card (or A/D card). This is a crucial process as the continuous signal (Figure 5a) is reduced to discrete digital data (Figure 5b). More precisely, the A/D card extracts samples of the continuous input signal in predetermined time intervals and passes this information on in digital form (18). Customized programming software such as LabVIEW™ (34; 56) or MatLab (5; 43; 88) is used for further computing.

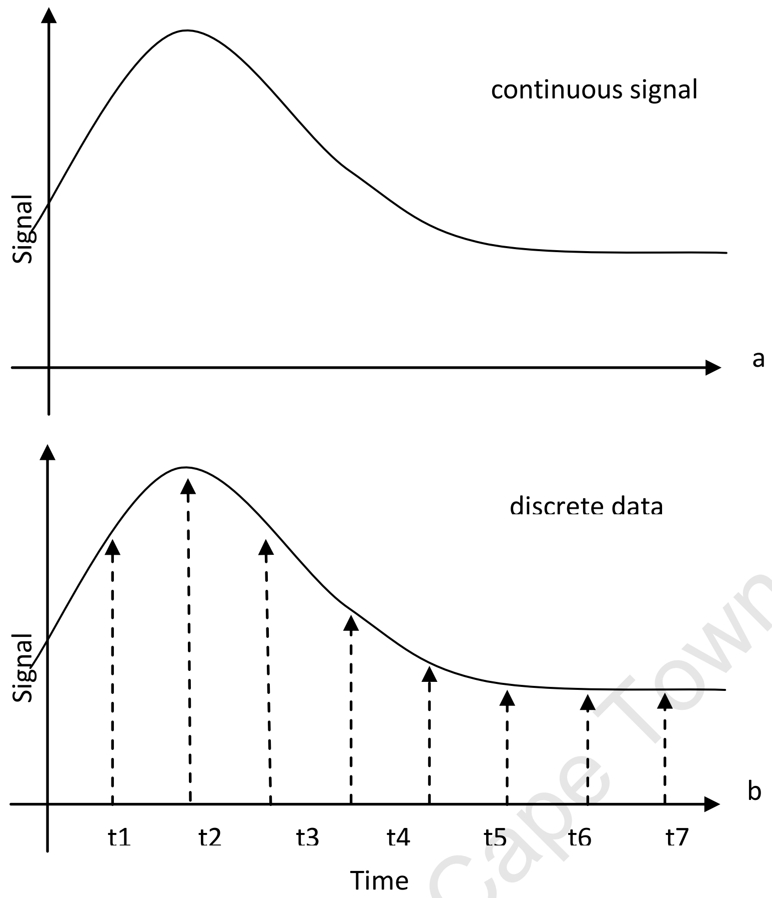


Figure 5: Conversion of a continuous signal (a) to discrete data (b)

Input - Output Relationship

To acquire an accurate digital reflection of the analog input, it is essential to define an appropriate correspondence between the analog input signal and the discrete digital output value representing the physical property in question (18). The correlation between input and output can be evaluated by producing inputs of known quantity and assigning digital outputs accordingly. This procedure is known as “calibration” (24).

Sampling Frequency

The sampling frequency (f_s) refers to the number of samples measured per time period (24).The reference time period is usually one second. In this case the sampling frequency is referred to as a Hertz (Hz) (88). Sample rate describes the time interval or change in time from sample point to sample point. For example, for frequencies presented in Hz, the sample rate 1 / f_sx is represented as one second divided by the according sampling frequency.

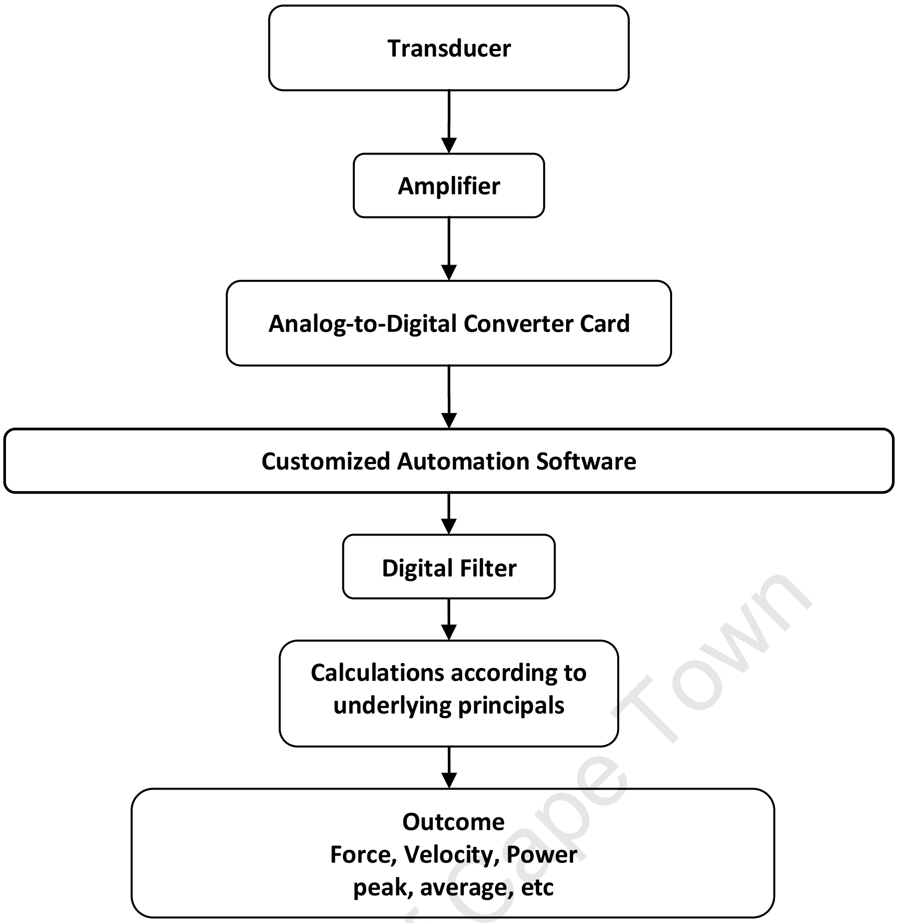


Figure 6: Schematic of data acquisition and processing

The signals acquired from a transducer can be effected by disturbances which can reduce the accuracy of measurement if appropriate adjustments are not made (77). The following section discusses this phenomenon.

1.4.2 Digital filtering and noise

Every signal inherits disturbances to some extent and additional modification of the signal is necessary to extract meaningful information for subsequent calculations (109). Therefore, the “raw data” are smoothed. Smoothing or filtering data is based on complex mathematical operations with the aim to eliminate excessive interference while preserving the original characteristics of the raw signal (107). The following section discusses various sources of interferences and the impact of different digital filtering on the raw signal.

1.4.2.1 Noise - Signal inherent interferences

Ideally, the acquired signal should only represent information of the movement investigated. However, the accuracy of the signal may be effected by artefacts and interferences during the process of acquisition (77). These interferences are called “signal noise” and can be described as additional signals representing sources other than those from the desired source (i.e. the movement) investigated (24).

“Ambient noise” refers to interferences from the environment. For example, magnetic or electric fields from power points and electric cables can be sources of ambient noise (77). Air conditions or machinery in use while testing can cause vibrations that may also affect the signal acquisition negatively.

“Internal noise” refers to interferences from sources within the apparatus (88). Every transducer inherits noise to some extent. This is mainly based on random fluctuations of the electrical current in these conductors (88). The internal noise level varies widely and is dependent on the technology used as well as the manufacturing quality (88). Most companies provide detailed information about the performance of their devices under specific conditions as a guideline for optimal operation.

“System noise” refers to the sum of noise that a signal shows in its digital form, which is used for all subsequent analysis. Therefore, system noise represents the technical error of the testing equipment (61). For example, if the technical error of a device measuring force is ± 5 N, then this device can measure force and any changes thereof within an accuracy range of ± 5 N.

Minimizing the technical error is therefore important to improve the accuracy of measurements and subsequently optimizes the reliability of an assessment method. Shielded wire, properly isolated wire connections and reduction of distances covered with wiring reduce the impact of noise to the signal (88). For further improvement of the data quality the acquired signals are smooth or filtered as described in the following section.

1.4.2.2 Effects of different digital filter configurations

To determine the most accurate filter can be complex depending on the original signal and the various noise levels. Some guidelines for the filtering of biomechanical data can be found in the literature (91).

"*Probably the most widely used method in human movement analysis was first published by Winter et al. (in (91)) and later confirmed by Pezzack et al. (in (91)). Winter suggested a so called Butterworth filter to successfully reduce the noise in kinematic signals and their derivates*" (91).

Consequently, many scientists have used a Butterworth filter for data smoothing (91). However, the specific configuration of the filter differs between research groups (Table 1). One example of such differences is the setting of the cut-off frequency. Briefly, cut-off frequencies determine the range of frequency signals that are preserved for subsequent data analysis as they are likely to be a source of the energy signals produced during the movement investigated (115). For example, Newton et al. (84) and Baker et al. (8) used a Butterworth filter with a cut-off frequency of 14 Hz, whereas LiLi et al. (75) and Harris et al. (56) chose a cut-off frequency of 5 Hz in their respective studies. It might therefore be useful to investigate the effects of different filter settings on the outcome of the data analysis. The results of such an investigation are presented in Appendix A. Table 1 presents the filter types and respective configurations used in research to process biomechanical data.

Table 1: Summary of testing equipment and respective configurations used in research associated with muscle power output during resistance exercises

Author	Equipment	Sampling Frequency / Filter / Cut-off frequency
Asci (5)	LPT	100 Hz, low pass filter, 8 Hz cut-off
Baker (8)	Smith machine, LPT (PPS)	1000 Hz, 4th Butterworth, 14 Hz cut-off
Cormie (32)	Power rack, Force plate, LPT	1000 Hz, rectangular smoothing with moving average half width of 12
Cronin (38)	Smith machine, LPT	200 Hz, low pass filter, 10 Hz cut-off
Cronin (37)	Force plate, LPT	1000 Hz, Hamming, 10 Hz cut-off
Harris (56)	Customized Hack squat machine, LPT	200-1000 Hz, 2nd Butterworth, 5 Hz cut-off
Hori (62)	Power rack, LPT and Force plate	200 Hz, Velocity = 4th Butterworth 16 Hz cut-off, Acceleration = same filter, but 10 Hz cut-off
LiLi (75)	High speed camera, Force Plate	Camera 60 Hz / Force Plate 960 Hz, Butterworth, 5 Hz cut-off
McBride (80)	Smith Machine, Force plate, LPT	1000 Hz, 4th Butterworth, 14 Hz cut-off
Newton (84)	Smith machine, Force plate, LPT (PPS)	1000 Hz Rotary: 4th Butterworth, 14 Hz cut-off
Wilson (113)	Smith machine, Force plate, LPT (PPS)	1000 Hz, 4th Butterworth, 14 Hz cut-off

LPT = linear position transducer,
PPS = Plyometric Power System (Plyopower Technologies, Lismore, Australia);

In summary, data acquisition entails sampling of real world phenomena, conversion into electrical equivalents with the aim to generate an accurate digital reflection of the observed phenomenon (77). This requires several conversions and modifications, resulting in approximated “snap shots” (i.e. discrete sample sets) of the originally continuous signals. Every raw signal is affected by noise and artefacts to some extent (88). Reducing ambient noise, whilst optimizing equipment design, can minimize the effect of noise to the signal. Subsequent signal filtering may further improve the data quality, but involves additional modifications of the original signal. Such modifications vary depending on the filter type and its specific configurations used for data smoothing. The typical error indicates the precision of measurement of the specific device and is an important component of the all over reliability of an assessment method (61).

The following section addresses the methodological concerns associated with muscle power assessment equipment.

1.5 PART FOUR - METHODOLOGICAL CONCERNS ASSOCIATED WITH TECHNICAL EQUIPMENT USED TO ASSESS MUSCLE POWER

So far, only a few research groups have compared power outcome measures derived simultaneously from different testing equipment (32). Each study addresses important though different methodological aspects of assessments associated with muscle power output which are summarised in the following section.

In a frequently cited paper by Dugan et al. (44), measures of power output during jump squats performed at loads of 20, 30, 50 and 70% 1RM from two subjects were discussed. The data were sampled simultaneously from a force plate, a linear position transducer and the combination of force plate and linear position transducer. It was demonstrated that there were substantial differences in measurements of power output between these commonly used techniques of assessment. Moreover, applying different methods of calculating power output for lower body resistance exercises resulted in distinctive representations of the power-load relationship. As both, assessment techniques and specific calculations showed substantial differences in measures of power output, Dugan et al. (44) emphasized the need for standardized testing procedures and detailed reporting of the methods and calculations used in research assessing muscle power. It is important to note, that in this study all interpretations were based on graphical presentation for only two subjects without any statistical analysis.

More recently, Cormie et al. (32) investigated peak power output derived from independent methods during free weight jump squats performed at loads of 30% 1RM and 90% 1RM. Data from nine subjects were sampled simultaneously using following three methods:
a) one linear position transducer (LPT) tracking vertical displacement of the bar; b) one LPT tracking vertical displacement + a force plate measuring ground reaction force, and c) two LPT tracking vertical & horizontal displacement of the bar + a force plate measuring ground reaction force;
Peak power outputs for the 90% 1RM load were significantly different between all three methods. However, only peak power output derived from the single LPT showed significant differences in measures of power output at 30% 1RM compared to the other two methods investigated. Not only were the measures of power output derived from the three methods significantly different at the same load (i.e. 90% 1RM), but the relationship between these differences seems to change under different loading conditions. Measures of mean power were not discussed in this study.

In another recent study Hori et al. (63) investigated simultaneously derived measurements of power output from four different methods during the jump squat. 30 Semi-professional Australian rules football players performed jump squats with an absolute load of 40 kg. Average and peak power was assessed using the following methods:
a) one LPT tracking vertical displacement of the bar, excluding body mass to calculate power; b) one LPT tracking vertical displacement of the bar, yet including body mass; c) a force plate measuring ground reaction force, including body mass to calculate; d) one LPT tracking vertical displacement of the bar + a force plate measuring ground reaction force, including body mass;
Measures of peak power were significantly different between these methods. In contrast, average power derived from method b and c showed no significant differences. This is a rather unexpected finding, as one would assume that mean and peak power are related and should therefore show similar statistical correlations. As expected, excluding body mass to calculate

power (method a) resulted in significantly lower power outputs compared to all other methods.

In summary, all three studies showed distinct differences between commonly used methods for assessing power output during resistance exercises. Interestingly, in the study by Cormie et al. (32) the relationship of measures of power output between the methods changed under different loading conditions. It may be concluded that the information on the comparability between various assessments of power is inadequate at present. In particular, there is only information for lower body free weight exercises (32; 63). No study has explored the effects of different methods to assess power output over a wider range of loads for both upper and lower exercises in a single study. It is therefore important to address these shortcomings in additional research.

1.6 SUMMARY OF THE LITERATURE REVIEW

Power output and the development thereof is thought to be a key component to successful performance in many sports. Thus, a large volume of research on dynamic muscle power output has been conducted. The research findings discussed in the first part of the literature review show that force, velocity and power share a variable relationship specific to exercise modality, loading condition and individual characteristics of the athlete tested (i.e gender, conditioning level, etc.). Therefore, a sound understanding of physical principles and technical details related to the assessment of dynamic muscle function is essential to acquire accurate measurements and interpret respective outcomes appropriately. The differences in equipment and calculation methods make it difficult to provide substantial information on power output in resistance training and its value to the improvement of athletic performance (2; 41). Furthermore, the effects of such methodological differences are poorly understood (44).

Chapter 2

THE NEUROMUSCULAR AND MUSCULOTENDINOUS STIFFNESS-UNIT

2.1 THE DATA ACQUISITION EQUIPMENT

The “NAMS-Unit” (Neuromuscular and Musculotendinous Stiffness-Unit) was developed by the University of Cape Town’s Research Unit for Exercise Science and Sports Medicine in cooperation with a local equipment manufacturer (Zest Manufacturing PTY, (Ltd), South Africa) (108). Initially, the unit consisted of a customized force plate and a modified Smith machine. In cooperation with a technical engineer a laser to track bar displacement was integrated and the data acquisition software was modified to meet the specific research questions.

The following sections introduce the different features of the NAMS-Unit.

2.1.1 The Smith machine

A Smith machine has a bar attached to vertical steel shafts on either side. The size and weight of the bar is similar to that of an Olympic bar. The linear bearings restrict bar movements to the vertical plane with minimal friction. Attached to the bar are hooks that latch into lockouts located on the frame of the machine. The Smith machine of the NAMS-Unit was designed to allow for the testing of various exercises including isometric and ballistic movements for the upper and lower body. It features a three meter tall frame structure, providing a bar movement range of up to 2.8 meters. The mass of the bar plus its linear bearings is 21.3 kg. Safety lockouts are provided every 20 cm along the frame. For additional safety, stoppers can be placed at any height, preventing major injury, should a subject being tested fail to control the (loaded) bar. The entire frame is reinforced to limit movements of the system and minimize additional friction of the bearings even during high force and/or velocity generation. For assessments of upper body exercises a bench can be bolted onto the force plate.

2.1.2 Force plate

Force plates are commonly installed on, or even into, the floor and measure the forces exerted on them (31; 117). One method is to install four load cells (Figure 7a) between a pair of squared plates, one in each corner of the plate (Figure 7b). Load cells have specific strain responds to force application. “Strain gauges” attached in line with the vertical plane of the load cell produce a voltage output analog to the forces exerted upon the cell. The sum of forces from all four load cells represents the total amount of vertical force ground reaction forces applied upon the force plate (31; 117).

The force plate of the NAMS-Unit was installed into the floor, so that the top plate was flush with the ground. The top and bottom steel plates measure 120 cm x 120 cm x 1 cm and were manufactured by Zest Manufacturing PTY, (Ltd), South Africa. Four load cells (Route Industrial Automation, Johannesburg, South Africa) each with a maximum load capacity of 2000 kg, were placed between the two steel plates as shown in Figure 7b.

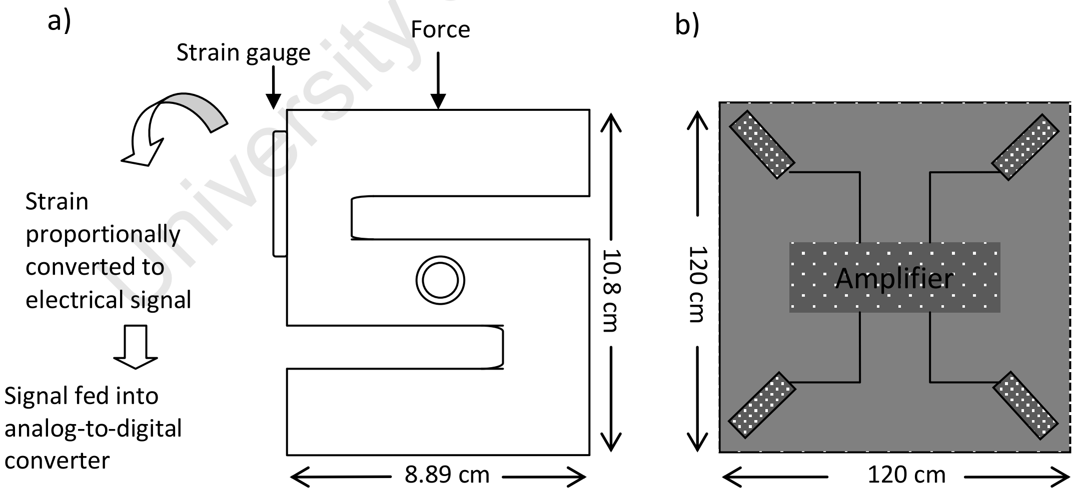


Figure 7: a) principle of load cell and strain gauge, b) schematic of force plate and load cell position

The signals from all four load cells are amplified by a strain gauge amplifier (RS Components International PTY (Ltd.)).

2.1.3 Time-of-flight - laser (displacement transducer)

A laser (LT3, Banner Engineering Corp. Minneapolis, MN U.S.A) was placed directly under the bar onto the lower right frame of the Smith machine to track bar displacement (Figure 8a). Measurement of displacement using this type of laser is based on the following principal (please also refer to Figure 8b). A short electrical pulse drives a semiconductor laser diode to emit a pulse of light. The emitted light is collimated though a lens, which produces a narrow laser beam. The laser beam bounces off the target, scattering some of its light through the sensor's receiving lens to a photodiode (receiver element), which creates an electrical pulse. The time interval between the electrical pulses (i.e. transmitting to receiving the beam) is used to calculate the distance to the target, using the speed of light as a constant.

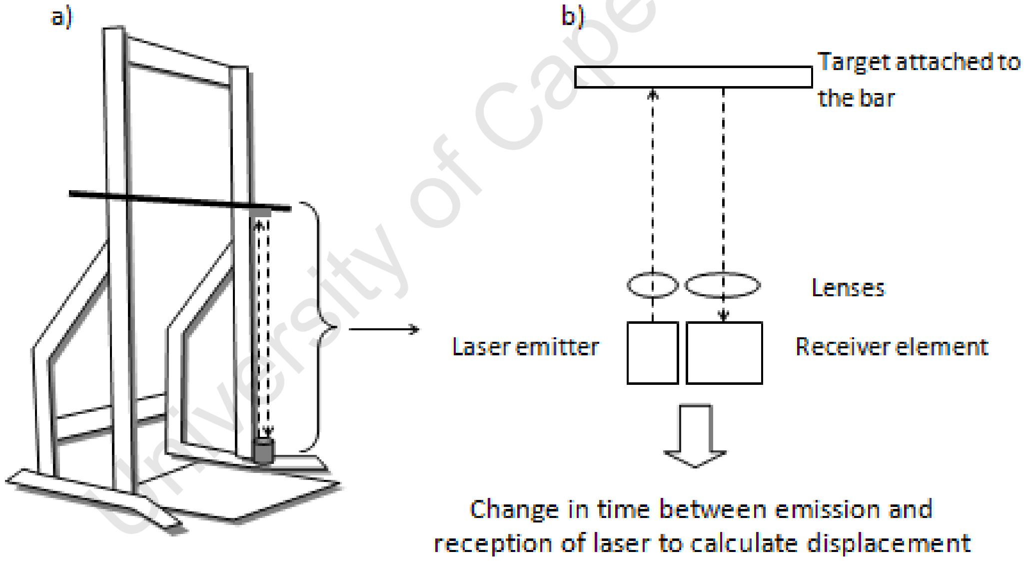


Figure 8: Schematic of the Smith machine and the integrated Time-of-Flight - laser

2.1.4 Analog-to-digital converter card

The signals from the force plate and laser are converted using an analog-to-digital converter card (PCI-MIO-16E-4, National Instruments, Austin, Texas, U.S.A). Ground reaction force and displacement signals are sampled at 2000 Hz.

2.1.5 Data acquisition software

LabVIEW™ programming software (Full Development System Version 7.1, National Instruments, Austin, Texas, U.S.A) was used for data processing. LabVIEW™ is a graphical programming language that presents the flow of the data in block diagrams (Figure 9).

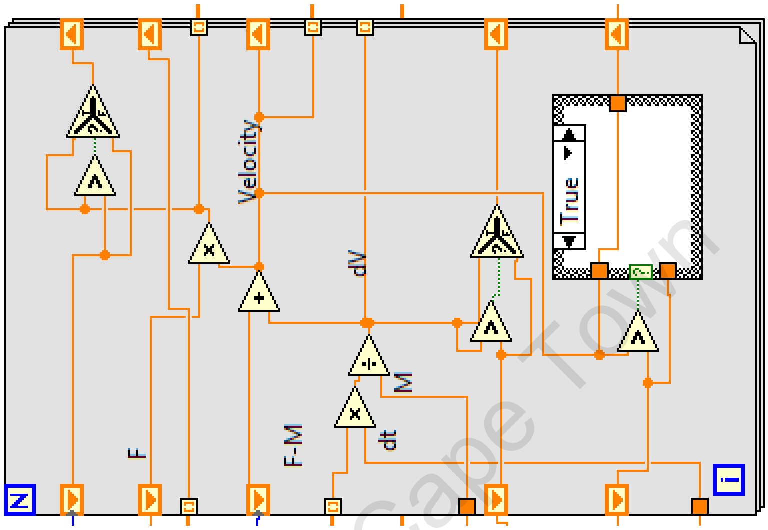


Figure 9: Example of the graphical programming software LabVIEW™

Digital filtering

Force and displacement data were filtered using a 2nd order Butterworth low-pass filter with a cut-off frequency of 5 Hz. Using only displacement data to derive force and power output, data underwent additional filtering using a Median filter with a rank of 20. Next to various other types of filters, this filter is part of the programming software package. Figure 10 shows a raw signal (spiky line) and the respective filtered signal (smooth line) using the median filter.

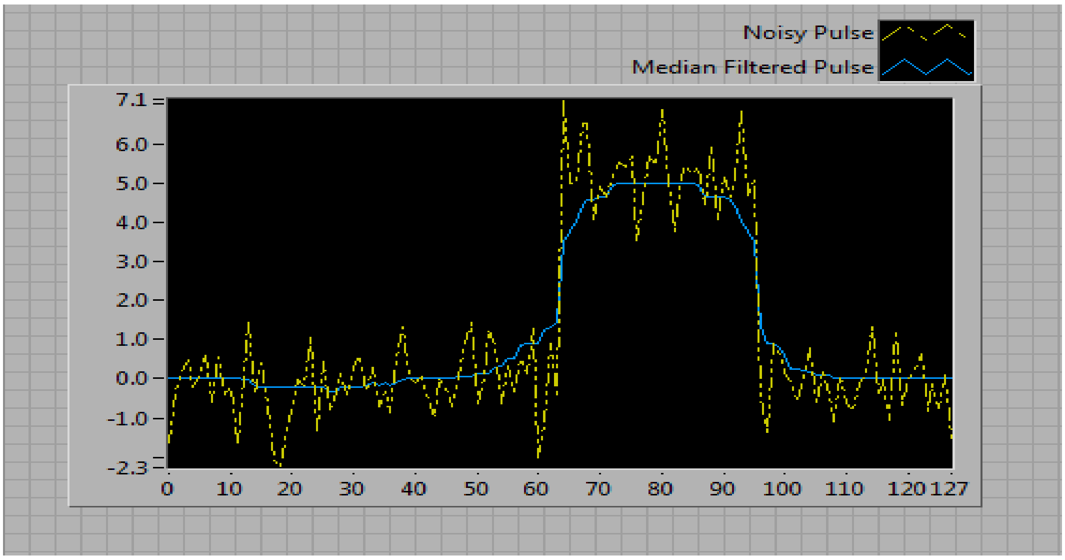


Figure 10: Example of a raw signal (spiky) and the filtered signal (smooth) using a median filter

2.1.6 Calibration procedure

The correlation between input and output can be determined by producing inputs of known quantity and assigning digital outputs accordingly. Measurement and automation explorer (Version 2.0.3.6, National Instruments, Austin, Texas, U.S.A) was used for calibration purposes.

