

## **Optimal Power Production: A review of the relationship b/n strength & power qualities to sports performance for training program design.**

For decades athletes have been improving their sports performance through strength training of many varieties. It can be argued that success in most sports depends upon attainment of some threshold level for maximum strength, power and speed (Newton & Kraemer, 1994). It is the ability to express explosive strength in the field of play is one of the essential elements of elite athletic performers. Therefore, the design of resistance training programs that can result in beneficial adaptation across a variety of performance skills is a challenging undertaking, especially when dealing with well-trained athletes. In order for resistance training to enhance performance, the isometric and dynamic force related characteristics and the power developed must transfer to these skills (Harris et al., 2000).

Researchers have endeavored to investigate the relationship of maximal strength to other strength qualities along the repetition maximum (RM) spectrum in an attempt to better associate different strength qualities with expression of power. Although varied in their content, methods and findings, current research has shed light on a range of strength training loads that result in optimal power output (Baker et al., 2001a, 2001b; Stone et al., 2003; Jones et al., 2001; Cronin et al., 2003), and greater enhancement in sports performance field tests (Wilson et al., 1993; Lyttle et al., 1996; McBride et al., 2002; Jones et al., 2001; Harris et al., 2000). More importantly, these results allow strength and conditioning coaches to accurately prescribe the correct training intensities for the attainment of optimal power development in athletes for their specific events. This literature review is designed to present the findings from current research on peak power production and its relationship to maximal strength and other strength qualities in athletes, of many competitive levels. The relationship of power and other speed-strength qualities to sports performance variables will be reviewed with an eye to recommend training applications and advanced training methods for the expression of explosive strength in the competition arena. Comparisons of training modes for peak power production will be discussed, with future investigation suggested in associated areas to strengthen the knowledge of training for peak power production and sport specific strength qualities.

### **Strength and power profiling**

Strength can be defined as the ability to produce force (Stone, 1993). Thus, strength can have a magnitude ranging from zero force production to maximum (Stone, 1993). Strength levels have traditionally been monitored using maximum isometric and 1RM strength methods for definition of an athlete's strength profile. These methods are used extensively in the strength-coaching field. However, the relative contribution of maximal strength scores to sport performance test outcomes are not high, with numerous research reporting low contributions of maximal strength to sport performance. An example is Mero et al (1983) showing a correlation between maximum isometric strength with maximum speed of 0.62 (38% explained variance) and starting speed of 0.46 (21% explained variance). In addition, the validity off these strength assessment methods can be questioned, as many do not simulate the actual conditions associated with sporting

movements and/or movements. Thus, researchers have traveled down other avenues to explain the contribution of muscular strength to sporting success.

Power can be defined as work/time or force x velocity (Stone, 1993). Baker (2001a) highlights the requirements of a high degree of lower body power for successful completion of various sports tasks in a number of sports. Maximising muscular power against resistance loads and at the velocities specific to each sport is required in various throwing, jumping, striking, and change of direction activities (Jones et al., 2001). During these activities, an athlete must maximize their muscular output because of the time over which they can apply force and accelerate the body or other masses is minimal (Jones et al., 2001). The ability to express power during sporting performance is generally considered to be the major factor for separating participants, as demonstrated by Baker and Nance (1999a, 1999b) in rugby league players of different grades. In agreement, Mel Siff (2000) highlights this argument in a detailed athlete development model, indicating the expression of explosive strength as a key element in the progression through to elite level performer.

Consequently, the muscular power output of the lower body and the methods to develop it are of considerable concern to sports coaches and researchers. Assessment of velocity related force production in early research typically used isokinetic testing on Cybex dynamometers during isolated joint movements and angles. Although informative to a degree in laboratory settings, this type of muscle action does not simulate the natural movements of the body, which include accelerations, and eccentric stretching phases before the concentric or shortening phases across numerous joints, body positions and movements. As such, the external and logical validity of findings from isokinetic research would appear questionable (Cronin et al., 2003).

