Optimal training load for the hang clean and squat jump in under-21 rugby players

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Declaration

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Abstract

This study investigated the optimal training load required for peak-power production in two types of exercises, namely an Olympic-type and a ballistic exercise. The *hang clean* and the *squat jump* were selected to represent these two types of exercise.

It was ascertained whether a change in strength levels and training status will have an effect on the optimal loads for peak-power production of rugby players. In addition, the influence that different playing positions have on power production was also investigated.

Fifty-nine under-21 male rugby players (Mean Age 19.3yrs; SD ± 0.7yr) from two rugby academies, performed a maximal-strength test in the hang clean and squat, followed by a power test in the hang clean and squat jump with loads ranging from 30 to 90% of maximal strength (1RM).

Testing was conducted in the pre-season phase and repeated during the in-season phase. Peak power for the hang clean was achieved at 90% 1RM in the pre-season and at 80% 1RM during the in-season. Peak power for the squat jump was achieved at 90% 1RM in the pre-season. However, this location of the optimal loading was not significantly higher than that of the other loadings (60, 70 and 80% 1RM).

During the in-season, peak power for the squat jump was reached at 90% 1RM. Here again, the optimal-loading location was not significantly higher than that of the other loadings (50, 60, 70 and 80% 1RM).

It was concluded that the optimal load for power production is 90% 1RM for the hang clean and 60-90% for the squat jump.

It was found that an improvement in strength levels of the subjects affected both peak-power production and the optimal load in both exercises.

During the in-season peak power in the hang clean was reached at 80% 1RM, and at 50% 1RM for the squat jump.

There were no significant differences in the performances of subjects from different playing positions (forwards versus backline players).

In the hang clean, peak-power production seems to be reliant on increased strength and results in peak-power output at high loads.

The squat jump, on the other hand, is more reliant on velocity due to its ballistic nature and is possibly better suited to developing power at lighter loadings. Because it produces peak power at a lower percentage load than the hang clean, the squat jump could be more effective in power development for players who are inexperienced in power training.

Long-term exercise periodisation in power training can therefore be employed progressively from simpler exercises (e.g., squat jump) using only the legs, to more complex exercises (e.g., Olympic-lifting) that involve the whole body.

This study confirmed that the specific requirements of different sport codes should be considered meticulously before selecting and prescribing exercises and loads for power-training programmes.

Key words: Power, optimal loads, hang clean, squat jump, peak power

Opsomming

Die hooffokus van hierdie studie was op die optimale oefenlading wat vereis word vir die produsering van piek-profkrag tydens die uitvoering van twee tipes oefening, naamlik ʼn Olimpiese- en ʼn ballistiese oefening. Die *hang clean* en die *squat jump* is geselekteer om bogenoemde twee tipes oefening te verteenwoordig.

Daar is bepaal of ʼn verbetering van die krag-vlakke en oefenstatus van rugbyspelers ʼn invloed het op die optimale ladings vir piek-plofkrag ontwikkeling. Verder is die moontlike rol van verskillende speelposisies ondersoek.

Nege-en-vyftig onder-21 mans-rugbyspelers (M-ouderdom 19.3jr; SD ± 0.7jr) vanuit twee rugbyakademies het ʼn maksimale-krag toets in die *hang clean* en *squat* uitgevoer. Dit is opgevolg deur ʼn plofkrag-toets in die *hang clean* en *squat jump* met ladings wat gewissel het van tussen 30 en 90% van maksimale werkverrigting (1RM).

Toetsing het plaasgevind in die voor-seisoen fase en is herhaal tydens die daaropvolgende speelseisoen. Piek-plofkrag vir die *hang clean* is bereik tydens ʼn oefenlading van 90% 1RM in die voor-seisoen en by 80% 1RM later in die speelseisoen. Piek-plofkrag vir die *squat jump* is behaal by 90% 1RM in die voor-seisoen fase. Hierdie optimale lading-lokasie was egter nie beduidend hoër as by die ander ladings van 60, 70 en 80% 1RM nie.

Tydens die speelseisoen is piek-plofkrag bereik in die *squat jump* by 90% 1RM. Die optimale lading-lokasie was weereens nie beduidend hoër as by die ander ladings van 50, 60, 70 en 80% 1RM nie.

Daar is tot die gevolgtrekking gekom dat die optimale oefenlading vir die ontwikkeling van piek-plofkrag vir die *hang clean* 90% 1RM is, en 60% vir die *squat jump*.

Daar is ook gevind dat ŉ verbetering in kragvlakke van die toetslinge, beide piek-plofkrag-produksie en die optimale oefenbelading in albei oefeninge beïnvloed.

Tydens die speelseisoen is piek-plofkrag behaal in die *hang clean* by 80% 1RM, en by 50% 1RM in die *squat jump*.

Geen beduidende verskille in werkverrigting is gevind tussen toetslinge uit verskillende speelposisies (voorspelers versus agterlyn-spelers) nie.

Dit blyk dat in die *hang clean*, die produksie van plofkrag beïnvloed word deur ŉ verbetering in krag en dat dit tot hoër optimale ladings vir piek-plofkrag produksie lei.

Die *squat jump*, in teenstelling, is meer afhanklik van snelheid en is moontlik beter geskik vir die produsering van plofkrag teen ligter oefenladings. Omdat die *squat jump* piek-plofkrag genereer teen laer ladings as die *hang clean*, kan dit meer effektief wees vir spelers met gebrekkige ervaring in krag-oefening.

Lang-termyn oefen-periodisering in plofkrag-oefening kan gevolglik progressief aangewend word vanaf eenvoudiger oefeninge (bv. *squat jump*), waar slegs die bene gebruik word, tot meer komplekse oefeninge (bv. Olimpiese-gewigoptel) waar die hele liggaam betrek word.

Hierdie studie bevestig dat die spesifieke vereistes van verskillende sportkodes deeglik oorweeg moet word alvorens oefeninge en ladings geselekteer en voorgeskryf word vir plofkrag-programme.

Sleutelwoorde: Plofkrag, optimale lading, piek plofkrag

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Chapter One

Introduction

In order to gain a competitive edge over opponents, coaches continuously scrutinize, revise and improve training regimens in their quest to produce stronger, faster and more powerful athletes.

Resistance training normally plays a crucial role in such programmes. Their design usually involves intricate manipulations of several components, for example, type of exercise and training load (Baechle & Earle, 2000).

To achieve specific outcomes, specific training loads are required (Baechle & Earle, 2000). For example, when determining the optimal loads prescribed for power, factors such as the nature of the exercise, type of movement, and training status of the athlete need to be considered.

The findings of previous studies regarding specific resistance exercises and training loads provide the basis for the experimental phase of this study.

Background

Power is measured in terms of power output and peak-power output (PPO). This is the muscles' ability to exert a powerful force when contracting at high velocity. As the force of a muscle increases, velocity decreases (Kawamori & Haff, 2004). There will therefore be an optimal load for both force and speed in order to achieve peak-power output. It is generally believed that PPO can occur at loads anywhere between 10 to 80% of maximal effort (1RM). This depends on factors such as the location and nature of exercises (e.g., upper-body, lower-body; single-joint, multi-joint exercises), as well as the athletes' training status, training experience, and strength levels (Baker, 2001a, 2001b, 2001c; Baker, Nance & Moore, 2001a; Baker, Nance & Moore 2001b; Garhammer, 1993; Kaneko, Fuchimito, Toji & Suel, 1983; Moss, Refsnes, Ablidraard, Nicolaysen & Jensen, 1997; Newton & Dugan, 2002).

From the above mentioned studies, it is clear that there is considerable debate regarding the optimal training load for power production.

Motivation for the study

Many sports involve movements that require the generation of force over a short period of time. In such activities power is the major determinant of the quality of performance (Kawamori & Haff, 2004). Thus, if athletes are able to increase their peak power, they could enhance their performance. Power training at different loads results in changes in the force-velocity relationship. This provides variability regarding the extent to which power output can be improved (Cormie, 2008).

Kawamori and Haff (2004) reviewed optimal training loads for development of muscular power and stated the need for further research regarding the measurement of power output under various loads for the Olympic type exercises. They also mentioned the requirement to investigate the difference in optimal training load between ballistic and Olympic type exercises. Recently the topics have been investigated by authors like Cormie (2008), Cromie et al. (2007b), Kilduff et al. (2007) and Bevan et al. (2010).

There is however controversy surrounding the training loads that should be applied for different types of exercise and provided the incentive for the author to empirically investigate what training loads will produce peak-power output in specific exercises.

As mentioned earlier, different sports have different power requirements. (e.g., speed-dominant versus force-dominant). In addition, in sports such as rugby, there is the added consideration of the dominant requirements of individuals occupying different playing positions (e.g., forwards versus backline players). For example, it is generally believed that forwards tend to use mostly force in their power production, whereas backline players employ mainly speed. It would therefore be useful to ascertain the relationship between different exercises for rugby players performing in different positions (Dugan, 2002).

Significance of the study

As mentioned earlier, prescribing optimal training loads for power depends on a variety of factors. Several of these factors will be addressed in this study.

Firstly, a large range of loads will be investigated (30 to 90% of 1RM). In most reported studies loads of such large ranges have seldom been used.

Secondly, the two exercises investigated in this study will be compared. They are the *hang clean* and the *squat jump,* both popular exercises in power development. To date there are a limited number of reported studies that compare an Olympic-type (weightlifting) exercise with a ballistic-type exercise when applying such a large range of loads. This study should shed more light on effective exercise prescription.

A third aspect to be investigated is the change in strength levels of athletes. Since most players in this study will be in their first year at a rugby academy, they will have limited experience of a periodised strength-and-conditioning programme. Subjects will be tested in the pre-season and then again towards the end of the season (when their performance is expected to peak). The possible effect that changes in their strength levels and training status could have on optimal training loads will be ascertained.

Finally, to date there is a dearth of information comparing optimal training loads of forwards and backline players when employing these specific exercises. The results may provide some insight into whether and how training load and/or exercise prescription for individuals playing in different positions should differ.

Previous studies (Bevan et al, 2010, Kilduff et al, 2007) involving rugby players did not divide the group according to playing positions. The participants were also older, professional players with a mean age of 25.5 years.

Thesis outline

Chapter Two deals with theoretical aspects and definitions regarding power. This includes a discussion of previous studies that dealt with various elements of power, power development, power training, optimal training loads for power development, and aspects influencing peak-power output.

The research problem is formulated in *Chapter Three*. The purpose of the research and appropriate research questions are also stated here, as well as the research methods employed. These include research parameters, place of study, subjects, inclusion/exclusion criteria, and testing procedures. The statistical methodology is also described.

In *Chapter Four* the research results and statistical analysis are reported.

Chapter Five contains a discussion of the results, conclusions and suggestions regarding the practical implications of the findings of this study. There is also a section dealing with the limitations of the study, followed by recommendations for future research.

Chapter Two

Theoretical Background

The term "power" is widely used in sport to describe a person's ability to exert maximum effort (Baechle & Earle, 2000). Muscular power is considered one of the most important performance determinants in sports that require high-force generation in a short period of time. The development of power through power training is therefore essential for participants in such sports (Kawamori & Haff, 2004).

Requirements for different sports

Several investigators (Balciunas, Stonkus, Abrantes & Sampio, 2006; Drust, Atkinson & Reilly, 2007; Gabbett, King & Jenkins, 2008) highlighted the importance of power production in various team sports.

Gabbett et al. (2008) reviewed the physiological demands of playing *rugby league* and emphasised the importance of power production involved in short sprints, agility (changing direction, accelerating and decelerating) and contact situations (e.g., tackles, leg drives, and wrestling for ball possession).

In *basketball,* a different type of game, jumping, passing, the high incidence of short sprints, the development op power, and power endurance are considered fundamental requirements for players (Balciunas et al., 2006).

Soccer involves action periods of varied intensities such as tackles, physical challenges of opponents, contesting ball possession, jumping when heading the ball, and throwing in the ball. These activities generally require quick, intense movements over a short period of time (Drust et al., 2007).

Rugby union is another team sport that relies on a rapid generation of force. A match lasts 80 minutes, but the ball is in play for only 30 minutes on average. The remaining time is mostly taken up by penalties, free-kicks, injury stoppages and restarts (e.g., scrums, kick-offs, drop-outs, and line-outs) (Cunniffe, Proctor, Baker & Davies, 2009, McLean, 1992).

The nature of the game of rugby union involves a great deal of jumping, tackling, rucking, accelerating, decelerating, scrumming and driving back attackers and defenders. All these movements require of players to produce a force rapidly (Mayes & Nuttall, 1995). The expected physical requirements of rugby players are also different depending on their playing positions (e.g., forwards versus backline players). The forwards consist of the two props, two locks, two flanks, the hooker and the eight man. The backline players are the scrum half, fly half, two centers, two wings and the full back (Bompa & Claro, 2009).

In a recent report on the physiological demands of rugby union during the 2010 Super-14 season, Tucker (2010) pointed out that forwards were on average involved in more than double the number (300) of impacts (e.g., rucks, tackles, and scrumming) than backline players (120) during an 80-minute match. On the other hand, it was reported that backline players do more running at high speed and obviously require more speed than forwards..

Bompa and Claro (2009) reported that backline rugby players (consist of the scrumhalf, flyhalf, centers, wings and fullback.) are involved in maximal sprinting between 19 to 31 seconds per match, whereas forwards (consist of front row, locks and lose forwards) sprint only 0 to 3 seconds per match. Backline players are also involved in high-speed running between 85 to 156 seconds per match, whereas forwards spend only between 27 to 68 seconds running at high speed. On the other hand, forwards are involved in high-intensity activities where they need to overcome external force (e.g., tackles, rucks, and mauls) between 55 to 71 times per match, while backline players are involved in these types of activities only 25 to 37 times per match. It is clear from this report that the forwards have to overcome external resistance more often than backline players. On the other hand, backline players need to generate high running-speed and acceleration more often than their forward teammates (Bompa & Claro, 2009)

In a study conducted by Duthie, Pyne and Hooper (2003) on a time-motion analyses of the 2001 and 2002 Super-12 rugby competition, it was reported that forwards spend an average of 7 minutes and 47 seconds more time in static exertion (e.g., tackles, rucks, mauls, and scrums) than backline players. In addition, it was revealed that backline players spend 52 seconds more sprinting per match than forwards and that the high-intensity efforts are mainly of a static-exertion type for forwards and sprints for backline players.

Power production is therefore essential in all rugby playing positions, but power and strength requirements may differ (Duthie et al., 2003). Lander and Webb (1983) suggested that more strength is required during contact situations. Since forwards are involved in more such situations than backline players, it is logical to expect that the strength capabilities of forwards should be better developed than those of backline players.

Crewther, Gill, Weatherby and Lowe (2009) compared the strength and power of 38 elite male rugby players. Eighteen forwards and 20 backline players were tested in the squat jump and bench throw for peak power, and squat and bench press for 1RM maximal strength. In general, the absolute scores of power and strength of the forwards were superior to that of the backline players.

The popular perception that backline players require more speed and forwards more strength was also mentioned by Miller (cited in Duthie et al., 2003), who reported a greater force at low-isokinetic speed among international forwards compared to backline players in the half squat. On the other hand, the backline players produced greater force at higher speeds.

Tong and Wood (1997) compared the upper-body strength of college rugby players and found no difference in the strength capabilities between forwards and backline players. This could be attributed to the young training age of this specific sample. Younger players might produce different strength and power scores compared to more experienced subjects. In fact, Baker (2002) reported a difference in the levels of strength and power of rugby-league players at different achievement levels.

Terminology

Before continuing the discussion of the foundations of power- and strength training, some concepts and terminology need to be clarified.

Power is the rate of doing work; where *work* is the product of force exerted on an object and the distance that the object moves in the direction in which the force is exerted. Therefore…

Work = Force x Distance (Baechle & Earle, 2000).

Velocity can be calculated by dividing the distance that an object moves by the time it takes to cover the distance. Therefore…

Velocity = Distance/Time (Baechle & Earle, 2000).

Muscular power as the force of muscular contraction, multiplied by the velocity of the contraction. Therefore…

Power = Force x Velocity (Cronin & Sleivert, 2005; Newton & Kraemer, 1994).

The *amount of work* done by a muscle is equal to the amount of force/strength it requires to move an object over a certain distance, whereas *strength* is the ability of the muscles to exert maximal force at a specific velocity (Knuttgen & Kraemer, 1987).

Siff and Verkhoshansky (1993: 1) define strength as:

> *…the ability of a given muscle or group of muscles to generate muscular force under specific conditions, thus, maximal strength is the ability of a particular group of muscles to produce a maximal voluntary contraction in response to optimal motivation against external load.*

The velocity of a muscle contraction is equivalent to the distance an object is moved divided by the time it took to move it. Muscular power is basically applying force at a certain speed. The faster the muscle can apply the force, the more powerful the muscle is.

There is an inverse relationship between force and velocity (speed) during concentric muscle action. As the velocity of a movement increases, the force a muscle can produce, decreases (Kawamori et al., 2005). Basically, the more force that is required to move an object, the slower the movement will become. *Power* can be seen as the maximal force that a muscle or muscle group can generate at a specific speed. *Maximum power* is therefore not achieved at maximum force or maximum velocity capacity of the muscular contraction, but at maximal force and maximal velocity against a given resistance (Siegel, Gilders, Staron & Hagerman, 2002).

Authors have used both the term *peak-power output* (PPO) and *maximal-power output (MPO)*. To prevent confusion, the term peak –power output will describes the highest power generated during a movement while Maximal-power output described the load that produces the highest peak power output, this occurs when both force and velocity are at optimum values (Stone, O'Bryant, McCoy, Coglianese & Lehmkuhl, 2003). The force-velocity curve (Figure 2.1) illustrates the inverse relationship between maximum force and maximum velocity.

As mentioned earlier, different sports require different forces and different speeds. The crucial element of force production is that it should be executed at speeds relevant to specific sport demands. In addition, in rugby, the forwards require more high-resistance, slow-speed strength because they are more involved in pushing, tackling, rucking, scrumming, and competing for ball possession. Their velocity of movement is slow because of the influence of the external force and mass of opposing players during contact, as well as the inertia of the opponents' body mass. This external force will restrict the rate at which the muscles contract and consequently the optimal action to exert force and power will be at a slow speed. In contrast, the backline players encounter less contact with opponents and therefore need more acceleration and rapid change of direction of their body mass. Because the speed of movement is faster, the ability to exert force and power at high speed is crucial (Claro, 2006).

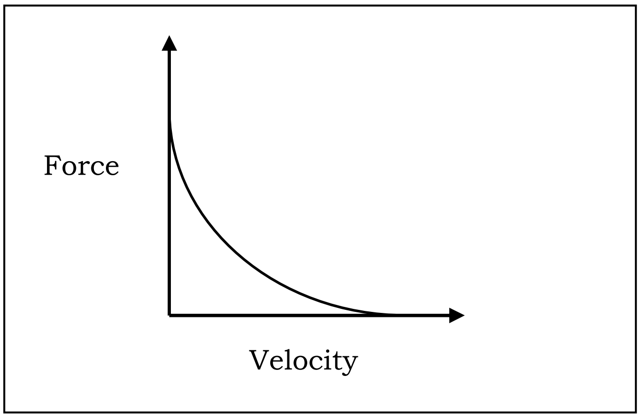


Figure 2.1 The force-velocity curve

It can confidently be concluded that both the generation of speed of movement and strength are critical for increased power. The adaptive response of the athlete will be determined by the type of exercise pattern that is employed.

A theoretical continuum of explosive-power development is presented in Figure 2.2.

Figure 2.2 Continuum of explosive power (Haff et al., 2001)

Factors contributing to peak-power production

There are several factors that play a role in power development. It is likely that improvement in sport performance through power development is reliant upon the unique movement, and the velocity and force that need to be overcome (Haff, Whitley & Potteiger, 2001). It is therefore essential to take note of the contributing factors in the development of muscular power and the appropriate training methods to achieve this.

Newton and Kraemer (1994) identified five factors that contribute to muscular power development (Figure 2.3).

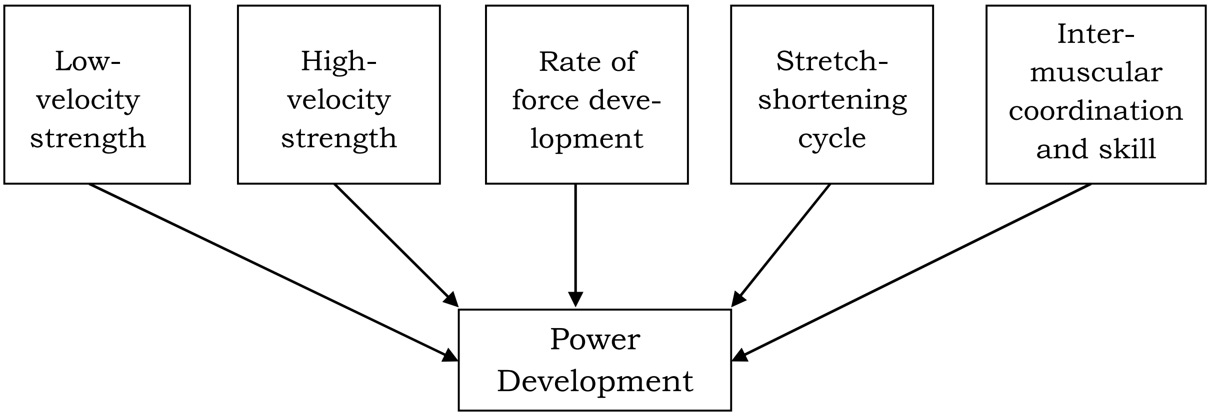


Figure 2.3 Factors contributing to muscular power development

Low-velocity strength (high force/low velocity)

Low-velocity strength (also known as maximal strength) is developed through heavy resistance training. Resistance training involves a systematic regimen of exercises applying the exertion of force on a load that would result in the development of strength (Plowman & Smith, 2003).

Baker and Nance (1999) consider maximal strength as the most important factor influencing maximal-power output in well-trained professional rugby league players. This is characterised by a strong relationship between upper-body strength and power.

Strength can be assessed by means of a single maximal effort. This is the maximum mass the athlete is able to lift once only through the entire range of movement.

Maximal strength is the highest force capability of high-force/low-velocity training and is performed at intensities of 80% or higher of the 1RM. This type of training should result in increased maximal strength (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000).

Several authors (Baker, 2002; Channell & Barfield, 2008; Cormie, McGuigan & Newton, 2010; Hakkinen, 1994; McBride, Triplett-McBride, Davie & Newton, 2002; Newton & Kraemer, 1994; Stone et al., 2003; Turbanski & Schmidtbleicher, 2010; Wilson, Newton & Murphy, 1993) investigated the effect that strength training has on power and the possible reasons for this.

Hakkinen (1994) proposed three possible reasons why maximal-strength training may affect peak-power output. Depending on the training status of athletes, strength training should have a positive effect on their strength levels. He firstly suggested that as athletes get stronger, a given mass would represent a smaller percentage load in the pre-training phase. Thus it would become easier for them to accelerate the mass, resulting in a higher power output.

Secondly, a stronger athlete would posses more Type-II muscle fibres. These comprise the primary motor unit contributing to muscular power and are therefore able to produce a high power output (will be discussed later).

Thirdly, maximal-strength training has a positive effect on muscular hypertrophy (depending on the training experience of the athlete). The increase in muscle size could have a positive effect on power output.

Stone et al. (2003) examined the relationship between the 1RM squat and peak-power production during a countermovement and static weighted and unweighted squat jumps. The results showed a strong correlation between the 1RM squat and power output generated during both countermovement and static squat jumps. These findings suggest that maximal strength is associated with high power-output employing both light and heavy weights. However, Wenzel and Perfetto (1992) reported that strength training was as effective as speed training in developing power in a group of football players.

In a study on the effect of an eight-week Olympic-, and traditional resistance-training programme, Channell and Barfield (2008) found that both resistance training (squats with various loads ranging from 30 to 100%) and Olympic-lift training (loads between 30-50%) increased vertical-jump performance. The study was done on 27 male football players with little previous resistance-training experience.

The author of the present investigation concludes that any form of high intensity resistance training would have a positive effect on vertical-jump results due to the neural adaptation provided by the initial training.

Wilson et al. (1993) compared the effect of different training methods on dynamic athletic performance. They reported a significant 7% increase in isometric rate of force development (RFD) in the vertical jump after 10 weeks of heavy-resistance training on 15 subjects with one-year training experience. Heavy-resistance training also increased the six-second cycling test results, and improved performance in the countermovement jump test, and maximal isometric-force test. They concluded that traditional weight training (high force/low velocity) has a positive effect on power production, but that this will diminish as the athlete becomes more accustomed to this type of training.

It would seem to confirm that the development of the high-force/low-velocity end of the power continuum is beneficial for power development. An increase in muscular strength will result from neural-muscular adaptation and the increase in muscle size. Initial increases can be attributed to neural-muscular adaptation (motor unit recruitment, rate of coding, and synchronization) while the increased muscle size (hypertrophy) facilitates a second form of adaptation (Baker, 2002).

According to Siff and Verkhoshansky (1993), increases in strength happen in three phases. The first phase is the increase in intermuscular coordination. This functional improvement occurs within the first two to three weeks of strength training. The second phase is the increase of intramuscular coordination. This enhancement of cooperation between muscle fibers happens during week four to six. The last phase is an increase in muscle growth (hypertrophy) and becomes prominent from the week six to twelve (each of these phases is discussed later on in this chapter).

Cormie et al. (2010) recently investigated the effect of a ballistic-power programme, and a strength-training programme on the power-production abilities of 24 relatively weak subjects. The strength-training group performed exercises with loads of 75 to 90% 1RM, while the ballistic-power group performed ballistic squat jumps (described later) with loads of 0 to 30% 1RM. Results indicated that both groups' sprinting and jumping scores improved significantly. However, the increase in strength was significantly higher in the strength-training group compared to the control group. It was concluded that both training methods have a positive effect on the power development of relatively weak individuals. The capacity of strength training to produce short-term performance improvement similar to ballistic-power training, along with the potential long-term benefits of improved maximal strength, makes strength training a more effective training mode for relatively weak individuals.