To determine the relationship between force and voltage signals from the load cells the force plate was loaded with twelve different loads. Using statistical software (Graphpad Instat Version 4.0, Graphpad Inc., San Diego, CA, U.S.A) a linear regression equation was used to determine the line of best fit:

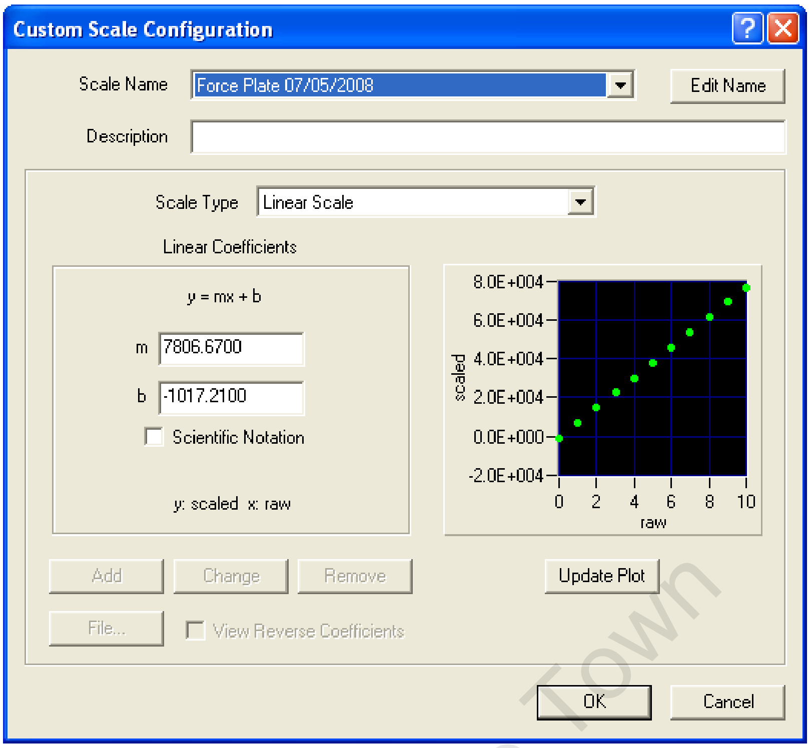
$Y = m * X + b$... (i)

$Y = 7806.7 *$ (voltage output) $- 1017.2$....................................... (ii)

(Where y = force)

and a correlation coefficient of $r = 0.9999$ ($p < 0.0001$).This equation was then used to configure the analog-to-digital conversion process.

Figure 11 shows the “custom scale configuration” feature, which was used to define the described input-output relationship as described above.



Scale Name: Force Plate 07/05/2008

Description:

Scale Type: Linear Scale

y = mx + b

m 7806.6700

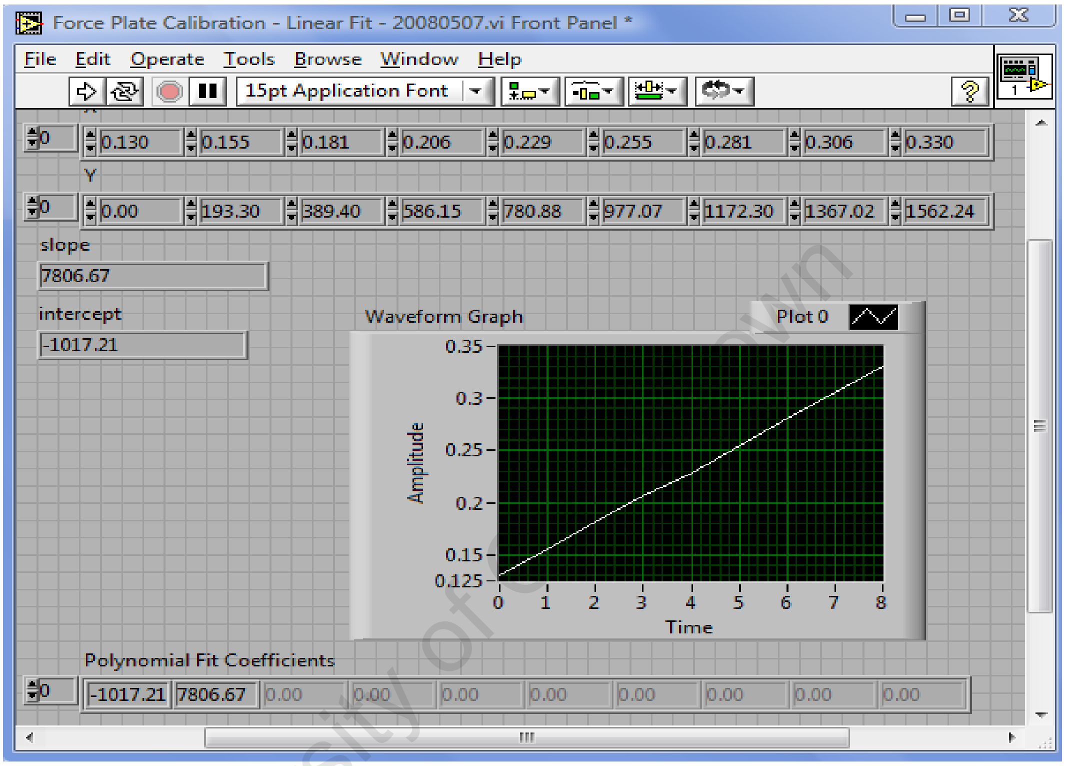
b -1017.2100

☐ Scientific Notation

y: scaled x: raw

Figure 11: Example of scaling factor configuration and graphical representation of the relationship between voltage and force for the force plate

Figure 12 shows a sub function of the customized software that allows for time efficient calibration checks. The values of the voltage signal and corresponding loading can be entered into the table. Next, the regression equation is automatically generated and adjustments of the scale configurations can be made if applicable.



0 | 0.130 | 0.155 | 0.181 | 0.206 | 0.229 | 0.255 | 0.281 | 0.306 | 0.330

Y

0 | 0.00 | 193.30 | 389.40 | 586.15 | 780.88 | 977.07 | 1172.30 | 1367.02 | 1562.24

slope: 7806.67

intercept: -1017.21

Polynomial Fit Coefficients

0 | -1017.21 | 7806.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00

Figure 12: Calibration check-feature to determine the regression equitation for the voltage-load relationship for the force plate

The relationship between voltage signal from the laser and displacement of the bar is determined by moving the bar through seven distances and recording the corresponding voltage using the same procedure as described for the force plate.

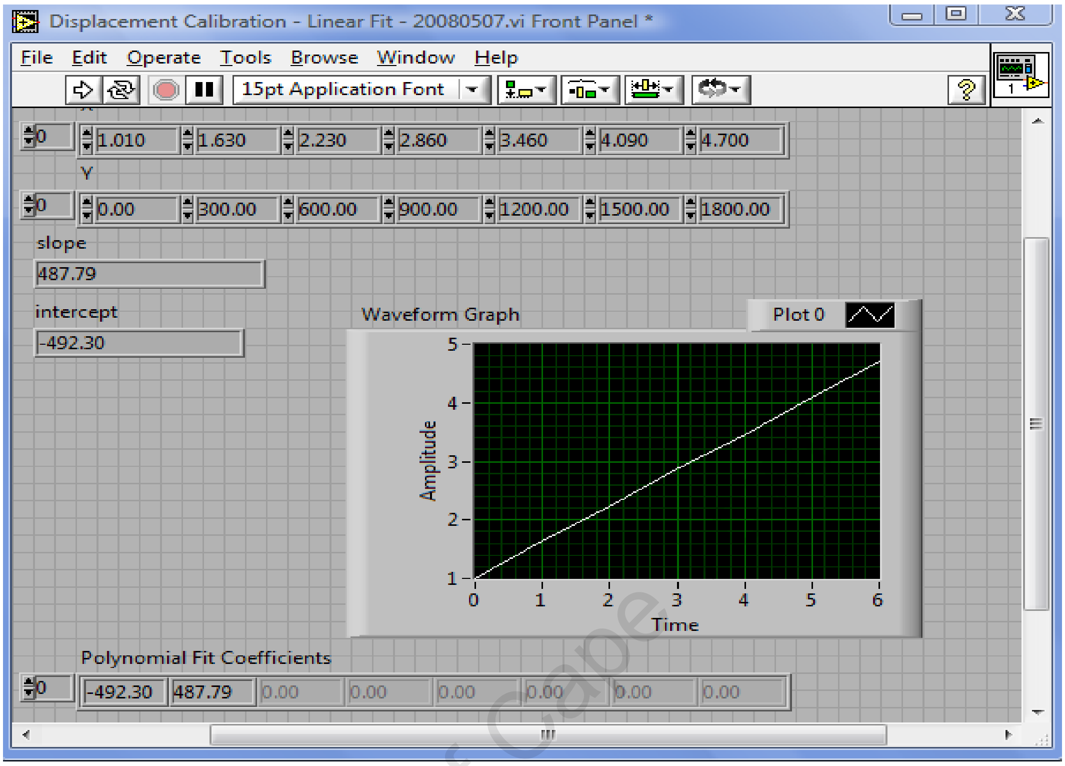
The linear regression equation for the displacement-voltage relationship resulted in following line of best fit:

Y= m * X + b.. (i)

Y = 487.79 * (voltage output) - 492.30............................ (ii)

(Where y = displacement)

and a correlation coefficient of r = 1.0000 (p < 0.0001) indicating a perfect linear relationship. Figure 13 shows the calibration check feature for the laser.



X: 0 | 1.010 | 1.630 | 2.230 | 2.860 | 3.460 | 4.090 | 4.700

Y: 0 | 0.00 | 300.00 | 600.00 | 900.00 | 1200.00 | 1500.00 | 1800.00

slope: 487.79

intercept: -492.30

Polynomial Fit Coefficients: 0 | -492.30 | 487.79 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00

Figure 13: Calibration check-feature to determine the regression equitation for the voltage-displacement relationship for the laser

2.1.7 Technical error of measurement

The technical error can be represented by the accuracy and precision for a specific measurement (61). Similar to the calibration procedure a range of loads or distances of known quantity are measured repeatedly. Subsequent results are then compared to the predefined loads or distances. To determine the technical error for displacement measurements the bar was moved through distances of 300 mm, 900 mm and 1500 mm. This was repeated ten times for each predefined distance during a single occasion. The distances were predefined using a steel tape measure (King CRAFT, pro, Batavia, IL, U.S.A.). To determine the technical error of measurements of ground reaction force, the force plate was loaded with weight plates of 20 kg, 100 kg, 180 kg and 220 kg resulting in forces of 196.20 N, 981.00 N, 1765.80 N and 2158.20 N respectively. Again ten trials per load were performed during a single occasion. The mean and standard deviation of the ten measurements for each predefined force or displacement input was used for subsequent calculations. Using the displacement data as an example, the relative accuracy of measurement was determined as follows:

Accuracy of measurement = (mean of measurements - predefined displacement) / predefined displacement * 100.. (i)

The relative precision of measurement for displacement readings from the laser was calculated as follows:

Precision of measurement = standard deviation of measurements / mean of measurements * 100.. (ii)

The resulting indicators of technical error are presented in Table 2 and 3 for measurements of displacement and force respectively.

Table 2: Indicators of the technical error of measurement of displacement from the NAMS-Unit laser

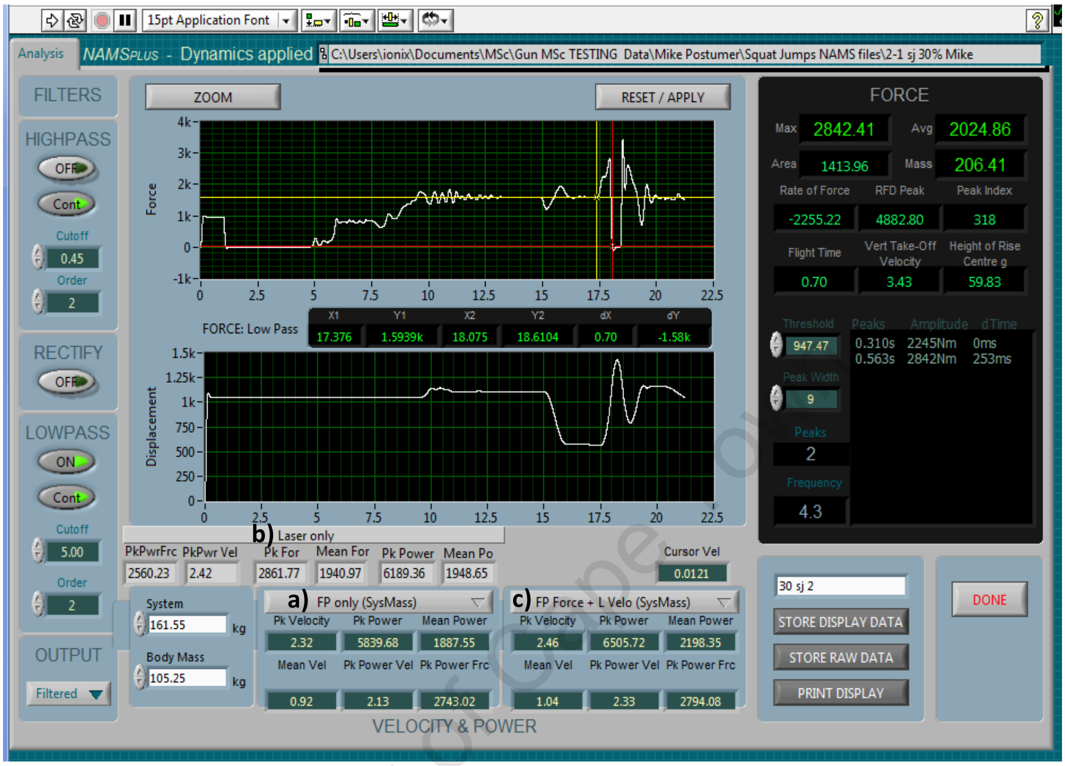
Predefined Displacement (mm)	Measurements of displacement (mm) Mean ± SD	Difference (mm)	Accuracy of measurement (%)	Precision of measurement (%)
300.00	301.52 ± 1.93	1.52	0.51	0.64
900.00	902.74 ± 2.25	2.74	0.30	0.25
1500.00	1503.00 ± 1.84	3.00	0.20	0.12

Table 3: Indicators of the technical error of measurement of ground reaction force from the NAMS-Unit force plate

Predefined force (N)	Measurements of force (N) Mean ± SD	Difference (N)	Accuracy of measurement (%)	Precision of measurement (%)
196.20	195.12 ± 1.53	1.08	0.55	0.78
981.00	980.78 ± 2.73	0.22	0.02	0.28
1765.80	1764.64 ± 4.13	1.16	0.07	0.23
2158.20	2159.34 ± 4.32	-1.44	-0.05	-0.20

2.1.8 Example of data analysis using the NAMS-Unit

The next section outlines the analysis of squat jump and bench throw data using the NAMS-Unit.



NAMSPLUS - Dynamics applied C:\Users\ionix\Documents\MSc\Gun MSc TESTING Data\Mike Postumer\Squat Jumps NAMS files\2-1 sj 30% Mike

HIGHPASS Cutoff 0.45 Order 2

LOWPASS Cutoff 5.00 Order 2

FORCE: Low Pass X1 17.376 Y1 1.5939k X2 18.075 Y2 18.6104 dX 0.70 dY -1.58k

FORCE
Max 2842.41 Avg 2024.86
Area 1413.96 Mass 206.41
Rate of Force -2255.22 RFD Peak 4882.80 Peak Index 318
Flight Time 0.70 Vert Take-Off Velocity 3.43 Height of Rise Centre g 59.83
Threshold 947.47
Peak Width 9
Peaks 2
Frequency 4.3

Peaks	Amplitude	dTime
0.310s	2245Nm	0ms
0.563s	2842Nm	253ms

b) Laser only

PkPwrFrc	PkPwr Vel	Pk For	Mean For	Pk Power	Mean Po
2560.23	2.42	2861.77	1940.97	6189.36	1948.65

Cursor Vel 0.0121

System 161.55 kg
Body Mass 105.25 kg

a) FP only (SysMass)

Pk Velocity	Pk Power	Mean Power
2.32	5839.68	1887.55
Mean Vel	**Pk Power Vel**	**Pk Power Frc**
0.92	2.13	2743.02

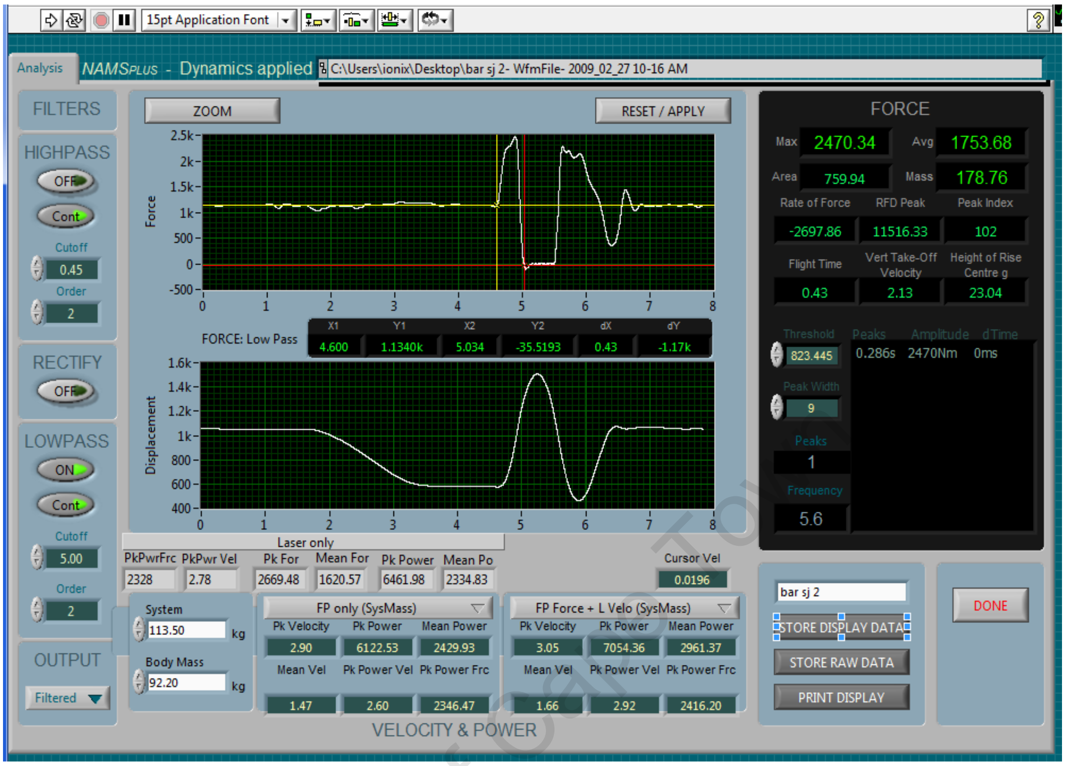
c) FP Force + L Velo (SysMass)

Pk Velocity	Pk Power	Mean Power
2.46	6505.72	2198.35
Mean Vel	**Pk Power Vel**	**Pk Power Frc**
1.04	2.33	2794.08

30 sj 2

Figure 14: Interface of the NAMS-Unit analysis software

Figure 14 shows the interface of the customized NAMS-software during the analysis of a squat jump. The top graph represents ground reaction force data as sampled during an assessment. The bottom graph indicates bar displacement. The controls next to the graphs on the left allow the configuration of the filter settings. The displays to the right of the graphs show various measures of force such as peak and average force or rate of force development. The indicators at the bottom show measurements of force, velocity and power derived from the three different methods, i.e. force plate data only (FP) (Figure 14a), laser data only (L) (Figure 14b) and the combination of force plate and laser data (FPL) (Figure 14c). All measurements refer to the data between the two cursors on the force graph. A “zoom” function allows for examining a particular part of the data to facilitate precise data analysis (Figure 15). The readings from all displays plus the corresponding sample set (i.e. between the cursers) can be saved to spreadsheets for further analysis.



C:\Users\ionix\Desktop\bar sj 2- WfmFile- 2009_02_27 10-16 AM

HIGHPASS Cutoff: 0.45
HIGHPASS Order: 2
LOWPASS Cutoff: 5.00
LOWPASS Order: 2
OUTPUT: Filtered

FORCE: Low Pass

X1	Y1	X2	Y2	dX	dY
4.600	1.1340k	5.034	-35.5193	0.43	-1.17k

FORCE
Max: 2470.34
Avg: 1753.68
Area: 759.94
Mass: 178.76
Rate of Force: -2697.86
RFD Peak: 11516.33
Peak Index: 102
Flight Time: 0.43
Vert Take-Off Velocity: 2.13
Height of Rise Centre g: 23.04
Threshold: 823.445
Peak Width: 9
Peaks: 1
Frequency: 5.6

Peaks	Amplitude	dTime
0.286s	2470Nm	0ms

Laser only

PkPwrFrc	PkPwr Vel	Pk For	Mean For	Pk Power	Mean Po
2328	2.78	2669.48	1620.57	6461.98	2334.83

Cursor Vel: 0.0196

System: 113.50 kg
Body Mass: 92.20 kg

FP only (SysMass)

Pk Velocity	Pk Power	Mean Power
2.90	6122.53	2429.93
Mean Vel	**Pk Power Vel**	**Pk Power Frc**
1.47	2.60	2346.47

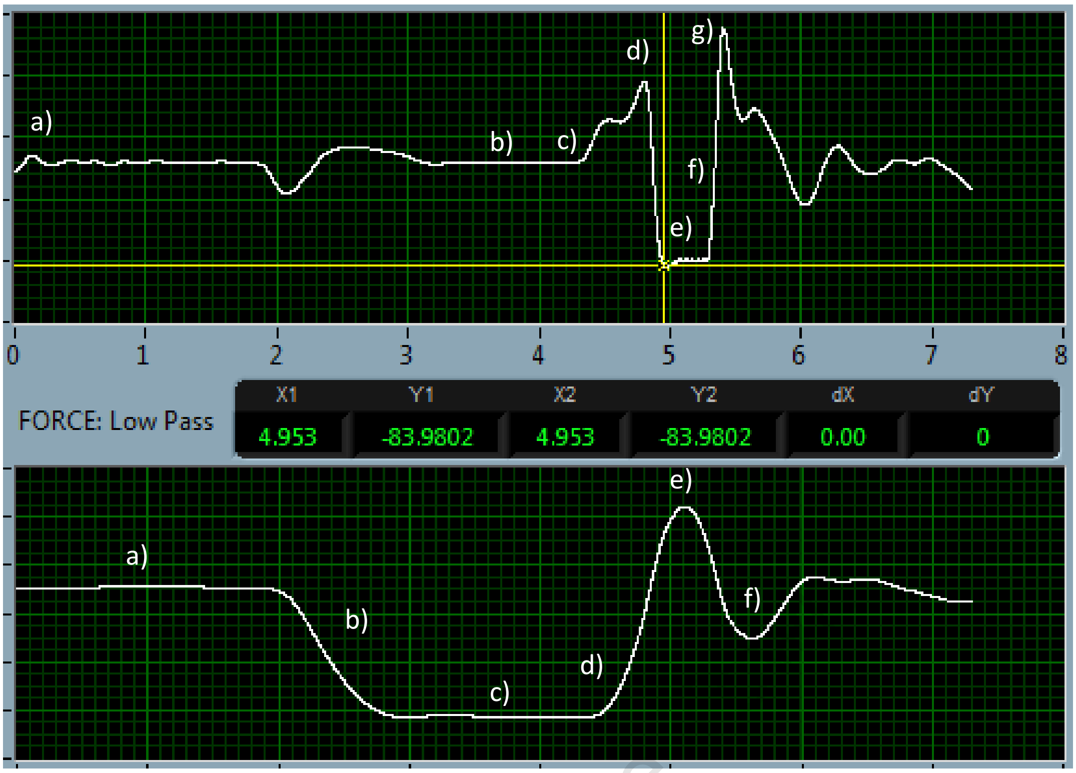
FP Force + L Velo (SysMass)

Pk Velocity	Pk Power	Mean Power
3.05	7054.36	2961.37
Mean Vel	**Pk Power Vel**	**Pk Power Frc**
1.66	2.92	2416.20

bar sj 2

Figure 15: Example of the “zoom” function

Specific movement phases for the squat jump and bench throw exercises are discussed on the following pages.



FORCE: Low Pass

X1	Y1	X2	Y2	dX	dY
4.953	-83.9802	4.953	-83.9802	0.00	0

Figure 16: Example of force data (top) and bar displacement data (bottom) during a squat jump

Figure 16 shows force and displacement curves acquired during a loaded squat jump. The top graph represents ground reaction force:

a = unhooking the bar,

b = remaining in the lowest position,

c = increase in force production, i.e. beginning of concentric phase,

d = peak force output,

e = take off, i.e. end of concentric phase,

f = landing phase,

g = maximum force during landing;

The bottom graph in Figure 16 shows corresponding bar displacement as follows:

a = initial bar position,

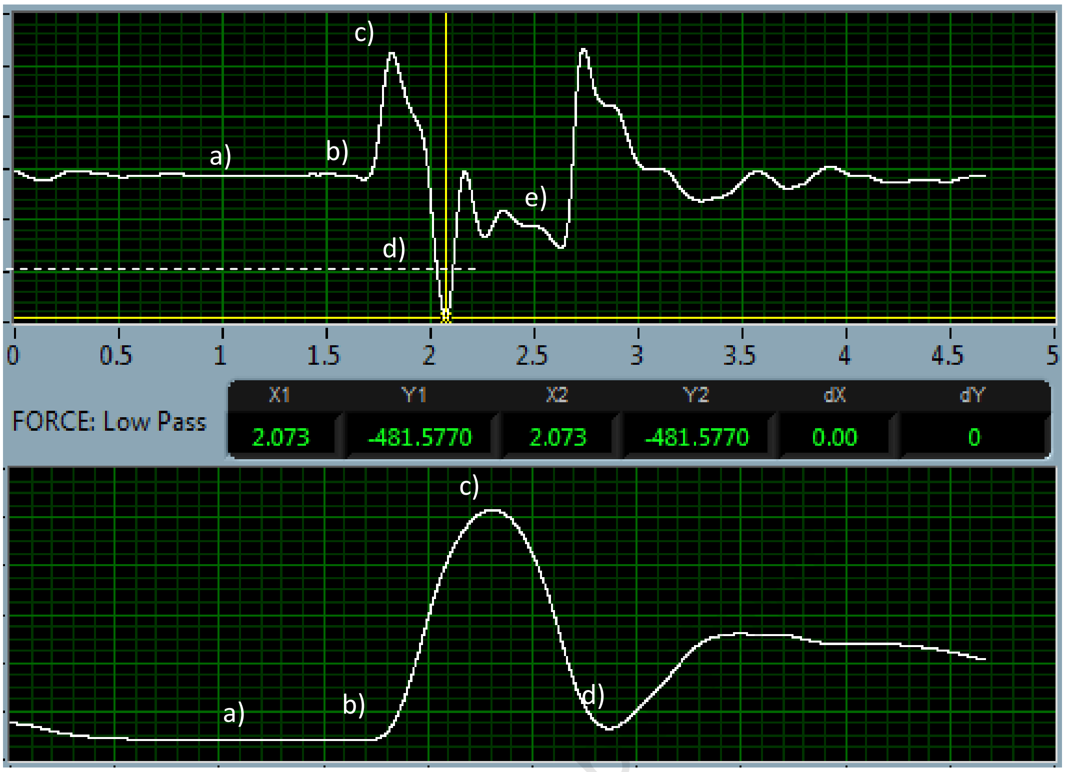
b = downwards movement,

c = remaining in the lowest position,

d = beginning of upwards movement,

e = peak bar displacement,

f = transition from the downwards movement to the upwards movement;



FORCE: Low Pass

X1	Y1	X2	Y2	dX	dY
2.073	-481.5770	2.073	-481.5770	0.00	0

Figure 17: Example of force data (top) and bar displacement data (bottom) during a bench throw

Figure 17 shows data collected during a bench throw. The top graph represents ground reaction force:

a = remaining in the lowest position,

b = increase in force production, i.e. beginning of concentric phase,

c = peak force output,

d = force below zero (dotted line), i.e. end of concentric phase,

e = beginning of catching the bar;

The bottom graph in Figure 17 represents corresponding bar displacement as follows:

a = remaining in the lowest position,

b = beginning of upwards movement,

c = peak bar displacement,

d = beginning of catching the bar;

Note: The weight of the bench and the subject was neglected for the analysis of force, velocity and power during bench throws.

Chapter 3

EXPERIMENTAL PHASE

3.1 METHODOLOGY

In the following sections the methodology of the investigation is described.