Understanding how various acute programming variables and their interactions affect either force or velocity would seem important in determining how to alter the performance capability of muscle for a given purpose. It has been proposed various factors in training, such as resistance training loads, should accommodate the differences of velocity and resistances encountered during specific sporting skills. Examining force-velocity and power-force relationships under isoinertial assessment (constant gravitational load), does not suffer the same problems with validity of isokinetic and isometric strength assessment to sports performance because this type of motion better simulates the movement patterns encountered in everyday and sporting activities (Cronin, et al., 2003). Further, isoinertial assessments have more recently been used in preference to the isokinetic and isometric methods, as they appear to be more characteristic of the dynamic capability of the neuromuscular system to function under varying loading conditions, and therefore, has considerable significance in the performance of movements in the sporting arena (Cronin et al., 2003).

### **Power assessment in the field**

Laboratory assessment of athletic strength and power using force platforms has been inaccessible and expensive, placing it out of reach for most strength and conditioning practitioners and sports clubs. Recent advancements in technology have provided the

strength and conditioning coach with the tools to accurately assess each athlete's strength and power profile under different loading conditions within their own training settings. The Plyometric Power System has been used extensively in research (Wilson et al., 1993; Baker et al., 201a, 2001b) and training purposes. The system involves subjects jumping with or throwing a bar in a Smith Machine in vertical movements. Additional weight can be added to the bar to get desired load for analysis. Attached to the bar is a rotary encoder that records the position and direction of the bar. This information is recorded, calculating the work done (mass x gravity x height) and the mean-power output (work/time) (Wilson et al., 1993). Updated and more powerful systems have been recently introduced to the marketplace, with broader range of variables available for analysis, and subsequent athlete evaluation, such as peak power and peak velocity. Included in these are the Gym-Aware products available from Kinetic Performance Technology, with portable hand-held palm-pilot computer for data analysis and interaction with Web-based support services (see [www.kinetic.com.au](http://www.kinetic.com.au)). These provide an extremely powerful tool for the strength and conditioning coach to enhance strength and power training prescription. The data enables the correct prescription of strength training means for enhanced athlete development, whilst providing accurate load ranges for the desired strength/power outcome. Figure 1 below outlines the power-load curves of a number of athletes for the bench press throw and the subsequent % of 1RM bench press corresponding to peak power output.

### **Insert Figure 1 Here...Bench Press Throw.**

#### **Loads for Peak Power Output**

Baker et al. (2001) states there has been considerable debate in the programming of training loads that elicit the most favorable adaptation in power development during explosive strength training and the different strength training regimes used to elicit the greatest effect on sports performance (Wilson et al., 1993; Lyttle et al., 1996; McBride et al., 2002; Jones et al., 2001; Harris et al., 2000). Low-resistance methods around 30% of 1RM for traditional weight training exercises were suggested by Kaneko and cohorts, with Schmidbleicher favoring the high resistance method of 80-90% of 1RM to produce favorable speed-strength and power training adaptations. Wilson et al (1993) and colleagues more recently argued that increases in power and performance in explosive sport related tasks would be better achieved through training with a resistance that maximizes the mechanical power output. Wilson et al (1993) argued that generating peak mechanical power by lifting the correct resistance or load would result in various specific neuromuscular adaptations that may in turn, more readily transfer to explosive sports performance. This argument has been founded by numerous studies reporting the beneficial effect of training with the optimal load for power production for enhancement of sports performance tests (Wilson et al., 1993; Lyttle et al., 1996; McBride et al., 2002; Jones et al., 2001; Harris et al., 2000). Most conclude that training with or near loads that produced maximal mechanical power output produced statistically superior results than unloaded plyometric and traditional strength training methods. Therefore, from research that has investigated peak power output across a broad spectrum of loads (Bemben et al., 1991; Kaneko et al., 1983; Mayhew et al., 1992; Moss et al., 1997; Newton et al., 1996) it has been generally recommended that loads of 30-45% of 1RM would provide the

optimal load for maximizing power output during resistance exercises, and would provide the foundation for load prescription in explosive power training.