After an eight-week heavy-resistance training programme involving eight wheelchair athletes and eight able-bodied athletes, a significant gain in both strength and power parameters were reported for both groups by Turbanski and Schmidtbleicher (2010). They recommended that heavy-resistance training should be given more serious consideration in the conditioning of wheelchair athletes.

It is surmised that increased strength levels increase power in the acceleration phase of a movement because all explosive movements start from zero or from a low velocity. As a muscle begins to reach higher velocity levels of shortening concentric contraction, low-velocity strength has less effect on the muscle's ability to produce power (McBride et al., 2002; Newton & Kraemer 1994). Stone and his co-researchers (2003) and McBride et al., (2002) reported that increased strength, increases force output at different loads and consequently has a beneficial effect on power production at different loads.

In a study by Baker (2002) comparing junior-high, senior-high, college-aged, and elite rugby-league players, significant differences were found in the strength levels of untrained juniors, trained juniors and trained high-school players. There was, however, no significant difference in their power production. This would suggest that there can be an increase in strength without an increase in MPO. It is assumed that inexperienced athletes are unable to effectively use their strength and speed simultaneously.

It would appear that during the initial phases of training, athletes are not adequately skilled in power-training exercises. The neural adaptation that occurs during heavy-resistance training seems to be vital in the development of the necessary skill and coordination to produce a movement with high-power output. A broad base of strength and muscle hypertrophy needs to be developed before implementing high-intensity power training (high-force/high-velocity). Heavy-resistance training would therefore be beneficial in power development for inexperience athletes, but it could reach a plateau that will result in minimal further increases in power. For power development Baker (2002) is of the opinion that additional specific power training may be warranted in the development of more experienced athletes.

In a review paper on explosive exercise and training, Stone (1993) explained that four factors are involved in the production of muscular force:

- Motor unit recruitment and activation patterns
- Rate of coding
- Synchronization
- Muscle cross-sectional area

It is beyond the scope of the present study to give a detailed explanation of the neuromuscular system and it will therefore be described only briefly.

Motor unit recruitment and activation patterns

A motor unit is composed of a motor neuron and muscle fibres. Fibres can be categorized into two distinct categories: *slow-twitch (Type-I)* and *fast-twitch (Type-II)* fibres. Fast-twitch fibres are bigger than slow-twitch fibres and also have a higher and more forceful contractile velocity than slow-twitch fibres (Baechle & Earle, 2000).

The contractile properties of muscles depend on the type of motor neuron that innervates the muscle fibre. The motor neurons of slow-twitch fibres are smaller than those of fast-twitch fibres. These smaller motor neurons are recruited at low work intensity and the larger motor neurons are required only when a higher force output is needed. Maximal voluntary contractions (MVC) between loads of 30 and 90% will be determined by the activation of slow-twitch fibres and small motor neurons. The low-threshold units are the first to be recruited, but as the demand for force increases to 90-100% of MVC, additional force will be produced by the activation of fast-twitch fibres (Deschenes, 1989; Sale, 1992). This is known as the "size principle" (Plowman and Smith, 2003). Hakkinen (1994) suggested that high-force training (> 80% 1RM) could increase the size of fast-twitch fibres and the recruitment of fast-motor units. (In the present study reference to high-force/low-velocity training will imply training at loads higher than 80% 1RM).

Duthie et al. (2003) reported that the *vastus lateralis* leg muscles of rugby players consist of 53-56% fast-twitch fibres. This is higher compared to soccer players (40-51%) who require less high-force/low-velocity action than rugby players.

Rate of coding

Apart from the size and recruitment of motor units, the increase in activity of motor neurons will also have a positive effect on force production. This is called "rate of coding" and occurs when there is an increase in the frequency of neural impulses transmitted to the already-activated motor neurons. This has a favorable effect, because the force that is generated increases without the recruitment of additional motor neurons (Haff et al., 2001).

When the activation frequency of the motor unit exceeds a point that is necessary for maximal force, the additional increase in activation will contribute to an increase in rate of force development (RFD) (Sale, 1992). RFD is the muscle's ability to exert force at the fastest possible rate. The higher the rate of force development, the higher the mechanical muscle output. Increased RFD is considered to be a vital component in high-power production because in powerful muscle action the time in which to apply force is limited. Increased motor-unit recruitment and rate of coding are therefore important in the development of explosive power (Newton & Dugan, 2002; Newton & Kraemer, 1994).

In a study on the effect of 14 weeks of heavy-resistance training on untrained athletes, Aagaard, Simonsen, Andersen, Magnusson and Dyhre-Poulsen (2002) found a significant increase in the rate of force development, impulse rate, and neuromuscular drive.

Several investigators (Behm & Sale, 1993; Cronin, McNair & Marshall, 2001b; Kawamori & Newton, 2006), however, believe that the rate of force development can only be enhanced if there is an *intention* to apply the force as rapidly as possible.

Behm & Sale (1993) investigated eight men and eight women in a 16-week programme of dorsiflexion-training at high velocity or isometric contraction. Training sessions consisted of five sets of 10 repetitions. They reported that the training responses associated with high-velocity resistance training, were present in isometric training that involved no movement. They concluded that repeated attempts to perform a rapid contraction could produce an increase in the rate of force development.

Cronin et al. (2001b) conducted a study with 21 female netball players. All had a provincial represented background in playing and no previous weight training history. The objective of the study was to determine whether velocity-specific resistance training was important for improvement in sporting performance. Subjects were assigned to either a strength-training (80% 1RM) or a power-training (60% 1RM) group. Both groups trained for 10 weeks and implemented both resistance training combined with sport-specific training. Post-test results revealed that the increase in both strength and power output was significantly greater in the strength group compared to the power group. Although not significantly higher, the strength group showed a greater increase in netball throwing velocity. They concluded that for a specific sporting task, intentionally moving a load as rapidly as possible could improve velocity of the movement by the improvement in coordination and activation patterns.

Velocity specificity of resistance training was reviewed by Kawamori and Newton (2006). They concluded that both the intent to move rapidly as well as the actual movement velocity are important to bring about the neural muscular adaptation for improved power production.

Synchronization

Synchronization is another type of neural adaptation that occurs during heavy-resistance training (high-force/low-velocity). This refers to the extent that motor-unit firing (activation) occurs simultaneously (Kawamori & Haff, 2004). In laymen’s terms, it could be compared to the effectiveness of pieces of dynamite exploding one at a time in contrast to many pieces exploding simultaneously in a synchronized way. A simultaneous activation will be more powerful than single explosions.

Muscle cross-sectional area

Another factor that contribute to an increment in muscular power is an increase (hypertrophy) in the muscle cross-sectional area.

There is a strong relationship between the cross-sectional area of a muscle and its strength and overall size (Fitts, McDonald & Schluter, 1991). Increased muscle size results in increased strength, and the stronger the muscle the more force it can produce, and the higher the force production, the higher the resultant power production (Power = Force x Velocity).

However, too much hypertrophy could have a negative effect on power production. An excessive increase in muscle size could have a detrimental effect on the range of motion, which could diminish the muscles' ability to produce force (Newton & Kramer, 1994).

Ostrowski, Wilson, Weatherby, Murphy and Lyttle (1997) investigated the effect of different weight-training volumes on muscular size and function. Twenty-seven moderately-trained males with one-to-four years' training experience were assigned to one of three groups: low-volume (3 sets per week), medium-volume (6 sets per week) or high-volume (12 sets per week) training. Ten weeks of training proved to be sufficient to produce a significant increase in muscle size, strength and upper-body power in all three groups. No significant differences were found between the performance (muscle hypertrophy, 1RM and power output) of the three training groups.

High-velocity strength (high-velocity/low-force)

As mentioned earlier, Baker (2002) proposed specific power-training methods for the power development of experienced athletes. One of these training protocols is based on the high-velocity/low-force approach. Heavy-resistance training improves the high-force portion of the force-velocity curve (power output at low velocity against high resistance), whereas velocity-type (explosive) exercises improve the high-velocity portion on the force-velocity curve (power output at high velocity against low resistance) (Jones, Bishop, Hunter & Fleisig, 2001; McBride et al., 2002; Moss et al., 1997; Newton & Kraemer, 1994).

Jones and his co-researchers (2001) investigated the effect of various resistance-training loads on velocity-specific adaptation of 26 trained basketball players. They found that both high-force/low-velocity and high-velocity/low-force training regimens over a period of 10 weeks showed a trend towards increased PPO in the 1RM-squat, depth jump, 30% squat jump, and 50% squat jump. However, the high-velocity/low-force (40-60% 1RM) group showed trends of increased peak velocity with lower-resistance testing (30 and 50% squat jumps).

The effect of differently loaded squat jumps on the development of strength, speed and power was investigated by McBride et al. (2002). Twenty-six well-trained male athletes with two-to-four years' experience in weight training were assigned to two groups: a light-resistance (30% 1RM) or a heavy-resistance (80% 1RM) group. Both groups trained at set loads for eight weeks and were instructed to move the bar as quickly as possible and to try and generate as much force as possible during each lift. The light-resistance group showed significant increases in velocity over all the loads tested, whereas the heavy-resistance group did not improve. The researchers concluded that the velocity, at which a person train, as controlled by the load used, will result in a velocity-specific change in the electrical activity in the muscle. Also, these high-velocity movements can increase the contractile speed of the muscle, which is a vital component for high power-production (Harris et al. 2000) stimulus for enhancing intra- and inter-muscular coordination.

Rate of force development

As mentioned earlier, rate of force development (RFD) is the muscle's ability to exert force at the fastest possible rate. According to Aagaard et al. (2002), developing RDF can be achieved by high-force/low-velocity training. Harris et al. (2000), however, concluded that high-force/low-velocity is not the only available approach. A high-velocity/low-force regimen might also yield positive results. Behm & Sale (1993), Cronin, McNair & Marshall (2001a), and Kawamori and Newton (2006) reported that even when the velocity of the movement is slow, it would still have a positive effect on RDF if there is an deliberate intention to move rapidly.

Stretch-shortening cycle (SSC)

A stretch-shortening cycle occurs when muscles are stretched rapidly, causing a reflexive action. This reflective response increases the activity in the muscle, thereby increasing the force that the muscle produces (Baechle & Earle, 2000).

A commonly-used approach is to employ plyometric training. In plyometric training, body-mass jumping movements are used to develop muscular power (Chu, 1998). In most cases, plyometric training involves the pairing of eccentric (contraction with muscle lengthening) and concentric (contraction with muscle shortening) action to develop the athlete's ability to use the eccentric force through the stretch-shortening cycle (Hansen & Cronin, 2009).

Several researchers have reported the positive effect of plyometric training on power production (Costello, 1984; Dodd & Alvar, 2007; Fatouros et al., 2000; O'Shea, O'Shea & Climstein, 1992; Rubley, Haase, Holcomb, Girouard & Tand, 2011).

Fatouros et al. (2000) recorded a 25.6% increase in power output during a vertical-jump test among untrained male subjects after a 12-week plyometric-training programme. Training loads were manipulated through a number of foot contacts (ranging from 80 to 220 per session). A variety of movement patterns were also employed.

Dodd and Alvar (2007) investigated acute explosive-training modalities to improve the lower-body power of 45 male baseball players. Plyometric training resulted in a significant increase in vertical-jump height. There was a greater percentage change in vertical-jump height in the plyometric mode than in the other training modes (complex- and heavy-resistance training).

More recently, Rubley et al. (2011) reported the positive effect of low-impact plyometric training of adolescent female soccer players. Sixteen players (M-age 13yrs) were allocated to one of the following three groups: a control group, a plyometric-training group, and a soccer/plyometric-training group. The plyometric-training group showed significant improvement in both kicking distance and vertical-jump height after 14 weeks of once-per-week low-impact plyometric training.

Inter-muscular coordination and skill

Young (1993) mentioned two adaptations that high-velocity/low-force training can bring about within and between muscle groups. These adaptations are intra- and inter-muscular adaptations.

According to Young (1991), intra-muscular coordination is reliant on the magnitude of motor unit activation within a muscle and is determined by the:

- number of motor units recruited
- rate of coding
- synchronized motor unit firing
- stretch-reflex input from muscle spindles and Golgi tendon.

Inter-muscular coordination (skill) is the coordination between muscles and muscle groups and is influenced by the:

- activation of synergist-muscles that work together with the prime mover or agonist muscles
- co-contraction of antagonist muscles.

The development of intra-muscular coordination enhances the ability to activate the entire muscle mass for force production. Inter-muscular coordination is the ability to transfer the generation of force in athletic movement. In other words, inter-muscular coordination allows an athlete to perform the movement skill powerfully (high force at high velocities) (Young, 1993).

Young (1993) explained that high-velocity training develops both intra- and inter-muscular coordination, but that high-force training is superior in developing intra-muscular coordination. Because inter-muscular coordination actually is skill- (coordination) training, it can only be developed by practising exercise movements that mirror the specific competition actions in terms of movement patterns and speed. Also, inter-muscular coordination can only be developed by using relatively light loads (< 50% 1RM) when practising actions that simulate the movement patterns required in competition.

In velocity training it is essential to maintain acceleration throughout the entire joint range of motion (Baker, 1995a). The problem with developing velocity with traditional resistance exercises is that usually the movement starts off rapidly, but about half-way through the motion the muscles begin to slow down the movement to avoid the "jerking" of the muscles/tendons at the termination of the movement (Newton et al., 1997). This action has a negative effect on acceleration, because it conditions the body to slow down in such situations. Ballistic exercises such as squat jumps and bench throws, plyometric exercises, and Olympic lifting are suitable in this regard. They allow for full acceleration without slowing down towards the end of the movement. They can be applied as high-velocity/low-force exercises (Young 1993).

McBride et al. (2002) compared light- versus heavy-load ballistic training (squat jump) and its effect on vertical- and horizontal-plane physical activities. Twenty-six male athletes, with two-to-four years' training experience, were tested. After eight weeks of training the light-load (30% 1RM) group showed an increase in movement speed regardless of the load used in the squat-jump test. The heavy-load (80% 1RM) training group increased their force output, but did not show an increase in their velocity at any given load.

These results concur with the findings of Kaneko, et al. (1983), who also used load-controlled velocity in an elbow-flexor exercise (0, 30, 60 and 100% 1RM). The group that trained with the lighter load (30% 1RM) produced the highest increase in velocity scores. The groups training with the heavier loads (60 and 100% 1RM) significantly improved their force scores, but not their velocity scores However, the training method used was not of a ballistic-, plyometric- or Olympic-type exercise and full acceleration could not be applied throughout the entire movement.

In summary: According to the discussed literature, both training methods usually employed to increase muscle power (high-force/low-velocity, and high-velocity/low-force training), contribute to different physiological adaptations that increase power output. Both have a positive effect on the power-generating capabilities of the muscles, but not to the same extent.

Table 2.1 provides is a summary of the major adaptations ascribed to the two methods.

Table 2.1 Neural and muscular adaptation during high-force/low-velocity and high-velocity/low-force training

High-force/Low-velocity	**High-velocity/Low-force**
• Increased recruitment of fast twitch fibres (Type II) • Increased rate of coding • Increased synchronization between motor unit firing • Increased intra-muscular coordination • Increased RFD	• Increased inter-muscular coordination and skill. • Increased intra-muscular coordination (especially RFD) • Increased muscle contraction speed.

Mixed-load training

It seems that light-resistance training with an emphasis on speed rather than force tends to improve power mainly on the right end of the continuum whereas maximal-strength training might only improve power on the left end (Figure 2.2). The simultaneous use of both methods is known as *mixed-load* training. This involves the use of both heavy and light loads within a single session, alternating training loads between sessions, and complex training, which involves *super setting*. The latter occurs when two exercises are performed directly one after the other without a rest between efforts. In such a situation the subject would perform both techniques (high-force/low-velocity, and high-velocity/low-force) immediately after each other (using heavy, and light loads directly after each other). Several researchers have suggested that this approach to power development may be superior because the training occurs over the full force-velocity-power spectrum (Hansen & Cronin, 2009; Harris et al., 2000; Hoffman, Cooper, Wendell & Kang, 2004).

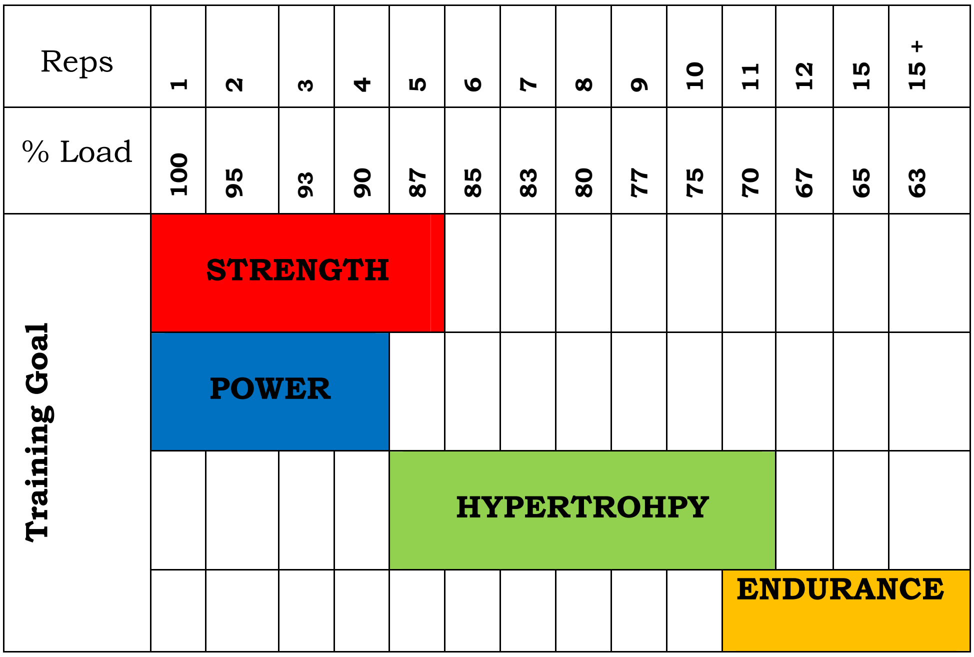
An eight-week mixed-training regimen was used by Newton, Kraemer and Hakkinen (1999) on 16 recreationally-trained male subjects. Loads varied from 30 to 80% 1RM and were applied in a single session. There was an increase in the vertical-jump performance. Harris et al. (2000), similarly, encountered an increase in maximal strength, jumping height and acceleration after a nine-week mixed-training programme with 13 male subjects who had at least one-year's training experience. Harris and his co-researchers (2000), however, split the different loads over alternate days, rather than applying them in a single session straight after each other.

Research by Newton et al. (2002) with untrained males indicated that a greater increase in squat-jump height occurred after heavy-resistance training compared to a mixed-method regimen. This could be the result of the nature of the sample of untrained subjects. As reported earlier by Baker (2002), athletes tend to first show an improvement in strength adaptation before they achieve an increase in speed of movement.

Optimal training loads for the development of muscular power

Traditionally training loads are prescribed to have a specific physiological effect on the muscle. Baechle and Earle (2000) mentioned several variables that need to be considered when designing a resistance programme. These include training load, and repetition. They proposed training loads and repetitions for specific training outcomes (Table 2.2). There are, however, several factors that should be considered when prescribing loads for power training (Table 2.3).

Table 2.2 The repetition maximal-loading continuum (adapted from Baechhle & Earl 2000)



Reps	1	2	3	4	5	6	7	8	9	10	11	12	15	15 +
% Load	100	95	93	90	87	85	83	80	77	75	70	67	65	63
Training Goal	**STRENGTH**													
	POWER													
					HYPERTROHPY									
											ENDURANCE			

It is evident that different training loads will have different effects on power development. All three methods mentioned (high-force, high-velocity and mixed method) can be used effectively in the development of muscular power and vary in the degree to which power output is improved, dependent on the needs of the athlete. There are, however, several investigators (Kaneko et al., 1983; McBride et al*.,* 2002; Winchester, Erickson, Blaak & McBride, 2005) who have indicated that training with a load that maximizes power output is more effective in improving maximal power production than either light or heavy loadings. An optimal load is where the specific load and the movement velocity will result in the greatest power output.

It is surmised that training at optimal loads will be superior to other training methods due to the specific adaptation of neural activation patterns (Kaneko et al., 1983; McBride et al., 2002). According to Cormie (2008) the adaptation will be similar to that of high-force or high-velocity training (recruitment of high-threshold motor units, increased firing rate, and synchronization of motor units, etc.). However, this is believed to be more pronounced in the stimulus that brings about physiological changes at loads and velocities that result in peak-power output. Despite a lack of empirical evidence, Cormie (2008) maintains that changes in the contractile ability of the muscles contribute to the adaptation after power training at optimal loads.

One of the first studies investigating the effect of specific loading during resistance exercises on MPO was conducted by Kaneko et al. in 1983. The testing was done with four loading conditions, 0, 30, 60 and 100% of maximal isometric strength (90° ankle). After 12 weeks of elbow-flexion training, maximal power production was improved significantly (26.1%) in the 30%-load group. The 30% loading group also was produce significantly higher scores in power output that the other three groups.

It can be concluded that the optimal load for the development of power is crucial. Loads ranging from 10 to 80% of 1RM have been reported in a variety of exercise modes (upper-body vs. lower-body, single-joint vs. multi-joint, traditional vs. explosive). However, there still remains a great deal of controversy regarding the optimal load and to which exercise mode it should be applied.

Variables affecting peak-power output

Kawamori and Haff (2004) identified several variables (Table 2.3) that could influence the load that should be considered when prescribing loads.

Table 2.3 Variables affecting peak-power output (Kawamori & Haff, 2004)

Variable	**Components**
Nature of exercise	Single-joint, upper body Multi-joint, upper body Multi-joint, lower body
Type of exercise movement	Ballistic Olympic
Strength levels	
Training status	
Methods and measurements	Data-collection equipment Inclusion/exclusion of body mass Free weights versus Smith machine • Mean- versus peak power • Instruction given to subjects

Single-joint, upper-body exercises

A single-joint, upper-body exercise can be described as a movement involving joints in the upper extremities and involves only one primary joint (Baechle & Earle, 2000).

Elbow-flexion exercises have been investigated by Moss et al. (1997) and Kaneko et al. (1983). Kaneko and his co-workers used 20 untrained male subjects who were assigned to four training groups based on their maximal isometric strength (0, 30, 60 and 100% of maximum voluntary contraction) (MVC). After testing it was observed that peak powet of elbow flexion was achieved at 30% of maximal isometric strength. The first three groups (0, 30 and 60% MVC) practiced elbow flexion using isotonic contraction (exercises involving movements with constant external resistance) while the other group that worked at 100% MVC, used isometric contraction. Training with loads that maximizes power output resulted in a greater increase in muscular power. Because the researchers PPO at only four loads, it does not mean that peak-power output was achieved at 30%. It could have been anywhere between 30 and 60% MVC.

Similarly, in a study comparing the effect of dynamic strength-training with different loads, Moss et al. (1997) reported that loads of 35% and 50% to be optimal for peak-power production. However, their sample comprised of 31 well-trained physical education students who were tested on dynamic movement instead of an isometric movement as was the case in the study by Kaneko et al. (1983).

Moss and his co-workers (1997) divided their subjects into three groups that trained at 90, 35 and 15% 1RM respectively. Maximal power and velocity were tested at loads of 15, 25, 45, 50, 70 and 90% 1RM (of the pre-training 1RM). All three groups showed an increase in power at loads of 15, 25 and 50% 1RM. The group that trained with 35% 1RM showed an increase across all the loads, whereas the 90%-group recorded a load-specific increase in power. It was concluded that training at 90% 1RM will increase power production at loads of 15 and 90% 1RM. However, training with a load (35%) that produces PPO will also increase power effectively over a wider range of loads.

Moss et al. (1997) reported an increase in power over various loads (15, 25, 45, 50, 70 and 90% 1RM) of a group that trained at 35% 1RM. The group training with 90% 1RM increased their power scores at loads as light as 15% of the pre-trained maximum. This may indicate that training with very light loads is not necessarily preferable to heavy loads for developing velocity and power.

Multi-joint, upper-body exercises

Multi-joint, upper-body exercises can be described as movements involving any joint in the upper extremities and involves two or more primary joints (Baechle & Earle, 2000). In most studies to date, derivatives of the bench press have been used to examine the power-load relationship in the upper body.

In order to determine the effect of heavy-resistance strength-training on bench-press power, Mayhew, Ware, John and Bemben (1997) measured absolute bench-press strength and bench-press power of 24 males before and after 12 weeks of weight training. The subjects were randomly assigned to training loads of 30, 40, 50, 60, 70 and 80% 1RM. PPO for each load was measured before and after training. Results revealed that the MPO during pre- and post-testing was produced at loads of approximately 40-50% 1RM.

A higher optimal load for power production was reported by Cronin et al. (2001a) after investigating different methods for power development. A group of 27 male club-rugby players performed concentric and rebound bench presses as well as concentric and rebound bench-press throws at loads of 30, 40, 50, 60, 70 and 80% 1RM. Results showed that peak-power output was reached at loads ranging from 50 to 70% 1RM.

According to Siegel et al. (2002) the load that results in peak-power output in the upper extremities, is 40-60% 1RM. They tested 25 male college-age volunteers who had some resistance-training background. However, bench-press tests were not performed with a regular barbell, but with a Smith machine at loads ranging from 30 to 90% 1RM.

Izquierdo, Hakkinen, Gonzalez-Badillo, Ibanez & Gorostiaga (2002) reported slightly lower loads for peak-power output. A group of 70 male subjects comprising of weightlifters, middle-distance runners, handball players, and cyclists was tested in the bench press across loads of 30, 40, 50, 60, 70, 80, 90 and 100% 1RM. The highest mean-power output was achieved at loads between 30-45% 1RM.