3.1.1 Experimental approach

This study was an acute randomized design. Fifteen subjects were recruited for the study. Muscle power output for their lower and upper bodies was assessed on the NAMS-Unit during the loaded squat jump and bench throw exercises respectively. Ground reaction force and displacement data were measured simultaneously during all tests. Force, velocity and power were derived using the three methods outlined above. The resulting data underwent statistical analysis to reveal similarities and differences for measurements of force, velocity and power between the three methods.

3.1.2 Subjects

Fifteen male subjects between the ages of age 18 - 35 years participated in this study. All subjects were involved in structured resistance training for at least 12 month prior to the onset of this project. Their sporting background was club level rugby (6 subjects), semi-professional level rugby (2 subjects), club level basketball (2 subjects) and recreational strength training (5 subjects). These criteria were chosen to reduce the risk of injury, limit any familiarization effect and make the results applicable to the moderately trained population.

Subjects with a history of anabolic steroid, human growth hormone, stimulants or any other related performance enhancement drug use were excluded from the study. Prior to testing, possible candidates were screened for the inclusion and exclusion criteria. Each subject completed a personal questionnaire regarding medical, training and general information according to the guidelines of the American College of Sports Medicine for exercise testing and prescription (17) (Appendix B).

Subjects were asked to refrain from any high intensity training that may cause severe muscle soreness for least 24 hours before testing and to keep any intense training to a minimum throughout the duration of the study. A logbook was provided to every subject to document all sporting and training activities (Appendix C). All potential subjects were informed about the study and the potential risks involved. Once the subjects' questions were answered their satisfaction they were required to sign a written informed consent form (Appendix D) before participating in the study (17).

3.1.3 Time line

The assessment was divided into three separate sessions, with at least 48-hours between sessions to ensure adequate recovery. The testing structure was as follows:

Day one:

- Body composition
  - Mass and stature
  - Percentage body fat
- Familiarization session on the subsequent power testing procedures for the bench throw and loaded squat jump
- One repetition maximum (1RM) test for the bench press and squat exercises

Day two and three:

- Randomized power testing for the bench throw or loaded squat jump

Body composition

Body mass was measured with an electronic scale (Seca, Model 708, Germany). Stature in centimetres was measured using a steel tape measure (King CRAFT, pro, Batavia, IL, U.S.A.). Body fat was assessed using the seven-site sum of skin folds method to approximate body fat content (92). Percentage body fat was determined using the equations of Durnin and Womersly (45).

3.1.4 Familiarization

During this session subjects were provided with information on the exact testing procedures. After every question was addressed individually, the informed consent was signed. This session also involved a detailed explanation and familiarization with the technical requirements of both, the loaded squat jump and the bench throw exercises. Emphasis was placed on the correct range of motion and technique of movement. Subjects performed test trials for both the upper and lower body exercises at various loads. If necessary, feedback and guidance was provided by the researcher.

3.1.5 Standardized Warm-up protocol

All testing was preceded by a standardized warm-up procedure (19). Subjects cycled continuously for 10 minutes at a self-selected pace followed by self-selected stretches for either the lower or upper body. Thereafter, the subject performed one set of either 10 full squat or bench press repetitions with a 21.3 kg load (i.e. bar only), followed by one minute rest. The subject then performed the relevant exercise (i.e. full squat or bench press) starting with a load that comfortably allowed seven to 10 repetitions. . After two minutes rest the load was then increased so that three to five repetitions could be completed and then after another rest period of two minutes the load was increased again so that two to three repetitions could be completed (19). During this procedure the foot and hand position of each subject was determined. Subjects were allowed to choose their positions within a predefined range of ± 5 cm (56). These positions were marked and maintained throughout the study. This method was used to allow for a certain degree of standardization, with reduced impact on performance, which might have occurred with feet and hand positioning restricted to one specific position.

3.1.6 1RM-Testing

After completing the warm-up and two to four minutes rest the subject performed the first 1RM attempt. All subjects did the 1RM test for the squat first, followed by a rest period of at least 10 minutes before doing the 1RM test for the bench press. If he failed, two to four minutes rest was provided and the load was decreased by approximately 2.5 - 5.0% for the upper body exercise and 5.0 - 10.0% for the lower body exercise. If the subject was successful the load was increased by approximately 2.5 - 5.0% for the upper body exercise and 5.0 - 10.0% for the lower body exercise. The subject was allowed to attempt another load, or loads, until both he and the researcher were confident that a 1RM was attained. This ideally occurred within two to three attempts (19).

For a valid 1RM attempt in the squat subjects had to bend their knees and hips, down until the upper thigh was parallel to the floor, hold briefly in this position, and then be able to move upwards again with good form and technique (19). For a valid bench press 1RM subjects had to lower the bar to 1 - 2 cm above the chest, hold briefly, and then be able to push the barbell up again, with the buttocks remaining in contact with the bench and straightening the arms to the initial position of the exercise (12). With the knees bent the feet were positioned onto the end of the bench. Verbal encouragement was provided during every 1RM attempt (105).

3.1.7 Tests of muscle power performances

The assessment of power outputs during the bench throw and the squat jump exercises were done on separate days following the familiarization day. As mentioned in the section “exercise modality” (page 12) the bench throw and squat jump are pure concentric and ballistic exercises. Pure concentric exercises allow for precise standardization of the movement. Adding the ballistic quality to the exercise allows for higher power outputs and is similar to the concentric phase during jumping and throwing (13; 14). Pure concentric ballistic exercises were chosen as a compromise between the sometimes complementary aims in research to closely simulate sporting movements while at the same time trying to standardize the testing procedures (60).

Loaded Squat Jump

The bar had to be centred on the base of the subject’s neck, i.e. supported on the trapezius and deltoid muscles. The barbell was supported in the “high” carrying position, which is located between vertebrae C7 and T1 (19; 100). The subject had to grip the bar slightly wider than shoulder width and was instructed to pull the bar tight against the body throughout the movement. Foot position had to be exactly the same as determined in the previous 1RM session. Four sub maximal squat jumps with the unloaded bar were performed. The subject was instructed to bend his knees and squat down to the point where his upper thighs were parallel to the floor. The subject had to remain in this position for one to two seconds, and then on command move upwards with maximum effort aiming for maximum jump height. If any countermovement occurred, that trial was repeated.

Bench Throw

For this test to be considered valid, subjects had to lie flat on their backs with their knees bent, and their feet resting on the end of the bench. Subjects were positioned so that the bar of the NAMS unit moved in the line of the nipples or 2 - 3 cm superior to the xyphoid process of the sternum. Grip width had to be exactly the same as determined in the previous 1RM session. The bar was lowered from lockout position to 2 - 3 cm above the chest. The subject was instructed to hold the bar in this position for one to two seconds and then on command throw the bar upwards with maximum effort. The subject was instructed to catch the bar at the highest point possible and focus on the controlled lowering of the bar. Safety precautions i.e. stoppers to prevent injury in the event of missing the bar or not being able to control it down were included. Once again, if there was evidence of any countermovement, the trial was repeated.

Range of loads tested

The subjects randomly performed testing with six loads at different percentages of their 1RM: 30, 40, 50, 60, 70, 80% 1RM and one absolute load of 21.3 kg (i.e. bar only). Two valid trials per load were required. A technique of stratified randomization was used. This method ensured that lighter loads (bar only, 30, 40, and 50%) were performed before heavier loads (60, 70, 80%) to minimize the risk of injury during testing. Subjects were given two minutes rest between the trials and loads.

3.1.8 Data acquisition

All technical specifications for the equipment used were discussed in detail in the previous chapter. However, the following paragraph summarizes the key facts in a manner that meets the requirements of “detailed reporting of research procedures” as suggested earlier on by Dugan et al (44) (page 26).

3.1.8.1 Acquisition equipment

The Neuromuscular and Musculotendinous Stiffness-Unit (NAMS-Unit) (Zest Manufacturing PTY, (Ltd) and University of Cape Town, Cape Town, South Africa) incorporates a customized force plate installed under a customized Smith machine (Zest Manufacturing PTY, (Ltd), South Africa) and a time-of-flight - laser (LT3, Banner Engineering Corp. Minneapolis, MN U.S.A) mounted directly under the guided bar tracking the displacement of the bar (page 32f). The force plate measures 120 cm x 120 cm x 1 cm and consists of a top and a bottom steel plate (Zest Manufacturing PTY, (Ltd), South Africa) and four load cells (manufactured by Route Industrial Automation, South Africa). Force and displacement signals were sampled at 2000 Hz by means of an analog-to-digital converter card (PCI-MIO-16E-4, National Instruments’, Austin, Texas, U.S.A). During testing the temperature of the load cells ranged between 13.8 - 16.9 °C and environmental temperature ranged between 15.3 - 18.7 °C, indicating that the accuracy of measurement was not influenced by changes in temperature.

3.1.8.2 Data processing

All subsequent processing was automated using customized LabVIEW™ software (LabVIEW™, Full Development System Version 7.1, National Instruments, USA). Data underwent digital smoothing using a 2^{nd} order, Butterworth low-pass filter with a cut-off frequency of 5 Hz. Using only displacement data to derive force and power output, data underwent additional median filtering with a rank of 20. For the bench throw the following applies: Once the subject lay on the bench the force plate reading was set to zero Newton to correct for the weight of the subject and the bench.

3.1.8.3 Methods of calculating power output

Force plate data only (FP):
Applying the impulse-momentum relationship velocity of the centre of gravity was derived from ground reaction force data. Power was calculated as the product of force and velocity for every sample point. Ground reaction force, as a sum of the total load lifted, was used to derive power output (i.e. body weight + bar weight in the lower body and bar weight only for the upper body).

Laser data only (L):
The distance the object travelled over time between two samples, divided by the respective time interval, yielded bar velocity data. Bar velocity data underwent additional median filtering with a rank of 20. Acceleration data were calculated by dividing the change in velocity between two samples by the respective change in time. The sum of bar acceleration and acceleration due to gravity ($9.81\ m.s^{-1}$) was multiplied by the total mass lifted (i.e. body weight + bar weight in the lower body and bar weight only for the upper body) to derive corresponding power output data.

Force plate + laser data (FPL)
Bar velocity was obtained as described for method L. Power was calculated by multiplying bar velocity and ground reaction force (body weight + bar

weight in the lower body and bar weight only for the upper body) for each sample point.

Peak and mean measures of force, velocity and power for the concentric phase of the squat jump and bench throw were obtained for method FP, L and FPL. The onset of the concentric phase was defined as the last point where velocity was less than 0.001 ($m.s^{-1}$) followed by a continuous increase in velocity up to its maximum (top graphs in Figure 16d and Figure 17b). For the squat jumps, the end of the concentric phase was defined as the last sample point of ground reaction force greater than 5 N before take off (Figure 16e). If the subject failed to take off, as it was the case at heavier loads, the end of the concentric phase was defined as the point coinciding with the smallest ground reaction force at the end of the upwards movement.

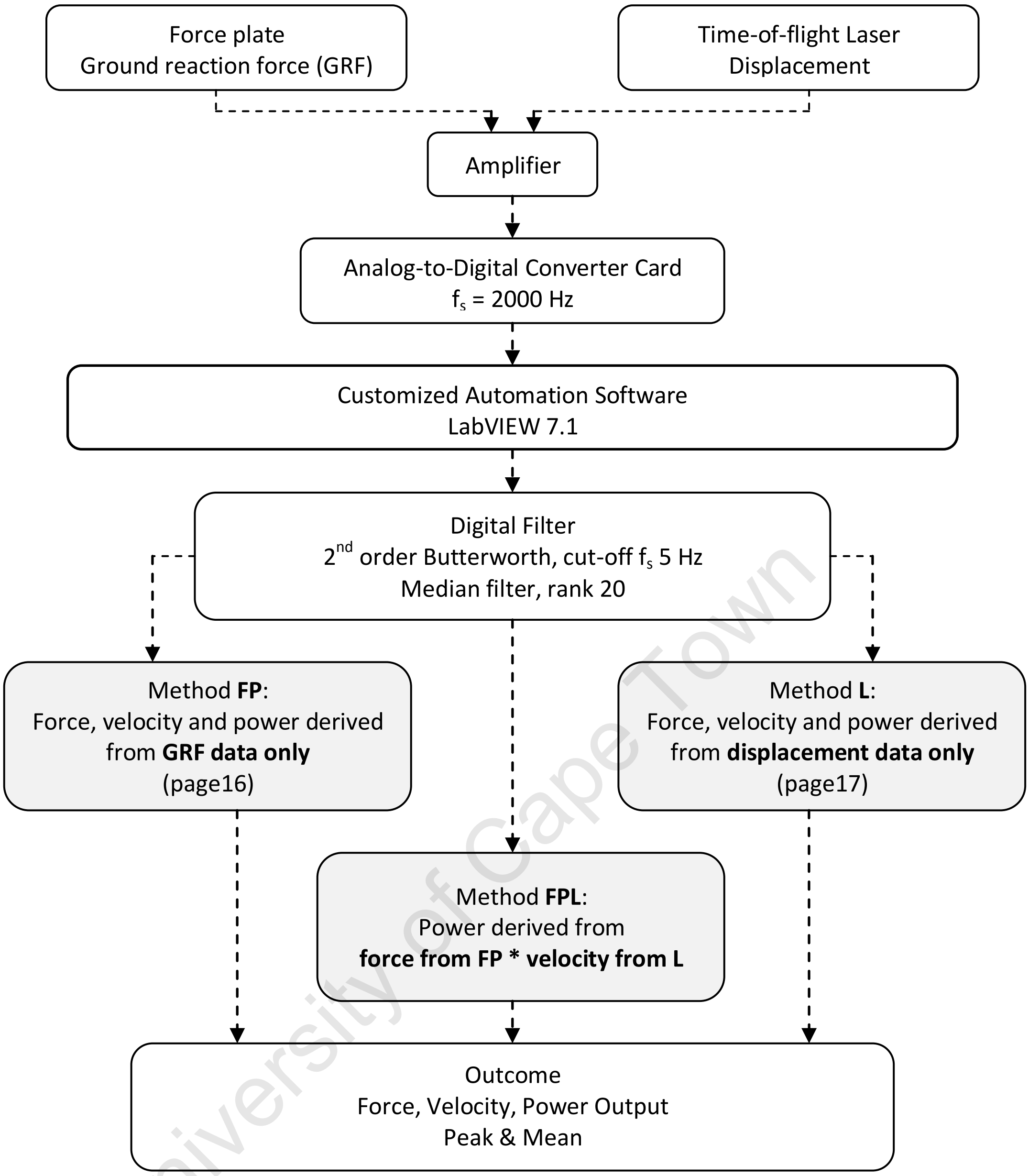


Figure 18: Schematic of data processing and methods of deriving force, velocity and power output via three methods: FP, L and FPL

3.1.9 Data analysis

Data are presented as mean and standard deviation (mean ± SD). The trial with the higher peak power output derived from the force plate method of the two trials per load was used for statistical analysis. Data analysis was performed with STATISTICA version 8.0 (Stat-Soft Inc., Tulsa, OK, USA). Statistical significance for all analyses was defined as $p < 0.05$. One-way analysis of variance (ANOVA) for repeated measures was used to determine whether significant differences existed between the measurements obtained from the three different techniques. If significant main effects (method and load) or interactions (method * load) were identified a Tukey's post-hoc test was performed to determine the specific nature of the differences. All the data met the precondition assumption of sphericity. Along with this analysis, the load that maximized mechanical power output (P_{max}) was determined for each method. The measures of power output for P_{max} were compared to the first subsequent load at either side of the load spectrum within the respective method and between the methods at the same load. Pearson's product moment correlation coefficients and the Bland-Altman limits of agreement (LOA) were obtained to further examine the relationship between the techniques (25). According to this test the mean of the difference (± 2SD) between two data sets was calculated. These results were plotted against the average measure of the two data sets. The closer the mean difference is to zero and the smaller the bandwidth between -2SD and +2SD, the more the agreement is between these sets of data. Furthermore, the relationship between the distributions of the differences between the two data sets, compared to the magnitude of the average measurement, indicates whether the data are homoscedastic (even distribution) or heteroscedastic (uneven distribution).

In addition, differences in means between variables were calculated and presented as relative percentages. Effect sizes, as suggested by Cohen (30) were determined to obtain additional information about the relationships between the techniques. Effect size was derived by dividing the change in mean between two groups by the SD of the whole group (30); the magnitude of which were interpreted using Cohen's scale (30): < 0.10, trivial; 0.10 - 0.29, small; 0.30 - 0.49, moderate; ≥ 0.50, large.

Indicators of reliability for variables within each technique were examined by calculating limits of agreement (following the same procedure as outlined above), interclass correlation coefficient (ICC) and typical error of measurement (TEM) expressed as absolute values and as percentages of the mean change scores (TEM%) between trial one and trial two and the test-retest correlation across all loads. The ICC, TEM, TEM% and test-retest correlation were calculated using a spreadsheet downloaded from www.sportsci.org. 95% Confidence intervals are presented in brackets for ICC, test-retest correlations, TEM and TEM%.

3.2 RESULTS

The following sections of results are divided into two main parts. In the first part indicators of reliability for each method are presented, and in the second part measures of force, velocity and power are compared between the three methods. In both parts of this section, results for the loaded squat jump are addressed first, followed by the results for the bench throw exercise.

The descriptive data of the fifteen research subjects are presented in Table 4.

Table 4: Descriptive data of subjects. Values are presented as mean ± SD, minimum and maximum, (n =15).

Variable	Mean	Minimum	Maximum
Age (years)	23 ± 4	20	35
Body mass (kg)	87 ± 10	74	105
Stature (cm)	178 ± 6	167	187
Sum of 7 skin folds (mm)	73 ± 24	38	129
Percentage body fat (%)	16.6 ± 3.7	9.8	22.9
Squat 1RM (kg)	137 ± 26	105	190
1RM body mass ratio	1.6 ± 0.3	1.2	2.0
Bench Press 1RM (kg)	107 ± 22	80	160
1RM body mass ratio	1.2 ± 0.2	0.9	1.7

3.2.1 Reliability of assessments for measures of power, force and velocity

The following sections present the results for measures of reliability of each method for the jump squat exercise.

3.2.1.1 Loaded Squat Jump

Indicators of reliability for the three methods are shown in Table 5; i.e. force plate only (FP), laser only (L) and force plate and laser (FPL). The data which are summarized in Table 5 are: Peak and mean values of power, force and velocity for trial one (T1) and two (T2), expressed as mean ± SD together with the corresponding intraclass correlation coefficient (ICC), absolute typical error of measurement (TEM) and typical error of measurement expressed as a percentage (TEM%). 95% Confidence intervals are presented in brackets for ICC, TEM and TEM%.

All measures showed good reliability with high ICC's (0.88 to 1.00), and relatively low TEM%'s (7.2 to 1.3%). Measures of peak power, force and velocity generally showed better reliability compared to respective measures of mean power, force and velocity (Table 5). Measures of mean force for L however, showed higher ICC's (0.97) and lower TEM%'s (2.1%) compared to ICC's and TEM%'s for measures of peak force (ICC = 0.92 and TEM% = 3.6% respectively) (Table 5).

Table 5: Indicators of reliability for measures of power, force and velocity between trial one and two during loaded squat jumps for each method, (n = 15 for each group).

Variable	**T1**	**T2**	**ICC**	**TEM**	**TEM%**
Force Plate only					
Peak Power (W)	3742 ± 695	3768 ± 702	0.97 (0.96 - 0.98)	116 (101 - 135)	3.3 (2.9 - 3.9)
Mean Power (W)	1371 ± 350	1377 ± 342	0.93 (0.92 - 0.94)	88 (77 - 103)	6.7 (5.9 - 7.9)
Peak Force (N)	2376 ± 383	2374 ± 386	1.00 (0.99 - 1.00)	37 (32 - 43)	1.6 (1.4 - 1.8)
Mean Force (N)	1790 ± 295	1792 ± 293	1.00 (0.99 - 1.00)	22 (19 -25)	1.3 (1.2 - 1.6)
Peak Velocity ($m.s^{-1}$)	1.80 ± 0.38	1.81 ± 0.38	0.99 (0.98 - 0.99)	0.05 (0.04 - 0.05)	2.7 (2.4 - 3.2)
Mean Velocity ($m.s^{-1}$)	0.81 ± 0.25	0.81 ± 0.25	0.95 (0.93 - 0.97)	0.05 (0.05 - 0.06)	7.2 (6.3 - 8.4)
Laser only					
Peak Power (W)	3936 ± 755	3932 ± 767	0.90 (0.85 - 0.93)	176 (153 - 205)	4.7 (4.1 - 5.6)
Mean Power (W)	1436 ± 379	1433 ± 370	0.88 (0.82 - 0.91)	94 (82 - 110)	7.0 (6.1 - 8.2)
Peak Force (N)	2499 ± 465	2495 ± 465	0.92 (0.88 - 0.94)	92 (80 - 107)	3.6 (3.2 - 4.2)
Mean Force (N)	1729 ± 295	1730 ± 291	0.97 (0.96 - 0.98)	35 (30 - 40)	2.1 (1.8 - 2.5)
Peak Velocity ($m.s^{-1}$)	1.86 ± 0.43	1.85 ± 0.41	0.97 (0.96 - 0.98)	0.05 (0.04 - 0.06)	2.6 (2.3 - 3.1)
Mean Velocity ($m.s^{-1}$)	0.90 ± 0.31	0.90 ± 0.30	0.92 (0.88 - 0.94)	0.06 (0.05 - 0.07)	6.7 (5.9 - 7.9)
Force Plate + Laser					
Peak Power (W)	4049 ± 846	4053 ± 850	0.96 (0.94 - 0.97)	120 (105 - 140)	3.2 (2.8 - 3.7)
Mean Power (W)	1566 ± 447	1567 ±439	0.94 (0.93 - 0.95)	101 (89 - 118)	6.4 (5.9 - 6.7)
Peak Force (N)	see Force Plate only				
Mean Force (N)	see Force Plate only				
Peak Velocity ($m.s^{-1}$)	see Laser only				
Mean Velocity ($m.s^{-1}$)	see Laser only				

T1 and T2 = trial one and trial two, ICC = intraclass correlation coefficient,
TEM / TEM% = absolute and relative typical error of measurement respectively,
95% Confidence intervals are presented in brackets for ICC, TEM and TEM%;

Table 6 shows the limits of agreement (LOA) ± 2SD with corresponding upper and lower limits of agreements (+LOA and -LOA respectively), relative change in mean (% Change mean) and test-retest correlation coefficient (*r*) between trial one and two for measures of power, force and velocity for the three methods. All variables for each method showed good reliability with a low relative change in mean (-0.7 to 0.2%) and high correlations (*r* = 0.93 to 0.98) (Table 6).

Table 6: Limits of agreement, relative change in mean and test-retest correlation coefficient for measures of power, force and velocity between trial one and two during loaded squat jumps for each method, (n = 15 for each group).

	Mean difference	+LOA	-LOA	% Change mean	*R*
Force Plate only					
Peak Power (W)	-25 ± 328	303	-354	-0.7	0.97 (0.96 - 0.98)
Mean Power (W)	-6 ± 250	244	-256	-0.4	0.94 (0.90 - 0.96)
Laser only					
Peak Power (W)	3 ± 497	500	-494	-0.1	0.95 (0.92 - 0.96)
Mean Power (W)	3 ± 264	270	-264	0.2	0.93 (0.90 - 0.96)
Force Plate + Laser					
Peak Power (W)	-3 ± 341	338	-345	-0.1	0.98 (0.97 - 0.99)
Mean Power (W)	-1 ± 287	286	-288	-0.1	0.95 (0.92 - 0.97)
Peak Force (N)					
Force Plate	2 ± 105	106	-103	0.1	0.99 (0.98 - 1.00)
Laser	4 ± 260	263	-256	0.2	0.96 (0.94 - 0.98)
Mean Force (N)					
Force Plate	-1 ± 62	61	-63	-0.1	0.99 (0.99 - 1.00)
Laser	-1 ± 99	98	-100	-0.1	0.98 (0.98 - 0.99)
Peak Velocity (m.s^{-1})					
Force Plate	-0.01 ± 0.13	0.12	-0.14	-0.7	0.99 (0.98 - 0.99)
Laser	0.01 ± 0.14	0.14	-0.13	0.2	0.99 (0.98 - 0.99)
Mean Velocity (m.s^{-1})					
Force Plate	-0.01 ± 0.15	0.14	-0.15	-0.6	0.96 (0.93 - 0.97)
Laser	0.01 ± 0.17	0.18	-0.17	0.2	0.96 (0.94 - 0.97)

Mean difference ± the two standard deviations of the mean differences,
LOA = limits of agreement, % Change mean = relative change in mean,
r = test-retest correlation coefficient, 95% Confidence interval of the correlation coefficient in brackets;

Figure 19 presents the graphs of the test-retest correlation coefficient for measures of power between trial one (T1) and two (T2) during squat jumps for each method.

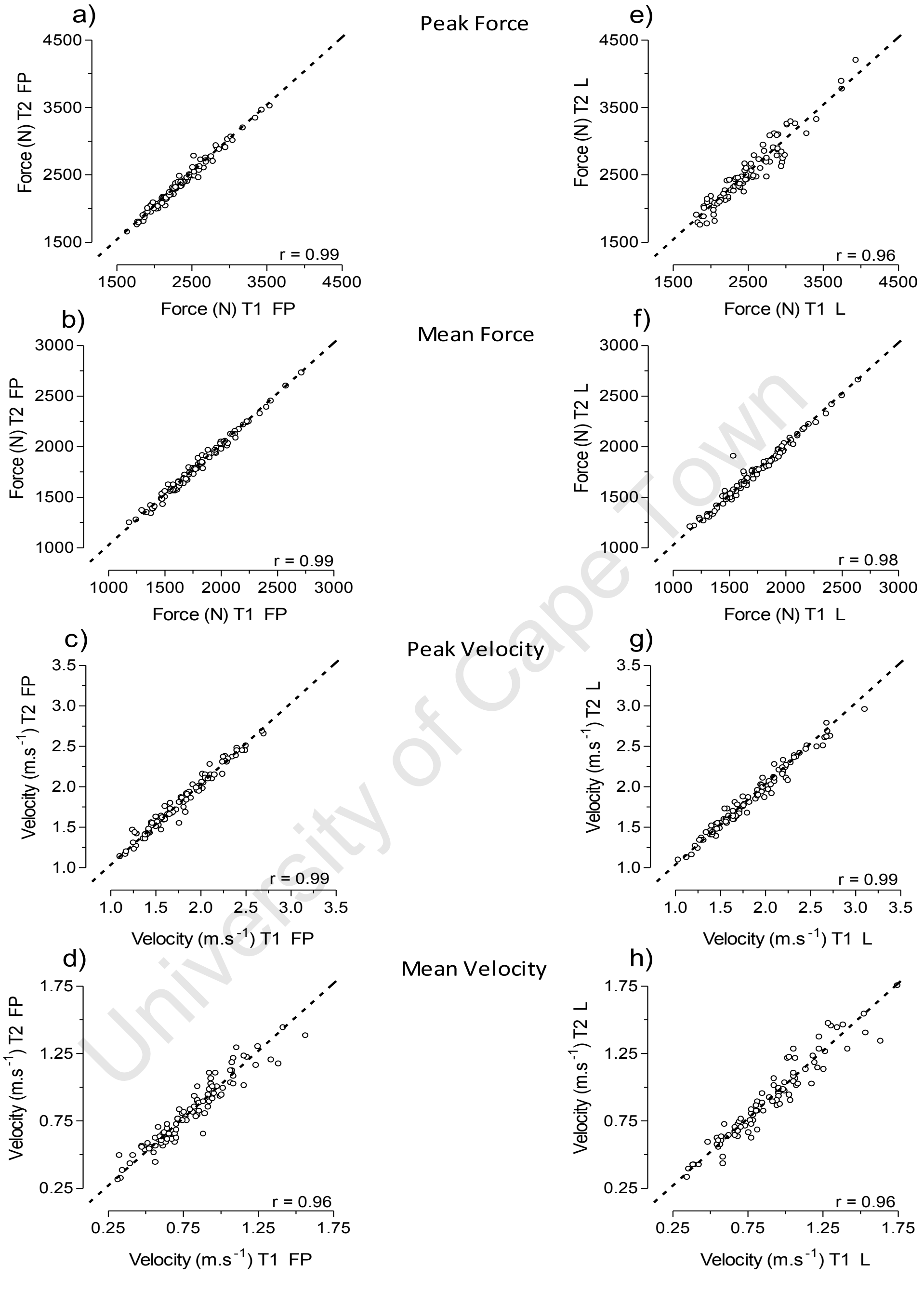


Figure 19: Test-retest correlation for measures of peak and mean power between trial one and two during squat jumps for each method, (n = 15 for each group).

r = correlation coefficient,T1 and T2 = trial one and trial two,
FP = force plate only, L = laser only, FPL = force plate + laser;

Figure 20 presents the graphs of the test-retest correlation coefficient for measures of force and velocity between trial one (T1) and two (T2) during squat jumps for each method.