However, a number of strength and conditioning coaches have recently argued that loads of 45% of 1RM fall short of producing peak power output in athletes with extensive backgrounds in strength and power training (Baker et al., 2001a, 2001b; Cronin et al., 2003; Tidow, 1995). Poprawski (1988), a strength practitioner, has stated that stronger athletes use loads that represent a higher percentage of 1RM (70%) and conversely less strong athletes use loads that represent a lower percentage of 1RM (50%). Recently, more studies have been published on the loads along the RM spectrum that creates optimal power production in upper and lower limb explosive movements in athletes of different strength levels and training history. Table 1 provides a summary of this research.

### **INSERT TABLE 1 HERE – Research Table**

The results from these power output studies are varied. Most of the study methodologies differ, providing a difficult analysis of results, with each recommending a differing range of loads for the optimal production of peak power in their subjects. The one factor that is agreed upon is the power output and the corresponding %RM to achieve peak power output depends on the nature of the exercise and the training level of the athlete (Baker, 1995). In this case, an extensive review and analysis of each studies participants, methods and subsequent results has allowed this author to suggest training intensities for optimal power production in different categories of athletes. Therefore, it is possible to provide more precise training guidelines for the prescription of %RM training loads for peak power production in training and in athlete development. In light of this, it is the purpose of this review to provide guidelines for strength and conditioning coaches in the development of maximal mechanical power through prescription of resistance training loads for a broad range of athletes, not just elite performers.

### **Review of Literature**

Baker et al. (2001a) reported peak average power output in the load range of 55-59% of 1RM in the bench throw and countermovement squat jump for professional rugby league players, with further examination revealing loads within the zone of 48-63% of 1RM allowing similar high power outputs. Closer examination of the methodology may shed light on the higher than normal %RM values for peak power production in this study. It appears that the reported %RM for peak power production may be the result of using the full range squat movement in accordance with Powerlifting federation guidelines for the 1RM testing value, which is more difficult to perform than the traditional 90degree squat used in other protocols. Additionally, participants were able to select their own depth for the countermovement squat jump. It is my experience that rugby players are able to develop higher power outputs with shorter depths on countermovement jumps, probably owing to the larger number of contractile units associated with a very powerful SSC movement at the top range of the squat movement, traditionally a stronger portion of the squat lift. There may have been more conservative ranges if a more standard methodology had been incorporated, such as a dip in the countermovement jump to 90

degrees knee angle and a comparison of a standard depth 1RM squat, with hamstrings parallel to floor.

There can be no disputing a load of 55% of bench press 1RM producing the highest mean power output for the bench throw exercise reported by Baker et al. (2001b), concluding a range of 46-62% of 1RM produced similarly high power outputs for the upper body movement and the lower body movements. There may be numerous explanations for the differences here, such as training history, comparable training loads for upper and lower body, and interference of other sports training on leg strength. However, the most logical explanation is that power output is determined by the nature of the exercise as stated by Baker (1995). It may be that the upper body has a higher power outputs to strength ratio, but also may represent a more simple exercise to produce power. In a review of a study by Cronin et al., (2003) similar results were extrapolated from the data showing peak power was established for both the rebound and static bench press throws at 50% of 1RM for the bench press. In addition, a similar range of 40-60% of 1RM for the bench throw previously reported produced similarly high power outputs in participants (Cronin et al., 2003), indicating a training range of 40-60% of 1RM bench press may be the optimal loading for peak power development in the bench throw exercise in resistance training programs.