After investigating the load that maximizes mean-power output during explosive bench-press throws, Baker et al. (2001a) as in the case of other studies, did not pinpoint a specific load but rather identified an optimal range of resistance that maximizes power output. Their study was conducted on 31 well-trained rugby-league players performing the bench-press throw with free weights. Loads of 50-60% 1RM were recommended for producing MPO rather than lighter loads (30-46% 1RM) or heavy loads (> 70%).

It appears that the load that maximizes peak power is slightly higher than the load that maximizes mean-power output (See Table 2.4).

Table 2.4 A comparison of peak-power and mean-power output in the bench press and bench throw

Peak-power output	Mean-power output
50-70% 1RM (Cronin et al., 2001a)	50-60% 1RM (Baker et al., 2001a)
0-50% 1RM (Mayhew et al., 1997)	30-45%1RM (Izquierdo et al., 2002)
40-60% 1RM (Siegel et al., 2002)	

Multi-joint, lower-body exercises

Baechle and Earle (2000) describe this type of exercise as movements of the lower extremities that involves two or more of the primary joints.

In earlier studies on power output of the lower-body, a larger variety of movements was used as compared to the upper-body investigations. Also, female subjects were included in some studies. In Table 2.5 the results of some reported studies on peak-power output of lower-body movements are compared.

Table 2.5 A comparison of peak-power and mean-power-output in the squat, and squat-jump variations

Study	Subjects	Power measurement	Max Power output	Max Power output (W)
Baker et al. (2001b)	32 Professional and semi-professional rugby league players	Jump squats across loads of 24, 36, 48 and 75% 1RM—Body mass included	47-63% 1RM (Mean power)	1851
Izquierdo et al. (2001)	26 middle-aged male (M-age 42yrs) and 21 elderly male (M-age 65yrs)	Countermovement half squat across loads of 0, 30, 45, 60 and 70% 1RM	60-70% 1RM for both aged groups (Mean-power output)	391-486
Izquierdo et al. (2002)	70 male subjects-(weightlifters, middle-distance runners, handball players, cyclist and control) (20-23 years')	Smith machine half squat across loads of 30, 40, 50, 60, 70, 80, 90 and 100% 1RM	45-60% 1RM (Mean-power output)	385-755
Siegel et al. (2002)	25 Male college students	Smith machine squat across loads of 30, 40, 50, 60, 70, 80 and 90% 1RM	50-70% 1RM	950
Stone et al. (2003)	10 subjects with training experience ranging from 7 weeks to 15 years'	Jump squat and countermovement jumps across loads of 10, 20, 30, 40, 50, 60, 70, 80 and 90% 1RM	Weaker subjects:10% 1RM Stronger subjects: 40% 1RM	Weaker: 3482 Stronger: 5635
Cormie et al. (2007b)	12 Division-One male football players, sprinters, and long jumpers	Squat and jump Squat across loads of 0, 2, 27, 42, 56, 71 and 85% 1RM (body mass included)	0% 1RM	6000
Thomas et al. (2007)	19 male and 14 female Division-One soccer players. One-year strength-training experience (19-21 years')	Squat jump in Smith machine across loads of 30, 40, 50, 60 and 70% 1RM	Males: 30-40% 1RM Females: 30-50% 1RM	Males: 1700-1800 Females: 1400-1500

Several investigators (Baker et al., 2001b; Bevan et al., 2010; Cormie, McCaulley, Triplett, McBride, 2007b; Izquirdo et al., 2001; Izquirdo, Hakkinen, Gonzalez-Badillo, Ibanez & Gorostiaga, 2002; Siegel et al., 2002; Stone et al., 2003; and Thomas et al., 2007) made use of more experienced weight-training athletes and reported lower loads for peak-power output (0-63% 1RM).

Izquirdo et al. (2002) reported on the power-load curves during concentric action with loads ranging from 30-100% 1RM. The half squat was performed by 70 male subjects from different sports. Mean-power output was reported after completing four to five repetitions on each load. It was concluded that power-output is maximized at 45-60% 1RM when executing the half squat.

Optimal training loads for different exercises were compared by Cormie et al. (2007b). Twelve Division-One male athletes were tested. The squat, and jump squat were used in this study and were assessed on loads ranging from 30 to 90% 1RM. Results indicated that the optimal load for the squat is at 56% 1RM. This was, however, not significantly different from the power output at 42% and 71% 1RM. The optimal load in the jump squat was located at 0% 1RM, but peak-power was achieved at loads of 12% and 27% 1RM but was not significantly different from 0% 1RM.

Thomas et al. (2007) reported that PPO was achieved at 30% 1RM. The investigation was done to establish if gender played a role regarding the optimal load for power production in different exercises. Nineteen male and 14 female Division-One soccer players with one-year's training experience participated in the study. It was concluded that for males the optimal load was located between 30 and 40% 1RM. For females the optimal range was a bit broader (30 to 50% 1RM). This result could be explained by Baker's (2001b) theory that as athletes become stronger and more powerful, the load that maximizes the power output is reduced when expressed as a percentage of 1RM. The implication is that less-experienced trained athletes will be more likely to produce power by utilizing force rather than velocity. When comparing the two types of movement used (squat versus squat jump) it is worth noting that Izquirdo et al. (2001), Izquirdo et al. (2002) and Siegel et al. (2002) recommended a higher training load for optimal-power production in the squat of 45 to 70% 1RM, as compared to the squat jump (0-63% 1RM) (Baker et al., 2001b; Bevan et al., 2010; Cormie et al., 2007b; Izquirdo et al., 2002; Stone et al., 2003; and Thomas et al., 2007).

One problem when comparing the data is that at this stage there is no standard definition for the squat-jump movement. One interpretation is that it is a movement that maximizes vertical leap with external load initiated after a controlled eccentric decent until the thighs are parallel to the floor (Dugan, Doyle, Humphries, Hasson & Newton, 2004). Alternatively, it could be interpreted as a countermovement vertical jump (CMJ) with additional external load (Schuna & Christensen, 2010). There is also a difference in the depth and speed of the eccentric lowering. The CMJ uses a more shallow (quarter-squat depth) and a faster eccentric dip when initiating the movement. The constant in both these techniques, is that there is acceleration throughout the movement with no deceleration towards the end of the movement such as in the traditional squat.

Noteworthy once again, is that as the velocity of the movement increases in ballistic-type exercises, such as the squat jump, the percentage load producing MPO is lower than in the case of slow movements, where there is a deceleration at the end of the movement (Baker, 1995a).

Newton et al. (1997) also attributed these differences to the deceleration at the end of traditional exercises such as the squat or bench press. They explained that the deceleration phase is accompanied by reduced electrical activity in the agonistic muscle doing the work and increased activation in the antagonistic muscle causing the slowing-down tendency.

Another factor that could contribute to peak-power production is whether body mass is taken into account when calculating the load in the squat jump. It is important here to distinguish between the absolute mass (which is the external mass only) and the system mass (body mass + additional external mass). The external load for the system mass will thus be lighter than the absolute mass and the athlete will be able to exert more velocity on the bar, thus producing a higher power output than when body mass is not taken into account (Dugan et al., 2004). With the exception of Thomas et al. (2007), all the researchers cited in Table 2.5 included body mass in their calculation of the squat-jump power-output and reported a higher power-output than Thomas et al. (2007).

Exercise movement

Ballistic exercises

Newton and Kraemer (1994) described ballistic training as, "acceleration of a high velocity, and with actual projection into free space." There clearly is a difference in power-production capability when comparing traditional resistance exercises to exercises of a ballistic nature (e.g., squat jump or bench throw). This is evident from the already-mentioned variables in power production in lower-body exercises.

As mentioned earlier, ballistic-type exercises such as the squat jump and the bench throw do not entail large deceleration periods such as in the case of the traditional squat or bench press. According to Baker et al. (2001b) this leads to ballistic exercises creating greater power output due to the higher velocity of movement and increased muscular activation. They suggest that it would be more correct to measure maximal strength using traditional resistance exercises because of their high-force element. Ballistic exercises should therefore be used to measure power output.

Ballistic exercises will therefore have different optimal loads when compared to their traditional counterparts. However, the question remains regarding the optimal load that will produce the highest power output in a ballistic movement. Previous studies (Bevan et al., 2010; Cormie et al., 2007b; Izquirdo et al., 2002; Stone et al., 2003; and Thomas et al., 2007) suggested that the optimal load for ballistic exercises, such as the squat jump, lies somewhere in the range of between 0 to 63% 1RM. This wide range can be attributed to the different techniques used in the execution of the squat jump. For example, Bevan et al. (2010) as well as Cormie et al. (2007b) suggested that the optimal load is at 0% 1RM. In both these studies, the subjects had to squat to a mandatory predetermined depth (90 degrees) and used countermovement action to perform the jump. Thomas et al. (2007) and Stone et al. (2003) employed a predetermined depth, but did not permit countermovement before the jump. Subjects had to perform the exercise from a static position.

The findings of the study by Baker et al. (2001b) suggested a higher load (47-63%) for PPO. (In the present study subjects were given the choice of their preferred depth of squatting).

It is then evident that the depth of the squat and whether it is performed from a static position or with countermovement will have an influence on the optimal load for PPO.

Olympic weightlifting

In the sport of weightlifting, participants attempt to lift the heaviest mass possible in the snatch, and the clean-and-jerk. There are variations of this type of lifts and they are used when training for power development. Traditionally the term “Olympic lifts” is used only in the case of elite athletes who compete in weightlifting at the Olympic Games (Hendrick & Wada, 2008). (As the term

"Olympic lifts" is well-known and commonly used, the present study will refer to "weightlifting" as "Olympic lifting").

Olympic lifts or Olympic-style lifts are considered some of the best exercises for developing quality athletic performance. These types of movements have been designed to generate high power output and the movement and velocity characteristics are relevant to many sporting activities. Olympic-style lifts have produced some of the highest documented power outputs of all resistance-training exercises (Garhammer, 1993; Kawamori & Haff, 2004). The explosive jump-and-pull, and dip-and-drive actions are executed in 0.2 to 0.3 seconds and peak-power production is 4 to 5 times higher than in the traditional squat or deadlift. The high-force/high-velocity nature of these exercises makes them ideally suited for developing muscular power. Stone (1993) reported power output of 3000watt during a barbell snatch compared to 1100watt produced during a traditional squat exercise by the same athlete. This underlines the importance that Olympic-style lifting has in the development of power.

As mentioned earlier, Olympic lifts traditionally consist of the snatch and the clean-and-jerk. One of the variations of the traditional lifts is the hang clean, used in the present study. The hang clean involves an explosive pull of the bar from the knee towards the chest while pushing through the legs in one movement (Newton, 2002).

One of the first studies of the loads that maximize power output in Olympic-style lifts was conducted by Garhammer (1993). Testing was carried out on experienced male weightlifters, performing the power clean (one of the derivatives of Olympic lifts) from the floor. Results showed an increase in power production when the load was lowered from 100 to 80% 1RM. However, it is not certain whether this is the actual load that produces the peak-power output, because the percentage load used did not go lower than 80% 1RM.

Haff et al. (1997) reported similar loads for the hang pull. This exercise is similar to the power clean, except that the movement starts from the knees and there is no catching of the bar at the end of the movement. Eight male athletes, with more than two years' experience in dynamic explosive exercises, performed maximum isometric and dynamic pulls. Lifts were performed at 80, 90 and 100% of power-clean 1RM. Results showed that highest power output was produced at 80% 1RM and the researchers recommended that training intensities of 80% 1RM or less should be employed for peak-power production.

More recently, Cormie et al. (2007b) reported similar findings to that of Garhammer (1993). Twelve Division-One male athletes, familiar with power training, produced the highest power output at 80% 1RM in the power clean. The big difference was that they applied a large range of loadings (30-90% 1RM). These results are similar to those from two other studies by Winchester et al. (2005) and Kawamori et al. (2005).

Winchester et al. (2005) tested 18 male Division-Three athletes with a minimum of one year weight-lifting experience and compared power output in the power clean at loads of 50, 70 and 90% 1RM. The optimal load shifted from 70 to 50% 1RM after four weeks of technique training. There was, however, no significant difference reported between the three loads. It is noteworthy, that as the technique of the subjects improved, they were able to produce higher power output at each of the loads tested and MPO was produced at a lower load. Because the same 1RM-values were used at the beginning and the end of the intervention, it could be surmised that improved technique (kinematics and kinetics of the bar-path), enhanced the velocity capability of the subjects.

Similar results were reported by Kawamori et al. (2005). Their subjects were 15 males from a variety of power sports (track-and-field, football, rugby, weightlifting, bobsledding, basketball, and one recreationally-trained individual) who were familiar with the hang clean and had at least six months of training in the particular lift. The group was divided into either a stronger (1RM > 110kg) or a weaker (1RM < 110kg) category. Power was tested over loads ranging from 30 to 90% 1RM. The stronger group achieved peak- as well as mean-power output at 70% 1RM. The weaker group produced MPO at 80% 1RM and mean power at 60% 1RM.

This was the first reported (Kawamori et al., 2005) study comparing strength levels of athletes and the load that produces peak-power output in Olympic-style lifting. It should be mentioned that there was no significant difference in the effect of loads ranging from 50 to 90% 1RM.

Kilduff et al. (2007) investigated the optimal load for peak-power output of rugby players performing the hang clean. Twelve professional male rugby players who had weight-training experience of more than two years, participated in the study. They were tested on loads ranging from 30 to 90% 1RM. Power output was measured using a *Kistler portable force platform*. The primary finding was that PPO was achieved at 80% 1RM. This was, however, not significantly different from the PPO achieved at 50, 60, 70 and 90% 1RM.

It would appear that the optimal load for producing MPO in Olympic-style lifting is between 70-80% 1RM, but this is not always different from loads of 50, 60 and 90% 1RM. Kilduff et al. (2007) suggested that the optimal load for the hang clean is subject to differences between individuals with regard to their strength levels and training experience. It should be pointed out that not all the studies investigated a wide range of loads and that some of the results were limited to loads between 80-100% 1RM. Two other notable findings were that improved technique increased bar velocity on the same absolute loads (Winchester et al., 2005) and that there was a difference between stronger and weaker subjects regarding the loads that produced MPO (Kawamori et al., 2005).

Kinematic comparison of Olympic and ballistic exercises.

The comparison of Olympic type movements and ballistic movement has been investigated by several authors (Baker & Nance, 1999; Cormie et al., 2007b; Garhammer & Gregor, 1992; Hori et al., 2008).

Garhammer and Gregor (1992) reported that, due to the eccentric dip of the knees and hips followed by a rapid concentric contraction in both weightlifting movements and the vertical jump, the stretch-shortening action is activated causing a powerful drive through the lower extremities. As mentioned earlier, these types of actions are commonly used in plyometric training leading to improved performance in power production. Garhammer and Gregor (1992) also suggested that the neural learning patterns for optimal motor unit recruitment are similar for both exercises.

According to Baker and Nance (1999), the thrust-portion (pushing through the legs by triple extension of the ankle, knee and hip joint) of the Olympic exercises are biomechanically very similar to the squat jump and that both squat jump and the hang clean measure the same capabilities of the neuromuscular system.

In a study to investigate whether hang clean performance can differentiate performance in jumping, Hori et al. (2008) concluded that there was a significant correlation between 1RM hang clean relative to body mass and performance in jumping.

The two exercise types are thus similar in not only movement patters, but also neuromuscular stimulation and correlates well with some aspects of physical performance.

Strength levels

The literature has been inconsistent in its prediction of the effect of different strength levels on optimal training loads for power. Stone et al. (2003) distinguished between stronger and weaker athletes when investigating power output during static and dynamic jumps. Noticeably, the weaker athletes produced peak-power output at lower loads (10%) than the stronger athletes (40%). This is in contrast with some earlier findings (Baker, 2001a). Baker (2001a) compared upper-body power of professional, and college-aged rugby-league players. He found that weaker college players' optimal training load for power production was 55% 1RM, compared to the 51% 1RM of the stronger professional players. Results from this study indicate that for the lower-level athletes, maximal strength was the major factor influencing PPO values, with a coefficient of determination of 67%. In the case of the more experienced trained athletes the coefficient of determination suggested that only 33% of maximal strength results relate to peak-performance output.

From these studies it could be assumed that strength levels will have an effect on the optimal training load and that optimal training loads should be monitored and adapted as athletes get stronger. Baker et al. (2001b) explained that as athletes get stronger, they improve their power by increasing the absolute load lifted, while still maintaining the same movement velocity. As athletes increase their strength, they will reach a point where base-level strength is achieved and further increases in maximal strength are limited. Increased power then becomes more reliant on the increased velocity of the movement.

Training status

The load that produces PPO could be affected by the yearly training cycle. The training effect of a macro cycle can influence the percentage load that produces the highest power output (Baker, 2001a). A macro cycle is a training phase within a yearly training plan, targeting a specific training adaptation (Bompa, 1999). Baker (2001a) suggested that the optimal load will shift according to the training effect that is stimulated. He proposed that during a phase that emphasises strength-orientated training, the optimal load will be higher than in a phase that targets speed-orientated training.

Once an athlete's optimal load has been established, it could be a meaningful tool for monitoring the effect and changes that the training programme has on the training status of the athlete. Newton & Dugan (2002) suggested that it could also be used to detect illness, staleness, and overtraining, in order to adapt the athletes' training programme accordingly.

Biological age

Bompa and Haff (2009) recommended that the biological age of players should be brought into consideration when comparing results of athletes that are still going thought their physical development stages. If athletes are still developing and hormonal changes still occur, changes in performance can be due to natural physical maturation and development and not necessarily the result of training. According to Bompa physical development is still expected in young adulthood (19-25 years).

Methods and measurement techniques

Thus far several factors (such as the nature of the movement, type of exercise, strength level, and training status of athletes), that could influence the optimal training load for peak-power production have been discussed. Apart from these factors, several other additional variables might also affect the results of power assessments (Dugan et al., 2004). These will be discussed briefly.

Data-collection equipment

Methods and measurement techniques to determine power output might influence the results. This should be taken into consideration when comparing the results from different investigations (Dugan et al., 2004; Hori, Newton, Nosaka & McGuigan, 2006).

Hori et al. (2007) recommended two different methods that could be used in measuring power output. Firstly, it is suggested that when measuring the power applied to a barbell, displacement-time data of barbell movement should be measured. This method is useful when the center of gravity (COG) of the barbell and the body do not move in parallel. This is commonly seen in Olympic-type movements where there is a push through the legs and a pull through the arms that prevent the barbell and body COG from moving in a synchronized way (Hori et al., 2006). Various devices such as linear-positioning transducers, rotary encoders or V-scopes could be used to accurately measure bar displacement (Dugan et al. 2004).

The second method recommended by Hori et al. (2007), involves ground-reaction force (GRF) where power is applied to the system (barbell + body). This method results in a more accurate measure of power output applied to the COG of a system during movement. For instance, during squat jumps, the bar and the body move as a unit and the COG of both objects move in a synchronized manner (Baker et al., 2001b; Baker & Nance, 1999; Chiu et al., 2003). This form of testing is done on a force platform that measures the force generated through the legs into the ground.

In an investigation comparing the reliability and validity of several methods to measure PPO, Hori et al. (2007) reported that the two above-mentioned methods are effective. However, they recommended that investigators should be cautious when comparing results from the two methods with each other. In comparing the two methods, Hori et al. (2007) reported significantly lower values for peak force, peak power and mean power applied to the barbell when using the first method (barbell displacement) compared to the power-to-system approach in both the hang clean, and squat jumps. In an earlier study by Hori et al. (2006), it was stated that this is to be expected since methods measuring only acceleration on the bar do not account for the acceleration of the lifter's body mass when performing the hang clean, and the squat jump. This, however, does not imply that the barbell-displacement method is incorrect. Measuring the power applied to the barbell is useful in determining performance when exerting power on an external object.

Even though there are differences in the values of measured power, Hori et al. (2007) confirmed that there is also a strong correlation (r = 0.65-0.81) between the results of the two methods (barbell-displacement method and power-to-system method).

Inclusion or exclusion of body-mass

As mentioned earlier, inclusion or exclusion of body mass could have a considerable influence on the calculation of test results. Previous studies have reported power calculations using both inclusion and exclusion of body mass. The inclusion of body mass entails the summation (system mass) of the mass of the barbell and the body mass of the subject. For example, if a person weighs 80kg and lifts a bar of 60kg, the system mass would be 140kg and power will be calculated on displacement of 140kg and not just the bar mass.

The inclusion of body mass is strongly recommended by Dugan et al. (2004). According to the authors, the ability of the leg extensors to produce force and velocity on the system is dependent on the total load of the bar and body mass. Both these properties need to be considered. When body mass is excluded from light loads, a greater percentage of the load is excluded. This results in diminished power values. The exclusion of body mass from higher loads will cause a much smaller reduction in the load; therefore, power at lighter loads is more affected by exclusion of body mass than power at higher loads. Dugan et al. (2004) reported that the optimal load may shift from 20 to 70% 1RM based on whether body mass is included in the calculation.

This, however, is only applicable when measuring the system mass. When performing a squat jump with the bar on the shoulders, both the bar and the body need to be displaced, but when performing the hang clean, the bar moves independently from the body and body mass is not included in the calculation (Hori et al., 2007). It would be advisable to be cautious when comparing results of power output in the squat jump where body mass is not included in the calculation of results.

Free weight versus Smith-machine weight

Performing a squat jump in a Smith-machine (a squatting apparatus in which the barbell is attached to both ends with linear bearings on two vertical bars, allowing only vertical movement) or with free weights (barbell only) is another factor that might influence power production.

In previous studies (Bevan et al., 2010; Izquierdo et al., 2001, Izquierdo et al., 2002; and Siegel et al., 2002) optimal loads for PPO were between 0-70% 1RM when performing the squat jump in a Smith-machine. A similar range (0 to 63% 1RM) was reported in other studies. Baker et al. (2001b), Stone et al. (2003), Thomas et al. (2007), and Cormie et al. (2007b) followed the free-weight method. Dugan et al. (2004) also compared a free-weight squat jump with a Smith-machine squat jump and reported that in both instances PPO was achieved at 20% 1RM. It would seem that both methods would be valid and can be compared when determining PPO in the squat jump. In a study by Schuna and Christensen (2010) it was reported there is no unique loading tool that is superior for power production in the squat jump (e.g., free weight, Smith machine, loaded vest, dumbbell or a specialised jump-training device).

Mean-versus peak power

The literature reports two different methods of power calculation. Studies focusing on squat jumps by McBride et al. (2002) and Cormie et al. (2007b) for instance, reported peak-power values and pointed out that the optimal training load for PPO should be at 0% 1RM. Baker et al. (2001b) and Izquierdo et al. (2001) presented mean-power values and concluded that the optimal load for power training should be between 47-70% 1RM.

This makes it difficult to compare the results from the different studies. According to Dugan et al. (2004) both approaches are technically correct, but should be taken into account when comparing results.

Instruction given to subjects

It is clear that a standardisation of a research protocol has not yet been established when comparing peak-power productions in Olympic-, and ballistic movements. It is therefore important that researchers specify the exact movement type of each exercise, because there are variations of a particular exercise. For example, when performing an Olympic-type movement, the instruction should be clear on whether a power clean (from the floor), a hang clean (from the knees), a hang clean (from mid-thigh), a high pull (no catch) or a power snatch (overhead) should be performed.

In the squat-jump, instruction should indicate the depth that a subject should go down before jumping and whether to use a countermovement jump. For example, Stone et al. (2003) reported the use of static and dynamic squat jumps from a position with the thighs parallel to the floor. In other studies (Baker et al., 2001b) participants were allowed to select their own preferred squat depth.

Chapter Three

Methodology

Research problem

It has been reported that peak-power output occurs at different training loads for different exercises, depending on the nature of the exercise (Baker et al., 2001a, 2001b; Garhammer, 1993; Newton & Dugan, 2002; and Stone et al., 2003). Unfortunately, the prescribed loads reported in the literature have generally been collected from different exercises involving different testing protocols and equipment.

Exercises should be categorised according to their nature (e.g., upper-body versus lower-body, single-joint versus multi-joint), movement type (e.g., Olympic, ballistic, traditional) and specific exercise equipment used (e.g., free-weight versus fixed-weights). These variables could influence the loads that produce MPO. Other factors that should also be considered when prescribing a load are the strength levels and training status of the participants. Stronger and weaker athletes produce different test results and training experience could also have an impact on the load that would produce peak-power output (PPO).

The present study aimed to provide a more accurate understanding of the range of loads that can be used for power development in specific exercises for rugby players. The resistance exercises used in this study were relevant to the specific physical demands placed on rugby players and also formed part of their normal on-going power-training regimen. Since training can cause a fluctuation in peak-power output during various stages of the training cycle, this study also monitored these variations.

Research design

The study is a quantitative, field experimental study, with probabilistic sampling, but without random assignment of participants.

Aim of the study

The purpose of this study was to investigate the effect of different training loads on maximal-power output (MPO) of rugby players for the hang clean (Olympic-type exercise), and squat jump (ballistic exercise). Also, it aimed to ascertain whether a change in the strength levels and training status of players had an effect on the loads that produce MPO. Additionally, a comparison between the different playing positions will be made to establish if there are any differences in loads that produce MPO.

Research questions

The following research questions were formulated:

- What is the optimal load (percentage 1RM) that will result in peak-power output in the hang clean, and squat jump?
- Does peak-power output occur at different percentage loads for Olympic-type, and ballistic exercises?
- Is there a fluctuation of the optimal load within a yearly periodised training-programme between macro-cycles?
- Do participants from different playing positions (forwards vs. backline) produce peak-power output at different loads?

Research parameters

The following aspects were assessed:

- Body mass (Seca 711 mechanical sliding weight beam scale)
- Maximal strength in the hang clean, and squat
- MPO over a range of loads (30-90% 1RM) in the hang clean, and squat jump
- Peak velocity over a range of loads (30-90% 1RM) in the hang clean, and squat jump

Participants

The sample for pre-season testing consisted of 59 male rugby players, from two rugby academies, who were familiar with both the hang clean, and squat jump, participated voluntarily in the study. They competed in the same league (Western Province Super-A) and trained at the same performance level. A sample of convenience was used.