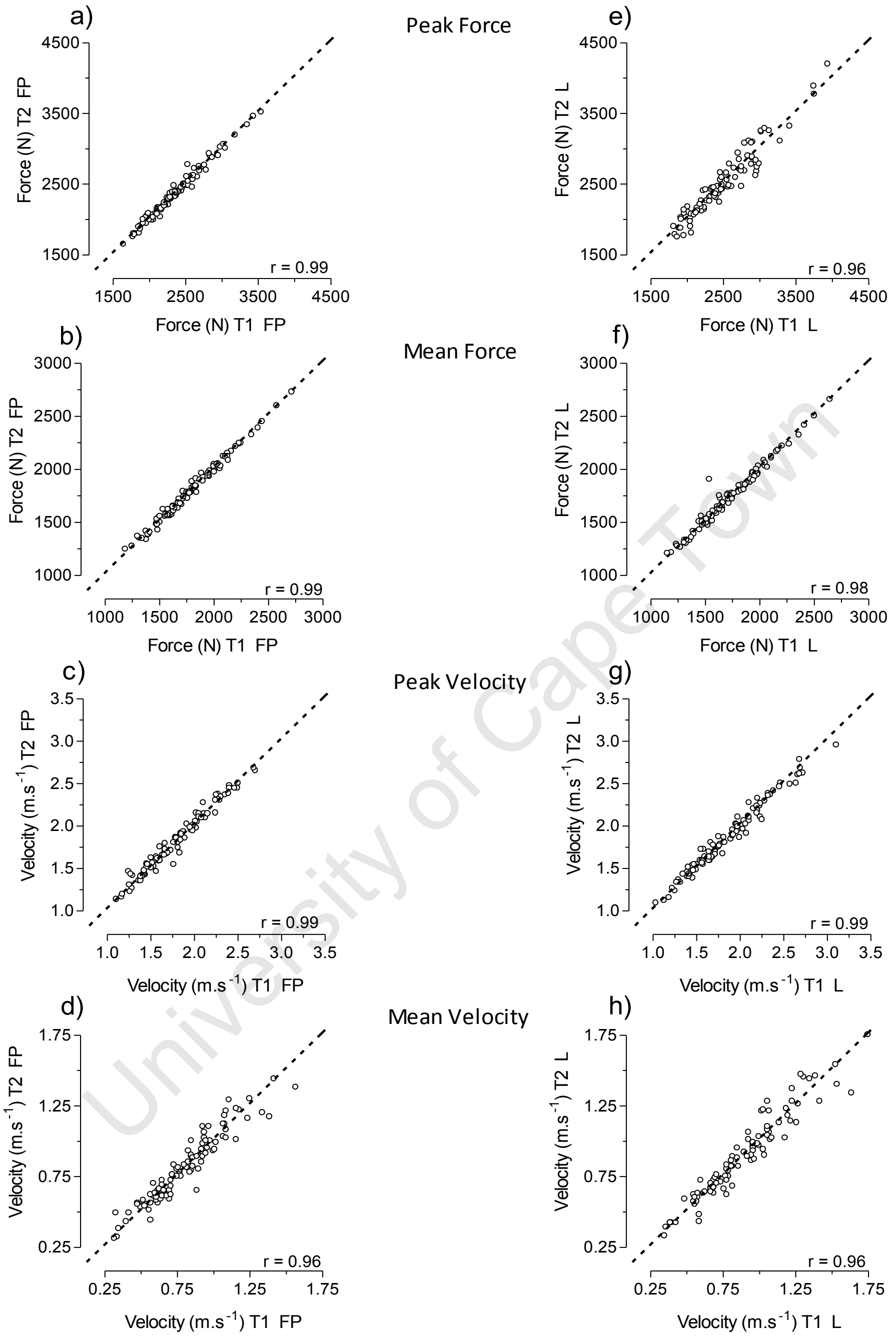


Figure 20: Test-retest correlation for measures of peak and mean force and velocity between trial one and two during squat jumps for each method, (n = 15 for each group).

r = correlation coefficient, T1 and T2 = trial one and trial two,
FP = force plate only, L = laser only, FPL = force plate + laser;

3.2.1.2 Bench Throw

Table 7 presents indicators of reliability for measures of power, force and velocity for the three methods in the same format as outlined for the squat jump exercise. All measures showed good reliability with high ICC's (0.91 to 0.99), and low TEM%'s (7.9 to 2.9%) (Table 7).

Table 7: Indicators of reliability for measures of power, force and velocity between trial one and two during bench throws for each method, (n = 15 for each group).

Variable	T1	T2	ICC	TEM	TEM%
Force Plate only					
Peak Power (W)	1151 ± 410	1171 ± 406	0.96 (0.94 - 0.97)	81 (70 - 93)	7.9 (6.9 - 9.3)
Mean Power (W)	660 ± 224	667 ± 223	0.96 (0.93 - 0.98)	41 (36 - 48)	6.7 (5.8 - 7.9)
Peak Force (N)	917 ± 218	925 ± 225	0.96 (0.93 - 0.97)	48 (42 - 55)	4.9 (4.3 - 5.8)
Mean Force (N)	691 ± 178	696 ± 178	0.99 (0.98 - 0.99)	18 (16 - 22)	2.9 (2.5 - 3.4)
Peak Velocity $(m.s^{-1})$	1.92 ± 1.04	1.94 ± 1.03	0.99 (0.98 - 0.99)	0.08(0.07 - 0.09)	5.6 (4.9 - 6.7)
Mean Velocity $(m.s^{-1})$	1.13 ± 0.61	1.11 ± 0.59	0.98 (0.98 - 0.99)	0.07 (0.06 - 0.08)	6.7 (5.8 - 8.0)
Laser only					
Peak Power (W)	986 ± 254	1002 ± 267	0.94 (0.91 - 0.96)	44 (38 - 52)	4.5 (3.9 - 5.3)
Mean Power (W)	516 ± 128	525 ± 131	0.91 (0.85 - 0.94)	27 (24 - 32)	5.9 (5.1 - 6.9)
Peak Force (N)	884 ± 247	886 ± 248	0.96 (0.93 - 0.97)	37 (32 - 43)	4.5 (3.9 - 5.2)
Mean Force (N)	659 ± 192	651 ± 161	0.98 (0.97 - 0.99)	17 (15 - 20)	3.0 (2.6 - 3.6)
Peak Velocity $(m.s^{-1})$	1.58 ± 0.71	1.60 ± 0.72	0.99 (0.98 - 0.99)	0.04 (0.04 - 0.05)	3.6 (3.2 - 4.3)
Mean Velocity $(m.s^{-1})$	0.95 ± 0.41	0.96 ± 0.42	0.98 (0.97 - 0.99)	0.04 (0.04 - 0.05)	5.0 (4.3 - 5.9)
Force Plate + Laser					
Peak Power (W)	983 ± 272	1002 ± 279	0.92 (0.89 - 0.94)	55 (48 - 64)	5.8 (5.0 - 6.8)
Mean Power (W)	569 ± 160	579 ± 162	0.93 (0.89 - 0.95)	30 (26 - 35)	5.7 (5.0 - 6.8)
Peak Force (N)	see Force Plate only				
Mean Force (N)	see Force Plate only				
Peak Velocity $(m.s^{-1})$	see Laser only				
Mean Velocity $(m.s^{-1})$	see Laser only				

T1 and T2 = trial one and trial two, ICC = intraclass correlation coefficient,
TEM / TEM% = absolute and relative typical error of measurement respectively,
95% Confidence intervals are presented in brackets for ICC, TEM and TEM%;

Next, the limits of agreement the limits of agreement (LOA) ± 2SD with corresponding upper and lower limits of agreements (+LOA and -LOA respectively), relative change in mean and test-retest correlation coefficient between trial one and two for measures of power, force and velocity are presented (Table 8). For each method all variables showed low relative change in mean (-1.7 to 0.9%) and high correlations (*r* = 0.95 to 0.99) (Table 8).

Table 8: Limits of agreement and test-retest correlation coefficient for measures of power, force and velocity between trial one and two during bench throws for each method, (n = 15 for each group).

	Mean difference	+LOA	-LOA	% Change mean	*r*
Force Plate only					
Peak power (W)	-19 ± 299	210	-248	-1.7	0.96 (0.94 - 0.97)
Mean power (W)	-7 ± 117	110	-124	-1.1	0.97 (0.95 - 0.98)
Laser only					
Peak power (W)	-15 ± 126	111	-141	-1.5	0.97 (0.95 - 0.98)
Mean power (W)	-9 ± 78	69	-87	-1.7	0.95 (0.93 - 0.97)
Force Plate + Laser					
Peak power (W)	-19 ± 156	137	-174	-1.9	0.96 (0.94 - 0.97)
Mean power (W)	-7 ± 87	79	-94	-1.3	0.96 (0.94 - 0.98)
Peak Force (N)					
Force Plate	-8 ± 137	129	-146	-0.9	0.95 (0.93 - 0.97)
Laser	-2 ± 105	103	-107	-0.2	0.98 (0.97 - 0.99)
Mean Force (N)					
Force Plate	-5 ± 53	49	-58	-0.7	0.99 (0.98 - 0.99)
Laser	2 ± 49	51	-47	0.9	0.99 (0.96 - 0.99)
Peak Velocity ($m.s^{-1}$)					
Force Plate	-0.01 ± 0.23	0.21	-0.24	-0.7	0.99 (0.98 - 0.99)
Laser	-0.01 ± 0.13	0.11	-0.14	-0.7	0.99 (0.98 - 0.99)
Mean Velocity ($m.s^{-1}$)					
Force Plate	-0.01 ± 0.19	0.17	-0.20	-1.3	0.99 (0.98 - 0.99)
Laser	-0.01 ± 0.12	0.11	-0.13	-1.3	0.99 (0.98 - 0.99)

Mean difference ± the two standard deviations of the mean differences,
LOA = limits of agreement, % Change mean = relative change in mean,
r = test-retest correlation coefficient , 95% Confidence interval of the correlation coefficient in brackets;

Figure 21 illustrates the test-retest correlation of peak and mean power between trial one (T1) and two (T2) for each method.

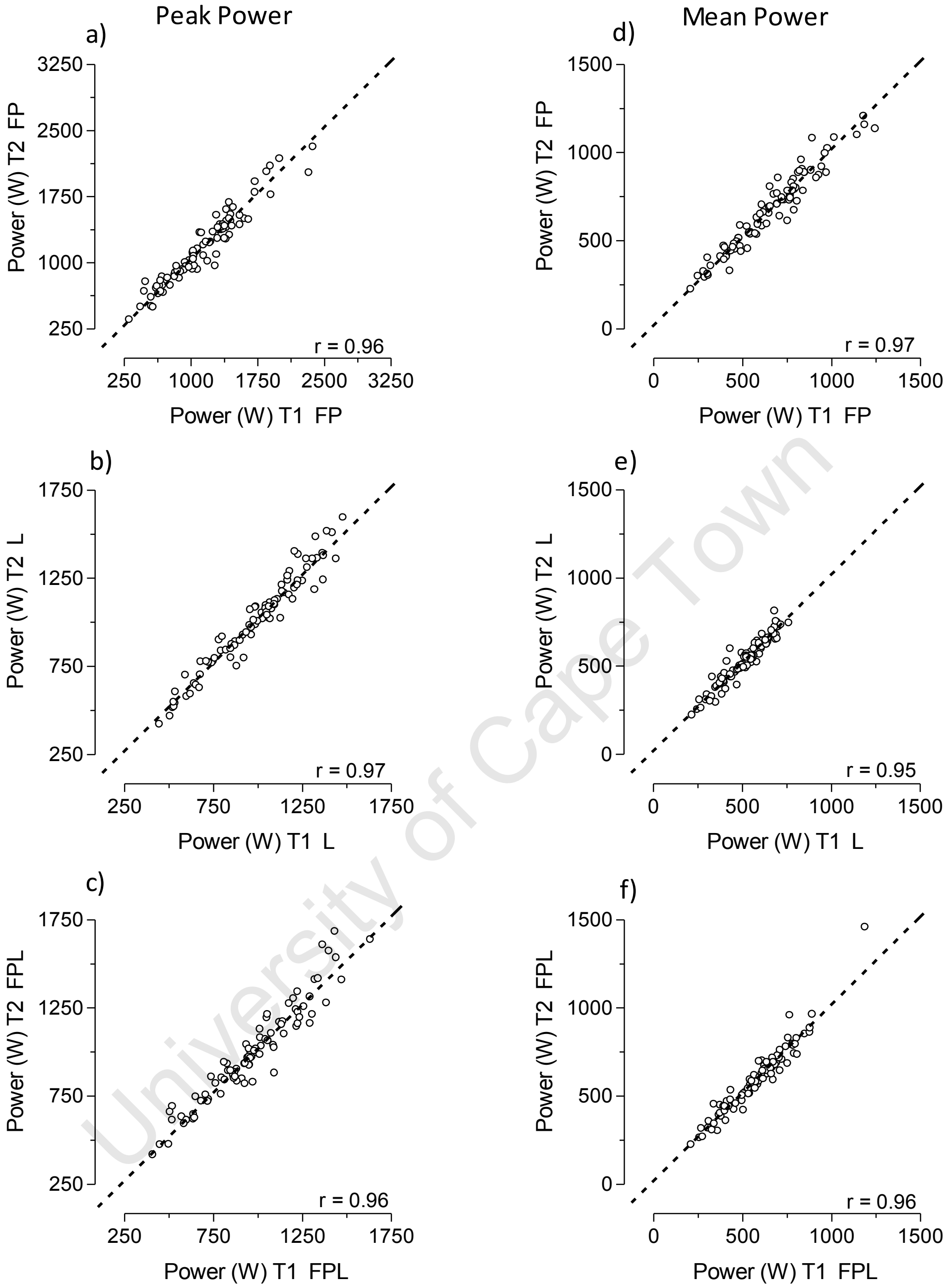


Figure 21: Test-retest correlation coefficient for measures of peak and mean power during bench throws between trial one and two for each method, (n = 15 for each group).

r = correlation coefficient,
FP = force plate only, L = laser only, FPL = force plate + laser;

Figure 22 illustrates the test-retest correlation for measures of force and velocity between trial one (T1) and two (T2).

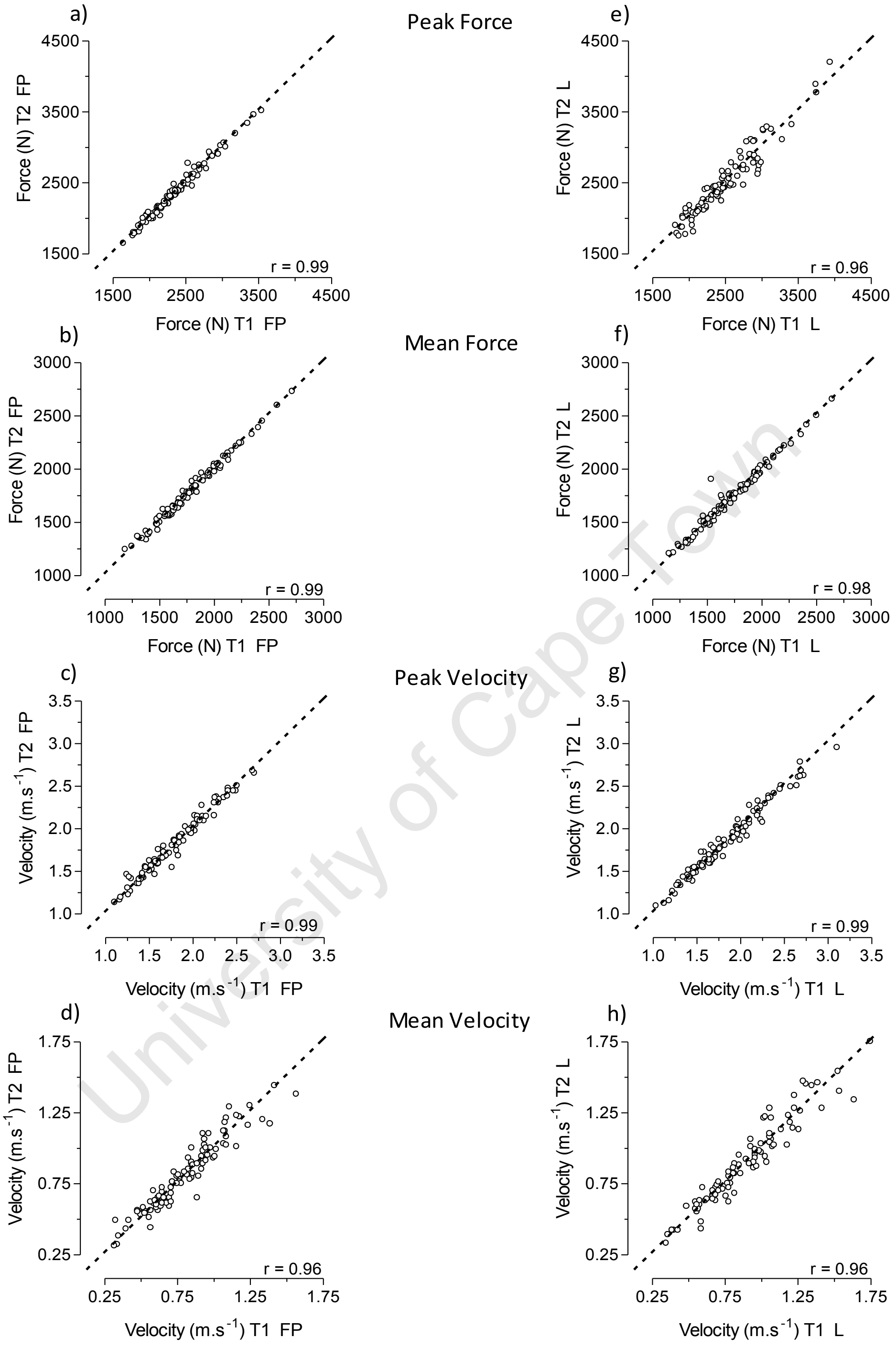


Figure 22: Test-retest correlation for measures of force and velocity during bench throws between trial one and two for each method, (n = 15 for each group).

r = correlation coefficient,
FP = force plate only, L = laser only, FPL = force plate + laser;

3.2.2 Comparison between the methods of assessment for measures of power, force and velocity

The subsequent sections present the results for measures of power, force and velocity derived from the three methods investigated; i.e. force plate only (FP), laser only (L) and the combination of force plate and laser (FPL). In an attempt to clarify the presentation of the results the same structure has been adopted for each variable, i.e.: a) table of peak and mean measures derived from respective methods at each workload; b) main effect (method), main effect (load), interaction effect (method * load); c) limits of agreements and effect sizes (Cohen's *d*); d) relative change in mean and Pearson's product moment correlation coefficient (*r*);

In addition, "lighter load(s)" or "heavier load(s)" always refer to the relative loads as derived from the subject's 1RM (e.g. "heavier load(s)" refer to heavier relative to the respective 1RM).

3.2.2.1 Loaded Squat Jump

Power-load relationship

Table 9 shows the measures of peak and mean power output for each workload derived from the three different methods. Maximum power (P_{max}) occurred at 30% 1RM for FP and L, whereas P_{max} occurred at the "bar only" workload for FPL. Power outputs for the subsequent loads at either side of P_{max} were not significantly different for all methods.

Table 9: Measures of peak and mean power output during the squat jump from each method*. Values are presented as group mean and ± SD, (n = 15 in each group).

Load (%1RM)	FP	L	FPL
Peak Power (W)			
Bar only	4097 ± 671	4317 ± 800	**4710 ± 892**
30	**4118 ± 700**	**4342 ± 766**	4543 ± 801
40	3897 ± 599	4194 ± 714	4291 ± 755
50	3849 ± 639	4059 ± 610	4136 ± 686
60	3660 ± 552	3873 ± 663	3883 ± 679
70	3581 ± 622	3709 ± 588	3702 ± 625
80	3194 ± 578	3302 ± 642	3337 ± 623
Mean Power (W)			
Bar only	**1647 ± 358**	**1739 ± 413**	**2007 ± 478**
30	1589 ± 300	1684 ± 337	1850 ± 386
40	1475 ± 258	1572 ± 298	1703 ± 335
50	1395 ± 285	1450 ± 302	1553 ± 315
60	1292 ± 212	1339 ± 251	1435 ± 266
70	1206 ± 250	1218 ± 265	1282 ± 284
80	1008 ± 233	1063 ± 261	1136 ± 264

*Load at which maximum power occurred in bold, Bar only = absolute load of 21.3 kg, FP = force plate only, L = laser only, FPL = force plate + laser;

Figure 23 illustrates the peak power-load relationship for each method of assessment. There was no significant difference for the main effect "method". However, there were significant differences within the main effect "load" and the interaction effect (method * load) ($p < 0.01$ respectively). Differences in the power-load relationship were more obvious at lighter loads and became less apparent towards heavier loads (Figure 23). In FPL peak power was maximised at the “bar only” load followed by a constant decrease of the power curve towards the heaviest load. Yet, the curves for FP and L showed an incline from “bar only” to 30% 1RM (i.e. P_{max} load), before gradually decreasing towards the heaviest load.

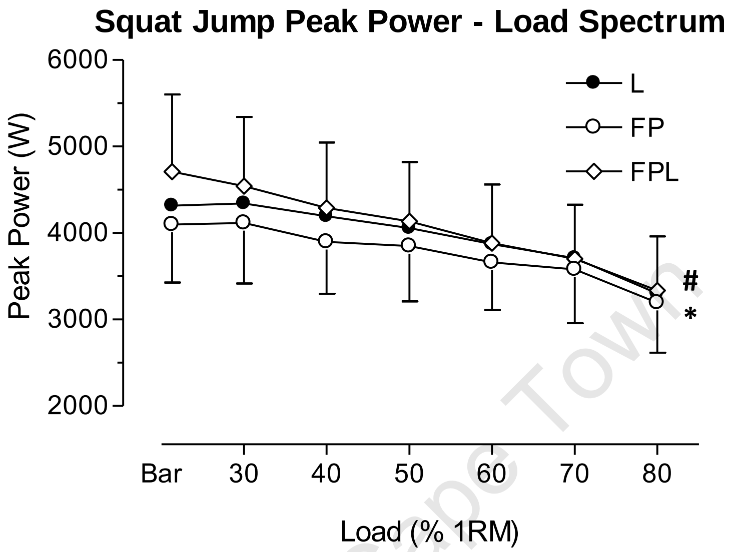


Figure 23: Peak power-load relationship for the squat jump derived from FP, L and FPL.
#: significance (p<0.01) method * load,
*: significance (p<0.01) load;

Figure 24 shows the mean power-load relationship for each method of assessment. There was no significant difference for the main effect “method”. However, there were significant differences for the main effect “load” and the interaction effect (method * load) ($p < 0.01$ respectively). Maximum mean power occurred at “bar only” for all methods. Power outputs for the subsequent load of P_{max} (i.e. 30% 1RM) were not significantly different for all methods. Differences in the power-load relationship were more obvious at lighter loads and became less apparent towards heavier loads (Figure 24). The power curves of all methods showed a constant decline from the “bar only” load towards the heaviest load.

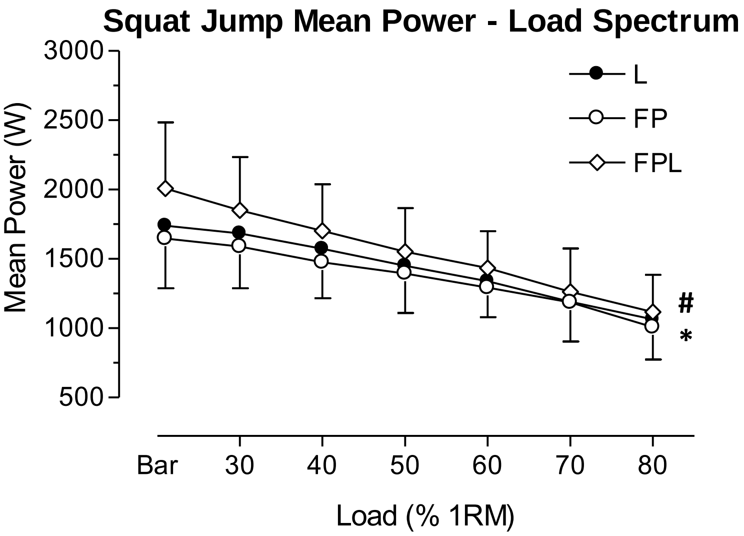


Figure 24: Mean power-load relationship for the squat jump derived from FP, L and FPL.
#: significance ($p<0.01$) method * load,
*: significance ($p<0.01$) load;

Differences in the power-load relationship between the methods were more evident for measures of peak power compared to measures of mean power (Figure 23 and 24 respectively). Mean and peak power outputs derived from FPL were consistently higher than respective measures derived from FP and L (Figure 23 and 24 respectively).

In the following graphs the limits of agreement (LOA) between the three methods for peak and mean power are presented (Figure 25). The distribution of the data generally shows a heteroscedastic pattern (i.e. uneven scatter), particularly for those comparisons involving method FPL (i.e. Figure 25 d,c,e,f). In other words, the differences between the measures of power increases as the magnitude of power output increases. Therefore, it should be noted that the mean differences and limits of agreements represent a summation of all the values (61). The heteroscedasticity was more obvious for mean power compared to peak power (Figure 25).

The effect size statistics are shown in the legend of Figure 25. These were highest in peak and mean power between FP and FPL (*d* = 0.41 and *d* = 0.49 respectively); and for mean power between FPL and L (*d* = 0.32).