In another study with a larger variation in the participant training background, Stone et al (2003) reported peak power output for the countermovement and static squat jump was produced at 10% of 1RM squat strength. In sight of this low range finding, the authors fragmented their group of 22 athletes into two groups for statistical comparison. This would appear very relevant considering the training background of the participants ranged from 7-weeks to 15-years. The results were quite conclusive, revealing the five athletes with the highest 1RM squat were able to produce peak power at 40% of 1RM in loaded squat jumps. In comparison, the five athletes with the lowest RM for back squat produced peak power production at 10% of 1RM. The authors concluding that maximal strength was a significant contributor to the higher peak power outputs across the loading spectrum of 10-100% of 1RM in the stronger subjects, and was also a significant factor in the higher % of 1RM load that produced peak power output in the same subjects. Therefore, for improved jumping power output maximum strength should be a primary component of training programs for athletes with a low training history and/or low maximal strength (1RM) for the back squat movement.

In the author's experience, I am yet to see an athlete reproduce results that produce peak power at 50-60% of 1RM. In professional rugby union setting, this author has observed players produce peak mechanical power outputs for both static (non-rebound) and countermovement loaded squat jumps at 30-45% of 1RM in players with higher levels of RM and strength/power training history, and 15-30% of 1RM in players with lower levels of RM and strength training backgrounds. These results are based on a methodology of 1RM squat depth with thighs parallel to floor, and a jump height with starting/dip height of 90 degree angle at the knees. These objective results are very similar to the findings published by Stone et al (2003) for the similar movements. In addition, the bench throw

ranges were a little higher, with loads ranging from 20-35% in low training history players, and 30-50% in higher RM and longer training history players.

One thing is for certain in most of these studies, loads greater than 65% of 1RM result in greater proportional decreases in velocity than increase in mass and consequently power decreases. Conversely, loads lower than the ideal range for high power production result in greater velocities resulting in decreased power output due to a greater proportional decrease in mass (Baker et al., 2001a, 2001b). In view of these research results, there needs to be refinement of the training load (% of 1RM) prescription for the development of maximal power production in athletes with different strength and power profiles. This has implications for the prescription of training loads for specific individuals rather than as a general number of 30-60% of 1RM, which appear on the high side for athletes of lower strength and power training histories, and may provide insufficient loading for athletes at the opposite end of the maximal strength and training background spectrum.

### **The contribution of maximal strength to mechanical power production**

Stone et al, (2003) is of the opinion that many and perhaps most coaches and athletes involved in strength-power sports currently believe that maximum strength is related to power production. This belief has a long history of theoretical (Henry et al., 1962; MacIntosh, 1974) and researched support (Baker et al., 2001a, 2001b; Baker and Nance, 1999; Stone et al., 2003; Schmidtleicher, 1992). Schmidtleicher (1992) suggests maximal strength affects power in a hierarchical manner with diminishing influence as the external load decreases to a point as to which other factors such as rate of force development become more important. This argument indicates that maximum strength should have its greatest influence on power output at heavy loads and that light loads should be influenced to a smaller degree by maximum strength levels. Recent studies have supported this theory with high contribution (63-80% explained variance) of maximal strength to peak power production in weighted jump and bench press throw movements of intensities 40-60% (Baker & Nance, 1999; Baker 2001a, 2001b). Furthermore, Stone et al., reported the highest correlation of maximal strength to power production occurred at 50% of 1RM ( $r = 0.94$  and  $0.86$  for the static and rebound condition, respectively), with a range of contribution of maximal strength to peak power of 60-71% at 10% of 1RM loaded conditions, 72-81% at 30% of 1RM, 77-88% for 50% 1RM, 70-81% at 70% of 1RM, falling to 35-56% at 90% of 1RM. Findings which agree with the hierarchical nature of maximal strength contribution to power output activities forwarded by Schmidtleicher, and exemplify the contribution, and therefore, the requirement of high maximal strength for high levels of peak power output.

### **The relationship between maximal strength and power output for loaded SSC**

The majority of studies have used SSC movements, such as the loaded countermovement squat jump and bench press throw, to determine optimal loading for peak power production (Newton et al., 1996; Baker and Nance, 1999; Baker et al., 2001a, 2001b; Cronin et al., 2003; Stone et al., 2003). In light of this, there is a consistency in the significantly high contribution of maximal strength to peak power production in these studies. A range of results with explained contribution of maximal strength to peak power production in the loaded SSC (countermovement) jumps and bench throws was provided

by Baker and cohorts (63-80%) and has been extensively agreed upon by the other papers.