Due to a high occurrence of injuries during the season, the sample size decreased to 29 players for the in-season testing.

The same testing protocol was followed with both academy groups. The conditioning trainers of the two institutions communicated regularly during the year regarding their training programmes to ensure that training variables were more or less similar.

All the participants were involved in a two-month intensive pre-season weight-training programme prior to testing. This prepared them to effectively perform the full squat, squat jump and hang clean exercises. They were therefore familiar with the tests as they regularly performed them as part of their normal training programme.

Participants completed a medical questionnaire at the beginning of the year and were cleared by medical professionals to participate in the training programmes of the two institutions. Since the testing phase was part of their training programme, no additional medical clearance was deemed necessary.

Prior to participating in the testing, all participants read and signed an informed-consent form and a health-history questionnaire.

Participants were made aware of any risk associated with participation in the study (Appendix A). Ethical clearance for the study was granted by Stellenbosch University.

Players were instructed not to participate in any other strenuous exercise other than the normal rugby practices during the week of testing and not to eat within two hours before testing.

All players were required to wear running shoes during testing.

Inclusion criteria

For players to be included in the research they had to be male rugby players, between the ages of 18 and 22 years, with at least two months experience in weightlifting and power training. The players must have mastered the correct technique in all the lifts involved and train regularly (three times per week). Both exercises are described later, but for a player to be considered competent in the lifts, it was important that the key biomechanical actions were used. As described earlier, the correct technique for the hang clean is when a player start from an upright position, prior to lifting, dip at the hips followed by an powerful triple extension of the ankle, knee and hip joint while pulling with the arms and catch the bar at shoulder height.

To be competent in the squat jump, a player must be able to perform a similar movement, but with the bar on the shoulders. During the jump phase, the bar must not leave the shoulders and players should be able to land in a safe quarter squat position.

Players nursing an injury or illness that could prevent them from exerting maximal efforts in the tests were not considered for testing. In the second series of tests, players were excluded from testing if they participated in fewer than 80% of the conditioning sessions.

Place and time of testing

Testing took place at the venues where players normally trained; so they were familiar with the equipment and surroundings.

The first group was tested at the Van der Stel Gymnasium in Stellenbosch. Tests were conducted indoors on an Olympic platform with a wooden surface.

The second group was tested at the campus of the *Rugby Performance Centre (RPC)* in Riebeeck West. Tests were also done indoors, but on a rubber surface.

In a recent study (Ebben, Flanagan, Sansom, Petushek, Jensen, 2010), ground reaction force on various surfaces was compared. The researchers concluded that for hard surfaces and wrestling mats the outcomes for most variables tested during plyometric training were similar. It should be mentioned that the rubber surface used in the current study was a hard rubber mat and it was highly unlikely that it would have affected the outcome of the test results.

All testing was conducted between 07h00 and 13h00.

Testing procedures

Testing took place over a period of two consecutive weeks with both groups being at the same stage in their preparation and subjected to the same mode and type of weight-training programmes during the year. The testing formed part of their training programme at the completion of the pre-season training phase and then again towards the latter part of the in-season programme.

Testing was carried out over a five-day period with three testing days and a rest day between tests to allow for recovery. The researcher, who is a certified strength and conditioning coach (CSCS) and the conditioning coach at the *Stellenbosch rugby academy,* conducted all the testing and was assisted by a biokineticist on both testing occasion.

Maximal strength

The hang clean, squat and the squat jump are very dynamic movements that produce high power output. Baker and Nance (1999) reported a significant (r = 0.79) relationship between the squat and the hang clean, and the squat jump.

These exercises were selected because of the similar joint angles and muscular requirements involved in the execution of these movements and that of most athletic movements (Hendrick & Wada, 2008). Hori et al. (2008) reported that athletes with a greater 1RM in the hang clean relative to their body mass, possess high maximal strength, power, and jumping and sprinting prowess.

Strength testing (hang clean and squat) was conducted on the first day. A ten-minute dynamic warm-up (squatting, jumping and light Olympic-type movements) preceded the actual testing. The maximal-effort trials for both tests were based on the protocol recommended by the *National Strength and Conditioning Association* (Baechle & Earle 2000) (See Table 3.1).

Table 3.1 Test protocol for maximal-strength testing

One-Repetition Max (1RM) protocol for the hang clean	**3 RM protocol for the squat**
Estimate warm-up load that allows for 8-10 repetitions by the athlete.	Estimate warm-up load that allows for 8-10 repetitions by the athlete
2-minute break	2-minute break
Load increase of 10%	Load increase of 10%
Athlete completes 4-6 repetitions on new load	Athlete completes 6 repetitions on new load
2-minute break	2-minutes break
Load increase of 10%	Load increase of 10%
Athlete completes 2-4 repetitions on new load	2-4 minute break
2-4 minute break	Athlete attempts a 3RM
Athlete attempts a 1RM	If athlete is successful, increase load with 5-10%
If athlete is successful, increase load with 5-10%	If unsuccessful, decrease load with 5-10%
If unsuccessful, decrease load with 5-10%	

Loads were continuously increased or decreased until the players could complete one repetition with proper technique. Players had to reach one repetition max (1RM) in the hang clean, and 3RM in the squat within five attempts (Baechle & Earle 2000).

The hang clean

A 1RM hang-clean test was conducted first using the method of Stone (cited in Kawamori et al., 2005). A free-weight Olympic barbell was used (See Figure 3.1).

The following procedures were followed:

- The movement is initiated from a standing position (feet shoulder-width apart) with the subject holding the bar with a closed grip (hands shoulder-width apart).
- From this starting position, the subject lowers the bar to knee height by pushing (flexing) the hips backward, while keeping the arms straight.
- The bar is lifted by extending the hips explosively and pulling with the arms.
- As the bar is lifted, the subject dips under the bar and catches it at chest (nipple line) height.
- The bar is caught in a quarter-squat position (depending on the subject's ability and technique). This action is done at maximal speed.
- A hang clean performed in a squat position with the thighs lower than parallel to the floor, is deemed unsuccessful.
- If a subject fails to lift the bar to chest height, the attempt is also ruled unsuccessful.
- After catching the bar, the player was required to extend the knee and hip fully for the lift to be successful.

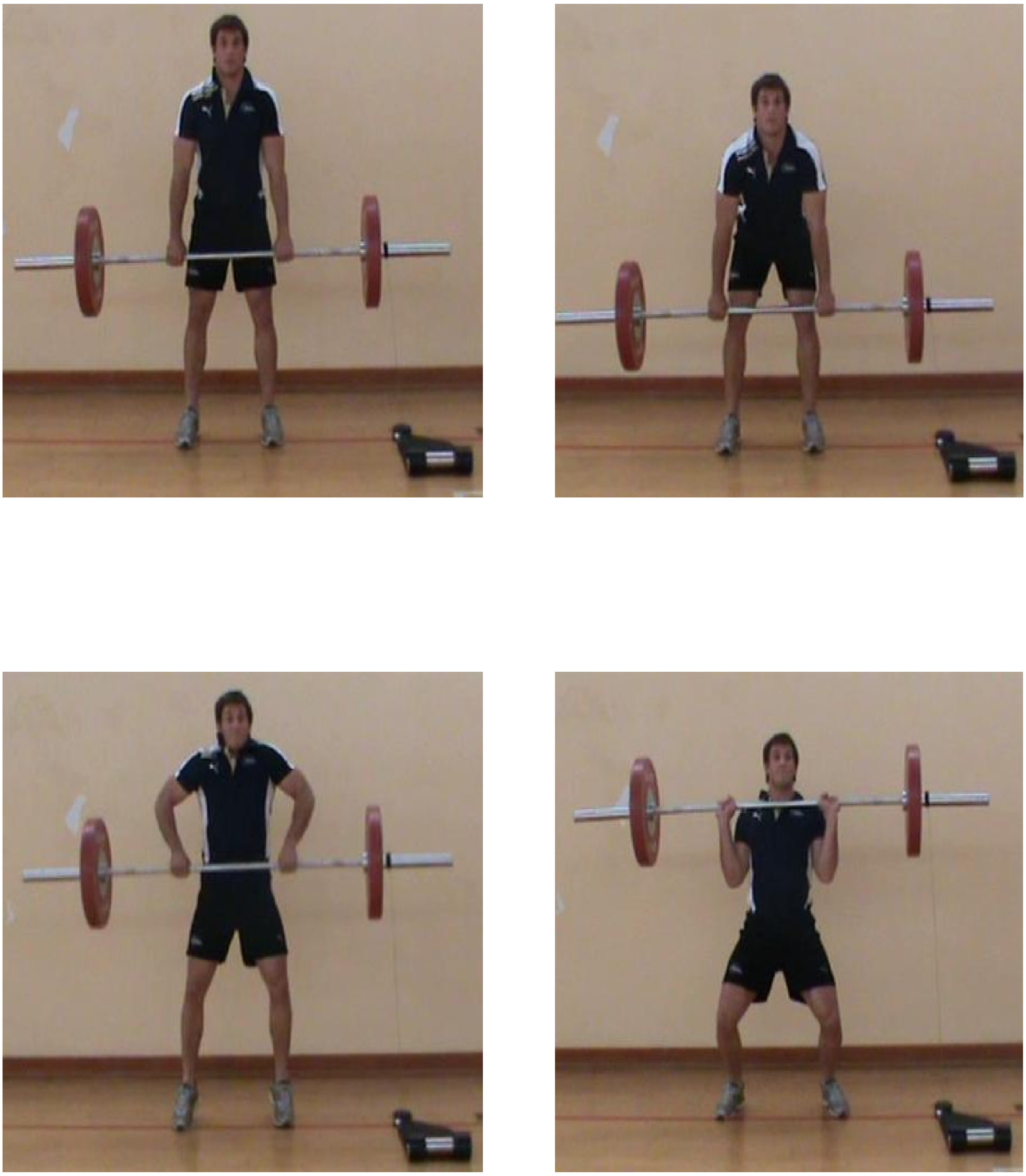


Figure 3.1 Visual images of the hang clean

It should be noted that the method recommended by Stone (cited in Kawamori et al., 2005) was slightly modified to suite the participants in the present study. Stone proposed that the bar should not drop below mid-thigh level prior to lifting. The participants in this study were all familiar with performing the lift from below the knees and were not accustomed to the lift prescribed by Stone. A compromise was made allowing for the bar to be dropped to knee height before lifting. Besides chalk (to facilitate gripping), no other aids such as writs, knee wraps or belts were permitted.

The hang clean is a full-body exercise and requires both upper-body and lower-body strength. This test was performed before the squat test (that requires lower-body strength). It is the researcher's opinions that by performing the hang clean first; it would have less influence on the subsequent squat test, than would be the case if the squat test was performed before the hang clean.

The squat

The second test, the squat, was performed on the same day, 30 minutes after the hang clean. The full squat was used as a strength test and the squat jump for the power test. Maximum strength was assessed by a 3RM full squat performed with a free-weight Olympic barbell. The 3RM-squat was preferred to the 1RM-squat, because, participants were not familiar with the 1RM testing procedure and the 3RM-test is considered safer (Tan, 1999). Three spotters where percent during all the 3 RM squat testing to provide support incase participant did not succeed in a lift.

According to the rules of the *International Power Lifting Federation* when doing the squat the subject must bend his knees and lower his body until the top surface of the leg at the hip joint is lower than the top of the knee (Groves, 2000). During testing this depth was assessed visually by the strength and conditioning coach.

From the 3RM-squat, a 1RM was determined by multiplying the 3RM by a standard correction factor of 1.08 (Baker, 1995b).

Power

The hang clean was performed on the third day of testing (similar to the strength test on day one) and the squat jump test was performed on the fifth day. It was decided on this order of testing because it gave participants sufficient rest between testing days. Once again, the hang clean was performed before the squat jump in an attempt to minimize the possible effect that the two movements will have on each other. During the power testing the peak-power output at different loads was measured.

The hang clean

Participants warmed up with similar movements to the subsequent test attempting maximal efforts in the hang clean (with the same protocol as in the maximal testing) at loads of 30, 40, 50, 60, 70, 80 and 90% 1RM (determined on day one). The order of loads was 30, 90, 40, 80, 50, 70, and 60% 1RM with two successful attempts on each load.

Taking the possibility of neuromuscular fatigue into consideration, it was decided to precede heavy lifts with lighter lifts. Since Hansen and Cronin (2004) suggested that the mix load method is a superior method for power development, a similar approach was used in the testing.

Participants were instructed and verbally encouraged to lift the bar with maximal effort in order to obtain peak-power output on each lift. A recovery period of at least three minutes was provided between trials to ensure maximal effort during the subsequent attempt.

The squat jump

The same warm up was performed prior to the squat jump as for the hang clean. The squat jump was performed as follows (See Figure 3.2):

- Participants set up for the squat jump in a standing position while holding a barbell across their shoulders.
- After instruction, participants initiated the squat jump through a downward countermovement. Participants could select their own preferred squatting depth before jumping (as described by Baker et al, 2001b). They were, however, instructed not to pause at the end of the downward movement but to jump immediately afterwards to optimize the elastic energy (Baechle & Earle, 2000).
- After the countermovement, participants performed a jump by triple extension of the leg. They were instructed to maintain constant downwards pressure on the barbell throughout the jump and were verbally encouraged to jump to a maximal height with each trial to maximize power output (Behm & Sale, 1993; Newton, Kraemer, Hakkinen, Humphries & Murphy, 1996). The bar was not allowed to leave the shoulders of the subject.
- Participants landed in a squatted position again to minimize the load on the lower back.

Training program

The periodized plan followed by both rugby academies was a linear periodisation (adapted from Bompa & Claro, 2009). The yearly cycle was divided into a 12 week pre-season phases, followed by two competition phases (in-season) lasting 10 weeks each. The pre-season training predominantly focused on injury prevention training while developing hypotrophy and strength. Weightlifting techniques were introduced from the beginning and power training started as soon as a player could perform the lift. The loads used were according to the repetition maximal-loading continuum (Table 2.2).

During the in-season, the focus of training shifted towards maximal strength training and power development. A mixed-method power training approach was used during this time, alternating high force/low velocity exercises with high velocity/low force excises. Weightlifting exercises were used at least once per week. Three weight training sessions per week were conducted per throughout the pre- and in-season.

Participants performed maximal effort squat jumps at loads of, 30, 90, 50, 60, 70, 80 and 90% 1RM (determined on day one). The order of loads was 30, 90, 40, 80, 50, 70, and 60% 1RM with two successful attempts on each load. The order of loading was selected for the same reason as in the hang clean test. No additional aids such as writs, knee wraps or belts were allowed.

A recovery period of at least three minutes was provided between trials to ensure maximal effort during the subsequent trial.

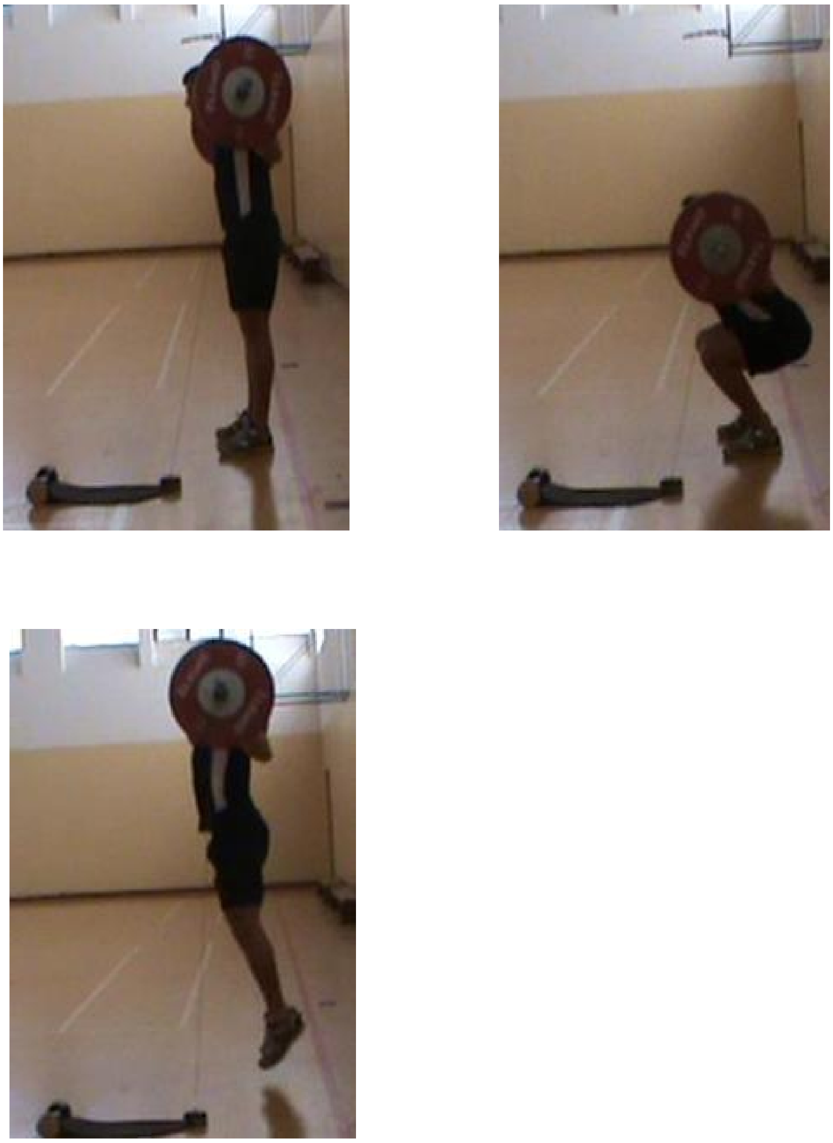


Figure 3.2 Visual images of the squat jump

The use of the TENDO Weightlifting Analyser

During testing the *TENDO Weightlifting Analyzer V-104 (TWA)* was used. In a study comparing the TWA with the *Fitrodyne Sport Powerlyzer (SP)*, it was reported that the TWA works with an error of under 3% (less than the Fitrodyne SP), which is considered acceptable for this type of testing equipment (TENDO sport machine, 2005).

Several researchers (Coelho, Hamar & Araujo, 2003a; Coelho, Velloso, Brasil, Vaisman & Araujo, 2003b; Jennings, Viljoen, Durandt & Lambert, 2005; Jones, Fry, Weiss, Kinzey & Moore, 2008; Rhea, Oliverson, Marshall, Peterson, Kenn et al., 2008a; Rhea, Peterson, Oliverson, Ayllon & Potenziano, 2008b) have used the TWA in their research on power output.

Jennings et al. (2005) reported that there was a positive ($r = 0.99$) repeatability in force versus speed of contraction curves in both single-joint (biceps curl) and multiple-joint squat-jump exercises for measuring peak-power output. The same protocol was later used by Rhea et al. (2008b) in a study measuring concurrent power and moderate-to-high intensity endurance training.

Jones et al. (2008) conducted a kinetic comparison of the use of a free weight versus a machine when performing the power clean. The Fitrodyne SP was used to assess the barbell force, velocity, and power. Similar to the TWA, the Fitrodyne SP is attached to the barbell with a light nylon tether.

As mentioned earlier, Hori et al. (2007) highlighted two factors in power measurement. The first being the displacement time of the barbell, and the second, ground-reaction force. The former being more applicable to measuring barbell movement, for example in the hang clean, and the latter for assessing power applied to the system such as the squat jump. The Fitrodyne SP was used in both since ground-reaction force equipment is expensive and sometimes impractical. Jennings et al. (2005) believe that the Fitrodyne SP is a very practical piece of equipment compared to other ergometers in that it is versatile and relatively inexpensive.

In the present study the TWA was used to analyze the displacement-time of the barbell. This device is attached to conventional resistance-training equipment and measures the speed of bar movement. Figure 3.3 illustrates the way the TENDO-TWA was attached to the barbell with the nylon line being pulled as the weight is lifted.

Muscle power was calculated from the production of force and speed of contraction. Data were collected from each of the lifts performed. The better effort with the highest PPO of the two lifts was used and plotted on a graph to determine at which percentage load of 1RM the highest power output was produced.

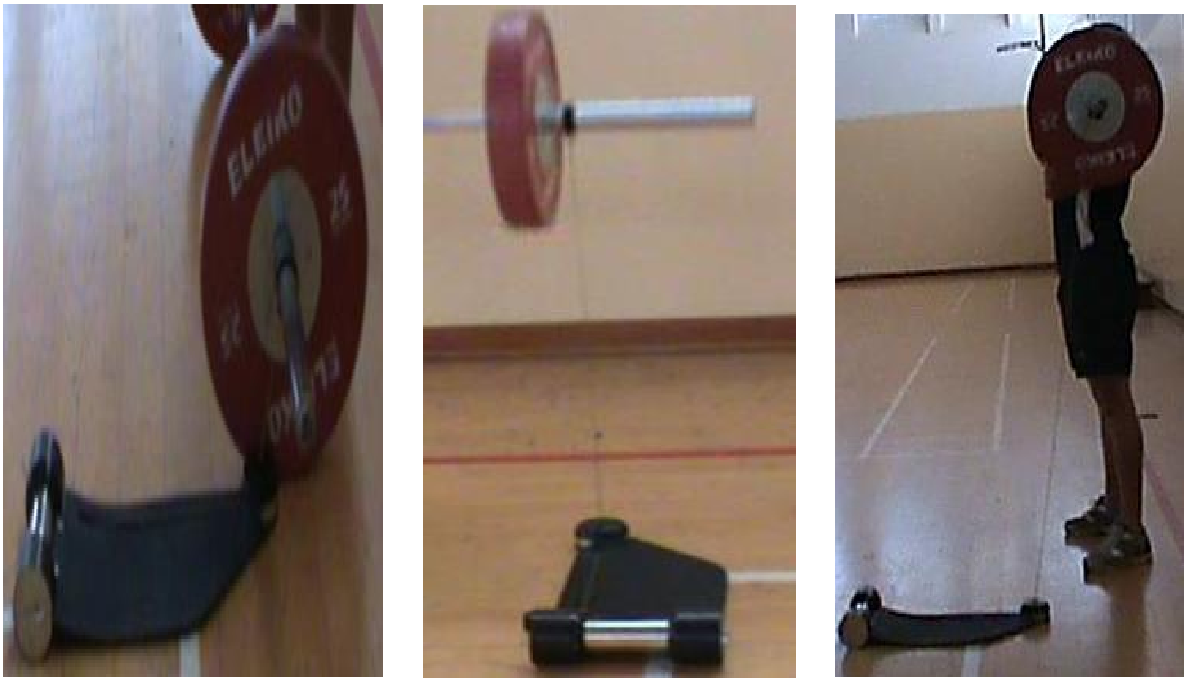


Figure 3.3 Visual image of the TWA in use

Table 3.2: Pre-season testing timeline

Pre-Season									
Week 1-Group 1 (SRA)					**Week 2-Group 2 (RPC)**				
Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
One RM Hang Clean and Squat Testing	No testing	Hang Clean Power output testing	No Testing	Squat Jump Power output testing	One RM Hang Clean and squat Testing	No testing	Hang Clean Power output testing	No Testing	Squat Jump Power output testing

Five month competition phase (April-August)

Table 3.3: In-season testing timeline

In –Season									
Week 1-Group 1 (SRA)					**Week 2-Group 2 (RPC)**				
Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
One RM Hang Clean and Squat Testing	No testing	Hang Clean Power output testing	No Testing	Squat Jump Power output testing	One RM Hang Clean and squat	No testing	Hang Clean Power output testing	No Testing	Squat Jump Power output testing

Statistical analysis

Means and standard deviations of the test data were calculated. A repeated-measures ANOVA was used for investigating group and season effects.

Cohen's effect size (ES) of changes for each parameter was also calculated. The values used for Cohen's effect size were ≥ -0.15 and < 0.15 (negligible effect), ≥ 0.15 and < 0.40 (small effect), ≥ 0.40 and < 0.75 (moderate effect), ≥ 0.75 and < 1.10 (large effect), ≥ 1.10 and < 1.45 (very large effect) and > 1.45 (huge effect) (Thalheimer & Cook, 2002).

For post hoc testing, the Fisher least significant difference (LSD) method was used.

Chapter Four

Results

The findings of the study will be presented in this chapter.

First, the maximal-strength scores of the entire sample for the hang clean and squat are reported. This is followed by the peak-power and peak-velocity scores for the hang clean and the squat jump. Lastly, the forwards' and the backline-players' 1RM-scores, peak-power, and peak-velocity values for the hang clean, as well as the peak-power, and peak-velocity results for the squat jump are compared.

Results of the total sample

Age and mass of the participants

The mean age of the participants at the first testing during the pre-season phase was 19.3 (±SD 0.5) years for the backline players and 19.3 (±SD 0.8yr) for the forwards. (Table 4.1).

Table 4.1 Body mass of the participants

	Pre-season test	**In-season test**
Backline players	77.4 (±SD 8.7)kg (n = 25)	82.5 (±SD 9.1)kg (n = 11)
Forwards	92.1 (±SD 11)kg (n = 34)	92.3 (±SD 10.3)kg (n = 18)

At the first (pre-season) testing session the mean body mass of the backline players was 77.4 (±SD 8.7) kilograms and 91.1 (±SD 11kg) for the forwards. It is interesting to note in Table 4.1 that the backline players showed a 6.5% gain (5.1kg) in body mass in the period between the two testing sessions (pre- and in-season) as compared to a mere 0.22% gain of only 0.2kg among the forwards. A possible explanation for this finding could possibly be the confounding influence of the data of the participants who were eliminated (for example those who were injured) from the second testing phase (forwards 56% dropout and backs 47 % drop out).

One-repetition Max (1RM)

The 1RM-scores for both the hang clean and the squat changed significantly ($p<0.01$) as the season progressed (Tables 4.2, 4.3 and 4.4).

Table 4.2 Descriptive data for the 1RM hang clean & squat during pre-and in-season.