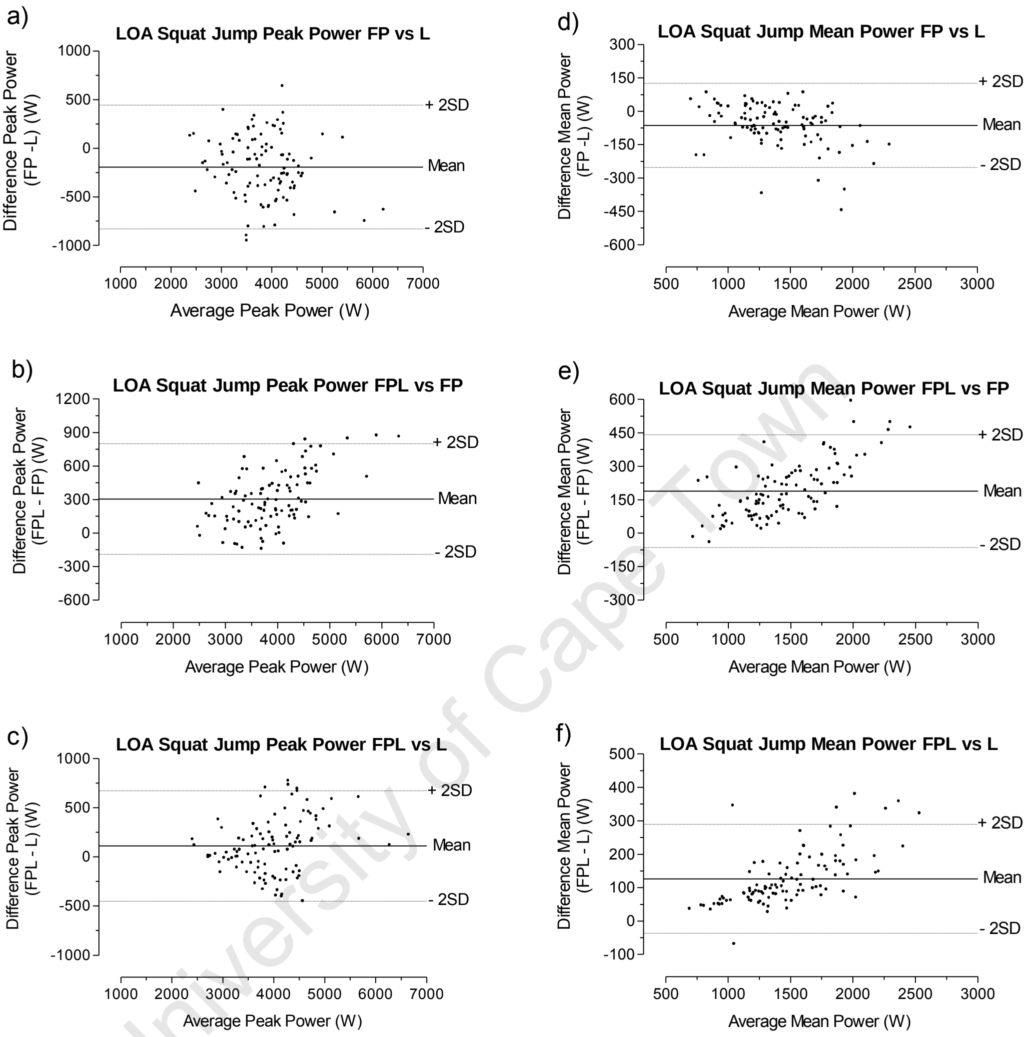


Figure 25: Limits of agreement for peak and mean power between FP, L and FPL during squat jumps.

LOA for peak power between	LOA for mean power between
a) FP and L (-199 ± 637 W), *d* = 0.28, %Δ mean = -5.1%	d) FP and L (-63 ± 189 W), *d* = 0.18, %Δ mean = -4.6%
b) FPL and FP (305 ± 496 W), *d* = 0.41, %Δ mean = 7.5%	e) FPL and FP (189 ± 126 W), *d* = 0.49, %Δ mean = 12.8%
c) FPL and L (112 ± 562 W), *d* = 0.15, %Δ mean = 2.8%	f) FPL and L (126 ± 164 W), *d* = 0.32, %Δ mean = 8.1%

LOA = limits of agreement; %Δ mean = relative change in mean, *d* = Cohen's *d* effect size, FP = force plate only, L = laser only, FPL = force plate + laser;

Table 10 presents the correlation for mean and peak power between the methods. All measures showed good correlations (*r* = 0.89 to 0.99). Nonetheless, correlations were higher for measures of mean power compared to respective measures of peak power (Table 10).

Table 10: Relationship between FP, L and FPL for the measurements of mean and peak power for the squat jump. Data are shown as the correlation coefficient (*r*) and the 95% Confidence intervals of the correlation coefficient in brackets.

	FP		**L**		**FPL**	
	Peak Po	Mean Po	Peak Po	Mean Po	Peak Po	Mean Po
FP	--				**0.96** (0.94 - 0.97)	**0.97** (0.96 - 0.98)
L	**0.89** (0.85 - 0.93)	**0.97** (0.95 - 0.98)	--			
FPL			**0.94** (0.91 - 0.95)	**0.99** (0.98 - 0.99)	--	

Po = Power (W), FP = force plate only, L = laser only, FPL = force plate + laser;

The following section presents the results for measures of peak and mean force.

Force -load relationship

Comparisons between measures of force apply only to method FP and L, as power from method FPL was a combination of the force derived from the force plate (FP) and velocity derived from the laser (L).

Table 11 shows the measures of peak and mean force output for each workload derived from the two different methods. Maximum force output occurred at 80% 1RM for peak and mean measures for both methods.

Table 11: Peak and mean force (N) measures obtained from FP and L for each load during the squat jump. Values presented as mean ± SD, (n = 15 in each group).

Load (%1RM)	FP	L
Peak Force (N)		
Bar only	1950 ± 178	2065 ± 187
30	2188 ± 261	2265 ± 264
40	2284 ± 276	2387 ± 299
50	2397 ± 288	2552 ± 310
60	2520 ± 316	2654 ± 397
70	2646 ± 331	2794 ± 394
80	**2700 ± 354**	**2874 ± 458**
Mean Force (N)		
Bar only	1460 ± 153	1394 ± 152
30	1619 ± 193	1561 ± 186
40	1714 ± 202	1658 ± 195
50	1794 ± 212	1738 ± 201
60	1897 ± 217	1838 ± 219
70	1992 ± 245	1924 ± 237
80	**2075 ± 264**	**2013 ± 259**

*Load at which maximum force occurred in bold, Bar only = absolute load of 21.3 kg, FP = force plate only, L = laser only, FPL = force plate + laser;

Figure 26 shows the peak force-load relationship for FP and L. Significant differences were found for the main effect “load” only ($p < 0.01$).

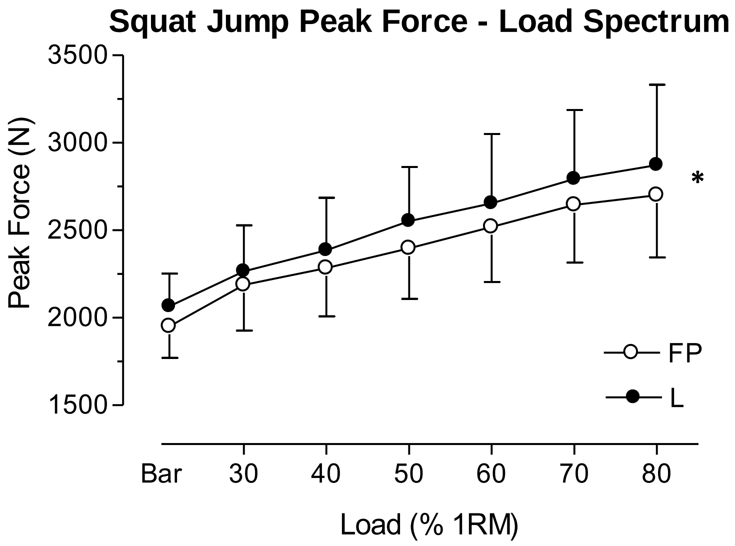


Figure 26: Peak force-load relationship for the squat jump derived from FP and L.
*: significance (p<0.01) load

Figure 27 illustrates the mean force-load relationship for FP and L. There were no significant differences within the main effect “method” and the interaction effect (method * load). The main effect “load” however, was significant (p < 0.01).

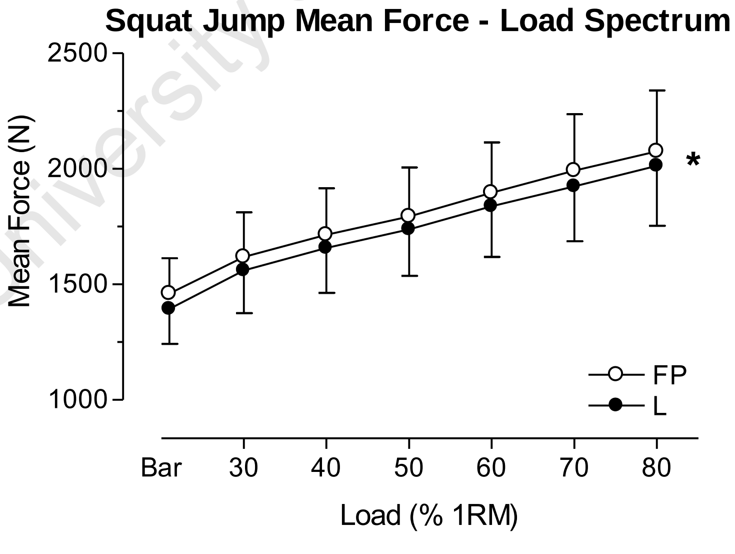


Figure 27: Mean force-load relationship for the squat jump derived from FP and L.
*: significance (p<0.01) load

Figure 28a shows the limits of agreement for peak force between FP and L. The magnitude of differences was moderate (*d* = 0.32) and relative change in mean was 5.4% (Figure 28a).

Figure 28b shows the limits of agreement for measures of mean force between FP an L. The magnitude of differences was small (*d* = 0.21) and relative change was 3.4%.

All parameters (effect size and relative change in mean) were higher for measures of peak force between FP and L (Figure 28).

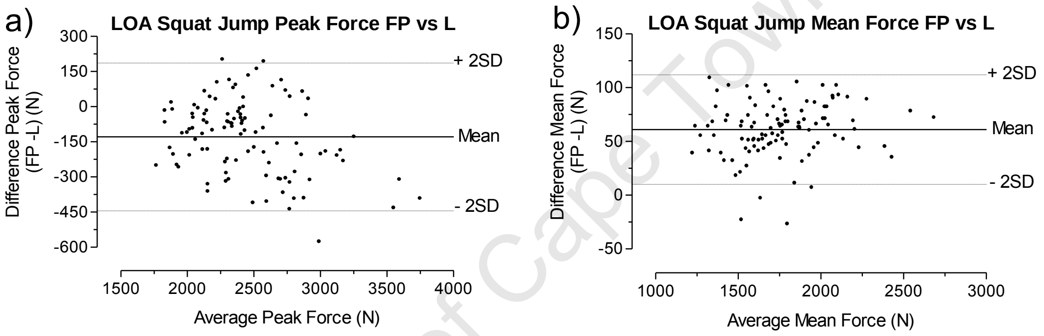


Figure 28: Limits of agreement for peak and mean force between FP and L during loaded squat jumps.

a) -129 ± 312 N, *d* = 0.32, %Δ mean = 5.4%	b) 61 ± 51 N, *d* = 0.21, %Δ mean = 3.4%

LOA = limits of agreement, %Δ mean = relative change in mean, *d* = Cohen’s *d* effect size,
FP = force plate only, L = laser only;

Figure 29a and b present the correlation for peak and mean force between FP and L respectively. Both, peak and mean force showed a good relationship between FP and L (*r* = 0.93 and *r* = 1.00 respectively).

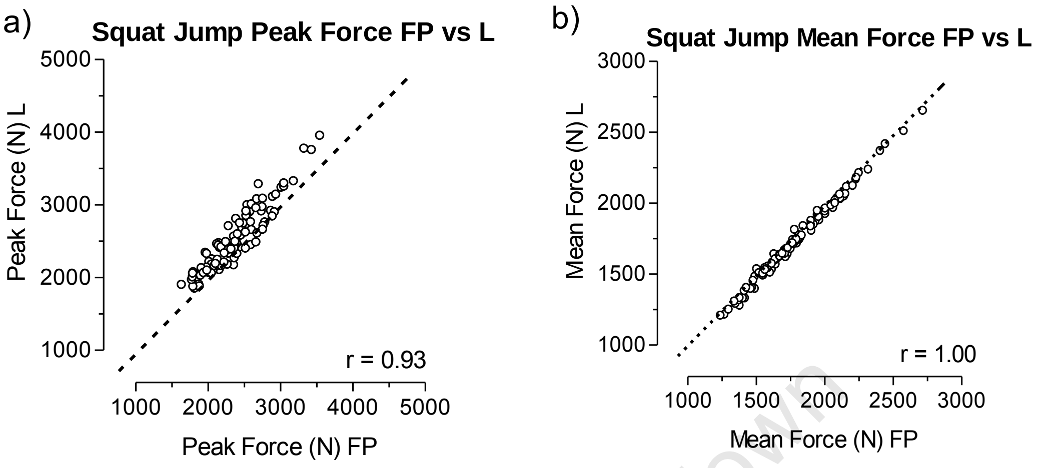


Figure 29: Relationship between peak force (FP vs. L) and mean force (FP vs. L) for the squat jump. Data are shown as the correlation coefficient *(r)* and the 95% Confidence intervals of the correlation coefficient in brackets.

a) *r* = 0.93 (0.90 - 0.95)	b) *r* = 1.00 (0.98 - 1.00)
FP = force plate only, L = laser only	

In the following section the results for measures of peak and mean velocity between FP and L are presented.

Velocity-load relationship

Table 12 shows the measures of peak and mean velocity output for each workload derived from method FP and L. As expected maximum velocity occurred at "bar only" for peak and mean velocity for both methods. Subsequent peak and mean velocity for the 30% 1RM load were significantly lower for FP and L ($p < 0.05$ respectively) (Table 12).

Table 12: Peak and mean velocity ($m.s^{-1}$) measures obtained from FP and L for each load during the squat jump*. Values presented as mean ± SD, (n = 15 in each group).

Load (%1RM)	FP	L
Peak Velocity ($m.s^{-1}$)		
Bar only	**2.36 ± 0.23**	**2.51 ± 0.32**
30	2.13 ± 0.18 †	2.23 ± 0.19 †
40	1.92 ± 0.14	2.00 ± 0.18
50	1.79 ± 0.15	1.84 ± 0.16
60	1.63 ± 0.13	1.66 ± 0.15
70	1.51 ± 0.15	1.51 ± 0.14
80	1.31 ± 0.15	1.34 ± 0.14
Mean Velocity ($m.s^{-1}$)		
Bar only	**1.17 ± 0.18**	**1.36 ± 0.23**
30	1.01 ± 0.12†	1.14 ± 0.15†
40	0.88 ± 0.10	1.00 ± 0.12
50	0.79 ± 0.12	0.86 ± 0.13
60	0.70 ± 0.10	0.76 ± 0.11
70	0.60 ± 0.12	0.63 ± 0.13
80	0.49 ± 0.10	0.54 ± 0.11

*Load at which maximum velocity occurred in bold, † significance ($p<0.05$) between velocity at "Bar only" and 30% 1RM-load,
FP = force plate only, L = laser only, Bar only = absolute load of 21.3 kg;

Figure 30 illustrates the peak velocity-load relationship for FP and L. There was no significant difference for the main effect "method". However, the main effect "load" and the interaction effect (method * load) were significant ($p < 0.05$ and $p < 0.01$ respectively). Differences in the velocity-load relationship were more obvious at lighter loads and became less apparent towards heavier loads (Figure 30). At loads from “bar only” to 60% 1RM peak velocity derived from L was higher than measures of peak velocity for FP.

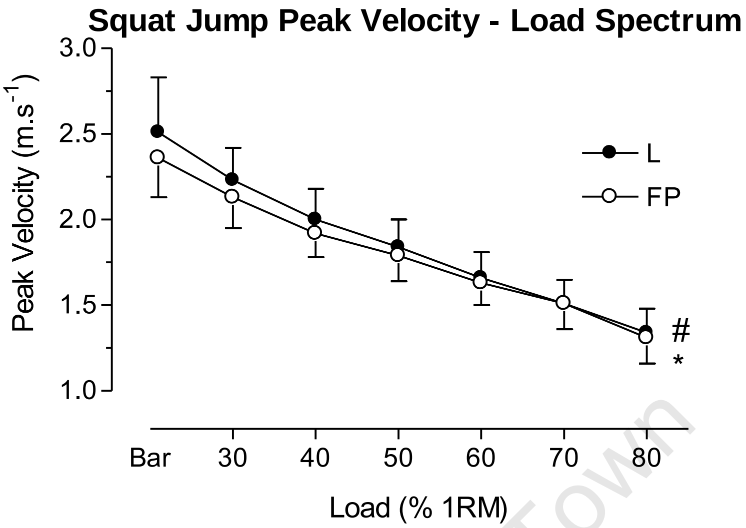


Figure 30: Peak velocity-load relationship for the squat jump derived from FP and L.
#: significance (p<0.01) method * load,
*: significance (p<0.01) load;

Figure 31 shows the mean velocity-load relationship for both assessment methods, FP and L. There were significant differences within the two main effects (method and load) ($p < 0.05$, $p < 0.01$ respectively) and the interaction effect (method * workload) ($p < 0.01$). Post hoc analysis showed significant differences for measures of mean velocity at the “bar only” load between FP and L ($p < 0.05$). Differences in the mean velocity-load relationship were more obvious at lighter loads and became less apparent towards heavier loads (Figure 31).

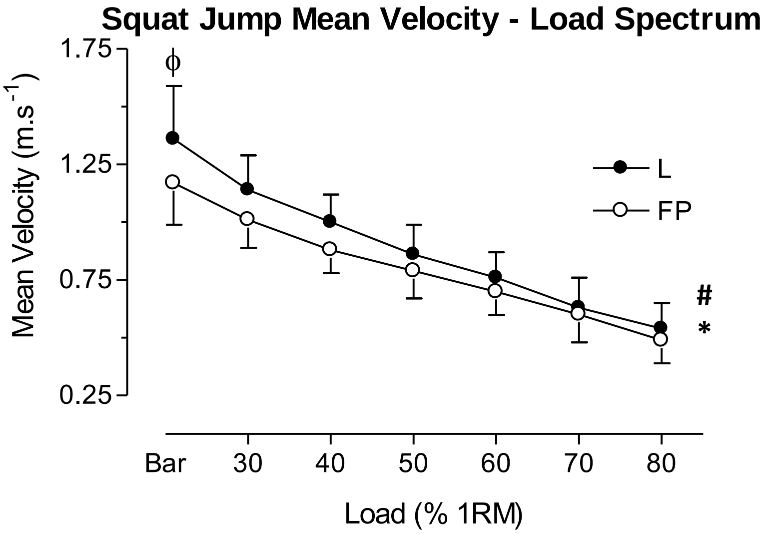


Figure 31: Mean velocity-load relationship for the squat jump derived from FP and L.
#: significance ($p<0.01$) method * load,
*: significance ($p<0.01$) load,
Φ: significance ($p<0.05$) FP vs. L;

Differences in the velocity-load relationship between the methods were more evident for measures of mean velocity compared to measures of peak velocity (Figure 30 and 31). For loads of “bar only” to 60% 1RM peak and mean velocity outputs derived from L were consistently higher than respective measures derived from FP (Figure 30 and 31).

Next, the limits of agreement for peak and mean velocity derived from FP and L are presented. The scatter plot (Figure 32a) reveals heteroscedasticity for measures of peak velocity between FP and L. The magnitude of differences was small (*d* = 0.15) and the relative change in mean was 3.4%. Limits of agreements for mean velocity between FP and L are shown in Figure 32b indicating a heteroscedastic relationship between the two methods for mean velocity. The magnitude of differences was moderate (*d* = 0.32) and relative change in mean was 11.3%. Relative change in mean and magnitude of differences were higher for mean velocity then for measures of peak velocity.

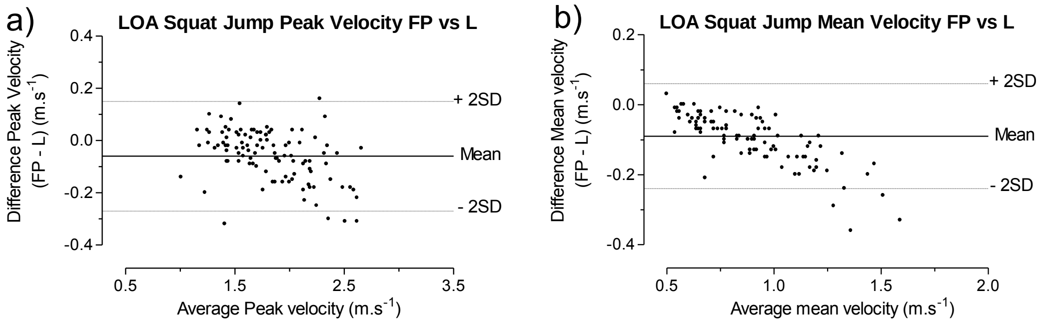


Figure 32: Limits of agreement for peak and mean velocity between FP and L during loaded squat jumps.

a) -0.06 ± 0.21 m.s^{-1}, *d* = 0.15, %Δ mean = 3.4%	b) -0.09 ± 0.16 m.s^{-1}, *d* = 0.32, %Δ mean = 11.3%

LOA = limits of agreement, %Δ mean = relative change in mean, *d* = Cohen's *d* effect size,
FP = force plate only, L = laser only;

Figure 33a and b illustrate the correlation between FP and L for measures of peak and mean velocity respectively. Both relationships were high (*r* = 0.98 and *r* = 0.99 respectively).

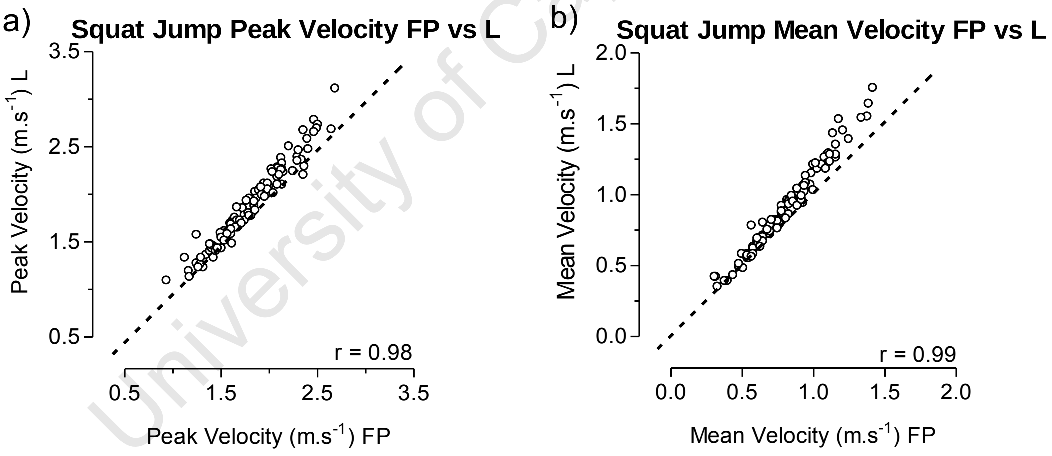


Figure 33: Relationship between peak velocity (FP vs. L) and mean velocity (FP vs. L) for the squat jump. Data are shown as the correlation coefficient *(r)* and the 95% Confidence intervals of the correlation coefficient in brackets.

a) *r* = 0.98 (0.96 - 0.99)	b) *r* = 0.99 (0.98 - 0.99)

FP = force plate only, L = laser only;

3.2.2.2 Bench Throw

Power-load relationship

Table 13 shows the measures of peak and mean power for each workload derived from the three different methods. The following applies to measures of peak and mean power similarly. Maximum power (P_{max}) occurred at the "bar only" load for FP and FPL, whereas P_{max} occurred at the 30% 1RM workload for L (Table 13). Significant differences in power output between P_{max} and subsequent loads were only found for FP (i.e. at 30% 1RM) ($p < 0.01$).

Table 13: Measures of peak and mean power output obtained from three techniques during the bench throw*. Values are presented as group mean and ± SD, (n = 15 in each group).

Load (%1RM)	FP	L	FPL
Peak Power (W)			
Bar only	**1866 ± 597**	1116 ± 177	**1354 ± 477**
30	1489 ± 321†	**1185 ± 199**	1211 ± 282
40	1269 ± 214	1173 ± 214	1119 ± 212
50	1222 ± 227	1064 ± 167	1050 ± 184
60	1066 ± 243	959 ± 173	960 ± 168
70	925 ± 213	820 ± 180	857 ± 179
80	703 ± 164	678 ± 172	697 ± 160
Mean Power (W)			
Bar only	**1032 ± 312**	595 ± 116	**756 ± 197**
30	863 ± 153†	**622 ± 102**	721 ± 123
40	763 ± 117	613 ± 103	668 ± 111
50	698 ± 111	554 ± 78	600 ± 88
60	597 ± 123	510 ± 87	538 ± 91
70	513 ± 91	447 ± 85	470 ± 90
80	365 ± 76	354 ± 78	366 ± 82

* Load at which maximum power occurred in bold, † significance ($p<0.01$) between power at "bar only" load and 30% 1RM-load, Bar only = absolute load of 21.3 kg, FP = force plate only, L = laser only, FPL = force plate + laser;

Figure 34 shows the peak power-load relationship for each method of assessment. There were significant differences within the two main effects “load” and “method” ($p < 0.01$ and $p < 0.05$ respectively) as well as within the interaction effect (method * load) ($p < 0.01$). In FP and FPL peak power was maximised at the “bar only” load followed by a constant decrease of the power curve towards the heaviest load. Yet, the curve for L showed an incline from “bar only” to 30% 1RM (P_{max} load), before gradually decreasing towards the heaviest load. In addition, measures of peak power for the “bar only” load were significantly different between all three methods ($p < 0.05$).

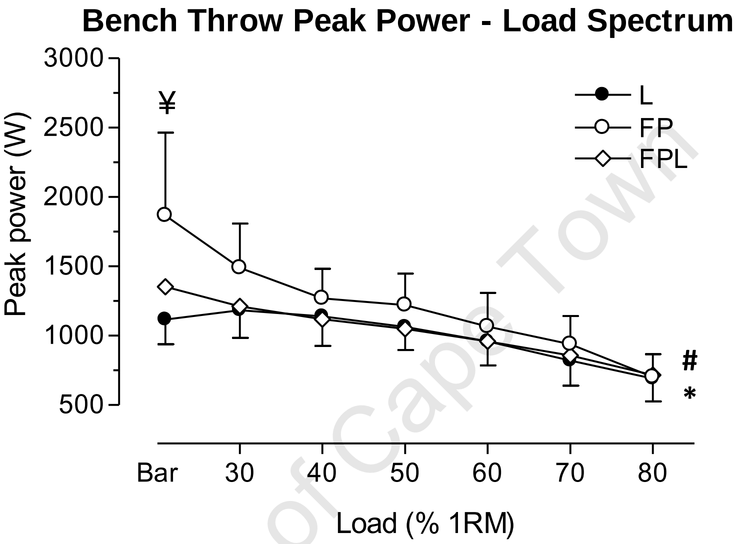


Figure 34: Peak power-load relationship for the bench throw derived from FP, L and FPL.
#: significance ($p<0.01$) method * load,
*: significance ($p<0.01$) load,
¥: significance ($p<0.05$) FP_{Pmax}, FPL_{Pmax} and L_{Bar};

Figure 35 shows the mean power-load relationship for each method of assessment. There were significant differences within the two main effects “load” and “method” as well as within the interaction effect (method * load) ($p < 0.01$ respectively). Measures of mean power were significantly different between the all three methods at the “bar only” load. Mean power output at 30% 1RM derived from L (i.e. P_{max}) was significantly lower compared to measures of mean power from FP ($p < 0.01$). Differences between the peak and mean power-load relationship were more obvious at lighter loads and became less apparent towards heavier loads (Figure 34 and 35).

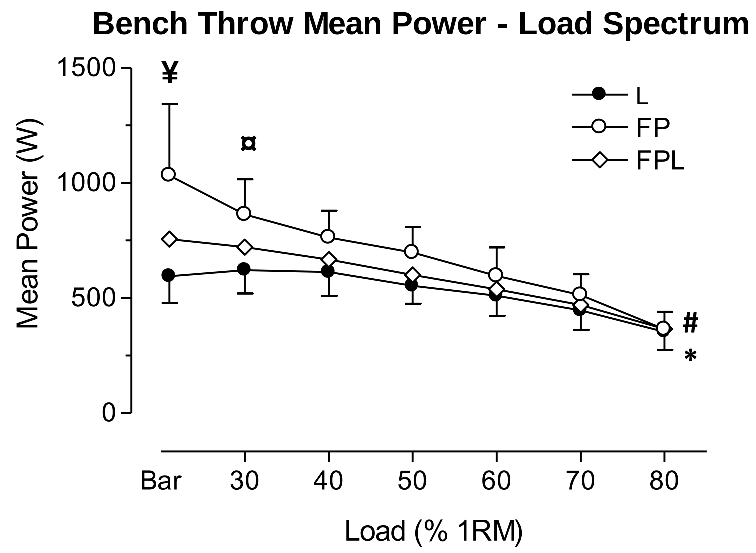


Figure 35: Mean power-load relationship for the bench throw derived from FP, L and FPL.
#: significance ($p<0.01$) method * load,
*: significance ($p<0.01$) load,
¥: significance ($p<0.01$) FP_{Pmax}, and FPL_{Pmax} and L_{Bar},
¤: significance ($p<0.01$) L_{Pmax} and $FP_{30\%\ 1RM}$;

Up to the 70% 1RM load, mean and peak power outputs derived from FP were consistently higher than respective measures derived from FPL and L (Figure 34 and 35).