Motion that uses rebound at the inception of the concentric phase producing greater initial instantaneous and mean power outputs is a factor that has been identified previously in most unloaded SSC activities (Schmidtblecher, 1992). However, it had been mentioned that loaded SSC activities would fall outside the time constraints that are required in most sporting situations, arguing that the contribution of maximal strength to produce power in the instantaneous concentric action of the SSC loaded movement may be unwarranted in the sporting sense, as the time to develop forces in competition falls significantly inside the time to develop maximal force. Thus, the relative contribution of maximal strength to instantaneous power output (>200ms) in loaded SSC activities was not documented and usually fell outside the scope of most power output studies. In light of this, Cronin et al (2000) investigated the association of maximal strength levels and load on initial power production in both static (concentric only) and countermovement (rebound) bench press movements, in subjects with high RM and low RM bench press scores. As with the findings reported by many studies, the group with high RM strength showed across all resistances that peak power was higher than their low RM counterparts. Further, Cronin et al (2000) distinguish that stronger participants produced greater power output in the first 200ms of loaded rebound activities at loading of 40-80% of 1RM when compared to the weaker subjects, highlighting the importance of possessing greater maximal strength when producing power in the initial 200ms of SSC activity in this loading range. The authors concluding that the ability to instantaneously (>200ms) maximize power output through the use of SSC with external resistances of 40-80% of 1RM would seem to be influenced by an individual's maximal strength. Cronin et al (2000) suggested that the ability of stronger muscles to generate higher active state at the inception of the concentric phase was the underlying mechanism responsible for this phenomenon. It is well documented that strength and power training can improve muscle stiffness, which in turn allows greater stretch-load tolerance, storage of elastic energy, and improved power and mechanical efficiency (Komi, 1986; Milner-Brown and Stein, 1975; Pousson et al., 1990; Sale, 1992; Wilson et al., 1994). Therefore, for SSC activity of short duration, greater maximal strength will result in greater instantaneous power production. In light of this finding, maximal strength training should be an integral training strategy for such SSC activities.

### **Contribution of maximal strength to power output in concentric only movements**

In a similar fashion to loaded SSC movements, maximum strength has been shown to have a significantly high contribution to peak power production in concentric only movements in the bench throws and loaded squat jumps (Newton et al., 1996; Stone et al., 2003; Cronin et al., 2003). However, Cronin et al (2000) highlights the discussion on the relative contribution of maximal strength to instantaneous concentric only power (>200ms). In an interesting finding, Cronin et al. (2003) revealed the contribution of greater maximal strength to concentric only power output in the initial 200ms for all loading intensities (40-80% of 1RM) was non-significant. Instead a high peak power output at 40ms produced vastly superior power output for the first 200ms of the concentric only condition. Thus, it would appear that being stronger is not important in

concentric only performance of less than 200ms across a range of loads 40-80% of 1RM. In contrast, this was not significant in SSC activities. Cronin et al (2000) stated that SSC movements relied more importantly on the contribution of maximal strength to peak power output in initial concentric phase of a rebound movement, rather than the ability to produce high power output in a short period of time (>40ms).