Exercise	**Season**	**Mean ± SD**	**p**	**Cohen's effect size (€)**
Hang clean	Pre-season (n = 57)	82.28 ± 11.99		
Hang clean	In-season (n =28)	91.43 ± 12.54	0.000014 *	0.74 (moderate)
Squat	Pre-season (n = 51)	158.18 ± 20.94		
Squat	In-season (n = 29)	181.02 ± 22.24	0.000008*	1.09 (large)

*$p< 0.01$

Table 4.3 Fixed effects for the 1RM-hang clean

Effect	Numerator degrees of freedom (*Num.DF*)	Denominator degrees of freedom (*Den.DF*)	*F*	*p*
Season	1	26	28.865	0.000014*
Group	1	55	0.876	0.3533
Season* Group	1	26	0.827	0.3716

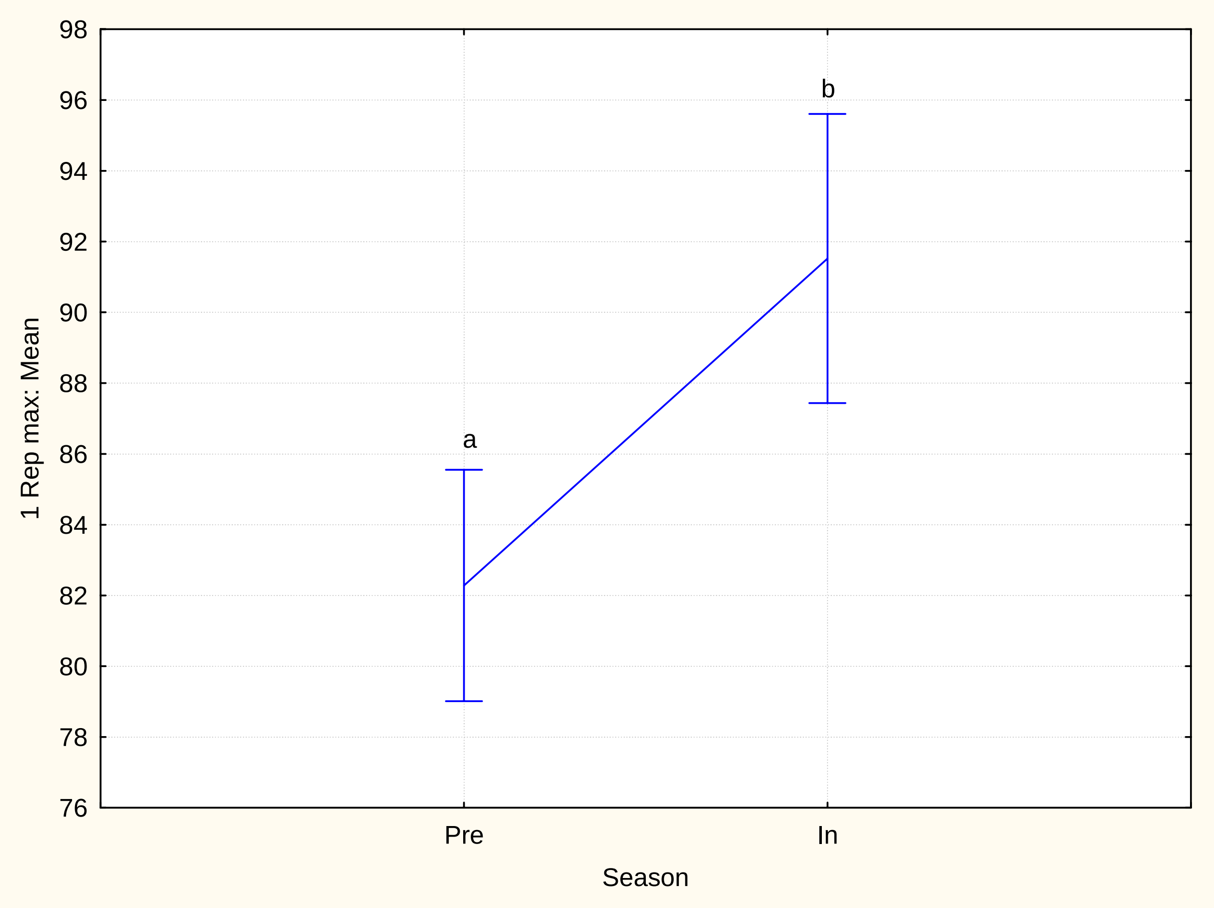
*$p < 0.01$

Table 4.4 Fixed effects for the 1RM-squat

Effect	*Num.DF*	*DenDF*	*F*	*p*
Season	1	24	29.35	0.000008 *
Group	1	52	1.97	0.1661
Season*Group	1	24	0.44	0.5120

*$p < 0.01$

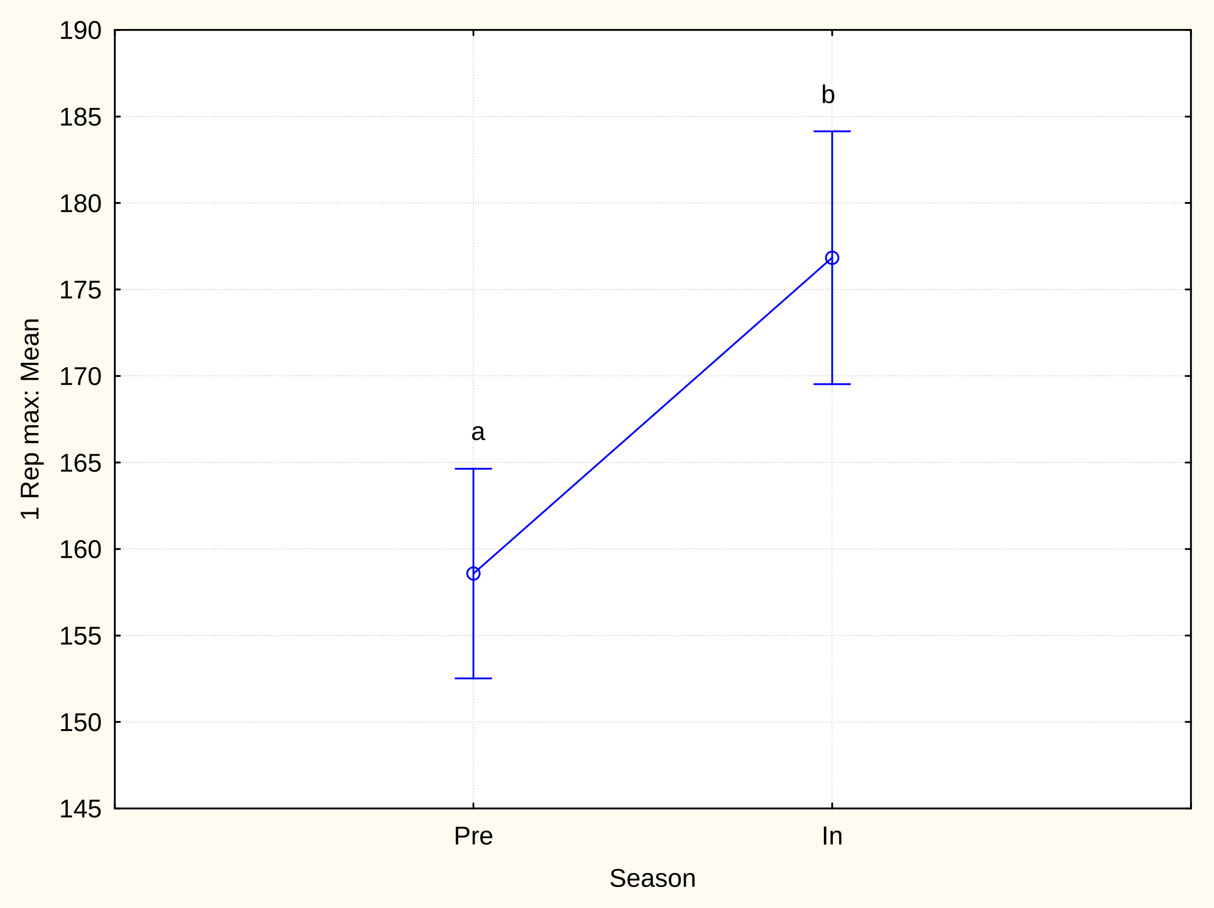
As can be seen in Figure 4.1, there was a significant increase (p<0.01) in performance achieved during the in-season testing for the hang clean. Participants attained a higher (82kg to 91kg) 1RM-score during the in-season compared to their pre-season scores for the hang clean. The increase in scores for the hang clean had a moderate (0.74) practical significant effect.



a-b p< 0.01

Figure 4.1 Max Rep-scores for the hang clean during pre-, and in-season testing

A similar result was obeserved in the 1RM-squat with a significant (*p*<0.01) increase (158kg to 181kg) at the in-season testing compared to the pre-season test scores (Figure 4.2). A large (1.09) practical significant effect was found.



a-b p< 0.01

Figure 4.2 Max Rep-scores for the squat during pre-, and in-season testing

Hang-clean peak power

Table 4.5 Descriptive data for hang clean peak power during pre-and in-season

% Load	**Season**	**Mean ± SD**	**P**	**ϵ**
30	Pre-season	688.46 ± 114.73		
40	Pre-season	815.78 ± 132.22	0.000000*	1.04 (large)
50	Pre-season	945.19 ± 145.46	0.000000*	0.73 (moderate)
60	Pre-season	1031.68 ± 155.10	0.000000*	0.78 (large)
70	Pre-season	1109.52 ± 165.64	0.000000*	0.49(moderate)
80	Pre-season	1190.43 ± 172.72	0.000000*	0.48 (moderate)
90	Pre-season	1246.24 ± 195.66	0.000229*	0.31 (small)
30	In-season	756.89 ± 139.21		
40	In-season	935.67 ± 205.48	0.000000	1.04 (large)
50	In-season	1085.07 ± 174.90	0.000000*	0.8 (large)
60	In-season	1183.28 ± 172.12	0.000001*	0.58 (moderate)
70	In-season	1272.32 ± 165.96	0.000130*	0.54 (moderate)
80	In-season	1325.07 ± 187.57	0.010654*	0.31 (small)
90	In-season	1337.071 ± 226.93	0.559810	0.06 (negligible)

*$p<0.01$

Results from the peak-power production of the hang clean reveal that both the percentage load and the season had a significant effect ($p<0.01$) on power production in this exercise (Table 4.6).

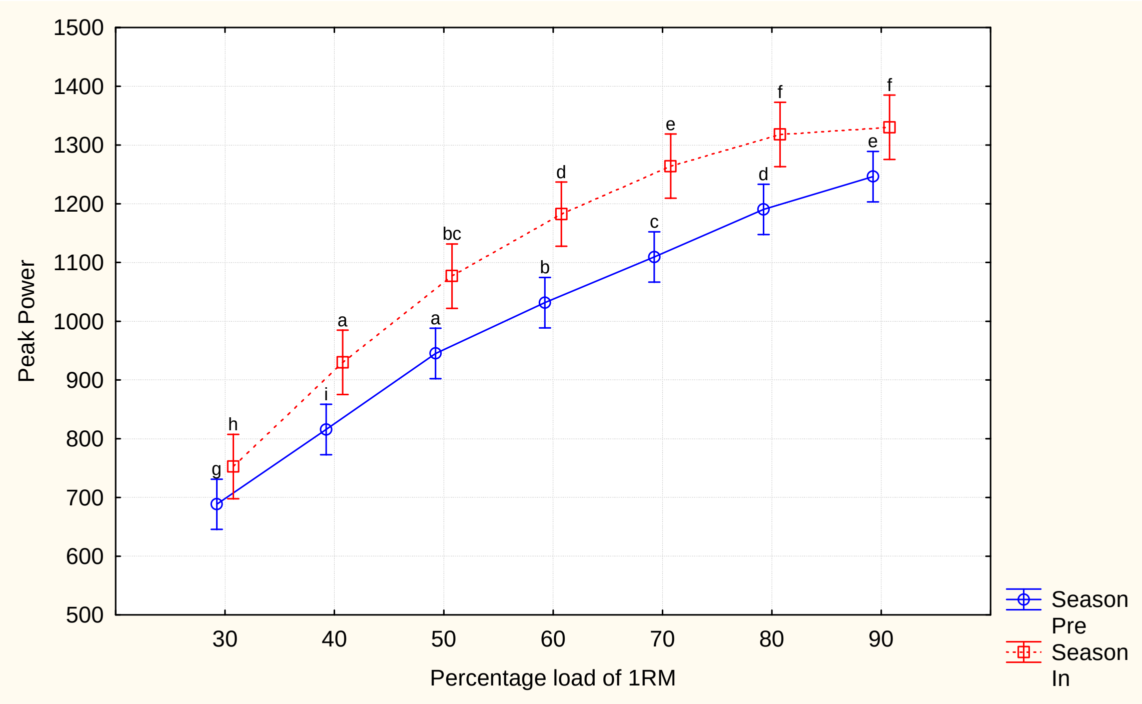
Table 4.6 Fixed effects for peak power in the hang clean

Effect	*Num.DF*	*DenDF*	*F*	*p*
Percentage	6	330	451.1223	0.000000*
Season	1	26	38.8599	0.000001*
Group	1	26	0.1957	0.6618
Percentage*Season	6	156	3.7245	0.0017*
Percentage*Group	6	330	1.4770	0.1852
Season*Group	1	26	6.0972	0.0204**
Percentage*Season*Group	6	156	1.3754	0.22777

*$p < 0.01$
**$p < 0.05$

Table 4.5 indicates that the optimal load for the hang clean at the pre-season testing was at 90% of 1RM (1246watt). Figure 4.3 shows that the peak-power output ascended with an increase in load from 30% up to 90% 1RM. There were significant (p<0.05) increases in all the loads tested. There was a small to large (0.31-1.04) practical significant increase (Table 4.5). Figure 4.3 indicated that during the pre-season testing there was no plateau in the curves, which continued to rise as the load increased. There was a significant (p<0.01) increase in peak-power production from the pre-season to the in-season. However, the shape of the two graphs was similar during both rounds of testing. This similar shape can be seen in Figure 4.3, indicating a rise in power production as the intensity of the load increased.

During in-season testing there was a significant (p<0.01) increase in power production between all the loads from 30-80% 1RM, with once again a small to a large (0.31-1.04) practical significant effect. There was however no increase in effect from 80% (1325watt) to 90% (1337watt) 1RM. The practical significant difference between the 80% and the 90% power output was negligible (0.06). The graph for the in-season testing started to show a plateau towards the higher loads where power productions no longer increased with accompanying load increases. In-season peak-power scores were significantly (p<0.01) higher at load intensities of 30, 40, 50, 60, 70, 80 and 90% 1RM than those attained at the pre-season testing.



Pre-season: g-i/i-a/a-b/b-c/c-d/d-e p< 0.01
In-season: h-a/a-bc/bc-d/d-e/e-f p< 0.01

Figure 4.3 Peak-power production in the hang clean at various loads during pre-, and in-season testing

Hang-clean peak velocity

Table 4.7 Descriptive data for hang clean peak velocity during pre-and in-season

% Load	**Season**	**Mean ± SD**	**P**	**€**
30	Pre-season	2.87 ± 0.34		
40	Pre-season	2.57 ± 0.3	0.000000*	0.94 (large)
50	Pre-season	2.35 ± 0.28	0.000000*	0.76 (large)
60	Pre-season	2.08 ± 0.24	0.000000*	1.04 (large)
70	Pre-season	2.02 ± 0.18	0.866980	0.29 (small)
80	Pre-season	1.86 ± 0.17	0.000006*	0.92 (large)
90	Pre-season	1.73 ± 0.16	0.000651*	0.79 (large)
30	In-season	2.74 ± 0.32		
40	In-season	2.53 ± 0.33	0.000020*	0.66 (moderate)
50	In-season	2.36 ± 0.22	0.000448*	0.62 (moderate)
60	In-season	2.20 ± 0.18	0.003877*	0.81 (large)
70	In-season	2.01 ± 0.14	0.000049*	1.2 (very large)
80	In-season	1.89 ± 0.18	0.011981*	0.76 (large)
90	In-season	1.66 ± 0.15	0.000006*	1.41 (very large)

*p<0.01

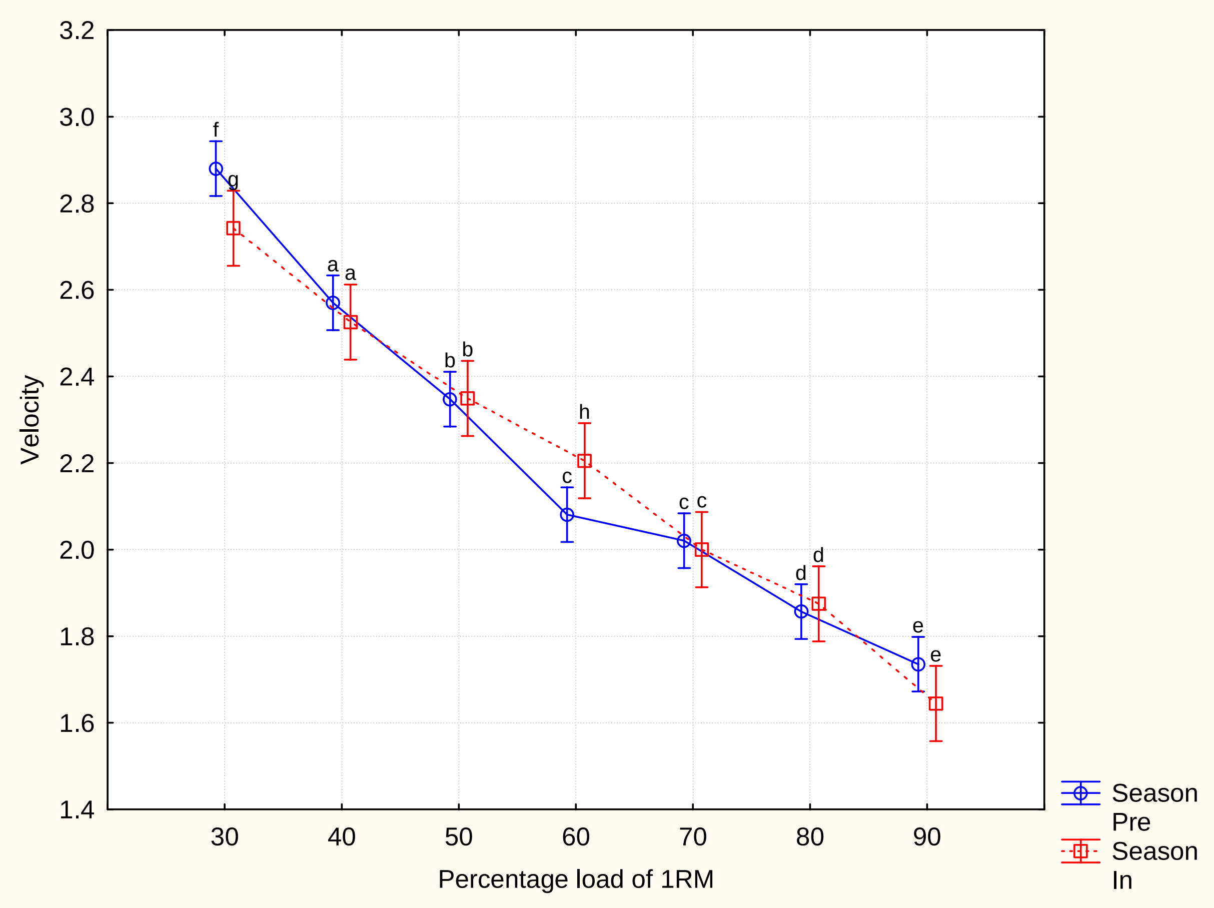
Table 4.8 Fixed effects for peak velocity in the hang clean

Effect	*Num.DF*	*Den.DF*	F	p
Percentage	6	336	462.8282	0.000000*
Season	1	27	31.7291	0.000006*
Percentage*Season	6	162	4.0244	0.000873*

**p< 0.01*

Peak velocity for the hang clean was significantly ($p<0.01$) affected by the percentage loads used as well as by the phase (season) ($p<0.01$) of the training-year when testing took place (Table 4.8).

Figure 4.4 indicates that at the pre-season testing, the velocity of the bar decreased significantly ($p<0.01$) with the increasing load. Bar velocity was lower at loads of 40-90% compared to 30% 1RM. Loads of 50-90% were also significantly lower than at 40% 1RM, whereas loads of 60-90% were significantly lower than 50% 1RM.



Pre-season: f-a/a-b/b-c/c-d/d-e $p<0.01$

In-season: g-a/a-b/b-h/h-c/c-d/d-e $p<0.01$

Figure 4.4 Peak velocity in the hang clean at various loads during pre-, and in-season testing

The decrease in velocity between loads of 60% 1RM and 70% 1RM did not influence the scores. There was no significant decrease in velocity of the bar at 60% (2.08 m/s) and 70% (2.02 m/s) 1RM (Table 4.7). The practical significant drop in velocity was small (0.29). Scores on loads of 80-90% were lower than 60% and 70% 1RM. The lowest velocity was reached at 90% 1RM. This was significantly ($p<0.01$) lower than the velocity at 80% 1RM with a large (0.79) practical significant effect. Except for the velocity at 60% and 70% 1RM, the graph (Figure 4.4) showed an inverted velocity-peak-power relationship.

The velocity on the bar during the in-season testing, indicated that the velocity of the movement significantly ($p<0.01$) decreased between all the loads (30, 40, 50, 60, 70, 80 and 90% 1RM) as the percentage load increased. When comparing the pre-season velocity to the in-season velocity (Figure 4.4), a significant ($p<0.05$) decrease in bar velocity at 30% 1RM during the in-season testing is evident. There was an inverse effect on bar velocity at 60% 1RM as the speed of movement increased significantly ($p<0.05$) with the in-season testing, compared to the pre-season testing. No significant change in bar velocity was evident at loads of 40, 50, 70, 80 and 90% 1RM. The decrease in bar velocity at loads of 40, 50, 70, 80 and 90% 1 RM did not influence the test scores.

Squat-jump peak power

Table 4.9 Descriptive data for squat jump peak power during pre-and in-season

% Load	Season	Mean ± SD	P	є
30	Pre-season	2562.28 ± 310.28		
40	Pre-season	2649.6 ± 324.43	0.000183*	0.39 (small)
50	Pre-season	2689.94 ± 313.46	0.079162	0.13 (negligible)
60	Pre-season	2737.04 ± 344.70	0.039551**	0.15 (small)
70	Pre-season	2732.34 ± 334.82	0.832583	0.02 (negligible)
80	Pre-season	2781.76 ± 336.63	0.031431**	0.15 (small)
90	Pre-season	2769.32 ± 356.80	0.763452	0.04 (negligible)
30	In-season	2734.27 ± 373.71		
40	In-season	2780.37 ± 381.71	0.124723	0.12 (negligible)
50	In-season	2861.10 ± 320.92	0.007915*	0.22 (small)
60	In-season	2837.10 ± 355.90	0.424243	0.07 (negligible)
70	In-season	2825.44 ± 348.43	0.703118	0.05 (negligible)
80	In-season	2864.93 ± 345.18	0.187789	0.04 (negligible)
90	In-season	2856.62 ± 316.36	0.772617	0.02 (negligible)

*$p < 0.01$ ** $p<0.05$

Table 4.10 shows that in the squat jump, the percentage load used and the season in which testing took place had a significant ($p<0.01$) influence on the peak-power produced during the exercise.

Table 4.10 Fixed effects for peak power in the squat jump

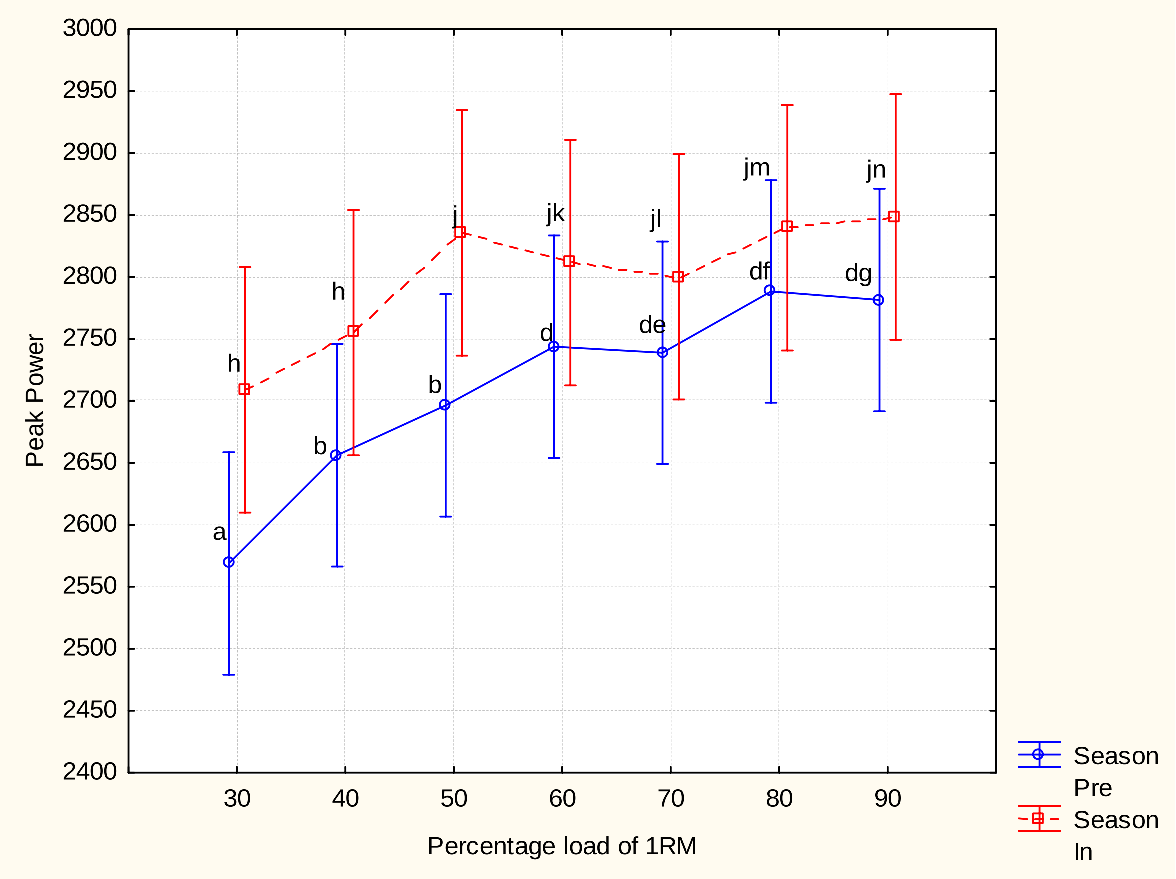
Effect	*Num. DF*	*Den DF*	F	p
Percentage	6	311	21.57216	0.000000*
Season	1	24	11.88335	0.002099*
Group	1	24	0.22924	0.636420
Percentage*Season	6	138	1.89668	0.085580
Percentage*Group	6	311	2.55877	0.019633**
Season*Group	1	24	1.10230	0.304220
Percentage*Season*Group	6	138	1.08362	0.375270

*****$p< 0.01$
******$p< 0.05$

Statistical analysis showed a significant effect of load intensity on peak-power output during the squat jump ($p<0.01$). Figure 4.5 shows that MPO was achieved between loads at 60-90% 1RM. Scores on loads from 40-90% 1RM were significantly ($p<0.01$) higher than at 30% 1RM. Also, the scores on loads from 50-90% were significantly ($p<0.01$) higher than at 40% 1RM. The load increase from 50-60% 1RM showed a significant ($p<0.01$) increase in scores, whereas the load increase from 60-70% 1RM had no significant effect on peak-power production. There was an increase in peak-power production from 60-80% and 60-90%, but this was not significant with a negligible to small (0.02-0.15) practical significant effect (Table 4.9). An increase in PPO from 50-80% 1RM and 50-90% 1RM was, however, significant ($p<0.05$). There was a slight non-significant decrease in PPO from 80-90% 1RM with a negligible (0.02) practical significant effect.