In the following graphs the limits of agreement (LOA) between the three methods for peak and mean power are presented (Figure 36). The distribution of the data generally shows a heteroscedastic pattern, particularly for those comparisons involving method FP (i.e. Figure 36a, b, c and d). As discussed on page 69, a heteroscedastic pattern indicates a change in the differences for measures of power between two methods as the magnitude of the power changes. The heteroscedasticity was more obvious for mean power compared to peak power (Figure 36).

The effect size statistics are shown in the legend of Figure 36. These were highest in peak and mean power between FP and L (*d* = 0.54 and *d* = 0.74 respectively); and in peak and mean power between FP and FPL (*d* = 0.48 and *d* = 0.46 respectively).

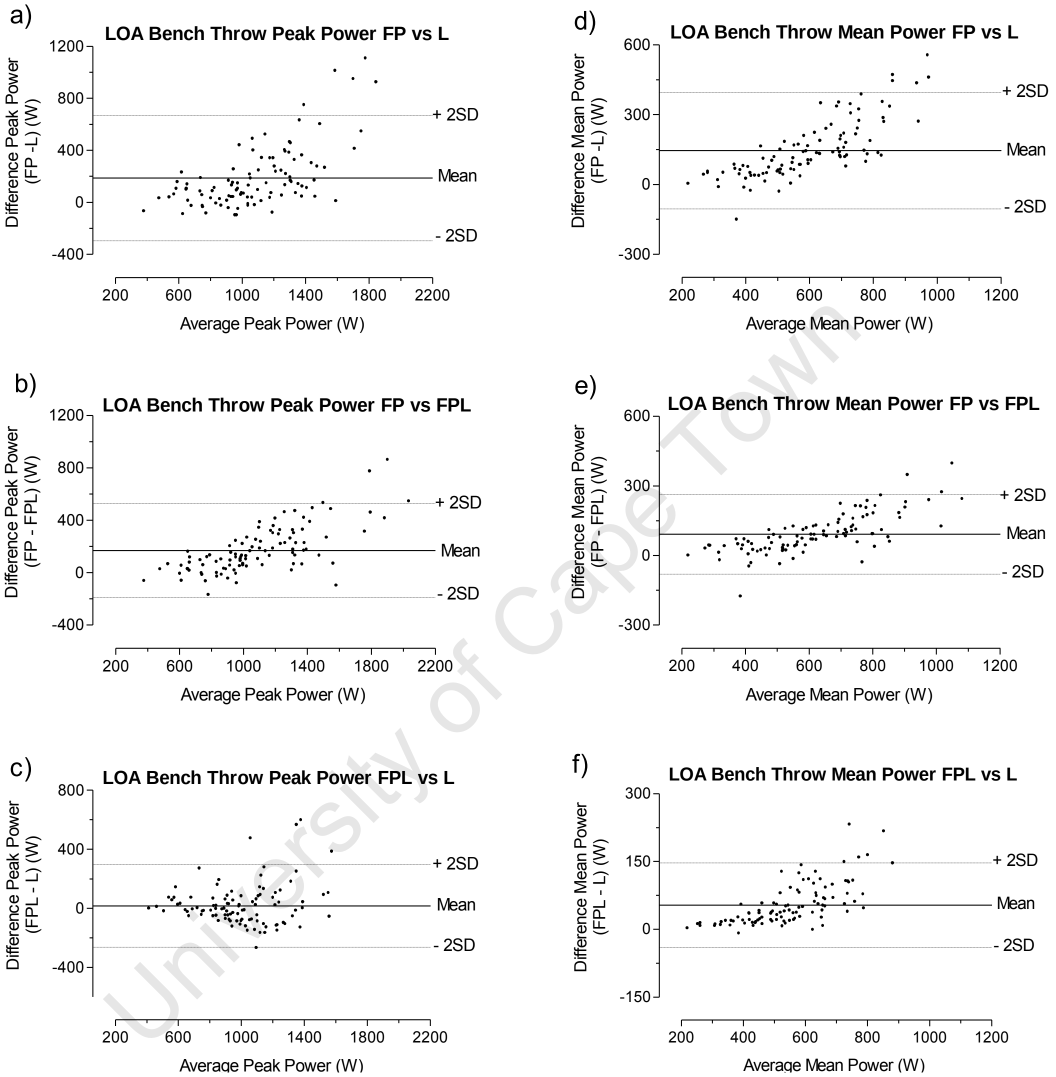


Figure 36: Limits of agreement for peak and mean power between FP, L and FPL during bench throws.

LOA for peak power between:
a) FP and L
(187 ± 482 W), *d* = 0.54, %Δ mean = 15.8%

b) FP and FPL
(170 ± 360 W), *d* = 0.48, %Δ mean = 14.4%

c) FPL and L
(17 ± 282 W), *d* = 0.07, %Δ mean = 1.7%

LOA for mean power between:
d) FP and L
(145 ± 250 W), *d* = 0.74, %Δ mean = 21.7%

e) FP and FPL
(92 ± 172 W), *d* = 0.46, %Δ mean = 13.7%

f) FPL and L
(54 ± 94 W), *d* = 0.36, %Δ mean = 9.3%

LOA = limits of agreement, %Δ mean = relative change in mean, *d* = Cohen's *d* effect size,
FP = force plate only, L = laser only, FPL = force plate + laser;

Table 14 presents the correlation for mean and peak power between the methods. There were low correlations between method FP and L and between FPL and L for peak power (*r* = 0.76 and *r* = 0.79 respectively). Correlations for mean power were higher compared to respective measures of peak power (Table 14).

Table 14: Relationship between FP, L and FPL for the measurements of mean and peak power for the bench throw. Data are shown as the correlation coefficient (*r*) and the 95% Confidence intervals of the correlation coefficient in brackets.

	FP		**L**		**FPL**	
	Peak Po	Mean Po	Peak Po	Mean Po	Peak Po	Mean Po
FP	--				**0.94** (0.91 - 0.96)	**0.95** (0.93 - 0.97)
L	**0.76** (0.67 - 0.83)	**0.85** (0.79 - 0.90)	--			
FPL			**0.79** (0.70 - 0.85)	**0.95** (0.93 - 0.97)	--	

Po = Power (W), FP = force plate only, L = laser only, FPL = force plate + laser;

The following section presents the results for measures of peak and mean force.

Force-load relationship

Table 15 shows the measures of peak and mean force output for each workload derived from the two different methods. Maximum force output occurred at 80% 1RM for peak and mean measures for both methods.

Table 15: Peak and mean force (N) measures obtained from FP and L for each load during the bench throw. Values presented as mean ± SD, (n = 15 in each group).

Load (%1RM)	FP	L
Peak Force (N)		
Bar only	717 ± 134	544 ± 61
30	786 ± 151	696 ± 199
40	844 ± 152	810 ± 166
50	929 ± 233	888 ± 185
60	987 ± 249	977 ± 203
70	1041 ± 195	1047 ± 204
80	**1069 ± 189**	**1088 ± 205**
Mean Force (N)		
Bar only	483 ± 74	390 ± 42
30	558 ± 95	502 ± 91
40	624 ± 111	581 ± 107
50	683 ± 113	640 ± 113
60	740 ± 135	702 ± 143
70	812 ± 150	740 ± 193
80	**869 ± 162**	**846 ± 157**

*Load at which maximum power occurred in bold; Bar only = absolute load of 21.3 kg, FP = force plate only, L = laser only, FPL = force plate + laser;

Figure 37 shows the peak force-load relationship for FP and L. There was no significant difference within the main effect “method” for measures of peak force. However, there were significant differences within the main effect “load” and the interaction effect (method * load) ($p < 0.01$ respectively). Differences in the force-load relationship were more obvious towards lighter loads and became less apparent towards heavier loads (Figure 37).

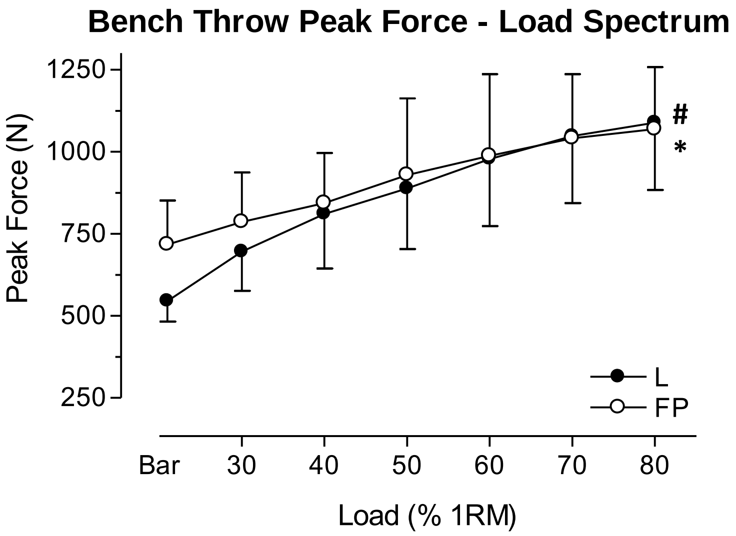


Figure 37: Peak force-load relationship for the bench throw derived from FP and L.
#: significance (p<0.01) method * load,
*: significance (p<0.01) load;

Figure 38 illustrates the mean force-load relationship for FP and L. Only differences within the main effect “load” were significant for measures of mean force between FP and L (p< 0.01).

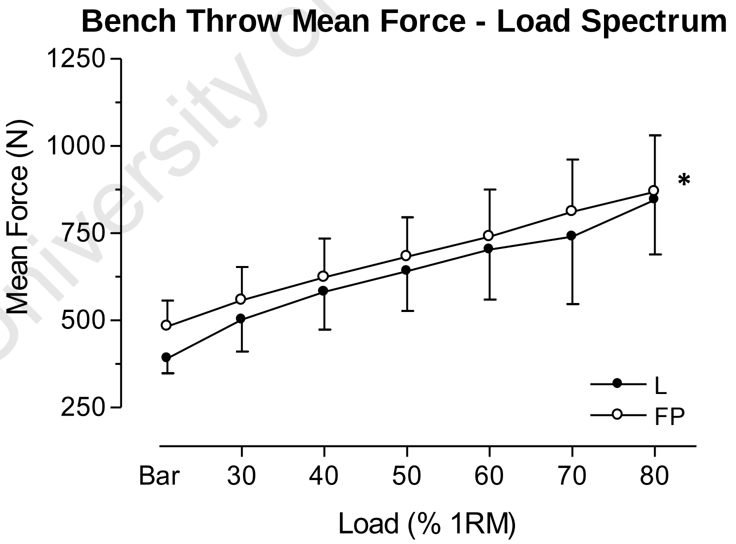


Figure 38: Mean force-load relationship for the bench throw derived from FP and L.
*: significance (p<0.01) load;

Figure 39a shows the limits of agreement for peak force between FP and L. The magnitude of differences was small (*d* = 0.17) and relative change in mean was 4.5% (Figure 39a).

Figure 39b presents the limits of agreement for mean force between FP an L. The magnitude of differences was small (*d* = 0.23) and relative change was 6.2% (Figure 39b). The data shows a heteroscedastic pattern for both, peak and mean force (Figure 39a and b respectively).

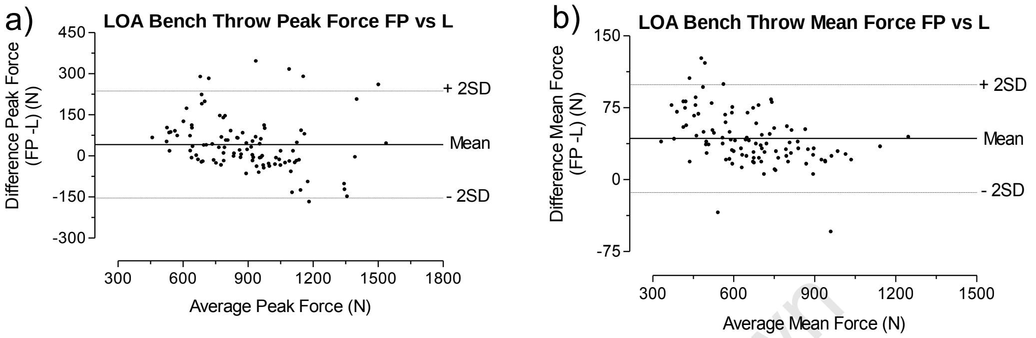


Figure 39: Limits of agreement for peak and mean force between FP and L during bench throws.

a) 41 ± 196 N, *d* = 0.17, %Δ mean = 4.5%	b) 43 ± 56 N, *d* = 0.23, %Δ mean = 6.2%

LOA = limits of agreement, %Δ mean = relative change in mean, *d* = Cohen's *d* effect size,
FP = force plate only, L = laser only;

Figure 40 illustrates the correlation for peak and mean force between FP and L. There was a low correlation for measures of peak force (*r* = 0.52), whereas measures of mean force showed a high correlation (*r* = 0.98) (Figure 40).

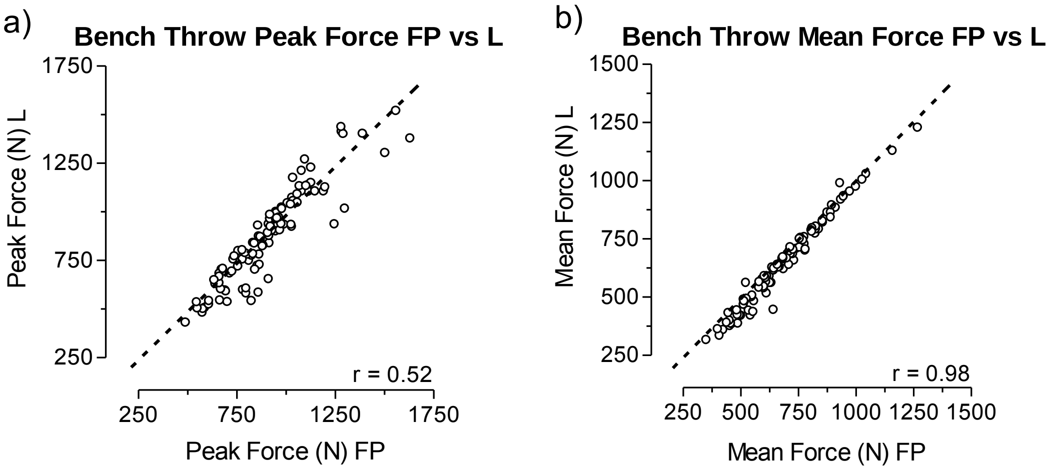


Figure 40: Relationship between peak force (FP vs. L) and mean force (FP vs. L) for the bench throw. Data are shown as the correlation coefficient (*r*) and the 95% Confidence intervals of the correlation coefficient in brackets.

a) *r* = 0.53 (0.37 - 0.66)	b) *r* = 0.98 (0.98 - 0.99)

FP = force plate only, L = laser only;

In the following section the results for measures of peak and mean velocity between FP and L are presented.

Velocity-load relationship

Table 16 shows the measures of peak and mean velocity output for each workload derived from method FP and L. Maximum velocity occurred at "bar only" for peak and mean values for both methods. Peak and mean velocity for the subsequent load (i.e. 30% 1RM) was significantly lower for FP ($p < 0.01$) (Table 16).

Table 16: Peak and mean velocity ($m.s^{-1}$) measures obtained from FP and L for each load during the bench throw*. Values presented as mean ± SD, (n = 15 in each group).

Load (%1RM)	FP	L
Peak Velocity ($m.s^{-1}$)		
Bar only	**4.06 ± 0.58**	**2.82 ± 0.22**
30	2.92 ± 0.39 †	2.23 ± 0.21
40	2.25 ± 0.27	1.91 ± 0.22
50	1.83 ± 0.33	1.54 ± 0.23
60	1.40 ± 0.26	1.25 ± 0.21
70	1.11 ± 0.25	0.97 ± 0.20
80	0.77 ± 0.21	0.75 ± 0.21
Mean Velocity ($m.s^{-1}$)		
Bar only	**2.24 ± 0.34**	**1.63 ± 0.19**
30	1.68 ± 0.25 †	1.38 ± 0.14
40	1.33 ± 0.14	1.14 ± 0.11
50	1.10 ± 0.15	0.93 ± 0.10
60	0.85 ± 0.10	0.76 ± 0.10
70	0.66 ± 0.12	0.60 ± 0.11
80	0.44 ± 0.10	0.43 ± 0.12

*Load at which maximum velocity occurred in bold; † significance ($p<0.01$) between velocity at "Bar only" and 30% 1RM load,
FP = force plate only, L = laser only, Bar only = absolute load of 21.3 kg;

Figure 41 presents the peak velocity-load relationship and Figure 42 shows corresponding mean velocity-load relationship for method FP and L. The following description applies similarly to both measures of peak and mean velocity. There were significant differences within both main effects "method" and "load" as well as within the interaction effect (method * load) ($p < 0.01$respectively). Differences in the velocity-load relationship were more obvious at lighter loads and became less apparent towards heavier loads (Figure 41 and 42). Measures of mean and peak velocity at “bar only” and 30% 1RM were significantly higher for FP than measures derived from L ($p < 0.01$ respectively).

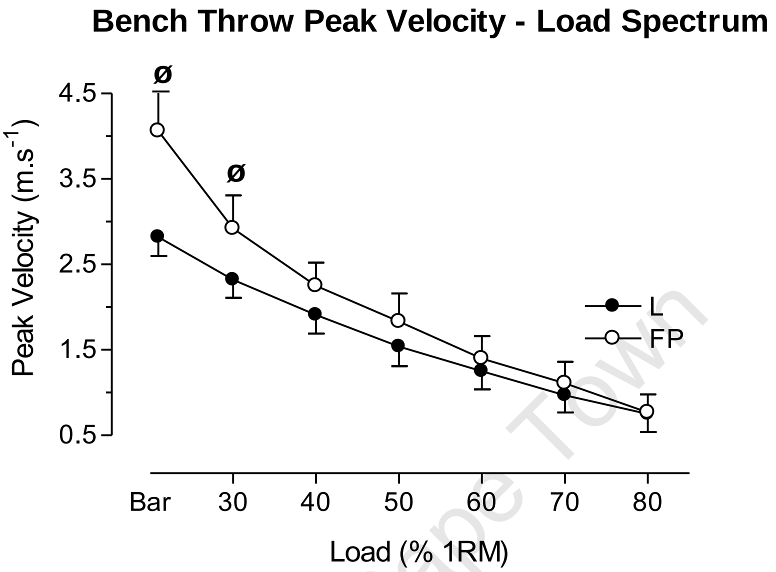


Figure 41: Peak velocity-load relationship for the bench throw derived from FP and L.
#: significance (p<0.01) method * load,
*: significance (p<0.01) load,
ø: significance (p<0.01) FP vs. L;

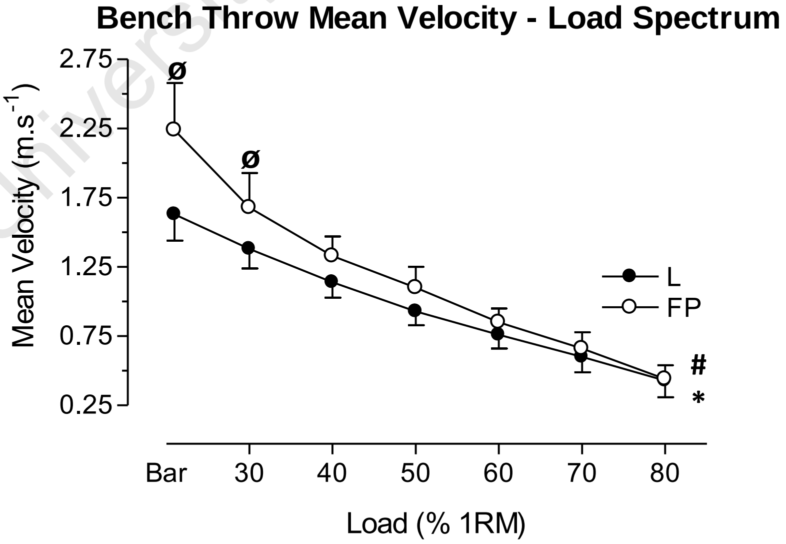


Figure 42: Mean velocity-load relationship for the bench throw derived from FP and L.
#: significance (p<0.01) method * load,
*: significance (p<0.01) load,
ø: significance (p<0.01) FP vs. L;

Next, the limits of agreement of peak and mean velocity between FP and L are presented. The distribution of the data clearly shows a heteroscedastic pattern for peak and mean velocity (Figure 43a and b respectively). The magnitude of differences for peak velocity was moderate (*d* = 0.42) and the relative change in mean was 3.4%.The magnitude of differences was moderate (*d* = 0.36) and relative change in mean was 16.6% for mean velocity (Figure 43a and b).

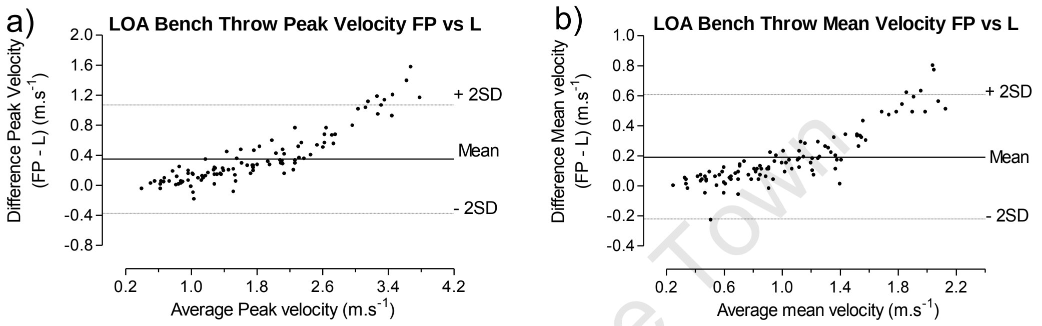


Figure 43: Limits of agreement for peak and mean velocity between FP and L during bench throws.

a) 0.35 ± 0.72 m.s^{-1}, *d* = 0.42, %Δ mean = 3.4% b) 0.19 ± 0.42 m.s^{-1}, *d* = 0.36, %Δ mean = 16.6%

LOA = limits of agreement, %Δ mean = relative change in mean, *d* = Cohen's *d* effect size, FP = force plate only, L = laser only;

The next figure illustrates the correlation for measures of peak and mean velocity between FP and L (Figure 44a and b respectively). There were good correlations for both, peak and mean velocity (*r* = 0.98 respectively).

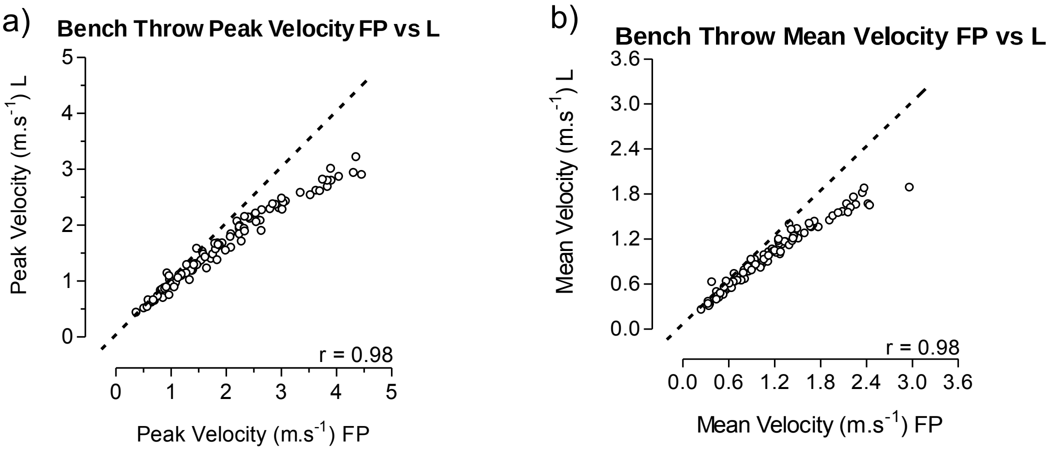


Figure 44: Relationship between peak velocity (FP vs. L) and mean velocity (FP vs. L) for the bench throws. Data are shown as the correlation coefficient *(r)* and the 95% Confidence intervals of the correlation coefficient in brackets.

a) *r* = 0.98 (0.97 - 0.99)	b) *r* = 0.98 (0.97 - 0.99)
FP = force plate only, L = laser only	

3.2.3 Discussion

The following discussion is divided into two parts. The first part addresses the findings for measures of reliability for each of the three methods. To obtain comprehensive information on the reliability of the different methods several parameters were analyzed (61). Quantifying the reliability is particularly important, as proper conclusions on the comparability between the different methods of assessing muscle power can only be made if the levels of reliability are high for each method. Following on from this section is the discussion on the comparability between the three methods of assessment.

3.2.3.1 Reliability of assessments for measures of power, force and velocity

Different statistical tests were used to determine the level of reliability for each method of assessment (page 53). The results for each measure of reliability are summarized below (Table 17). The main finding is that measures of force, velocity and power during the squat jump and bench throw exercises performed using a Smith machine were shown to be reliable (Table 17). In particular, this finding indicates sufficient reproducibility of measurements within all three methods of assessment (Table 5 and 7). Therefore, it can be argued that the differences observed for the outcome measures between the three assessments were mainly due to methodological differences rather than random variations of the measurements. This suggests that the experimental design was adequate to interpret the data and formulate an answer to the research question on comparability between different methods of assessment.

Table 17: Summary of results for indicators of reliability for the squat jump and bench throw exercises. *

ICC	0.90 - 1.00 **
TEM%	1.3 - 7.9%
% Change in mean	-1.9 - 0.9%
r	0.93 - 0.99

*Data are presented as the range of magnitude found for each parameter
ICC = intraclass correlation coefficient, **= except for mean power during squat jumps for "laser only" (ICC = 0.88),TEM% = relative typical error of measurement
% Change mean = relative change in mean, *r* = test-retest correlation coefficient;

In the following section general issues associated with the reliability of methods assessing power output as mentioned in the literature review (page 10) are discussed.

One major concern when the literature are summarised refers to the lack of sufficient reliability for assessments of dynamic muscle function during resistance exercises (41). However, based on the findings of this study it can be concluded that performance parameters (i.e. force, velocity and power output) have good levels of reliability when measured under well controlled conditions as described in this study. These data (Table 5, 6, 7 and 8) therefore contribute to the reducing the deficiency in knowledge which exists in the literature.

Another issue of debate refers to the question of whether peak or average power output is more useful and interpretable (32; 41). In the context of reliability, measures of peak values for force, velocity and power were more reliable than the respective measures of mean values, in particular for the squat jump exercise (Table 5). This was also shown by Hori et al. (63) who found higher intraclass correlation coefficients and lower coefficients of variation for measures of peak power compared to respective values for mean power during free weight jump squats. Moreover, from a practical point of view, determination of peak values is less prone to errors than the determination of mean values (page 19). Thus, in the context of reliability, measures of peak values are superior compared to mean values. It is, however important to investigate the effects of methodological differences of power, force and velocity for both, peak and mean values.