These results seem to indicate that the neuromuscular basis of peak power output at 40ms differs to maximal strength qualities, and as such, starting strength (initial rate of force development) and explosive-strength (maximum rate of force development) have greater importance for rapid concentric power output in the initial stages of movement. In viewing these results, the authors contribute numerous factors that may affect rate of force development and therefore initial power output at the onset of concentric only muscle activation, such as increased firing frequencies, selective recruitment of the fast motor units, synchronization, preferential recruitment of fast muscles, depressed inhibitory and/or improved facilitatory reflexes, myosin light chain composition, and type of troponin and tropomyosin isoforms (Goldspink, 1992; Hakkinen, 1989; Komi, 1986; Pousson et al., 1990; Sale, 1992). Cronin added that for concentric only motion requiring high rates of initial power production, maximal strength training is not recommended, and should be viewed as secondary to the ability of the neuromuscular system to produce the greatest amount of power per unit time. Instead, methods that improve the rate of power development would appear the better training option for the development of motor performance of short duration concentric only movements, even when the external resistance is high. However, for sports which appear to have a greater time component for power production, such as tight-5 players in rugby scrums, requiring high levels of power <200ms of duration, a training program focusing on the attainment of maximal strength for the movement would have a significant contribution, and possibly be the determining factor in the outcome of that sport or contest.

### **Training Guidelines for Peak Power Development**

In light of the above findings, guidelines for the prescription of strength training intensities for peak power production and development need to be recommended with a view on the current training status and training history of each participant. In addition, strength and power analysis is required to determine the specific contraction modes (SSC or concentric only movements) and duration of force application for different sports and positions within a team. Table 2 provides a summary of the training loads for the development of peak power for athletes of different strength levels and training backgrounds.

#### **High strength and power athletes**

The prescription of %RM intensities for elite level athletes appears to be more simplistic than the lower level counterparts. Professional rugby league players with extensive strength and power training backgrounds are recommended to lift with intensities ranging from 48-63% of 1RM for optimal power production (Baker et al., 2001a, 2001b). It

seems appropriate that this range of % 1RM be applied to long-term trainers with high maximal strength levels and extensive power training experience. Peak power production,

as indicated by appropriate testing methods, in the loading range of 50-60% of 1RM appears to be the ultimate training goal that strength and conditioning practitioners can aim for with their athletes.

**Insert Table 2 Here: Loading for power development.**

A large range of power loads for the elite level athletes seen in table 2 is necessary for the gradual increase in training intensity as the competitive season approaches. Figure 2 outlines an example of a seasonal periodised strength and power-training plan for rugby union players with different strength and power profiles determined by testing. As with all training factors, the necessary periodisation of power training intensities is required, even for athletes with previous training history. Therefore, there is progression from early pre-season to the start of the competition period for power training load and volume variables, which are then cycled throughout the in-season (competition) training period.

**Strength athletes with minimal power training history**

Loads ranging from 40-60% of 1RM may not be appropriate for athletes who have a strong background in maximal strength training but limited experience in power development training. Therefore, it would be recommended that ranges be developed that correspond to the current % 1RM for peak power output for each individual athlete, with a gradual progression in intensity and volume as the training season progresses. However, if the resources are not available to evaluate the exact loading, it would be advised that strength athletes with minimal backgrounds in power based training may work between the loading range of 20-30% of 1RM to develop peak power in the initial stages of pre-season, with an view to progress onto ranges of 30-50% of 1RM as the ability to optimize power output increases at these loads. There is no research outlining a time-scale of the adaptations for increases in peak power with training. Therefore, it remains the responsibility of the strength and conditioning coach to evaluate the athlete's progress and adjust the training loads indicated by improvement in power production.

**Low level strength and power athletes**

Athletes with low RM for given exercises, coupled with short training history, should continue to utilise strength training methods with a focus on increasing their 1RM scores, which in turn, will exhibit corresponding increases in Pmax values, which is in line with conclusions from many researchers (Stone et al., 2003, more). One problem with this method is defining a point where maximal strength increases no longer contribute to increased peak power output, which would require a switch in the focus of training from maximal strength to training for power output in associated sporting movements. Therefore, it is important to look at specificity of velocity of movement in sport, which may require certain athletes to have a similar focus on the combination of maximal strength training with optimal power training to provide the specific means of strength and power development. It is with this view that training prescription guidelines for power development in this group fall within a range of 10-20% of 1RM in the initial training periods to initiate power develop training, with progression in loading as the athlete develops 1RM capacities and the ability to handle increasing loads in these

exercises. However, this is of secondary importance to the further development of maximal strength levels.