Statistical analysis for the in-season testing revealed a significant ($p<0.01$) increase in peak-power production as the load intensity increased from 30% to 50% 1RM. Load increases above 50% 1RM failed to have a significant effect on peak-power production with a negligible (0.02-0.07) practical significant effect. PPO was achieved at 90% 1RM, but this was not significantly higher than the PPO generated at 50, 60, 70 and 80% 1RM, indicating that PPO can be achieved in the range from 50-90% 1RM.

When comparing the pre-season PPO scores to the in-season scores, a similar trend can be observed where PPO monotonically increased with each percentage load before the in-season PPO reached a plateau at 50% (Figure 4.5). During the pre-season testing, the plateau was reached at 60-90% whereas the in-season testing a plateau emerged at lower intensities (50-90% 1RM).



Pre-season: a-b p< 0.01, b-d p< 0.05
In-Season: h-i p< 0.01

Figure 4.5 Peak-power production in the squat jump at various loads during pre-, and in-season testing

It would appear that power production ascended with increased loads up to 50% 1RM before it reached a plateau between 50-70% 1RM in the in-season, where the load increase did not have an effect on power production. Peak-power production was not influenced by the increase in loads from 60-80% and from 60-90% 1RM.

Squat-jump peak velocity

Table 4.11 Descriptive data for squat jump peak velocity during pre-and in-season

% Load	**Season**	**Mean ± SD**	**P**	**€**
30	Pre-season	2.47 ± 0.18		
40	Pre-season	2.40 ± 0.17	0.00023*	0.4 (moderate)
50	Pre-season	2.29 ± 0.16	0.000000*	0.67 (moderate)
60	Pre-season	2.20 ± 0.17	0.000043*	0.55 (moderate)
70	Pre-season	2.11 ± 0.18	0.000000*	0.52 (moderate)
80	Pre-season	2.02 ± 0.23	0.000009*	0.44 (moderate)
90	Pre-season	1.93 ± 0.21	0.000009*	0.4 (moderate)
30	In-season	2.40 ± 0.18		
40	In-season	2.24 ± 0.19	0.000000*	0.88 (large)
50	In-season	2.16 ± 0.2	0.003550*	0.42 (moderate)
60	In-season	1.99 ± 0.2	0.000000*	0.87 (large)
70	In-season	1.89 ± 0.2	0.000160*	0.51 (moderate)
80	In-season	1.80 ± 0.18	0.001137*	0.48 (moderate)
90	In-season	1.73 ± 0.18	0.006475*	0.08 (negligible)

*$p< 0.01$ ** $p<0.05$

It would appear that peak velocity in the squat jump was significantly (p<0.01) influenced by percentage load used as well as by the season of testing (p<0.01). There was no significant (p>0.10) (Table 4.11 & 4.12).

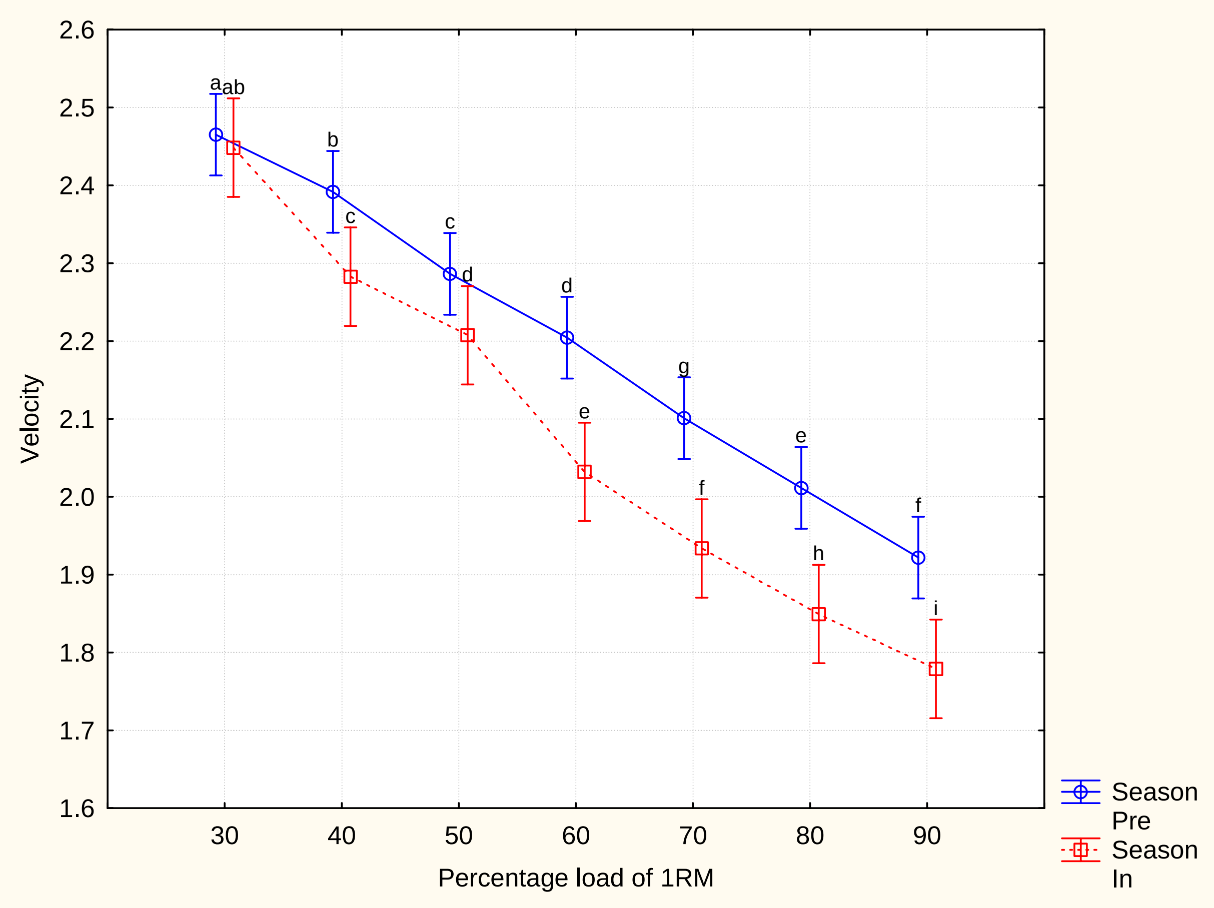
Table 4.12 Fixed effects for peak velocity in the squat jump

Effect	*Num.DF*	*Den.DF*	*F*	*p*
Percentage	6	311	347.0255	0.000000*
Season	1	24	24.8275	0.000043*
Group	1	24	0.5700	0.457605
Percentage*Season	6	138	6.2132	0.000009*
Percentage*Group	6	11	2.5012	0.022294**
Season*Group	1	24	0.0002	0.98904
Percentage*Season*Group	6	138	1.3488	0.239782

*p< 0.01
**p< 0.05

Figure 4.6 provides information about the bar velocity during the squat jump. Bar velocity decreased significantly (p<0.01) as the percentage load increased at the pre-season testing. The highest velocity on the system (bar plus body) was achieved at the lightest load (30%). The velocity on the bar then showed an incremental drop as the load of the system increased.

The lowest velocity (1.92 m/s) was during the highest load of 90% 1RM. There was a significant (p<0.01) decrease in velocity on the system between all the loads (30, 40, 50, 60, 70, 80 and 90% 1RM) with a moderate (0.4-0.67) practical significant effect (Table 4.11).



Pre-season: a-b/b-c/c-d/d-g/g-e/e-f p< 0.01
In-season: ab-c/c-d/d-e/e-f/f-h/h-I p< 0.01

Figure 4.6 Peak velocity in the squat jump at various loads during pre-, and in-season testing

Results indicate that the intensity of the load had a significant effect on the velocity of the system mass during the in-season testing. The velocity reached in the squat jump, dropped significantly (p<0.01) as the percentage load increased from 30-90% 1RM. The velocity on the system decreased significantly

($p<0.01$) with the increase of each percentage load (30-40, 40-50, 50-60, 60-70, 70-80 and 80-90% 1RM). For loads from 30-80% 1RM the practical significant effect was moderate to large (0.42-0.88,) but from 80-90% 1RM the effect was negligible (0.08).

The velocity graph in Figure 4.6 shows a familiar shape; with significant decreases of velocity with accompanying increased percentage loading through all the loads tested. With the exception of 30% 1RM (where there was no significant difference between the pre-and-in-season load), there was a significant ($p<0.05$) decrease in the velocity of the system between equal loads from pre-, to in-season testing. It would appear that there was a larger difference (7-9%) in velocity decrease at higher loads (60-90% 1RM) than was the case in the lower loads (30-50% 1RM), where the decrease in velocity was minimal (0.8-4.5%).

A comparison of forwards and backline players

One-repetition Max (1RM)

Table 4.13 Descriptive data for 1RM values of the hang clean and squat during the pre-and-in-season for the forwards and the backs.

Exercise	**Position**	**Season**	**Mean ± SD**	**P**	**є**
Hang clean	Forwards	Pre-season (n=33)	83.18 ± 13.33		
Hang clean	Forwards	In-season (n=17)	91.76 ± 13.80	0.00046*	0.69 (moderate)
Squat	Forwards	Pre-season (n=20)	157.3 ± 21.5		
Squat	Forwards	In-season (n=18)	180.1 ± 23.3	0.0009*	1.08 (large)
Hang clean	Backs	Pre-season (n=24)	81.04 ± 10		
Hang clean	Backs	In-season (n=11)	90.90 ± 10.92	0.002795*	0.67 (moderate)
Squat	Backs	Pre-season (n=21)	159.42 ± 20.56		
Squat	Backs	In-season (n=18)	182.55 ± 21.27	0.006472*	1.15 (very large)

*$P<0.01$

No significant differences were found between the 1RM-values of the forwards and the backline players (Table 4.14) in the hang clean. However, both groups improved their scores significantly ($p<0.01$) from the pre-season to the in-season testing. The practical significant effect in the hang clean for both groups was moderate (0.67-0.69) (Table 4.13).

Table 4.14 Fixed effects for the 1RM-hang clean

Effect	*Num.DF*	*Den. DF*	*F*	*p*
Season	1	26	25.88762	0.000027*
Forwards/Backs	1	55	0.39903	0.530209
Season*Forwards/Backs	1	26	0.00321	0.955238

*$p< 0.01$

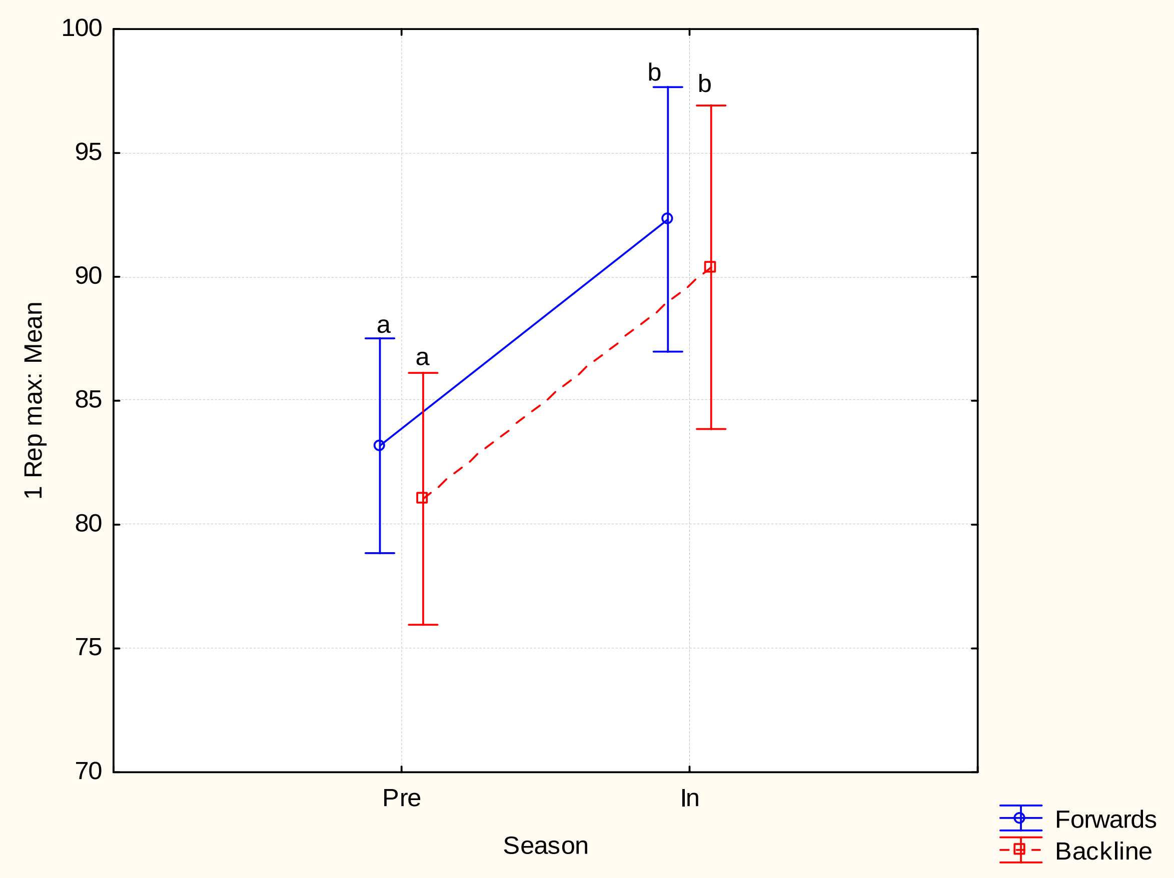
The squat test showed similar results (Table 4.15) with no significant difference between the forwards and backline players in the 1RM-values on both testing occasions (pre- and in-season). However, both groups improved their scores significantly ($p<0.01$) from the pre-season to the in-season test. There was a large (1.08) practical significant effect for the forwards and very large (1.15) effect for the backs.

Table 4.15 Fixed effects for the 1RM-squat

Effect	*Num.DF*	*Den.DF*	*F*	*p*
Season	1	24	27.15694	0.000024*
Forwards/Backs	1	52	0.0048	0.982578
Season*Forwards/Backs	1	24	0.20802	0.652422

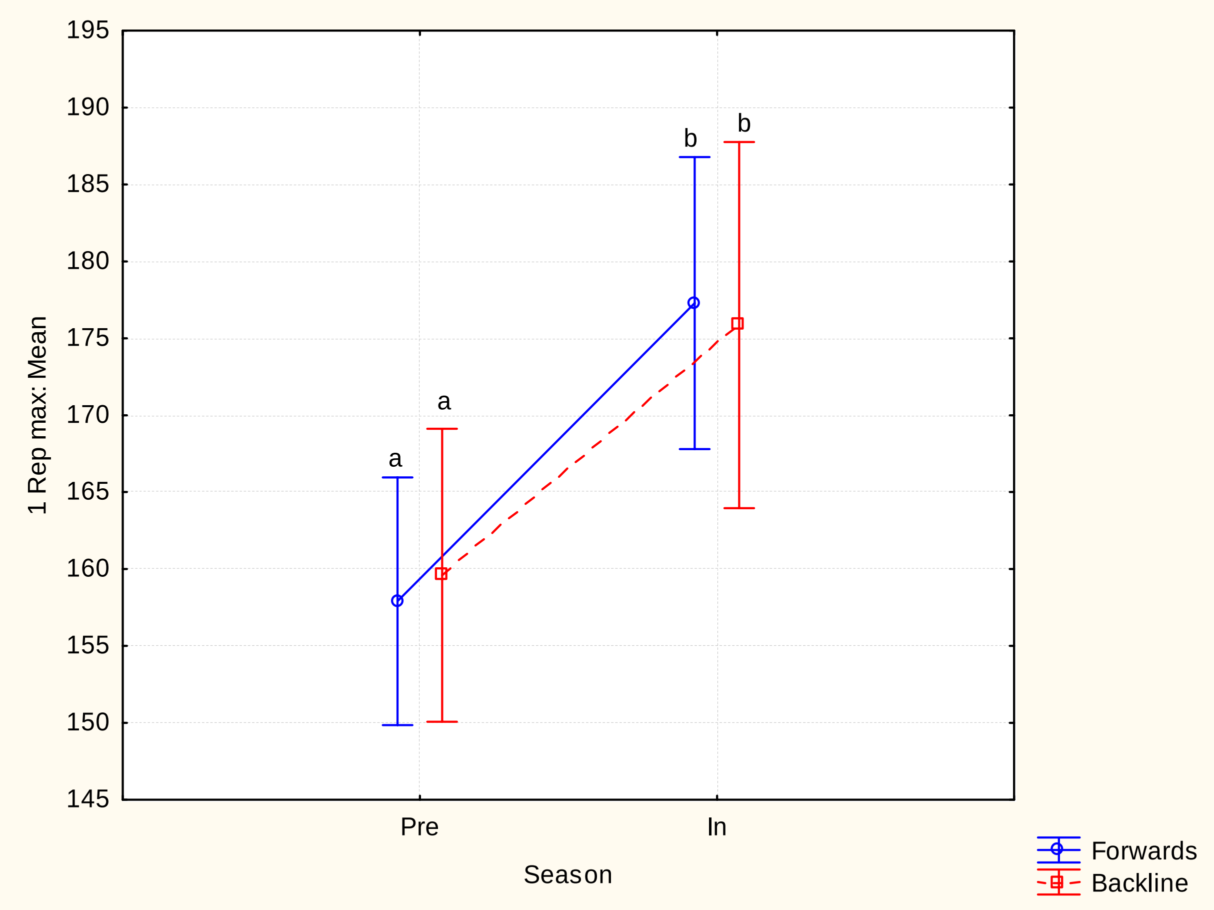
*$p< 0.01$

Figures 4.7 and 4.8 indicate that there was a significant (*p*<0.05) increase in strength scores for both forwards and backline players from the pre-, to the in-season testing in both the hang clean and the squat exercises. The strength scores for both exercises were similar among the forwards and backline players during the in-season testing, with no significant difference in the test results.



Forwards: a-b p< 0.01
Backline: c-d p< 0.01

Figure 4.7 Max Rep-scores in the hang clean for forwards and backline players during pre-, and in-season testing



Forwards: a-b p< 0.01
Backline: c-d p< 0.01

Figure 4.8 Max Rep scores in the squat for forwards and backline players during pre-, and in-season testing

Hang-clean peak power

Table 4.16 Descriptive data for the hang clean peak power for forwards and backs during the pre-season.

% Load	Position	Mean	± SD	P	Є
30	Forwards (n=33)	719.92	117.75		
30	Backs (n=24)	698.26	139.25	0.440093	0.17 (small)
40	Forwards	859.86	174.82		
40	Backs	848.74	161.69	0.919547	0.07 (negligible)
50	Forwards	997.00	164.76		
50	Backs	983.09	175.23	0.556742	0.08 (negligible)
60	Forwards	1098.94	179.39		
60	Backs	1056.89	168.49	0.109212	0.25 (small)
70	Forwards	1171.20	184.87		
70	Backs	1151.66	179.48	0.443293	0.11 (negligible)
80	Forwards	1239.32	190.60		
80	Backs	1228.31	186.17	0.480000	0.06 (negligible)
90	Forwards	1297.92	214.04		
90	Backs	1245.09	201.96	0.124825	0.25 (small)

Table 4.17 shows the effect of different variables on peak-power production. Peak power production for the hang clean was significantly (*p*<0.01) influenced by both the season and percentage load. This was indicated earlier in the chapter (Figure 4.3).

The third variable investigated regarding peak-power production was the role of different playing positions. Table 4.16 indicates there was no significant difference between the peak-power production scores of forwards and backline players.

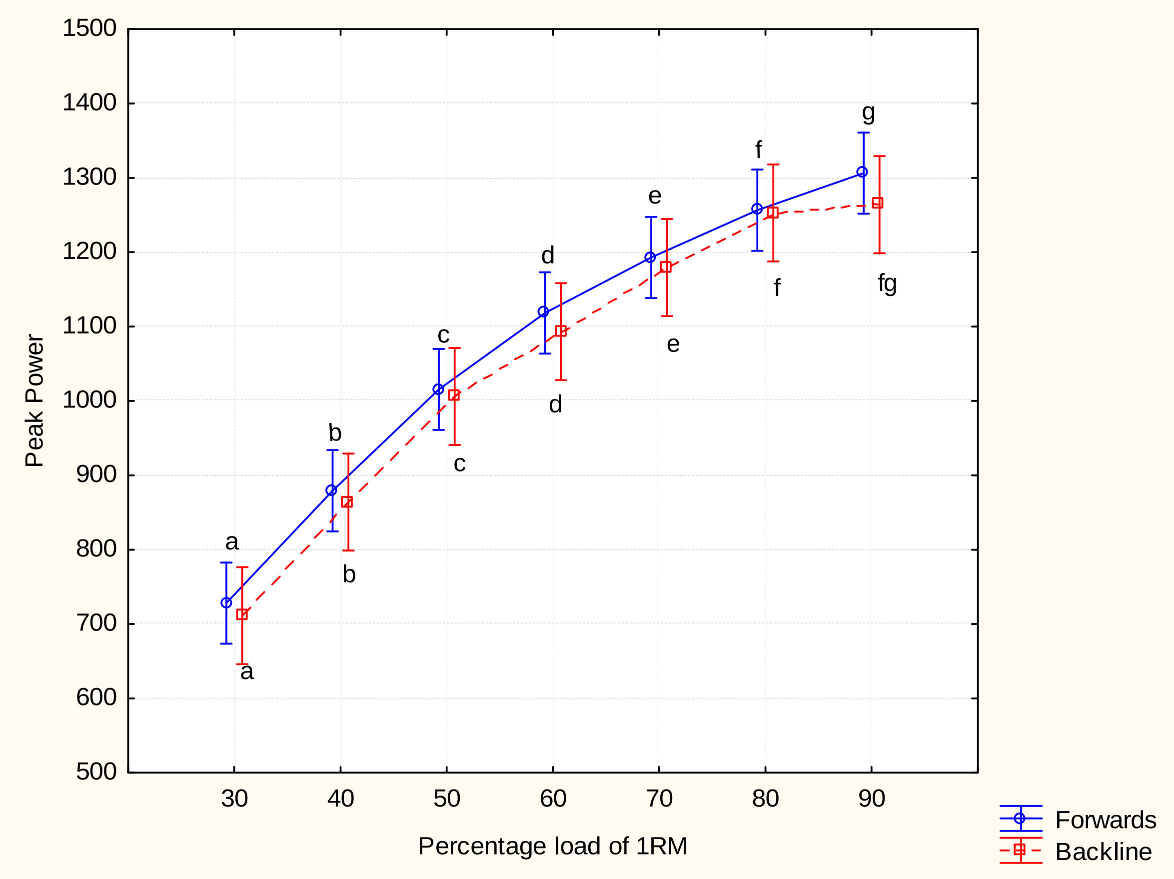
Table 4.17 Fixed effects for peak power in the hang clean

Effect	*Num.DF*	*Den. DF*	*F*	*p*
Percentage	6	330	443.848	0.000000*
Season	1	26	32.1496	0.000006*
Forwards/Backs	1	26	0.2139	0.647576
Percentage*Season	6	156	4.1107	0.00736*
Percentage*Forwards/Backs	6	330	0.4049	0.875629
Season*Forward/Backs	1	26	0.8836	0.355858
Percentage*Season*Forwards/ Backs	6	156	0.9849	0.437458

*$p < 0.01$

During the pre-season testing, the forwards produced a slightly higher power output than the backline players. This difference, however, was not significant. There was a negligible to small (0.06-0.25) practical significant effect between the forwards and backs in pre-season testing.

The in-season data showed similar results. Figure 4.9 indicates a significant increase (p<0.05) in PPO for both the forwards and the backline players in the hang clean, but no significant difference between the power produced at each load of forwards and backline players.



Forwards: a-b/ b-c/ -c-d/ d-e/ e-f/ f-g p< 0.01
Backline: h-i/ i-j/ j-k/ k-l/ l-m p< 0.01

Figure 4.9 Mean peak-power production in the hang clean at various loads for forwards and backline players during pre-, and in season testing.