As pointed out earlier in the literature review (page 15) differences exist between trained and untrained individuals with regards to their force, velocity and power output characteristics. Ballistic muscle performance tests carried out by well trained athletes showed good reliability (6). In this study muscle performance tests were found to be reliable for subjects with moderate levels of conditioning. It might therefore be concluded that the assessment of muscle performance during the squat jump and bench throw exercises performed using a Smith machine can be used for a broader spectrum of athletes with varying conditioning levels.

3.2.3.2 Comparison between the methods of assessment for measures of power, force and velocity

The next section discusses the results of the comparison between the three methods of measuring power, force and velocity for the loaded squat jump and bench throw exercises. The discussion follows a similar structure as adopted for the presentation of the results. The main findings for measures of power from FP, L and FPL are outlined first; results for measures of force and velocity derived from FP and L are integrated into the subsequent discussion about the reasons for the differences between the methods of assessment. In addition, discussions on potential differences between methods of assessment always refer to methods similar to those used in this study.

Loaded Squat Jump

The main finding of the study was that there were significant differences for the power-load relationship between the three methods of assessment (i.e. interaction of method * load). More specifically the power-load relationship derived from FP, L and FPL showed significantly different curve characteristics, particularly at lighter loads (Figure 23). Consequently, P_{max} occurred at different workloads (i.e. at 30% 1RM for FP and L and at “bar only” for FPL) for measures of peak power. P_{max} for mean power output occurred at “bar only” for each method (Figure 24). Measures of power were generally lowest for FP and highest for FPL. Differences in power output at similar loads were not statistically significant, but might be considered meaningful for practical applications, such as comparisons of muscle power capacities between athletes (16; 52). For example, Baker (9) was able to discriminate between rugby players of different playing levels based on a mean difference of 301 W in their mean power output capacities during jump squats (20 kg load). Yet, the observed difference for mean power in this study was 360 W at the “bar only” load (i.e. 21 kg) between FP and FPL.

The following considerations might explain the reason for the observed differences. As outlined in the methodology section (page 44), the reference point of measurement using force plate technique is the center of gravity of the object (i.e. bar + body), whereas for the linear position transducer measurements are derived from the displacement of the bar. This is illustrated in Figure 45. Thus, measures of velocity, force and power are only comparable, if these two points of reference show a similar movement pattern over time during the exercise (63).

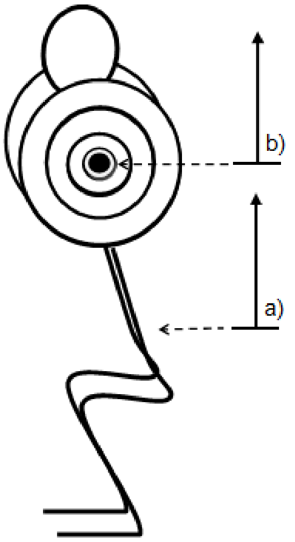


Figure 45: Schematic of reference point of measurement
a) force plate only = center of gravity of the object (body + bar)
b) displacement transducer only = bar

However, the velocity-load relationships derived from FP and L showed significant differences (i.e. interaction of method * load). Deriving velocity from the displacement of the bar generally resulted in higher measures of velocity compared to measures derived from ground reaction force with significantly higher measures of mean velocity at the "bar only" load for L compared to FP (Figure 31). Subsequent calculations of power output were higher for L compared to FP (Figure 23 and 24). Hori et al. (63), investigating related methodologies, reported similar differences between measures of velocity derived from displacement of the bar and ground reaction force (Table 18). Therefore, it is suggested that these differences occurred because the center of gravity of the object (i.e. bar + body) and the bar did not travel in parallel (63). Consequently, depending on the reference point of measurement (i.e. bar or center of gravity of the object) force-time and velocity-time relationships were different. This resulted in different interactions of force and velocity and subsequently to different calculations of power over time. In this context it is noteworthy that measures of maximum force and velocity for L were higher than those for FP, yet measures of power output for FPL showed substantially higher power outputs. This is clarified in

Figure 46. Similar effects were reported in the aforementioned study by Hori et al. (63) (Table 18).

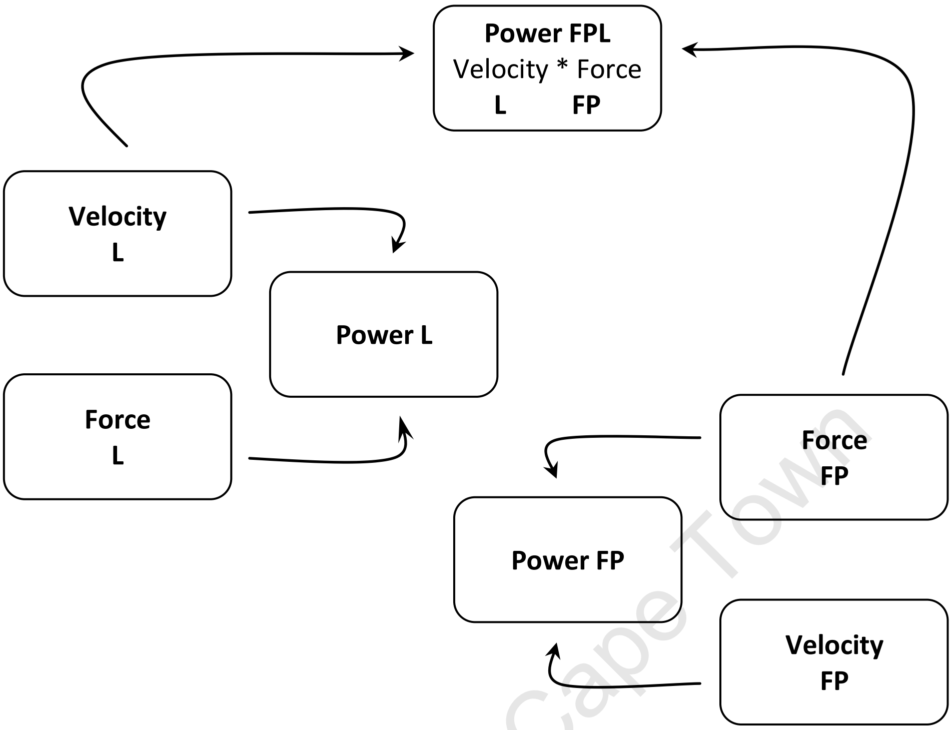


Figure 46: Illustration of the magnitude for measures of power, force and velocity for FP, L and FPL
FP = force plate only, L = laser only, FPL = force plate + laser;

Table 18:Measures of peak velocity, force and power derived from different methods as reported by Hori et al. (63).

	Peak Velocity (m.s^{-1})	Peak Force (N)	Peak Power (W)
FP	1.99 ± 0.12	2151 ± 172	3866 ± 451
LPT	2.23 ± 0.16**	2159 ± 231	3567 ± 494*
FP + LPT	2.23 ± 0.16**	2151 ± 172	4427 ± 557**

* significantly different from FP ($p<0.05$), ** significantly different from FP ($p<0.01$),
FP = force plate only, LPT = linear position transducer only, FP + LPT = force plate + linear position transducer;

Combining data of velocity derived from bar displacement and data of force from ground reaction force seems to result in a more favourable force-velocity interaction over time, as power outputs for FPL were substantially higher compared to measures of power for FP and L (page 66). The reason why such differences were less apparent at heavier loads might be explained by the following. The generation of velocity decreases significantly towards heavier loads and differences between velocity for L and FP become smaller than for lighter loads (page 66). Therefore, it is suggested that calculations of power are less effected by differences in measures of velocity between L and FP at relatively heavy loads. From a principal perspective, combining measures of force derived from force plate technique and velocity derived from bar displacement is not valid as this is a mismatch of physical quantities from two different objects (bar vs. body). Therefore, power measures derived from FPL represent neither the power applied to the bar nor the power applied to the ground (32; 63). In accordance with this, differences between the methods were most obvious for comparisons involving FPL (page 69).

In addition, changes in power output at subsequent loads of P_{max} were relatively small for all methods. For example, for measures of peak power the change in power output ranged from 21 W to 167 W (page 66). Similarly small differences in power output for subsequent loads of P_{max} were reported by Harris et al. (56) for peak and mean power output during half squats. Thus, even small differences between methods of assessment for measures of power might result in differences for P_{max}. Hence, comparisons of P_{max} for a specific exercise between different methods are problematic, due to the substantial differences in the power-load curves observed at lighter loads in this study (page 67).

In summary, caution should be applied when comparing power-load relationships derived from different methods, particularly at lighter loads. Such differences might be one reason for the contradictory findings associated with the exact identification of P_{max} in certain exercises such as ballistic type exercises, where maximum power occurs at relatively light loads (79; 84). If possible, scientists and practitioners should use the same method of assessment for each testing occasion to ensure high levels of comparability between the results of the tests.

Even though outcome measures for the three methods showed distinct differences, the correlation coefficients for measures of power, force and velocity were high (0.93 - 1.00) (page 70, 74 and 78). Therefore, it would be useful to evaluate prediction equations (e.g. regression analysis) which correct for the anomalies between methods in future research.

Bench Throw

The main finding was that the power-load relationships were significantly different between the methods, in particular at lighter loads (page 80 and 81). P_{max} for measures of peak and mean power occurred at “bar only” for FP and FPL, but at 30% 1RM for L. Peak power output was significantly different between all three methods at “bar only” and between FPL and L for measures of mean power at 30% 1RM (page 81). Power outputs for FP were consistently higher compared to FPL and L (page 80 and 81). Therefore, measures of power during the bench throw exercise assessed with different data acquisition technologies and methods of calculating power are not directly comparable.

In addition, the force-, and velocity-, load curves were significantly different between measures derived from ground reaction force and displacement of the bar (page 85 and 89). Mean and peak measures of velocity at “bar only” and 30% 1RM were significantly higher for FP compared to L (page 89). Differences due to a mismatch in the reference point of measurement, as discussed for the squat jumps, do not apply to the bench throw exercise, as the bar is the system on which all external forces act (48). It may be speculated that the system mass used to derive velocity from force plate data and force from data of the displacement tracking laser was the main source for the observed differences.

The following explanation supports this argument. The mass used for the calculations of power output was the mass of the loaded bar. This resulted in an underestimation of the total mass (i.e. system mass) involved in the movement, as parts of the arms are lifted upwards as well (90). This underestimation of system mass, in turn, has distinctive effects on measures of velocity derived from ground reaction force (Equation (i)) and on measures of force derived from displacement of the bar (Equation (ii)):

ΔVelocity = Force * Time / System Mass....................................... (i)*

Force = Acceleration * System Mass... (ii)*

*(*adapted from page 16 and 17)*

Table 19 presents the measures of force, velocity and power during the bench throw with the "bar only" load based on the mass of the bar (i.e. 21.3 kg) and respective measures based on the mass of the bar plus 4.7 kg (estimated correction for the part of the mass of the arm involved in the upwards movement) i.e. total mass was 26.0 kg. Note, that in FP, division by a smaller mass resulted in a *higher* velocity value, whereas, in L multiplying a smaller mass and acceleration resulted in a *lower* force value.

Table 19: Effects of changes in system mass for calculating force velocity and power during the bench throw exercise*

Force Plate only			
System Mass (kg)	Force (N)	Velocity (m.s^{-1})	Power (W)
21.3	820	4.62	2320
26.0	820	2.86	**1370**
Laser only			
System Mass (kg)	Force (N)	Velocity (m.s^{-1})	Power (W)
21.3	540	2.93	1090
26.0	720	2.93	**1330**

*Values were calculated using the NAMS – software from bench throw data obtained during a "bar only" trial using a correction for arm mass of 4.7 kg.

The contribution of the effect of upper limb inertia is relatively larger at lighter loads compared to its contribution at heavier loads (33). This is in principle similar to the effects of inclusion or exclusion of body mass during lower body exercises. This therefore explains why the differences between measures of power, force and velocity were more obvious at lighter loads and became less apparent at heavier loads (page 80, 85 and 89). Determining the exact contribution of upper limp mass would involve time consuming procedures (e.g. based on Archimedes principle, where the apparent loss in weight of a body immersed in a fluid is equal to the weight of the displaced fluid (28). Such procedures might be considered for research purposes, but lacks practicality as required for field testing. Generalized correction factors based on anthropometrical data might increase both, the accuracy and comparability of measures derived from ground reaction force and displacement of the bar.

In summary, neglecting arm mass as a contributor to system mass results in an underestimation of power for L and to a greater extent to an overestimation of power for method FP. Due to the smaller relative contribution of arm mass for heavier bar loads these differences become less apparent towards the right side of the load spectrum. Generalized correction factors might increase the accuracy and comparability of outcome measures derived from bar displacement tracking devices and force plate techniques and might be useful for practical applications. Differences in the reference point of measurement, as for the lower body, are not a concern for upper body exercises. Thus, the combination of velocity from L and force from FP is valid and subsequent power measures are more accurate than power measures based on L or FP only, especially as no excessive data manipulation is necessary to acquire force data from a force plate and velocity data from a linear position transducer (32; 63).

Data Processing

The following section discusses the observed differences between the three methods of assessment on the background of technical considerations and aspects of data acquisition processes used to derive measures of velocity, force and power for the three methods.

Data acquisition and signal processing can influence the outcome measures substantially (page 24), in particular, when only displacement data are available to derive velocity force and power. Deriving velocity from displacement is relatively straight forward. Yet, additional filtering is necessary to derive acceleration from velocity data, which is already a derived measure itself. Thus, small inaccuracies in the original measurement might be amplified during subsequent calculations of power output. Moreover, it is suggested that the specific equipment configurations such as type of filter and cut-off frequencies used for signal processing have different effects on the calculation of velocity, force and power (Appendix A and (63)).

3.2.3.3 Conclusion

In the following sections the conclusions of this study are formulated based on the findings presented in the discussion. A short evidence-based answer will be provided for each research question outlined at the onset of the thesis:

Question 1

> *For data acquired simultaneously during the squat jump and bench throw exercises with three different methods of assessment, i.e. force plate, displacement sensor, and a combination of force plate and displacement sensor:*

How reliable are measurements of force, velocity and power for each method?

Answer

It may be concluded that measurements of velocity, force and power had good levels of reliability for each method of assessment, at least when measured under the conditions described in this study (i.e. a modified Smith machine, broad spectrum of athletes). Peak values showed slightly higher levels of reliability compared to mean measures for all variables. Thus, peak values should be the preferred measure, in particular if small changes/differences in the outcome measures are considered meaningful.

Question 2

> *For data acquired simultaneously during the squat jump and bench throw exercises with three different methods of assessment, i.e. force plate, displacement sensor, and a combination of force plate and displacement sensor:*

Are there significant differences in the power-load relationship derived from these three methods for the squat jump and bench throw exercises?

Answer

Loaded Squat Jump

It can be concluded that a comparison of the power-load relationships derived from different methods, should be made with caution at the lighter loads. This finding may explain the contradictory results from studies which have attempted to identify the P_{max} in certain ballistic type exercises where maximum power occurs at relatively light loads. It is suggested that these differences occurred because the center of gravity of the system (i.e. bar + body) and the bar did not travel in parallel. Consequently, depending on the reference point of measurement (i.e. bar or center of gravity of the system) force-time and velocity-time relationships were different, which resulted in different interactions of force and velocity and subsequent calculations of power. From a principle perspective, combining measures of force derived from force plate technique and velocity derived from bar displacement is not valid as this is a mismatch of physical quantities from two different systems (bar vs. body). Therefore, power measures derived from FPL represent neither the power applied to the bar nor the power applied to the ground.

Bench Throw

Neglecting the mass of the subject's arm as a contributor to the system mass results in an underestimation of power output for L and to a greater extent to an overestimation of power output for method FP. Due to the smaller relative contribution of arm mass for heavier bar loads these differences become less apparent at heavier loads. Generalized correction factors might increase the accuracy and comparability of outcome measures derived from bar displacement tracking devices and force plate techniques and might be useful for practical applications. Differences in the reference point of measurement, as for the lower body, are not a concern for upper body exercises. Thus, the combination of velocity from L and force from FP is valid and subsequent calculations of power are more accurate than measures of power based on L or FP only, especially as no excessive data manipulation is necessary to acquire force data from a force plate and velocity data from a linear position transducer.

This study was a very basic investigation on the comparability of different methods assessing muscle power output. Thus, choosing “concentric only” movements allowed for precise control of the movement (not so easy with stretch-shortening cycle movements). In turn, precise standardisation of the phenomenon during which data were acquired simultaneously from three different methods should improve the results/conclusions for the experiment, i.e. “are there significant differences between the methods for measures of power output?” (which has not previously been investigated in concentric only movements). The next research study could include stretch shortening cycle movements and investigate whether the results are concurrent with those of the “concentric only” study.

Reference List

1. Reflections on the Force-Velocity Curve. [Online]. http://www.sportsci.com/SPORTSCI/JANUARY/F-V%20CURVE.htm, accessed: 17.07.2008.

2. **Abernethy P, Wilson G and Logan P**. Strength and power assessment. Issues, controversies and challenges. *Sports Med* 19: 401-417, 1995.

3. **Alemany JA, Pandorf CE, Montain SJ, Castellani JW, Tuckow AP and Nindl BC**. Reliability assessment of ballistic jump squats and bench throws. *J Strength Cond Res* 19: 33-38, 2005.

4. **Allerheiligen B**. In-season strength training for power athletes. *J Strength Cond* 25: 23-28, 2003.

5. **Asci A and Acikada C**. Power production among different sports with similar maximum strength. *J Strength Cond Res* 21: 10-16, 2007.

6. **Baker D**. The relationship of running speed and measures of strength and power in professional rugby league players. *J Strength Cond Res* 13: 230-235, 1999.

7. **Baker D**. Acute and long-term power responses to pwer training: Observations on the training of an elite power athlete. *J Strength Cond Res* 23: 47-56, 2001.

8. **Baker D**. Comparison of upper-body strength and power between professional and college-aged rugby league players. *J Strength Cond Res* 15: 30-35, 2001.

9. **Baker D**. Differences in strength and power among junior-high, senior-high, college-aged, and elite professional rugby league players. *J Strength Cond Res* 16: 581-585, 2002.

10. **Baker D**. Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *J Strength Cond Res* 17: 493-497, 2003.

11. **Baker D and Broncos B**. Combining scientific research into practical methods to increase the effectiveness of maximum power training. *Australian Strength & Conditioning Association.* 2005.

12. **Baker D and Nance S**. The relationship between strength and power in professional rugby players. *J Strength Cond Res* 13: 224-229, 1999.

13. **Baker D, Nance S and Moore M**. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J Strength Cond Res* 15: 20-24, 2001.

14. **Baker D, Nance S and Moore M**. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *J Strength Cond Res* 15: 92-97, 2001.

15. **Baker D and Newton RU**. Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes. *J Strength Cond Res* 20: 541-546, 2006.

16. **Baker D and Newton RU**. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J Strength Cond Res* 22: 153-158, 2008.

17. **Balady G, Berra K and Golding L.** *ACSM's Guidelines for exercise testing and prescription*. Philadelphia: Lippincott Williams & Wilkins, 2007.

18. **Baud M, Mercier M and Chatelain F**. Transforming signals into quantitative values and mathematical treatment of data. *Scand J Clin Lab Invest Suppl* 205: 120-130, 1991.

19. **Beachle TR and Earle R.W.** *Essentials of Strength Training and Conditioning / NSCA*. Champain, Illinois: Human Kinetics Books, 2000.

20. **Behm DG and Sale DG**. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol* 74: 359-368, 1993.

21. **Behm DG and Sale DG**. Velocity specificity of resistance training. *Sports Med* 15: 374-388, 1993.

22. **Bemben MG and Rohrs DM**. Effect of resistance training on upper body strength, power and performance. *Appl Sports Sci Res* 5: 162-171, 1991.

23. **Bennet S**. Testing and Evaluation; Protocols and Use, Part 1. *J Strength Cond* 30: 39-41, 2008.

24. **Beyon JY**. *LabVIEW. Programming, data acquisition and analysis*. London: Prentice-Hall Int. (UK), 2001.

25. **Bland JM and Altman DG**. Measuring agreement in method comparison studies. *Stat Methods Med Res* 8: 135-160, 1999.

26. **Bourque JP and Sleivert G**. *Determinants of load at peak power during maximal effort squat jumps in endurance and power trained athletes* (Dissertation). Department of Kinesiology, University of New Brunswick, Canada: 2003.

27. **Bradley PS, Olsen PD and Portas MD**. The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *J Strength Cond Res* 21: 223-226, 2007.

28. **Brooks GA, Fahey TD, Withe TP and Kenneth MB.** *Exercise Physiology - Human Bioenergetics And Its Application*. McGraw Hill Education, 2005.

29. **Cormie P**. Powerlifting versus weightlifting for athletic performance. *J Strength Cond* 29: 55-57, 2007.

30. **Cohan J**. *Statistical Power Analysis for the Behavioural Sciences*. (second edition). Hillsdale, New Jersey: Lawrence Erlbaum, 1988.

31. **Cordova ML and Armstrong CW**. Reliability of ground reaction forces during a vertical jump: implications for functional strength assessment. *J Athl Train* 31: 342-345, 1996.

32. **Cormie P, Deane R and McBride JM**. Methodological concerns for determining power output in the jump squat. *J Strength Cond Res* 21: 424-430, 2007.

33. **Cormie P, McBride JM and McCaulley GO**. The influence of body mass on calculation of power during lower-body resistance exercises. *J Strength Cond Res* 21: 1042-1049, 2007.

34. **Cormie P, McCaulley GO, Triplett NT and McBride JM**. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340-349, 2007.

35. **Cronin J and Hansen KT**. Strength and power predictors of sports speed. *J Strength Cond Res* 19: 349-357, 2005.

36. **Cronin J and Henderson ME**. Maximal strength and power assessment in novice weight trainers. *J Strength Cond Res* 18: 48-52, 2004.

37. **Cronin J, Hing RD and McNair PJ**. Reliability and validity of a linear position transducer for measuring jump performance. *J Strength Cond Res* 18: 590-593, 2004.

38. **Cronin J, McNair PJ and Marshall RN**. The role of maximal strength and load on initial power production. *Med Sci Sports Exerc* 32: 1763-1769, 2000.

39. **Cronin J, McNair PJ and Marshall RN**. Developing explosive power: a comparison of technique and training. *J Sci Med Sport* 4: 59-70, 2001.

40. **Cronin J, McNair PJ and Marshall RN**. Force-velocity analysis of strength-training techniques and load: implications for training strategy and research. *J Strength Cond Res* 17: 148-155, 2003.

41. **Cronin J and Sleivert G**. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Med* 35: 213-234, 2005.

42. **Currell K and Jeukendrup AE**. Validity, reliability and sensitivity of measures of sporting performance. *Sports Med* 38: 297-316, 2008.

43. **Delmonico MJ, Kostek MC, Doldo NA, Hand BD, Bailey JA, Rabon-Stith KM, Conway JM, Carignan CR, Lang J and Hurley BF**. Effects of moderate-velocity strength training on peak muscle power and movement velocity: do women respond differently than men? *J Appl Physiol* 99: 1712-1718, 2005.

44. **Dugan EL, Doyle TL, Humphries B, Hasson CJ and Newton RU**. Determining the optimal load for jump squats: a review of methods and calculations. *J Strength Cond Res* 18: 668-674, 2004.

45. **Durnin J.V.G.A. and Womersly J.** Body fat assessment from total body density and its estimation from skinfold thickness: measurements on 481 men and women from 16 to 72 years. *Br J Nutr* 32: 77-97, 1974.

46. **Duthie GM, Young WB and Aitken DA**. The acute effects of heavy loads on jump squat performance: an evaluation of the complex and contrast methods of power development. *J Strength Cond Res* 16: 530-538, 2002.

47. **Elliott BC, Wilson GJ and Kerr GK**. A biomechanical analysis of the sticking region in the bench press. *Med Sci Sports Exerc* 21: 450-462, 1989.

48. **Falvo MJ, Schilling BK and Weiss LW**. Techniques and considerations for determining isoinertial upper-body power. *Sports Biomech* 5: 293-311, 2006.

49. **Faulkner JA**. Terminology for contractions of muscles during shortening, while isometric, and during lengthening. *J Appl Physiol 95*: 455-459, 2003.

50. **Fricke O and Schoenau E**. Examining the developing skeletal muscle: Why, what and how? *J Musculoscelet Neuronal Interact* 5: 225-231, 2005.

51. **Fry AC, Schilling BK, Staron RS, Hagerman FC, Hikida RS and Thrush JT**. Muscle fiber characteristics and performance correlates of male Olympic-style weightlifters. *J Strength Cond Res* 17: 746-754, 2003.

52. **Gabbett TJ**. Physiological characteristics of junior and senior rugby league players. *Br J Sports Med* 36: 334-339, 2002.

53. **Garhammer J**. A review of power output studies of Olympic and powerlifting: Methodology, Performance Prediction, and Evaluation Tests. *J Strength Cond Res* 7: 76-89, 1993.

54. **Gulch RW**. Force-velocity relations in human skeletal muscle. *Int J Sports Med* 15 Suppl 1: S2-10, 1994.

55. **Harman E.A., Kraemer W.J. and et al.** Estimation of human power output from vertical jump. *J Appl Sport Sci Res* 5: 116-120, 1991.

56. **Harris NK, Cronin JB and Hopkins WG**. Power outputs of a machine squat-jump across a spectrum of loads. *J Strength Cond Res* 21: 1260-1264, 2007.

57. **Hill AV**. The mechanics of active muscle. *Proc Roy Soc Lond* 141: 104-117, 1953.

58. **Hoffman JR, Cooper J, Wendell M and Kang J**. Comparison of Olympic vs. traditional power lifting training programs in football players. *J Strength Cond Res* 18: 129-135, 2004.

59. **Hoffman JR, Ratamess NA, Cooper JJ, Kang J, Chilakos A and Faigenbaum AD**. Comparison of loaded and unloaded jump squat training on strength/power performance in college football players. *J Strength Cond Res* 19: 810-815, 2005.

60. **Hopkins W**. Considerations for research designs in sport science [Online]. http://www.sportsci.org/research_resources, accessed: 15.07.2008.

61. **Hopkins WG**. Measures of reliability in sports medicine and science. *Sports Med* 30: 1-15, 2000.

62. **Hori N and Newton RU**. Comparison of different methods of determining power output in weightlifting exercises. *J Strength Cond* 28: 36-40, 2006.

63. **Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR and Nosaka K**. Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *J Strength Cond Res* 21: 314-320, 2007.

64. **Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR and Nosaka K**. Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *J Strength Cond Res* 22: 412-418, 2008.

65. **Hornby AS**. *Oxford Advanced Learner's Dictionary of Current English*. Oxford: Oxford University Press, 1995.

66. **Hrysomallis C and Kidgell D**. Effect of heavy dynamic resistive exercise on acute upper-body power. *J Strength Cond Res* 15: 426-430, 2001.

67. **Izquierdo M, Hakkinen K, Gonzalez-Badillo JJ, Ibanez J and Gorostiaga EM**. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *Eur J Appl Physiol* 87: 264-271, 2002.

68. **Izquierdo M, Ibanez J, Gorostiaga E, Garrues M, Zuniga A, Anton A, Larrion JL and Hakkinen K**. Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiol Scand* 167: 57-68, 1999.

69. **Izquierdo M, Ibanez J, Hakkinen K, Kraemer WJ, Ruesta M and Gorostiaga EM**. Maximal strength and power, muscle mass, endurance and serum hormones in weightlifters and road cyclists. *J Sports Sci* 22: 465-478, 2004.

70. **Jennings CL, Viljoen W, Durandt J and Lambert MI**. The reliability of the FitroDyne as a measure of muscle power. *J Strength Cond Res* 19: 859-863, 2005.

71. **Josephson RK**. Contraction dynamics and power output of skeletal muscle. *Annu Rev Physiol* 55: 527-546, 1993.

72. **Kawamori N and Haff GG**. The optimal training load for the development of muscular power. *J Strength Cond Res* 18: 675-684, 2004.

73. **Kelln BM, McKeon PO, Gontkof LM and Hertel J**. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active,young adults. *J Sport Rehabil* 17: 160-170, 2008.