Insert Figure 2. Yearly training plan for strength and power development in rugby players

### **Training for SSC power and concentric only power**

The need for strength and power requirements in athletes is sport specific. Individual sports, such as track and field, often have very specific strength and power profiles with predetermined requirements allowing a more simplistic prescription of training requirements by the coach. In contrast, many field sports, such as rugby, do not have this advantage, where a greater range of strength variables needs to be considered. These include loaded and unloaded strength and power activities, in both static (concentric only) and in SSC properties. Therefore, it is a requirement to be able to distinguish an athlete's current strength and power in these respective qualities, with concurrent prescription of strength and power dependant on the results. An index of explosive strength could be used to determine an individual athletes strength and power profile, leading to the correct prescription of training variables. An example of this testing may be with strength athletes who have a greater power output in static jump conditions compared to countermovement jump (SSC). Therefore, these athletes would need to focus on a period of SSC countermovement jumps to counterbalance the development of peak power in both conditions. For this reason, an index of explosive strength could be used in athlete evaluation to determine the correct prescription of SSC movements and static lifting movements. Obviously, the specific requirements of the sport need to be assessed in the first place. However, a protocol that determines a switch from SSC (countermovement) power training static power training, and vice versa, will enhance the prescription abilities of the strength and conditioning coach with efficient strength and power training program design.

### **Loading for maximal power improvement in training**

Should an athlete currently involved in power training for Pmax lift at the load that optimizes Pmax (optimal loading), or should they train above and below (contrast load) in an attempt to develop the capabilities of Pmax. It is important to obtain data on every participant's % 1RM for Pmax, allowing for precise training program development for the specific component of an athletes physical profile. It is unclear whether the development of Pmax is enhanced through contrasting loads above and below the current %RM training load that optimizes power output. Most of the research published in the loading parameters for peak power production reported similar power outputs and no significant difference for a range of loads near the optimal load for Pmax. Baker et al (2001a, 2001b) reported loads range of 46-63% of 1RM producing similar Pmax, with most other papers also reporting a range of loads around Pmax that did not significantly differentiate power output. In light of this, it would appear that training at optimal loading for Pmax development may be sufficient stimulus for the development of peak power

characteristics, with contrast loading used as an additional training tool if desired. Further research is warranted in this area.

### **Power profiling procedures**

The use of evaluation tools in specific movements used for power development is essential in determining the correct range of loads to be used for these athletes in training. Figure 1 shows the force-power curve of five athletes for a countermovement bench throw indicating a loading curve that would be specific for each athlete in the prescription of training loads for power development.

Testing procedures for peak power output need to be repeatable and provide reliable information for the evaluation of an athlete's current and future strength and power requirements. The procedures used by Baker et al (2001a, 2001b) should provide a basis for the development of a power testing protocol that can be implemented by most strength and conditioning coaches fortunate to have access to the plyopower or gymaware systems. In light of this, variables that need to be consistent within the protocol are 1RM squat testing depth, depth of rebound jumps, and starting height of static jumps. If these variables are kept consistent, then it will empower the coach with an accurate power profiling method, and a powerful tool for the appropriate prescription of each athlete's strength and power training programs.

### **Conclusion**

The prescription of the appropriate load for peak power development has been discussed with a view to specific requirements for athletes of different strength and power training histories. It is proposed that athletes with high levels of strength and power continue to develop peak power capabilities at loads around 50% of 1RM strength through a periodised program corresponding to the training cycles in their yearly plan. Athletes with low to medium levels of maximal strength are advised to continue the development of maximal strength levels, with a secondary emphasis on power training at lower intensities (20-40% of 1RM). Further, maximal strength was significantly related to the instantaneous power production in loaded stretch-shortening-cycle movements, but not in concentric only movements. It was discussed that the role maximal strength plays in the instantaneous production of power differs for these conditions, with attention warranted for the prescription of these characteristics in strength and power training programs.

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