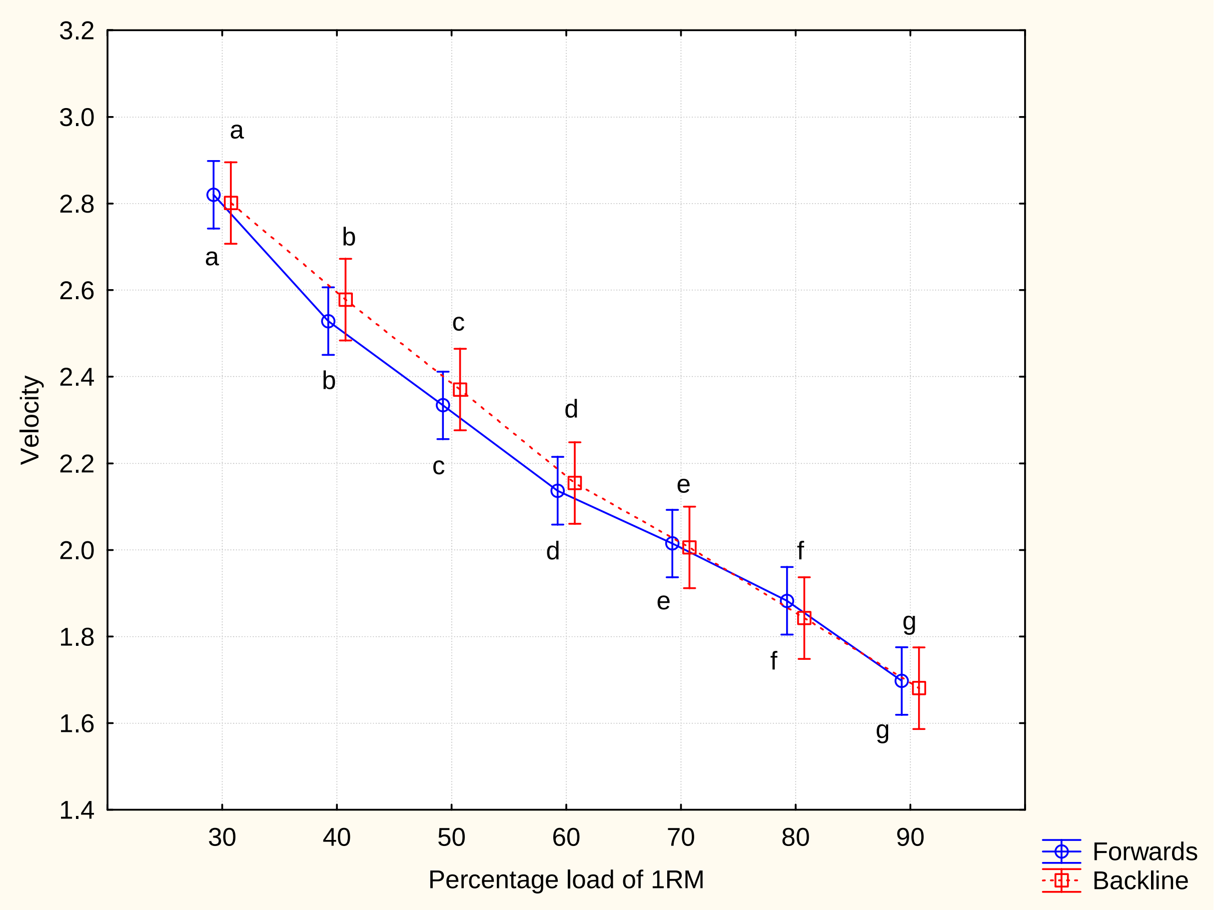
Hang-clean peak velocity

From Table 4.18 it is evident that there was no significant difference in peak velocity during the hang-clean exercise for the different playing positions. Figure 4.10 shows the corresponding mean velocity of movement for both the forwards and backline players over all the loads tested.

Table 4.18 Fixed effects for peak velocity in the hang clean

Effect	*Num.DF*	*Den.DF*	*F*	*p*
Percentage	6	330	283.258	0.000000*
Season	1	26	0.1632	0.689550
Forwards/Backs	1	26	0.0039	0.950932
Percentage* Season	6	156	4.2400	0.000553*
Percentage*Forwards/Backs	6	330	0.4836	0.820525
Season* Forwards/Backs	1	26	2.4323	0.130946
Percentage*Season*Forwards/ Backs	6	156	0.2522	0.957794

*$p < 0.01$



a-b/b-c/c-d/d-e/e-f/f-g/ p< 0.01

Figure 4.10 Mean peak-velocity production in the hang clean at various loads for forwards and backline players during pre-, and in-season testing.

Squat-jump peak power

Table 4.19 Descriptive data for the squat jump peak power for forwards and backs during the pre-and in-season.

% Load	Position	Season	Mean	± SD	p	€
30	Forwards	Pre-season	2648.59	291.94		
30	Forwards	In-season	2739.17	414.11	0.019274**	0.27 (small)
30	Backs	Pre-season	2443.10	301.39		
30	Backs	In-season	2726.27	315.28	0.001305*	0.96 (large)
40	Forwards	Pre-season	2733.03	326.47		
40	Forwards	In-season	2769.50	421.72	0.043944**	0.01(negligible)
40	Backs	Pre-season	2534.38	290.91		
40	Backs	In-season	2798.18	324.11	0.003681*	0.9 (large)
50	Forwards	Pre-season	2751.97	337.25		
50	Forwards	In-season	2860.67	342.48	0.006532*	0.33 (small)
50	Backs	Pre-season	2604.29	260.89		
50	Backs	In-season	2861.82	298.29	0.005290*	0.97 (large)
60	Forwards	Pre-season	2822.38	371.78		
60	Forwards	In-season	2850.33	416.06	0.31784	0.07 (negligible)
60	Backs	Pre-season	2619.19	269.19		
60	Backs	In-season	2815.45	244.04	0.074152	0.78 (large)
70	Forwards	Pre-season	2789.62	369.24		
70	Forwards	In-season	2840.28	395.41	0.132757	0.14 (negligible)
70	Backs	Pre-season	2653.24	269.17		
70	Backs	In-season	2801.18	270.37	0.323013	0.57 (moderate)
80	Forwards	Pre-season	2840.03	358.68		
80	Forwards	In-season	2872.11	369.20	0.266678	0.09 (negligible)
80	Backs	Pre-season	2701.29	292.92		
80	Backs	In-season	2853.18	318.84	0.294812	0.52 (moderate)
90	Forwards	Pre-season	2880.40	364.29		
90	Forwards	In-season	2859.84	342.75	0.837324	0.06 (negligible)
90	Backs	Pre-season	2602.70	277.62		
90	Backs	In-season	2850.50	276.34	0.007932*	0.93 (large)

$^{*}p < 0.01$ $^{**}p < 0.05$

As in the case of the hang clean, no significant difference was found in the peak-power production in the squat jump between the scores of players from different playing positions (Table 4.20).

Table 4.20 Fixed effects for peak power in the squat jump

Effect	*Num.DF*	*Den.DF*	*F*	*p*
Percentage	6	311	20.82160	0.000000*
Season	1	24	12.59533	0.001632*
Forwards/Backs	1	24	2.60336	0.119710
Percentage*Season	6	138	2.08707	0.058533
Percentage*Forwards/Backs	6	311	0.59324	0.735711
Season*Forwards/Backs	1	24	1.39515	0.249110
Percentage*Season*Forwards/Backs	6	138	1.17262	0.324489

*$p < 0.01$

Figure 4.11 shows that the forwards tend to produce a higher power output at each load than the backline players. However, this was not significant. Neither the forwards nor backline players recorded a significant increase in peak-power production from the pre-, to the in-season testing for the squat jump. However, there was a trend among the backline players to produce higher peak-power values at the lower loads (30%, 40%, 50% and 60% 1RM) during the in-season testing. All of these loads show a large (0.78-0.96) practical significant effect. (Table 4.19) This trend is illustrated in Figure 4.11, showing a larger gap between the pre- and in-season lines at the beginning of the split (30-60%) for the backline players.

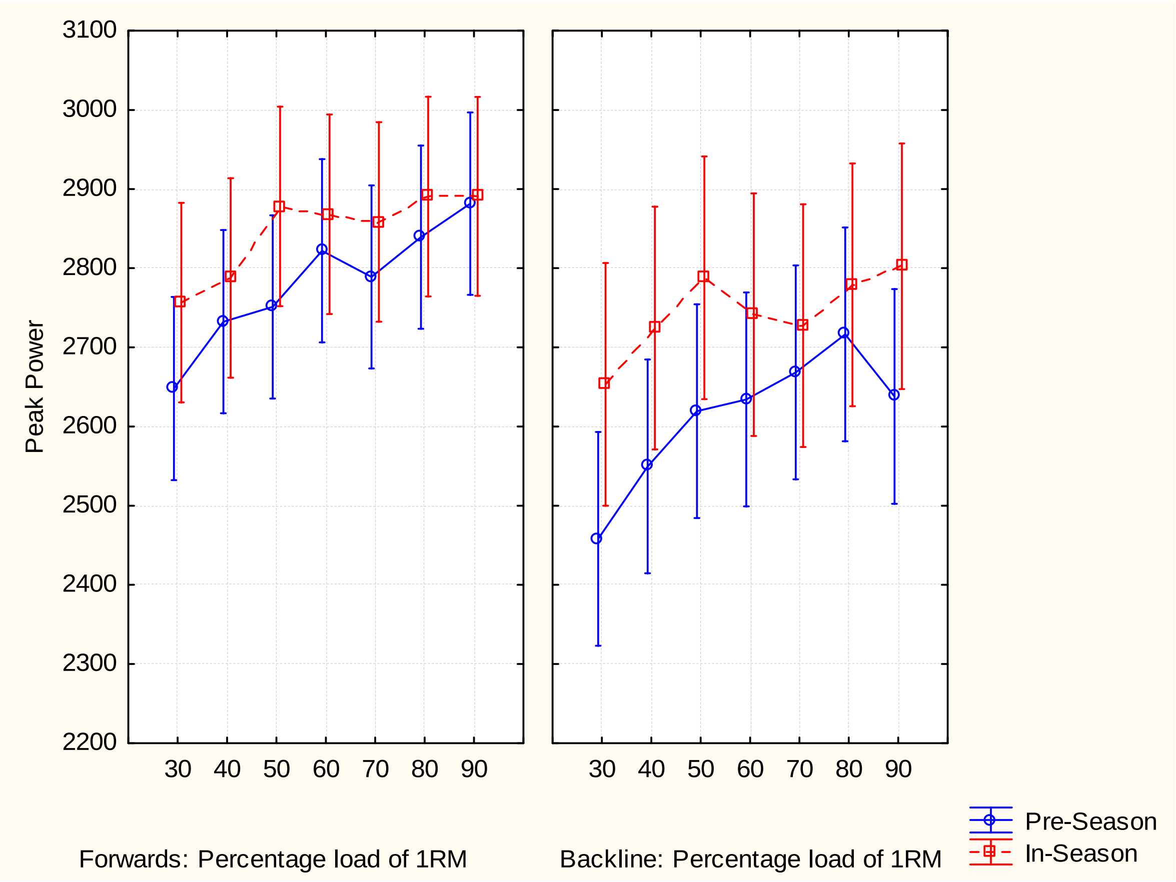


Figure 4.11. Peak power in the squat jump at various loads for different playing positions during pre-, and in-season testing

Squat-jump peak velocity

Table 4.21 Descriptive data for the squat jump peak velocity for forwards and backs during the in-season.

% Load	**Position**	**Mean**	**± SD**	**P**	**Є**
30	Forwards	2.36	0.18		
30	Backs	2.49	0.16	0.046676**	0.78 (large)
40	Forwards	2.19	0.21		
40	Backs	2.32	0.14	0.047908**	0.87 (large)
50	Forwards	2.13	0.18		
50	Backs	2.22	0.22	0.135105	0.48 (moderate)
60	Forwards	1.99	0.20		
60	Backs	1.98	0.20	0.881984	0.05 (negligible)
70	Forwards	1.89	0.21		
70	Backs	1.89	0.18	0.988851	0 (negligible)
80	Forwards	1.80	0.19		
80	Backs	1.80	0.18	0.985302	0 (negligible)
90	Forwards	1.74	0.19		
90	Backs	1.71	0.15	0.606170	0.18 (small)

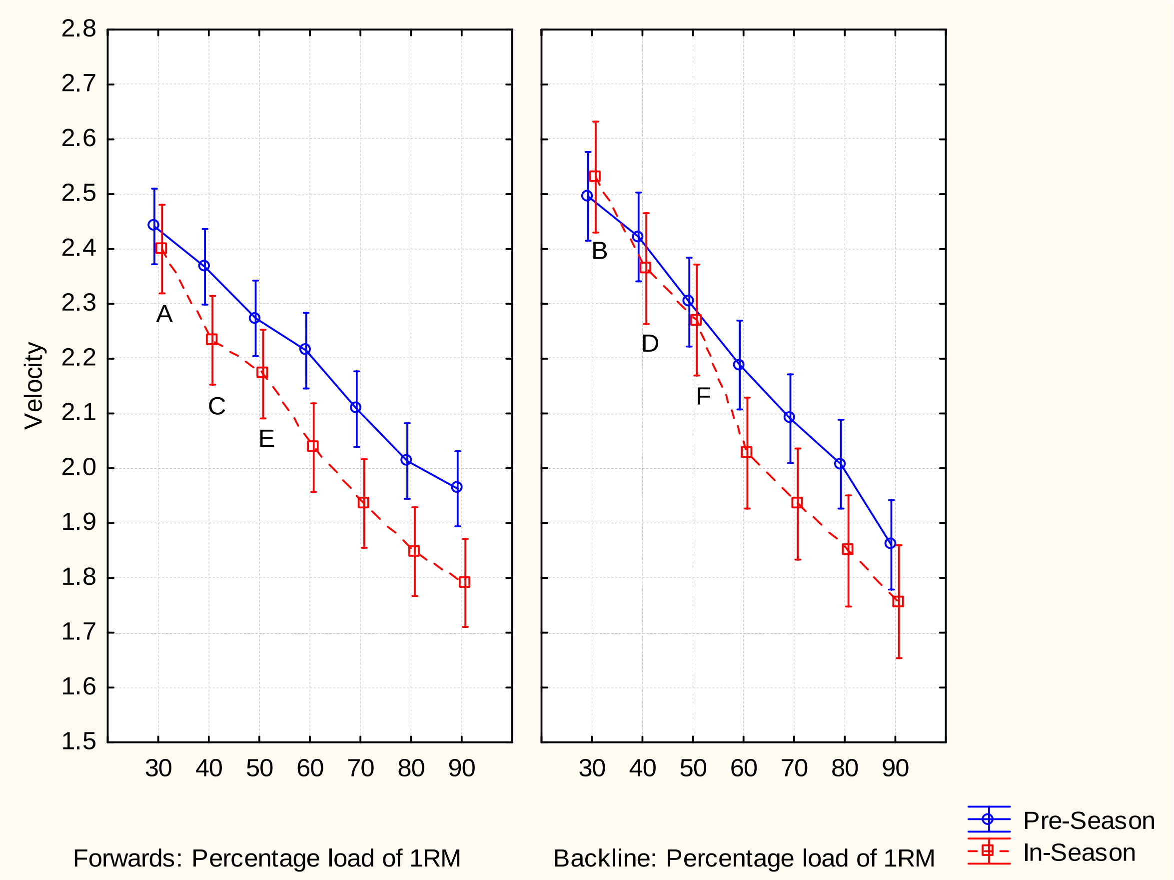
** $p<0.05$

Table 4.22 Fixed effects for peak velocity in the squat jump

Effect	*Num.DF*	*Den.DF*	*F*	*p*
Percentage	6	311	401.9172	0.000000*
Season	1	24	21.7757	0.000097*
Forwards/Backs	1	24	0.2203	0.643013
Percentage*Season	6	138	7.9227	0.000000*
Percentage*Forwards/Backs	6	311	7.4478	0.000000*
Season* Forwards/Backs	1	24	0.9316	0.344072
Percentage*Season*Forwards/Backs	6	138	0.5212	0.791510

*$p < 0.01$

Peak veloctiy for the squat jump was affected by the percentage loads and by the season of testing (Table 4.22). Different playing positions did show a significant ($p<0.05$) effect on lower loads (30 and 40% 1RM) during the in-season testing. There was a moderate to large (0.48-0.87) practical significant difference between the different playing postions, with the backs producing higher velocities at the lower loads (30-50%) than the forwards. Loads beyond 50% 1RM, failed to yield differences between the velocities achieved by the two playing positions (figure 4.12).



A-B/C-D/E-F $p < 0.05$

Figure 4.12 Peak velocity in the squat jump at various loads for different playing positions during pre-, and in-season testing

Chapter Five

Discussion, Conclusions and Recommendations

The findings of this study will be discussed around the research questions stated in Chapter Three.

Optimal load for the production of peak power

Hang clean

The primary finding of this investigation regarding the hang clean is that peak-power output was achieved at 90% 1RM during the pre-season testing. The high percentage load is an indication that the participants depended largely on their force-generating capacity to produce power rather than velocity. As mentioned earlier, Baker et al. (2001b) pointed out that power will initially be increased by an increase in absolute mass lifted at the same movement velocity. This means that for inexperienced athletes, power production is largely dependent on force rather than velocity of movement. The more strength-dependent the athlete is for power production, the higher the percentage load will be for producing MPO.

During the in-season testing, there was an increase of 6.8% in peak-power production at 90% 1RM. This could largely be ascribed to the increase in strength as evident in the 1RM testing. Power is the product of force and velocity (Newton & Kraemer, 1994) and increased strength would enable the athlete to produce higher force. This explains the significant increase in power production across all the loads tested. Similar to the pre-season testing, MPO was once again achieved at 90% 1RM, but it should be noted that this was not significantly higher than the power output achieved at 80% 1RM. Again the power output was positively influence by increased load. A plateau towards the end of the power curve could be an indication that it began to peak at a lower percentage load than in the pre-season. There appears to be a slight trend of the optimal load shifting towards a lower percentage (from 90% pre-season to 80% in-season) as the season progressed.

There are two possible reasons for this shift from pre-season to in-season. Firstly, it should be noted that the 1RM-scores for the hang clean improved (10.1%) from the pre-season testing to the in-season testing. There was a definite accompanying improvement in maximal strength for this specific type of lift. An increase in maximal strength was expected since the participants followed a training programme that combined hypertrophy, maximal strength and power training over a period of five months. Since most of the participants were inexperienced (< 1 year) with this type of exercise, a rapid increase in strength was expected with improvement in both intra- and inter-muscular coordination (Young, 1993).

Baker (2001a) mentioned that stronger athletes tend to produce MPO at lower loads than weaker athletes. Kawamori et al. (2005) also reported that weaker participants produced MPO at a higher percentage load (80% 1RM) than their stronger counterparts (70% 1RM). Since the 1RM-scores improved significantly, this could have had an influence on the shift of the optimal-training load.

A second factor that could possibly have influenced these results, is training experience. Winchester et al. (2005) reported that peak-power values shifted from 70% to 50% 1RM after four weeks of technique training. Their participants were relative young and inexperienced. In the present study five months of additional training and coaching in Olympic-type weightlifting, might have helped subjects to perform the lifts more efficiently. Consequently, more efficient lifting could have been the reason for the optimal load shifting towards lower loadings.

From Table 5.1 it is evident that in the present study, increased power production for the hang clean was dependent on increased strength, rather than increased velocity. In other words, power production from the pre-season to the in-season was not increased by improvement in bar speed, but rather by the moving of the bar at the same velocity with an increased absolute mass on it.

Table 5.1 shows that when bar velocity at 50% is compared to velocity at 80%, it is evident, that at the same bar velocity, a heavier load was moved. At 50% 1RM for instance, the bar speed for both pre-, and in-season testing was 2.35m/s & 2.36 m/s respectively, but the power output increased by 15% from 945watt to 1085watt. This is due to the 12% increase in absolute mass that could be lifted at the same velocity.

The velocity of the bar at 80% 1RM was also similar for both pre-, and in-season testing (1.86 m/s and 1.89 m/s respectively), but the participants were able to lift an 11% heavier mass at the same movement velocity, resulting in an 11% increase in power output.

The velocity pattern for the hang clean in Figure 4.4 shows an almost identical shape during the pre-season and the in-season testing. Kawamori et al. (2005) reported an inverse relationship between force and velocity. This explains the significant decrease in velocity of the movement as the load increased. There was, however, a shift in the graph from the pre- to the in-season testing, as was the case with the power graph (Figure 4.3). There was no significant change in bar velocity, even though the absolute mass on the bar increased. This once again could indicate that the improvement in power production was more related to increased strength, than to an increase in velocity.

In comparison with other studies, the initial testing (pre-season testing) showed a higher percentage load for PPO than that found by previous researchers. Studies (Cormie et al., 2007b; Garhammer, 1993; Haff et al., 1997; Kawamori et al., 2005; and Winchester et al., 2005), reported MPO for an Olympic-type exercise to be achieved between loads of 70-80% 1RM. It should be noted that participants from these studies were more experienced in strength training and more familiar with performing Olympic-style weightlifting than the participants of the present study. The in-season test results could lean more towards the findings of previous researchers with the load that maximizes power output shifting towards a lower percentage (80% 1RM) loading.

Table 5.1 A comparison of average peak power achieved in the hang clean at various loads during pre- and in-season testing

Pre-season				In-season			
% Load	**Absolute mass(kg)**	**Peak Power (watt)**	**Peak Velocity (m/s)**	**% Load**	**Absolute mass(kg)**	**Peak Power (watt)**	**Peak Velocity (m/s)**
90%	74	1246	1.73	90%	82	1337	1.64
80%	66	1190	**1.85**	80%	73	1325	**1.87**
70%	58	1109	2.02	70%	64	1272	1.99
60%	49	1031	2.08	60%	55	1183	2.01
50%	41	945	**2.34**	50%	6	1085	**2.34**
40%	33	815	2.57	40%	37	935	2.52
30%	25	688	2.87	30%	27	756	2.74

Squat jump

To date there have been substantial research on the power output during the squat jump (Baker et al., 2001b; Bevan et al., 2010; Cormie et al., 2007b; Harris, Cronin & Hopkins, 2007; Izquierdo et al., 2001, 2002; Siegel et al., 2002; Stone et al., 2003; and Thomas et al., 2007). As mentioned earlier, variations in the testing procedures of the squat jump resulted in equivocal results. Previous studies reported loads from 0 to 70% 1RM to produce PPO. Factors such as countermovement (Izquierdo et al., 2001), squat depth (Baker et al., 2001b), data-collection equipment (Cormie et al., 2007a; Harris et al., 2007), free weight versus fixed weight (Bevan et al., 2010; Cormie et al., 2007a), and bar mass versus system mass (Cormie, McBride & McCaulley, 2007a; Stone et al., 2003,) could possibly have had an influence on test findings. Several of these factors were considered in the test protocol of the present study. This could make the findings of the study a worthy contribution to the body of knowledge in the power-load relationship in the squat jump.

The optimal load for producing peak-power output in the squat jump was identified at 90% 1RM during the pre-season testing. There is, however, a non-significant increase in PPO from 60-90% 1RM, which indicates that there was no difference in the participants' power-producing capabilities from 60% to 90% 1RM during the pre-season. This finding would suggest that participants reached their PPO within a range of 60-90% of their 1RM. Results from the pre-season testing (Figures 4.5 & 4.6) showed that the velocity of the movement decreased significantly with an accompanying increase in loading, but that the power output failed to increase beyond 60% 1RM. This would mean that an increase in mass did not have a significant effect on power production for loads heavier than 60% 1RM.

When keeping in mind the inverse relationship between force and velocity (Kawamori et al., 2005) it is evident from the present study that the velocity of the bar in the squat jump decreased with increase load. PPO ceased to increase once the load was increased beyond 60% of 1RM. This indicated that 60% 1RM was light enough for the participants to generate high velocities (2.2 m/s) and that the load provided enough resistance to produce a substantial force output. With power being the product of force and velocity (Cronin & Sleivert, 2005), this would therefore be the most favourable combination of force and velocity to produce the desired power output.

The results for the in-season testing, indicated, once again, that peak-power output was reached at 90% 1RM (2856watt). The power produced at 90% 1RM was, however, not significantly higher than the power output produced at 80, 70, 60 or 50% 1RM. Peak-power output at 80% 1RM was less than 0.5% higher than the peak-power output at 50% 1RM (2861 watt). As in the case with the pre-season testing, it could be concluded that the optimal load for the squat jump falls within a range of loads rather than at a specific load. In the case of the in-season testing it would appear that this range was between 50-90% 1RM. This would mean that any load higher than 50% 1RM would not significantly improve power production in the squat jump.

In Figure 4.5 there is a clear indication of significant increases in power output from the pre-season to the in-season testing across all the loads (30-90%) in the squat jump. This could largely be due to the increase in 1RM-scores in the squat (158kg to 181kg) from the pre- to in-season testing. As in the case with the hang clean, the periodised programme followed by the participants over a five-month period could possibly have had a positive effect on their strength levels. As Baker (2001a) mentioned, an increase in power of inexperienced athletes are mostly due to an increase in strength levels. The participants in the present study showed significant increases in strength levels, therefore an increase in power was to be expected during later testing (Figure 4.2).

Table 5.2 gives an indication that power-producing capability in the squat jump was more influenced by the change in the participants’ strength levels than velocity. At a movement velocity of 2.29 m/s, participants were able to produce a power output of 2686watt (50% 1RM) during the pre-season testing. During the in-season testing, participants were able to produce a power output of 2780watt (40% 1RM) at the same movement velocity. A similar trend can be seen at higher loads. Participants produced a power output of 2781watt (80% 1RM) with a velocity of 2.02 m/s during the pre-season testing, while a higher (2837 watt at 60% 1RM) power output was produced during the in-season with a similar movement velocity (1.99 m/s).