74. **Kraemer WJ and Newton RU**. Training for muscular power. *Phys Med Rehabil Clin N Am* 11: 341-68, vii, 2000.

75. **LiLi L, Olson MW and Winchester JB**. A proposed method for determining peak power in the jump squat exercise. *J Strength Cond Res* 22: 326-331, 2008.

76. **Loren ZF, Chui MS and Cormie P**. Does an optimal load exist for power training? *J Strength Cond* 30: 67-69, 2008.

77. **Mainardi LT, Bianchi AM and Cerutti S**. Digital biomedical signal acquestion and processing. In: The Biomedical Engineering Handbook. Florida, IEEE Press, 2000.

78. **Mayhew JL, Ware JS, Johns RA and Bemben MG**. Changes in upper body power following heavy-resistance strength training in college men. *Int J Sports Med* 18: 516-520, 1997.

79. **McBride JM, McCaulley GO and Cormie P**. Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. *J Strength Cond Res* 22: 750-757, 2008.

80. **McBride JM, Triplett-McBride T, Davie A and Newton RU**. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res* 16: 75-82, 2002.

81. **Miyaguchi K and Demura S**. Muscle power output properties using the stretch-shortening cycle of the upper limb and their relationships with a one-repetition maximum bench press. *J Physiol Anthropol* 25: 239-245, 2006.

82. **Murphy AJ and Wilson GJ**. The assessment of human dynamic muscular function: a comparison of isoinertial and isokinetic tests. *J Sports Med Phys Fitness* 36: 169-177, 1996.

83. **Newton RU, Hakkinen K, Hakkinen A, McCormick M, Volek J and Kraemer WJ**. Mixed-methods resistance training increases power and strength of young and older men. *Med Sci Sports Exerc* 34: 1367-1375, 2002.

84. **Newton RU, Murphy AJ, Humphries BJ, Wilson GJ, Kraemer WJ and Hakkinen K**. Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *Eur J Appl Physiol Occup Physiol* 75: 333-342, 1997.

85. **Newton RU and Wilson G**. The kinetics and kinematics of powerful upper body movements: the effect of load. Champain, Illinois: Human Kinetics Books, 1993.

86. **Ostojic SM, Mazic S and Dikic N**. Profiling in basketball: Physical and physiological characteristics of elite players. *J Strength Cond Res* 20: 740-744, 2006.

87. **Paavolainen L, Hakkinen K, Hamalainen I, Nummela A and Rusko H**. Explosive-strength training improves 5-km running time by improving running economy and muscle power. *J Appl Physiol* 86: 1527-1533, 1999.

88. **Paton BE**. *Sensors, Transducers & LabVIEW*. London: Prentice Hall, PTR, 1998.

89. **Rahmani A, Viale F, Dalleau G and Lacour JR**. Force/velocity and power/velocity relationships in squat exercise. *Eur J Appl Physiol* 84: 227-232, 2001.

90. **Rambaud O, Rahmani A, Moyen B and Bourdin M**. Importance of upper-limb inertia in calculating concentric bench press force. *J Strength Cond Res* 22: 383-389, 2008.

91. **Robertson DG and Dowling JJ**. Design and responses of Butterworth and critically damped digital filters. *J Electromyogr Kinesiol* 13: 569-573, 2003.

92. **Ross W.D. and Marfell-Jones M.J.** *Physiological Testing of the High-Performance Athlete*. Champain, Illinois: Human Kinetics Books, 1991.

93. **Sale DG**. Postactivation potentiation: role in human performance. *Exerc Sport Sci Rev* 30: 138-143, 2002.

94. **Sands WA, Smith LS, Kivi DM, McNeal JR, Dorman JC, Stone MH and Cormie P**. Anthropometric and physical abilities profiles: US National Skeleton Team. *Sports Biomech* 4: 197-214, 2005.

95. **Sato K, Smith SL and Sands WA**. Validation of an accelerometer for measuring sport performance. *J Strength Cond Res* 23: 341-347, 2009.

96. **Schmidtbleicher D.** Training for power events. p. 381-395 In: Strength and power in sports. London: Blackwell Scientific, 1992.

97. **Schmidtbleicher D. and Buehrle M.** Neuronal adaptations and increase of cross sectional area studying different strength training methods. In: Biomechanics X-B, edited by Jonsson B. Champain, Illinois: Human Kinetics Books, 1981.

98. **Siegel JA, Gilders RM, Staron RS and Hagerman FC**. Human muscle power output during upper- and lower-body exercises. *J Strength Cond Res* 16: 173-178, 2002.

99. **Sleivert G and Taingahue M**. The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol* 91: 46-52, 2004.

100. **Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M and Schilling B**. Power and maximum strength relationships during performance of dynamic and static weighted jumps. *J Strength Cond Res* 17: 140-147, 2003.

101. **Stone MH, Sanborn K, O'Bryant HS, Hartman M, Stone ME, Proulx C, Ward B and Hruby J**. Maximum strength-power-performance relationships in collegiate throwers. *J Strength Cond Res* 17: 739-745, 2003.

102. **Takarada Y, Hirano Y, Ishige Y and Ishii N**. Stretch-induced enhancement of mechanical power output in human multijoint exercise with countermovement. *J Appl Physiol* 83: 1749-1755, 1997.

103. **Thomas M, Fiatarone MA and Fielding RA**. Leg power in young women: relationship to body composition, strength, and function. *Med Sci Sports Exerc* 28: 1321-1326, 1996.

104. **Thompson CJ and Bemben MG**. Reliability and comparability of the accelerometer as a measure of muscular power. *Med Sci Sports Exerc* 31: 897-902, 1999.

105. **Tod DA, Iredale KF, McGuigan MR, Strange DE and Gill N**. "Psyching-up" enhances force production during the bench press exercise. *J Strength Cond Res* 19: 599-603, 2005.

106. **Trew M and Everett T**. *Human Movement: An Introductory Text*. Edinburgh: Churchill Livingstone, 2001.

107. **Vaughan CL**. Smoothing and differentiation of displacement-time data: an application of splines and digital filtering. *Int J Biomed Comput* 13: 375-386, 1982.

108. **Viljoen LW**. *Musculotendinous Stiffness and Muscle Function* (PhD Dissertation). Department of Human Biology, University of Cape Town, South Africa, 2004.

109. **Vint PF and Hinrichs RN**. Endpoint error in smoothing and differentiating raw kinematic data: an evaluation of four popular methods. *J Biomech* 29: 1637-1642, 1996.

110. **Vos de NJ, Singh NA, Ross DA, Stavrinos TM, Orr R and Fiatarone MA**. Optimal load for increasing muscle power during explosive resistance training in older adults. *J Gerontol A Biol Sci Med Sci* 60: 638-647, 2005.

111. **Walshe AD, Wilson GJ and Ettema GJ**. Stretch-shorten cycle compared with isometric preload: contributions to enhanced muscular performance. *J Appl Physiol* 84: 97-106, 1998.

112. **Weiss L.W. Fry AC, Magu B, Chiu LZF, Buchanan K, Scates C, Bondurant BW, Schilling BK and Henderson S.** Relative external loads eliciting maximum concentric force and power during non- countermovement squats. *J Strength Cond Res National Conference XXV* 2002.

113. **Wilson GJ, Newton RU, Murphy AJ and Humphries BJ**. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 25: 1279-1286, 1993.

114. **Wisloff U, Castagna C, Helgerud J, Jones R and Hoff J**. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38: 285-288, 2004.

115. **Wood GA**. Data smoothing and differentiation procedures in biomechanics. *Exerc Sport Sci Rev* 10: 308-362, 1982.

116. **Young WB**. Transfer of strength and power training to sports performance. *Int J Sports Physiol Perform* 1: 74-83, 2006.

117. **Zink AJ, Perry AC, Robertson BL, Roach KE and Signorile JF**. Peak power, ground reaction forces, and velocity during the squat exercise performed at different loads. *J Strength Cond Res* 20: 658-664, 2006.

APPENDICES

APPENDIX A

EFFECT OF A CHANGE IN CUT-OFF FREQUENCY ON MEASUREMENTS OF FORCE, VELOCITY AND POWER

To explore such differences further measurements of force, velocity and power were compared applying a 2nd order Butterworth filter with a cut-off frequency of 5 Hz and 14 Hz. The data was derived from vertical ground reaction forces during squat jumps using only the bar (21.3 kg) and at 80% 1RM (Table 1).

Table 1: Effects of changes in cut off frequency using a 2nd Order Butterworth filter on measures of force, velocity and power output during squat jumps at loads of "bar only" (21.3 kg) and 80% 1RM

Peak outputs	Cut-off frequency		%Δ	Mean outputs	Cut-off frequency		%Δ
	5 Hz	14 Hz			5 Hz	14 Hz	
"bar only" load (21.3 kg)							
Force (N)	2345	2399	2.3		1718	1672	2.7
Velocity (m.s^{-1})	2.79	2.88	3.2		1.41	1.51	7.1
Power (W)	5889	6219	5.6		2280	2091	9.0
80% 1RM load							
Force (N)	3514	3552	1.1		2721	2651	2.6
Velocity (m.s^{-1})	1.48	1.50	1.4		0.54	0.56	3.7
Power (W)	4706	4851	3.1		1466	1449	1.2

The results presented in Table 1 indicate, that velocity and power output are more affected by a change in cut-off frequency compared to force. In addition, an increase in cut-off frequency generally results in an increase in magnitudes for peak measures, whereas mean measures decrease. However, for measures of velocity both, peak and mean values increase as a result of the respective change in cut-off frequency. In the context of the findings for this study and related research (32; 44; 63) , it is important to gain a better understanding as to how different filter types and configurations effect outcome measures.

APPENDIX B

PERSONAL INFORMATION FORM

UNIVERSITY OF CAPE TOWN

UCT/MRC Research Unit for Exercise Science & Sports Medicine

PERSONAL INFORMATION FORM WITH REGARDS TO EXERCISE TESTING AND BIOMEDICAL RESEARCH

The validation of muscle power output measures in lower and upper body resistance exercise

CLIENT NUMBER/CODE

COMPLETE NAME

POSTAL ADDRESS

Date of birth	**Age**	**Gender**
yyyy / mm / dd		M ☐ F ☐

Telephone numbers	**E-mail address**
(h) (w) (Cell)	

1) Do you take part in any Sport?
(Active participation in the last 12 months)

___ Rugby
___ Soccer
___ Running
___ Hockey
___ Tennis
___ Swimming
___ Cycling
___ Basketball
___ Rowing
Other:
____
____

2) For how many years have you been actively participating in this sport?

1	2	3	4	5	6	7	8	9	10 or more

Please specify at which level

social	club	provincial	national

3) During the last 3 months, how many times on average, per week, have you trained? (Sessions of 30 min or more of structured exercise)

1	2	3	4	5	6	7	8	9	10 or more

4) Do you have any *resistance* training experience?
If yes, please specify for how many years

Y	N

<1	1	2	3	4	5	6	7	8	9 or more

5) During the last 3 months, how many times on average, per week, do you presently perform *resistance* training? (Sessions of 30 min or more of structured exercise)

1	2	3	4	5	6	7	8	9	10 or more

6) Please list any illness, hospitalisation or surgical procedure within the past 2 years.

If there is any other information in general or related to your health status, which might be deemed important with regards to this study you would like to mention, please use the space below.

I, the undersigned, _______________________, state that all the information I have given in the above questionnaire is accurate and correct according my knowledge.

DATE:		**NAME (SUBJECT):**	
		SIGNATURE (SUBJECT):	
DATE:		**NAME (WITNESS):**	
		SIGNATURE (WITNESS):	
DATE:		**NAME (TESTER):**	
		SIGNATURE (TESTER):	

Once again thank you for your willingness to participate in this study and support the field of exercise science and biomedical research.

Kindest regards,
Gunnar Schoeler

Contact Gunnar Schoeler: Tel: + 27 21 650 4569
Cell: +27 74 111 5747
Email: gunnar.schoeler@uct.ac.za

AHA / ASCM Health / Fitness Facility

Pre-participation Screening Questionnaire*

Assess your health status by marking all *true* statements

History
You have had:
___ a heart attack
___ heart surgery
___ cardiac catheterization
___ coronary angioplasty (PTCA)
___ pacemaker / implantable cardiac defibrillator / rhythm disturbance
___ heart value disease
___ heart transplantation
___ congenital heart disease

Symptoms
Do you experience:
___ chest discomfort with exertion
___ unreasonable breathlessness
___ dizziness, fainting, or blackouts
___ take heart medications

Other health issues
Do you have:
___ diabetes
___ asthma or other lung disease
___ burning or cramping sensation in your lower legs when walking short distances
___ musculoskeletal problems that limits your physical activity, if yes please specify at the bottom of the form
___ concerns about the safety of exercise
___ take any prescription medication(s), if yes please specify at the bottom of the form

Cardiovascular risk factors
___ You are a man older than 45 years
___ You smoke, or quit smoking within the last 6 months
___ Your blood pressure is > 140 / 90 mm Hg
___ You do not know your blood pressure
___ You take blood pressure medication
___ Your cholesterol level is > 200 mg / dl
___ You do not know your cholesterol level
___ You have a close blood relative who had a heart attack or heart surgery before age 55 (father brother) or age 65 (mother sister)
___ You are physical inactive (i.e. you get < 30 minutes of physical activity on at least 3 days per week)
___ You are 20 pounds (i.e. 9.07 kg) overweight

If you marked any of the statements above please consult a doctor and get medical clearance if applicable.

Please specify your musculoskeletal problems /injuries

Please specify type and indication of your medication

Date **Signature**

***** Modified from American College of Sports Medicine and American Heart Association. ACSM/AHA Joint Position Statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health and fitness facilities. Med Sci Sports Exerc 1998: 1018

APPENDIX C

TRAINING LOG

Name …………. Date	Trained		Duration (min)	Emphasis on **S**trength or **E**ndurance		Intensity	Emphasis on **L**ower / **U**pper body		Remarks/Comments
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
1.Testing	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	
	Y	N		E	S	1 2 3 4 5	L	U	

APPENDIX D

INFORMED CONSENT

UNIVERSITY OF CAPE TOWN

UCT/MRC Research Unit for Exercise Science & Sports Medicine

essm

GENERAL INFORMED CONSENT WITH REGARDS TO EXERCISE TESTING AND BIOLOGICAL RESEARCH

The validation of muscle power output measures in lower and upper body resistance exercise

1. EXPLANATION OF THE TESTS

The MRC/UCT Research Unit of Exercise Science and Sports Medicine will be conducting a study focused on the test of upper and lower body power output during bench throws and weighted squat jumps using a customised Smith machine and its attachments developed in our institute (NAMS-Unit, Zest Manufacturing PTY (LTD), Cape Town, South Africa).

The testing will be over three days, with a minimum of 48-hour rest between testing days to ensure adequate recovery. The following tests will be performed:

Day 1: **(approximately 2 hours)**

- Body composition
    - Mass, stature, percentage body fat
- One repetition maximum test for both squat and bench press exercises
- Familiarisation session on the power testing procedures for the bench throw and weighted squat jumps

Day 2 & 3: (**approximately 1.5 hours each session)**

- Randomized testing of power for either the bench throw or weighted squat jumps

Each power testing session will consist of 6 loads representing 30, 40, 50, 60, 70, and 80 % of 1RM of the involved exercise with 3 trials at each load. Two – three minutes rest will be provided between the trials to minimise the effects of fatigue. The first session will take up 2 hours. Session two and three will require 1.5 hours of your time, which adds up to 5 hours in total.

2. ATTENDANT RISKS AND DISCOMFORTS

It is of utmost importance that you are injury free in the involved areas. If not, then this information should be shared with the tester beforehand and after consultation with a qualified medical doctor at the research unit, decided if the subject can participate in the study or not. Due to the nature of the testing, there is always the risk of musculoskeletal injury during the 1RM and power tests if the subject does not warm-up adequately, performs the exercise with bad form or technique, or is carrying an injury. This risk is however minimal and certainly no greater than the risks associated with a typical weight training session, if the subject follows the prescribed test protocol completely. Emergency equipment and trained personal are available to deal with unusual situations that may arise. The project has insurance cover under the UCT no-faults insurance. A medical doctor will be on site during testing.

3. RESPONSIBILITIES OF THE PARTICIPANT

Please pass any information about your health status or previous experiences of disease related symptoms or current changes of these on to us (see also “Personal Information Form”). It is important that the subjects follow the instructions of the tester completely throughout the testing time-period. For each testing day, you should be completely rested and should not have trained at all for at least 24 hours before each testing day.

4. BENEFITS TO BE EXPECTED

Each subject will receive a brief summary of their test results regarding e.g. body composition, percentage body fat, and power output of the lower and upper body. They will further have the knowledge that they have contributed to developing new scientific research in the field of exercise science and human biology.

5. INQUIRIES

You may feel free to ask any questions regarding the testing procedure and research at any time during, before or after the testing procedures.

6. RESEARCH USE OF PERSONAL INFORMATION

Your personal information will be handled confidential and only used in a decoded manner. It is not to be released or revealed to any person without your written consent. However, the information obtained may be used for statistical analysis or scientific purposes with your right to privacy retained.

7. FREEDOM OF CONSENT

Your participation is entirely voluntary. If you feel the need to withdraw from the study, you can do so at any time. Notice of this decision should however be given to the researcher involved.

I confirm that the above-mentioned tests have been thoroughly explained to me. I acknowledge that the personal information required by the researchers and those derived from the testing procedures will remain strictly confidential and no reference to my name will be revealed in any publication or statistical analysis. I have read this form and I understand the testing procedures that I will have to perform, my rights as a subject and the attendant risks, complications and discomforts. Knowing these risks, complications and discomforts, and having the opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this study and offer my full cooperation.

DATE:		**NAME (SUBJECT):**	
		SIGNATURE (SUBJECT):	
DATE:		**NAME (WITNESS):**	
		SIGNATURE (WITNESS):	
DATE:		**NAME (TESTER):**	
		SIGNATURE (TESTER):	

Contact: Gunnar Schoeler Tel: + 27 21 650 4569
Cell: +27 74 111 5747
Email: gunnar.schoeler@uct.ac.za

APPENDIX E

INCLUSION VS. EXCLUSION OF BODY MASS TO CALCULATE POWER OUTPUT DURING SQUAT JUMPS

The effect of inclusion vs. exclusion of body mass for calculations of power output during squat jumps on the power-load relationship derived from the three different methods; i.e. force plate only (FP), laser only (L) and a combination of force derived from FP and velocity derived from L (FPL).

The following results were derived from the data as discussed in the main part of this thesis. Thus, the same principles were applied to derive power output for each respective method of assessment. Yet, power output was calculated using two different methods:

a) Including the effect of body mass

Power $_{+BM}$ = Force * Velocity ………………………………………….………..   (i)

b) Excluding the effect of body mass

Power $_{-BM}$ = (Force - Body mass * 9.81) * Velocity …………………..   (ii)

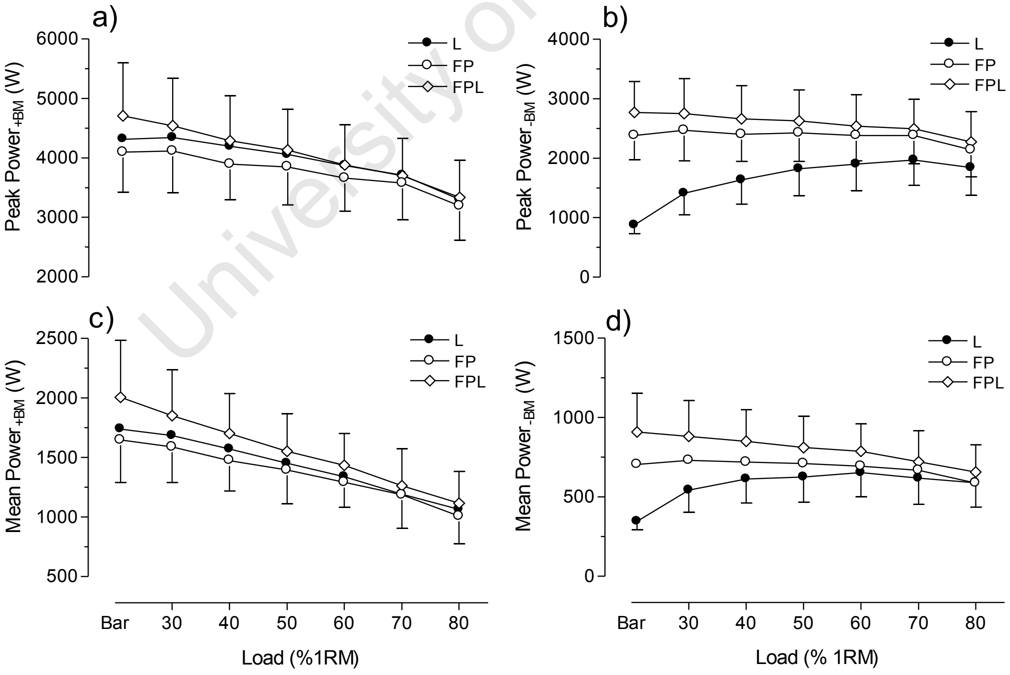


Figure 1: Effects of inclusion vs. exclusion of body mass to calculate power output for FP, L and FPL

a) peak power including body mass c) peak power excluding body mass

b) mean power including body mass d) mean power excluding body mass

FP = force plate only, L = laser only, FPL = force plate + laser;

Table 1: Measures of peak and mean power output including body mass during the squat jump for each method *. Values are presented as group mean and ± SD, (n = 15 in each group).

Load (%1RM)	**FP**	**L**	**FPL**
Peak power (W)			
Bar only	4097 ± 671	4317 ± 800	**4710 ± 892**
30	**4118 ± 700**	**4342 ± 766**	4543 ± 801
40	3897 ± 599	4194 ± 714	4291 ± 755
50	3849 ± 639	4059 ± 610	4136 ± 686
60	3660 ± 552	3873 ± 663	3883 ± 679
70	3581 ± 622	3709 ± 588	3702 ± 625
80	3194 ± 578	3302 ± 642	3337 ± 623
Mean power (W)			
Bar only	**1647 ± 358**	**1739 ± 413**	**2007 ± 478**
30	1589 ± 300	1684 ± 337	1850 ± 386
40	1475 ± 258	1572 ± 298	1703 ± 335
50	1395 ± 285	1450 ± 302	1553 ± 315
60	1292 ± 212	1339 ± 251	1435 ± 266
70	1206 ± 250	1218 ± 265	1282 ± 284
80	1008 ± 233	1063 ± 261	1136 ± 264

*Load at which maximum power occurred in bold, Bar only = absolute load of 21.3 kg,
FP = force plate only, L = laser only, FPL = force plate + laser;

Table 2: Measures of peak and mean power output excluding body mass during the squat jump from each method *. Values are presented as group mean and ± SD, (n = 15 in each group).

Load (%1RM)	**FP**	**L**	**FPL**
Peak power (W)			
Bar only	2385 ± 410	875 ± 142	**2771 ± 520**
30	**2472 ± 514**	1413 ± 365	2753 ± 586
40	2402 ± 456	1637 ± 408	2661 ± 560
50	2429 ± 484	1823 ± 449	2627 ± 522
60	2384 ± 428	1903 ± 445	2540 ± 530
70	2383 ± 478	**1967 ± 423**	2495 ± 496
80	2142 ± 454	1841 ± 464	2277 ± 506
Mean power (W)			
Bar only	705 ± 179	346 ± 53	**909 ± 244**
30	**730 ± 176**	542 ± 140	881 ± 226
40	719 ± 154	612 ± 150	850 ± 201
50	710 ± 176	626 ± 159	811 ± 197
60	694 ± 138	**654 ± 154**	787 ± 173
70	668 ± 178	618 ± 166	722 ± 196
80	587 ± 143	590 ± 155	656 ± 171

*Load at which maximum power occurred in bold, Bar only = absolute load of 21.3 kg,
FP = force plate only, L = laser only, FPL = force plate + laser;

The following section presents the correlation coefficient between Power $_{+BM}$ and Power $_{-BM}$ for each method of assessment.

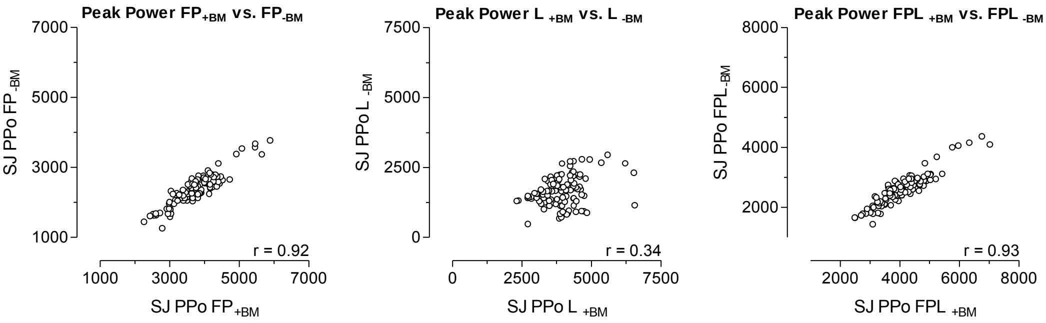


Figure 2: Correlation between peak power measures derived by including body mass ($_{+BM}$) or excluding body mass ($_{-BM}$) for each method.

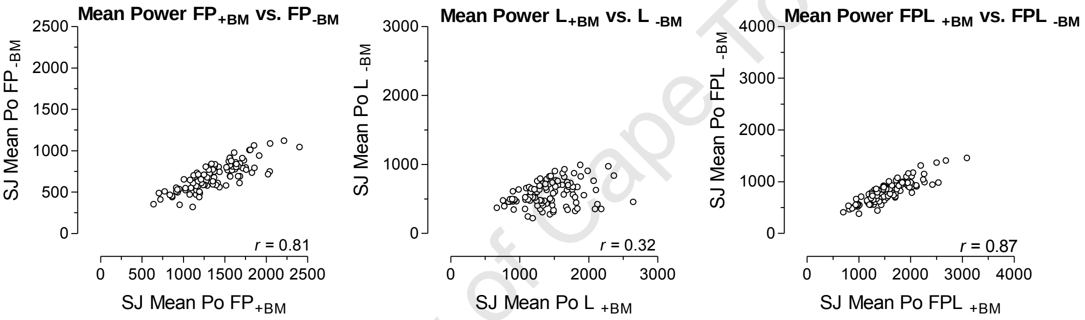


Figure 3: Correlation between mean power measures derived by including body mass ($_{+BM}$) or excluding body mass ($_{-BM}$) for each method.

Table 3: Relationship between measures of power when including body mass vs. excluding body mass during the squat jump, (n = 15 for each group). Data are shown as the correlation coefficient (*r*) and the 95% Confidence intervals of the correlation coefficient in brackets.

	FP$_{+BM}$		L $_{+BM}$		FPL $_{+BM}$	
	Peak Po	Mean Po	Peak Po	Mean Po	Peak Po	Mean Po
FP$_{-BM}$	**0.92** (0.88 - 0.94)	**0.81** (0.73 - 0.87)	--		--	
L $_{-BM}$	--		**0.34** (0.16 - 0.50)	**0.32** (0.13 - 0.48)	--	
FPL $_{-BM}$	--		--		**0.93** (0.89 - 0.95)	**0.87** (0.81 - 0.91)

Po = Power (W),
+BM = calculation of power including body mass,
-BM = calculation of power excluding body mass,
FP = force plate only, L = laser only, FPL = force plate + laser;

The results indicate that the power-load relationship changes when excluding body mass for calculating power output during squat jumps (Figure 1). Consequently, P_{max} occurs at different percentages of 1RM (Table 1 and 2). In particular calculations derived from the displacement of the bar were affected when excluding body mass to calculate power output (Figure 1). Consequently, the correlation coefficient between Power $_{+BM}$ and Power $_{-BM}$ was lowest for method L compared to the respective correlation coefficients for FP and FPL (Table 3).