From Table 5.2 it is evident that there was a decrease in velocity from the pre-season to the in –season at the same percentage load. This is due increase in absolute mass at each load (Table 5.1). As mentioned previously, there is an inverse relationship between force and velocity and as the mass of an object increase, the velocity will decrease.

Table 5.2 A comparison of average peak power achieved in the squat jump at various loads during pre- and in-season testing

Pre-season			**In-season**		
% Load	**Peak Power (watt)**	**Peak Velocity (m/s)**	**% Load**	**Peak Power (watt)**	**Peak Velocity (m/s)**
80%	2781	**2.02**	80%	2864	1.80
70%	2732	2.11	70%	2825	1.89
60%	2737	2.2	60%	2837	**1.99**
50%	2689	**2.29**	50%	2861	2.16
40%	2649	2.40	40%	2780	**2.24**
30%	2562	2.47	30%	2734	2.40

It would appear that power output is produced at sub-maximal loads for the squat jump. It is also evident that the optimal load for producing PPO is sensitive to changes in the strength levels of the participants since an increase in 1RM shifted the optimal load from 60% 1RM to 50% from the pre- to the in-season testing. These findings are similar to those of previous studies on power production in the squat jump where Baker et al. (2001b), Stone et al. (2003), and Thomas et al. (2007) also reported that PPO was reached at sub-maximal loads (30-63% 1RM). More recently Bevan et al. (2010) and Cormie et al. (2007b) reported that loads of 0% 1RM (of absolute load) produced the highest power output in the squat jump. This suggests that the body mass of an athlete provides sufficient resistance to produce PPO. The studies of Baker et al. (2001) and Bevan et al. (2010) are similar to the present study in that they involved rugby players, who performed a countermovement squat jump with free weights. These studies also included body mass in the calculations.

It would appear that the use of sub-maximal loads (50-80% 1RM) is a more favourable approach for producing peak-power output in the squat jump. Further, there are indications that increase in strength will shift the optimal load for power production to a lower percentage.

Peak power at different percentage loads for Olympic-type and ballistic exercises

Power output in an exercise can be influenced by various factors such as the nature of the exercise, strength level of participants, their training status, test protocol, data-collection equipment, and how the results are calculated. Few studies considered all these factors when comparing different lifts with each other.

There are several differences when comparing the test results of the two lifts. Firstly, when comparing the power-production capability of the lifts, the squat jump produced a higher power output than the hang clean at all percentage loads. This could be ascribed to the larger difference in 1RM-scores for the squat than for the hang clean (159kg and 82kg) respectively for pre-season testing. For this reason at any given load, the squat jump will be using almost twice as much mass as the hang clean. It is therefore more likely to produce higher power output (Power = Force x Velocity). Furthermore, when comparing velocity, the squat jump produced a greater velocity than the hang clean at relative mass.

Table 5.3 A comparison of average peak power and absolute mass used at different loads for the hang clean and squat jump

Pre-season hang clean			**Pre-season squat jump**		
% Load	**Absolute mass(kg)**	**Peak velocity (m/s)**	**% Load**	**Absolute mass(kg)**	**Peak velocity (m/s)**
90%	74	1.73	90%	143	1.93
80%	**66**	1.86	80%	127	2.02
70%	58	2.02	70%	111	2.11
60%	49	2.08	60%	95	2.2
50%	41	2.35	50%	79	2.29
40%	33	2.57	40%	**63**	2.40
30%	25	2.87	30%	48	2.47

In Table 5.3 one can compare the velocities of a similar mass for the hang clean and squat jump. At 80% 1RM hang clean (66kg) the velocity was 1.86 m/s. This mass was similar to the 40% of the squat jump (63kg), but the velocity was 2.40m/s. In other words, for a similar barbell mass, the squat jump produced a higher (33%) peak velocity than the hang clean.

The higher PPO achieved in the squat jump is therefore to be expected since a higher absolute mass is used for all the percentage loads, and a higher peak velocity is achieved at relative loads,.

The second noticeable difference between the two exercises is the percentage load that produces the MPO. Kaneko et al. (1983) and McBride et al. (2002) suggested that training at a load that produces peak-power output is a superior training method for developing power. From previous studies (Baker et al., 2001b; Bevan et al., 2010; Cormie et al., 2007b; Garhammer, 1993; Haff et al., 1997; Kawamori & Haff, 2004; Kawamori et al. 2005; Stone et al., 2003; Thomas et al., 2007: and Winchester et al., 2005) it is evident that there is a difference in the load that produces PPO for ballistic (0-63%), and Olympic-type movements (70-80%).

In the present study, the hang clean produced MPO at a higher load (90%) than the squat jump (60-90%) during the pre-season testing. It is therefore evident that power output is influenced by the nature of the movement. The hang clean is a movement that involves high-force and high-velocity (Hendrick & Wada, 2008). Cormie et al. (2007b) suggested that in movements of this nature, power output will occur at heavier loads (>70%) than in other exercises. Baker (2010) believes that the hang clean only becomes effective for power training with loads heavier that 70% 1RM.

As mentioned earlier, the squat jump is a ballistic exercise involving acceleration throughout the movement with no deceleration towards the end of the movement (Newton & Kraemer, 1994). The continuous acceleration in ballistic movements caused PPO to occur at lighter loads than in traditional resistance training and Olympic-type training, where both rely on force for power output in inexperienced lifters (Newton et al., 1996).

Changes in the participants' strength levels influenced power production in the squat jump. However, this does not mean that the squat jump is more reliant on force than velocity for power output. It would seem, regardless of the type of exercise, that the initial increase in strength will always increase power (Baker, 2001a). However, for ballistic movement the longer acceleration causes higher peak velocity. This could affect power production more than other types of exercises.

Although there is no supporting evidence in the literature; it is the present researcher's opinion that for Olympic-type movement's lighter loads are affected by the catch phase of the lift, causing deceleration of the movement before maximal velocity is achieved. For heavier loads, this problem does not seem to occur as the bar is accelerated for a shorter period and maximal velocity is reached before the catch. Jones (2010) mentioned that novice lifter has a problem with completing the pull in the hang and power clean, causing a deceleration in the most explosive part in the movement. He suggested that a movement with a longer range of motion, like the power snatch or releasing the bar after the pull (so that there is no catch), could be beneficial in lower loads.

From the findings of the present study it would appear that the nature of the exercise (Olympic vs ballistic) would have a definite effect on the percentage load that produces a higher power output. This concurs with the findings of Cormie et al. (2007b), suggesting higher percentage loads (> 70%) for Olympic-type movements than for ballistic movements (< 70%).

Fluctuation of the optimal load within a yearly macro cycle-length periodised training programme

Previous findings reported in the literature produced contradictory observations regarding the influence of training status on the optimal training load. Baker (2001a) and Kawamori et al. (2005) suggested that athletes with higher 1RM-values produced MPO at lower loads and that an increase in strength would shift peak-power production towards lower loads. The opposite was reported by Stone et al. (2003), suggesting an upward shift in load that produces MPO as the athletes became stronger. Jones (2010) suggested that stronger professional rugby players produce MPO at higher loads than the weaker players.

The findings of the present study indicate that changes in strength, and training status of the participants had an effect on the load producing MPO. In both the hang clean and squat 1RM-values increased from the pre-, to the in-season and in both exercises the optimal load shifted towards a lower percentage, although this shift was not significantly different between the pre- and in-season. (Figures 4.1 and 4.2).

From the results of the present study one could speculate that the initial increase in strength levels of the participants had a significant effect on the increase in power production and the shift of the optimal load in both exercises. This result concurs with reports from both Baker (2001a) and Kawamori et al. (2005) suggesting that increased strength levels shift the optimal load downwards.

It should however be noted that there are various factors that could have influenced the training status of the players. As mentioned before, the biological age of the players in this study should be brought into consideration when analyzing the results. All of the players were still in a development age (18-22 years) and increases in strength levels and change in training status can be influenced by players that are still developing, compared to players that are of a more sexual mature age. A second factor that should be considered is the training program. Rugby training programs put a large emphasis on power development due to the nature of the sport. A significant increase in strength levels was observed, but this was not the only bio-motor ability that was developed and other factors such as speed and power training, that is common in in-season rugby programs (Bompa & Claro, 2009), could also influence the results.

Lastly, Winchester et al. (2005) mentioned that improvement in technique can also alter power production. As the players got more familiar with the lifts and regular coaching, the technique could have improved, resulting in an increase in power production.

It is thus important to be aware that a number of variables could influence the training status of the players. It is however not the primary focus of this study to investigate all the variable affecting the training status. It is nevertheless clear that the strength levels of the players did increase substantially and could have influence the power production.

Different playing positions and peak-power production

The reason for comparing the performance of participants from different playing positions is mainly to test the stated belief of Miller (cited in Duthie et al., 2003) and Duthie et al. (2003) that different playing positions require different power-production capabilities. According to these researchers forwards will tend to be more reliant on force generation and backline players on velocity of movement for power production.

When comparing the 1RM-scores in the present study of the two main categories of playing positions (forwards vs backline players) during the pre-season, no difference was found between the forwards and the backline players in both the hang clean and the squat tests. Both groups increased their strength during the season where testing also revealed no differences in strength scores between the two groups. These results could be ascribed to the young training-age of the participants. Tong and Wood (1997) reported similar findings when comparing upper-body strength of forwards and backline players. They ascribed the results to the subjects' lack of strength-training experience. Since both groups of players in the present study followed the same training programmes over the five-month period, similar results in strength gains could be expected, especially because of the pre-season training status also being identical.

As mentioned earlier, it would seem that in the hang clean, inexperienced participants are more dependent on force generation than on velocity of movement for power production. With identical strength results for the forwards and the backline players, it is expected then that their power production capabilities in the hang clean would also be similar. Forwards and backline players both produced PPO at 90% 1RM during the pre-season testing and as their strength increased the optimal load shifted towards 80-90% 1RM during the in-season testing.

The increase in movement velocity during the in-season testing occurred in both groups. Although not significant, both the forward and backline groups showed an increase in movement velocity from the first round of testing to the second later on in the season.

Both the forwards and the backline players produced MPO at similar loads (60-90% 1RM) for the squat jump test during the pre-season. Due to strength gains in the squat for both groups during the season, the increase in PPO across all the loads was expected in both groups. MPO shifted toward a lighter load (50-90% 1RM) for both the forwards and the backline players.

Although both the forwards and the backline groups increased their PPO over all the loads from the pre-season to the in-season of testing, the backline players showed a stronger trend than the forwards in increasing their MPO at lower loads of 30-50% (Table 4.19). Since both groups had similar results in the in-season squat test, the reason for this trend could be found in the increased velocity of the movement.

Both groups showed similar velocity patterns during the initial pre-season testing, but the backline players showed a trend of improved squat-jump velocity during the in-season testing, while the forwards did not (Table 4.20). This increase in velocity occurred at the lighter loads (30-50% 1RM), similar to the optimal load (50-90% 1RM) for power production in the squat jump.

As mentioned earlier, because of the ballistic nature of the squat jump, the power production in this exercise could be influenced more by velocity than in the case of the hang clean. This could explain why the backline players showed greater improvement in power production and velocity than the forwards in this exercise. Because of the nature of rugby, backline players are more dependent on speed and acceleration than forwards, who must overcome external force more often (Bompa & Claro, 2009). Backline players could consequently be more capable of producing power in this exercise than the forwards.

Conclusion

Training with optimal loads that maximize power output is strongly recommended in order to develop and improve peak-power output (Kaneko et al., 1983; Kawamori & Haff., 2004). A high power output is required in a contact sport such as rugby. The dynamic nature of the game involves acceleration and contact in which external force needs to be overcome (e.g., tackling, rucking, and scrumming). The ability to apply force over a short period of time is therefore critical for success; and effective training accordingly is vital.

The primary aim of this study was to investigate the optimal loads for under-21 rugby players using exercises (Olympic-type and ballistic) commonly used in rugby training because of their dynamic nature and comparing them to each other. A secondary aim was to determine if changes in training status would affect these loads during the training year. Changes in training status were done by monitoring the strength level of the participants. Lastly, optimal training loads of different playing positions (forwards vs backs) were also compared.

To date inconsistent results led to a wide range of loads being prescribed for power training. This study was conducted to determine the optimal load (relevant to the type of the exercise and the training status) for under-21 rugby players.

For the hang clean, MPO was achieved at 90% 1RM in the pre-season testing phase. The optimal load during the in-season testing five months later was 80-90% 1RM. In the squat jump MPO was also reached at 90% 1RM. But, since this was not significantly greater that the power achieved at 60% 1RM, a load of 60% would be considered optimal for achieving PPO. The in-season testing five months later, once again shifted the optimal load to a lower percentage of 50% 1RM.

It could be concluded that there is a difference between the optimal loads of the hang clean and the squat jump. The hang clean is more reliant on force for power production resulting in the higher loads (80-90%) to be optimal for power training. On the other hand, the squat jump is more reliant on acceleration and velocity for power production than the hang clean, resulting in lower loads (50-60%) to be optimal for power training.

Both exercises were affected by a change in training status resulting in lighter loads to be optimal for PPO. This change in training status and strength levels took place over a five-month period. The effect that a 12-24 month periodised-training plan would have on the training load is unknown to rugby players with limited strength-training experience.

When comparing different playing positions, it would appear that both groups (forwards and backline players) produce MPO at the same percentage loads and that the optimal load for both groups is similar in both exercise types. This supports the findings of Tong and Wood (1997) who mentioned that a lack of training experience would influence the optimal loads of forwards and backline players. Backline players did, however, record a greater increase in velocity scores for the squat jump. This could indicate that the ballistic exercises, which largely depend on acceleration, are more beneficial for players that are more involved in sprinting activities.

Practical implications

Training load is one of several factors to consider when designing a training programme. Power training should form a large part of any rugby conditioning programme and training at a load that maximizes power output is essential in order to improve peak muscular power.

The findings of this study indicate that power output for the hang clean is maximized at high loads (>80% 1RM) among rugby players who are inexperienced in weight-training. Even though near-maximal loads are used, the players should still attempt to move the loads as rapidly as possible in order to recruit the desired muscle fibres (Type IIB) and produce peak-power output.

On the basis of the results of the present study and others studies (Cormie et al., 2007b; Kawamori et al., 2005), it is suggested that the optimal load for peak-power output would be between 70-90% 1RM. Load prescriptions would depend on the training status and strength levels of the participants and should be monitored throughout the training year. As the training status of a player changes and strength levels increase, the load that produces PPO needs to be adapted to a range of 70-90% 1RM. The more experienced the athlete is in strength training, the lower the percentage load that produces PPO becomes.

Load prescription for the squat jump is difficult since there is such a wide range recommended by previous studies. The results of this study suggest that sub-maximal loads of 50-60% 1RM would be optimal for peak-power production of players. It should be noted that these loads would be relevant for athletes who are inexperience in strength training (< 1 year) and where body mass is included in the calculation of the system mass. In addition, it should be noted that these loads are applicable to the squat jump performed with free weights and using a countermovement jump, with the depth determined by the participants.

As in the case with the hang clean, load prescription should be adapted towards the latter part of the training year, since a change in players' training status and strength levels could influence the optimal load for PPO. Training loads should therefore be modified in the period between pre-season training to the peaking phase during the in-season.

Since optimal training loads for the two exercise types are not the same, exercise selection should be carefully considered when designing a power-training programme.

It would appear that the velocity in the squat jump is more sensitive to load increases than is the case in the hang clean. The squat jump also produces higher velocities at similar absolute loads than the hang clean. The squat jump is more reliant on velocity than the hang clean and might be better suited to develop power at lighter percentage loads. It should therefore be employed for players required to produce velocities at light loads. Since the squat jump also requires less absolute load for PPO than the hang clean, this exercise is a better option for developing power for inexperienced players who have not yet mastered Olympic-style lifts.

The power production in the hang clean, on the other hand, is dependent on increased loads. Heavier loads should therefore be used in this exercise for power development and may be a more effective training exercise for players requiring high velocities against heavy loads.

Considering the dissimilar power requirements of different playing positions in rugby, the two exercises could be applied for these different training needs. From this study it would appear that rather than using different training loads for different positions, different exercises should be employed for the power demand of different positions.

The hang-clean exercise would be more beneficial for forwards, who require generating high velocities against high loads such in for example scrumming, rucking, and tackling. For the backline players who require higher velocities at light loads, the squat jump might be a more effective exercise to meet their power demands.

A periodised plan for power-training exercises could also be given consideration when studying the results of the present study. Since the squat jump produces MPO at a lower percentage load than the hang clean, it could be better suited for players who are inexperienced in power training. Long-term periodisation of exercises introduction in power training can therefore progress from a simple exercise (e.g., the squat jump) involving only the legs and require a lower percentage load for MPO, to more complex exercises (Olympic-type lifting) involving the whole body. More complex exercises place a greater demand on the body since a very high (80-90%) percentage load is required to train optimally.

It should be mentioned that power training with loads that produce MPO is not the only method applicable to power training. An overall resistance-training programme should be periodised for developing hypertrophy, maximal strength and speed, especially for players who are inexperienced in strength training. For power development, training with optimal loads for MPO should thus be incorporated into a periodised-training plan and form part of a total conditioning programme, targeting all the bio-motor requirements of a specific sport.

Limitations of the study

The following factors were identified as possible shortcomings of the present study:

Training inexperience of participants

Most of the participants in this study had limited experience in gymnasium training, let alone power training. Understanding how to move powerfully is something that athletes learn over time and the pre-season testing could have been too soon for some participants to move powerfully. The hang clean is a fairly technical exercise and two months' training could have been insufficient time to master the lift. When interpreting the results, care should be taken not to generalize the findings too hastily. It should be kept in mind that the pre-season testing was done on inexperienced players.

Exercise selection and technique

Since some participants were lacking in proper technique in the hang clean, it could have influenced their results. A more basic lift such the high pull (similar to the hang clean, but without catch) could possibly have been more suited to this study.

The consistency in the squat depth of the participants is questionable. Since the depth of the squat was visually determined during testing, errors could have been made resulting in inconsistencies. A mandatory predetermined depth (such as a box squat for example) might have been a better option.

Homogeneity of groups

Although everything was done to ensure that the two groups from the two rugby academies involved in the testing were as similar as possible, testing the two groups on different dates and at different venues was not ideal, despite the fact that the conditioning coaches of the two institutions corresponded regularly. Training programmes and periodisation plans could have differed, albeit only slightly.

Sample size

For the pre-season testing 59 participants were involved. Unfortunately, due to injuries and participants who failed to participate in at least 80% of conditioning sessions, the sample size for the final in-season testing was reduced to only 29 participants. The sample size in both rounds of testing, but especially for the in-season testing, should ideally have been larger.

Testing equipment

The *TENDO weight analyzer* was used in this study to measure the power output of the participants. The reliability of this piece of equipment has been established, but unfortunately not the validity. Different testing equipment and calculations are some of the factors that might lead to inconsistencies in test scores. When comparing the power output achieved in this study, practitioners should be careful when comparing it with power output achieved with other types of equipment. This is especially important in the case of the squat jump where ground force could be measured with a power plate for instance.

Recommended future research

The following recommendations regarding future research in this area are proposed:

- There are variations of Olympic-style lifts. Some, such as the *power clean* and the *snatch,* have a greater range of motion and the bar needs to be accelerated for a longer time period. Baechle and Earle (2000) point out that this could be an important factor since power is the result of work divided by time. They also define work as the product of mass and distance and conclude that the distance an object is moved has an effect on power production. This implies that lifts that have a greater range, move an object a greater distance, resulting in a different power output. Comparing these lifts' optimal loads could lead to a greater understanding of power production at lower loads (30-50% 1RM).
- Examining the effect that chain or rubber bands will have on power production compared to ballistic exercises. Chain and band training have been design to increase the load on the bar as the range of the lift increase. The increase in load causes a natural deceleration of the bar. The athlete thus does not have to decelerate the bar himself since the increase load causes this to happen. The high working load and the acceleration will thus be present in these lifts while ballistic lifts depends largely on acceleration.
- An investigation similar to the present study could be conducted on more experienced rugby players with a longer training history. Such a study could provide a better understanding of why more experience players produce MPO at a lower percentage load 1RM than the relatively inexperienced players. This might also result in a more clear-cut

difference between the performances of participants from different playing positions in power production in more experienced samples.

- The results indicating that backline players produced higher power output than the forwards at lighter loads in the squat jump were vague and not significant. This trend could be further explored with a larger sample and focusing specifically only on power production in the differences playing positions in the lower loads (30-50%) of the squat jump.
- Rugby is a sport that requires the development of a variety of bio-motor abilities. Power training, albeit important, is only one of several components that needs to be developed. Investigating participants who focus on only one part of power development such as sprinters (high-velocity/low-force) or weightlifters (high-force/high-velocity) might give more useful results when comparing different exercises.

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Apendix A

Consent to participate in research

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

Optimal training loads for maximum power production in a ballistic and Olympic-style exercise for rugby players

You are asked to participate in a research study conducted by Nico de Villiers (Hons. B.A. Sport Science US), from the Department of Sport Science , Stellenbosch University for a Master's degree. You were identified as a possible participant in this study.

PURPOSE OF THE STUDY

The purpose of this study is to determine the optimal training loads for producing maximal power output in the hang power clean and the squat jump. There will also be an investigation into the effect that the yearly training programme has on the optimal training loads.

PROCEDURES

If you volunteer to participate in this study, we will ask you to do the following:

Perform a one-repetition max test in the hang power clean and a three-repetition max test in the back squat. After determining your maximal loads, you will be required to perform the hang power clean and the squat jump at various loads, ranging from 30-90% to determine at which load you can produce the most power. You will have two attempts at each load. You are expected to execute all the tests at 100% effort to ensure reliable results.

The testing will be done over a five-day period, with the maximal-strength test (hang clean and back squat) on day one and the power test on day three (hang power clean) and day five (squat jump).

The procedure will take one hour each day and will be performed at the van der Stel Gymnasium for Stellenbosch players and at the RPC Gymnasium in Riebeeck West for students from the RPC.

The test will be repeated towards the end of the season (September) and the same testing protocol will be followed.

POTENTIAL RISKS AND DISCOMFORTS

The strength tests (hang power clean and back squat) will be maximal-effort tests and will require you to execute them at maximal exertion. This type of testing is intense and could be exhausting for participants who are not used to them. In maximal-effort testing there may be a risk of injury, but with a proper warm-up and supervision, the risk will be minimal.

Herewith I confirm that:

1. In the event of an accident, injury or loss of any kind, I shall not deem Stellenbosch University or the Department of Sport Science liable.
2. I will be participating at my own risk.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

Results of the research will be made available to participating players, coaches and trainers.

The test results will give you and your coaches a good indication of your level of strength and power. The information gained from the research will enable you to improve your conditioning programme and train at correct loads in order to develop optimal power and strength.

This study will have benefits for sport science in general, since it can provide more clarity on optimal training loads for power development in different modes of training.

PAYMENT FOR PARTICIPATION

Subjects will not receive any payment for participating in the study. It’s on a voluntary basis only.

CONFIDENTIALITY

Any information that is obtained in this study and that can be identified with you, will remain confidential and will be disclosed only with your written permission or as required by law. Confidentiality will be maintained by means of safe storage of research data on a computer hard drive and a printed copy. This information will be kept safely locked away with no other person but the researcher having access to it.

Results of the study will be released to the participants and their coaches. It will be released if there is an interest in the study or when being published. Names of the participants will be kept confidential.

PARTICIPATION AND WITHDRAWAL

You may choose whether to be included in this study or not. If you volunteer to participate, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

If, for safety reasons the researcher finds that you lack the proper technique, or are unable to perform tests at full effort, you will be withdrawn from the study.

IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact one of the following:

Nico de Villiers
083 56 28 720
021 887 7432
nicodevilliers@gmail.com
6 Schoongezight Street
Stellenbosch. 7600

Dr. Ranel Venter (Supervisor)
083 309 2894
021 808 4915
rev@sun.ac.za
Department of Sport Science, Stellenbosch University
Private Bag XI
Matieland 7602

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development of Stellenbosch University.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

Herewith is certified that:

- In event of an accident, injury or loss of any kind I shall not deem the University of Stellenbosch liable.
- I participate at my own risk.

The information above was explained to me by Nico de Villiers in [*Afrikaans/English*] and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Subject/Participant

______________________________________ _______________

Signature of Subject/Participant **Date**

SIGNATURE OF INVESTIGATOR

I, declare that I explained the information given in this document to ____________________ ______________________. He was encouraged and given ample time to ask me any questions. This conversation was conducted in Afrikaans/English.

______________________________________ _______________

Signature of Investigator **Date**

Apendix B

Letters of Supervisors

Stellenbosch voluit rugby
Rugbyakademie voluit student

Vir Wie Dit Mag Aangaan

Hiermee wil ek bevestig dat ek die toetsing wat Nico de Villiers op ons studente gaan uitvoer, sal oorsien.

Ek neem volle verantwoordelikheid om toe te sien dat hy nie van sy gesagsposisie sal misbruik maak nie.

Die deelname van ons studente sal vrywillig wees en toetsing sal geen student benadeel of in gevaar stel nie.

Vir verdere navrae kontak my by 021 877432 of per epos: coach@stellenboschrugbyakademie.co.za

Emile Neethling

BESTUURDER: VOLTYDSE KURSUS

2010-02-10

Stellenbosch voluit rugby
Rugbyakademie voluit student

To Whom It May Concern

I hereby give permission to Nico de Villiers to use our students for his research.

I take responsibility to oversee the testing and that students will volunteer in the testing. Students may choose not to participate and can leave the testing whenever they wish.

ALIE BRAND

Head
STELLENBOSCH RUGBYAKADEMIE

RPC
rugby performance centre
• perfection in execution •

To Whom It May Concern

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I take responsibility to oversee the testing and that students will volunteer in the testing. Students may choose not to participate and can leave the testing whenever they wish.

Sean Surmon

Director: Strength & Conditioning
NSCA CSCS
Registered Biokineticist
BSc Sport Science (Stell)
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Master in Sport Science (Stell)
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