Combining scientific research into practical methods to increase the effectiveness of maximal power training

by

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Introduction

Power is the most desired physical quality for a number of sports because it entails both force (strength) and velocity (speed) aspects. Power is typically defined as the rate at which work is performed (Mass x Distance / Time). For coaches and sports people it is more often described as strength x speed. Because both strength and speed can be improved by many different training variable manipulations, training to improve power output has been described as requiring a multi-faceted approach (Newton and Kraemer, 1994).

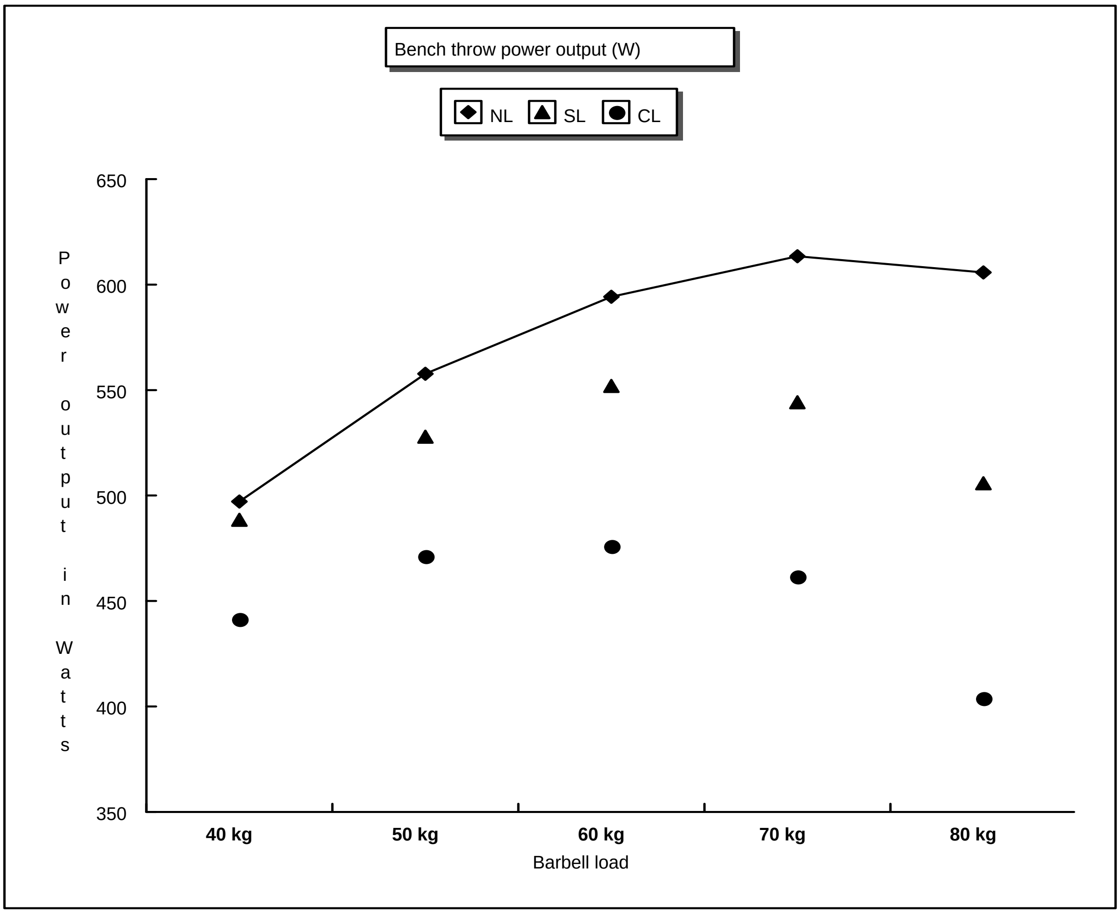
However a cursory glance at many resistance training programs or recommendations aimed at increasing muscular power would typically reveal a high proportion of Olympic weightlifting (eg. power cleans, pulls), plyometric exercises (eg. jumping, bounding) or even rubber tubing exercises (Baker, 1995, Haff et al., 2001, Hydock, 2001). While Olympic weightlifting methods of training often produce tremendous increases in lower body power, other methods or exercises, especially for developing upper body power, appear less explored. For example, maximal upper body pressing/pushing power is of importance to football players (rugby league, union, Australian and American football) as well as boxers and martial artists to enhance the ability to push away/strike opponents. However most articles concerning power-training methods involve Olympic weightlifting exercises and lower body plyometrics, paying scant regard to the upper body requirements. However there has been some tremendous research done lately, (especially in Australia or by Australians) that has inspired coaches to be more creative in their power training prescriptions and methods.

The purpose of this article is to outline some of this research and how it can be used in your program to develop both upper and lower body power. Most importantly practical methods that improve the effectiveness of maximal power training are detailed. Astute coaches will be able to determine the relevance and application of these concepts and methods to the broader area of athlete preparation for their sports.

Maximal power and the load-power curve

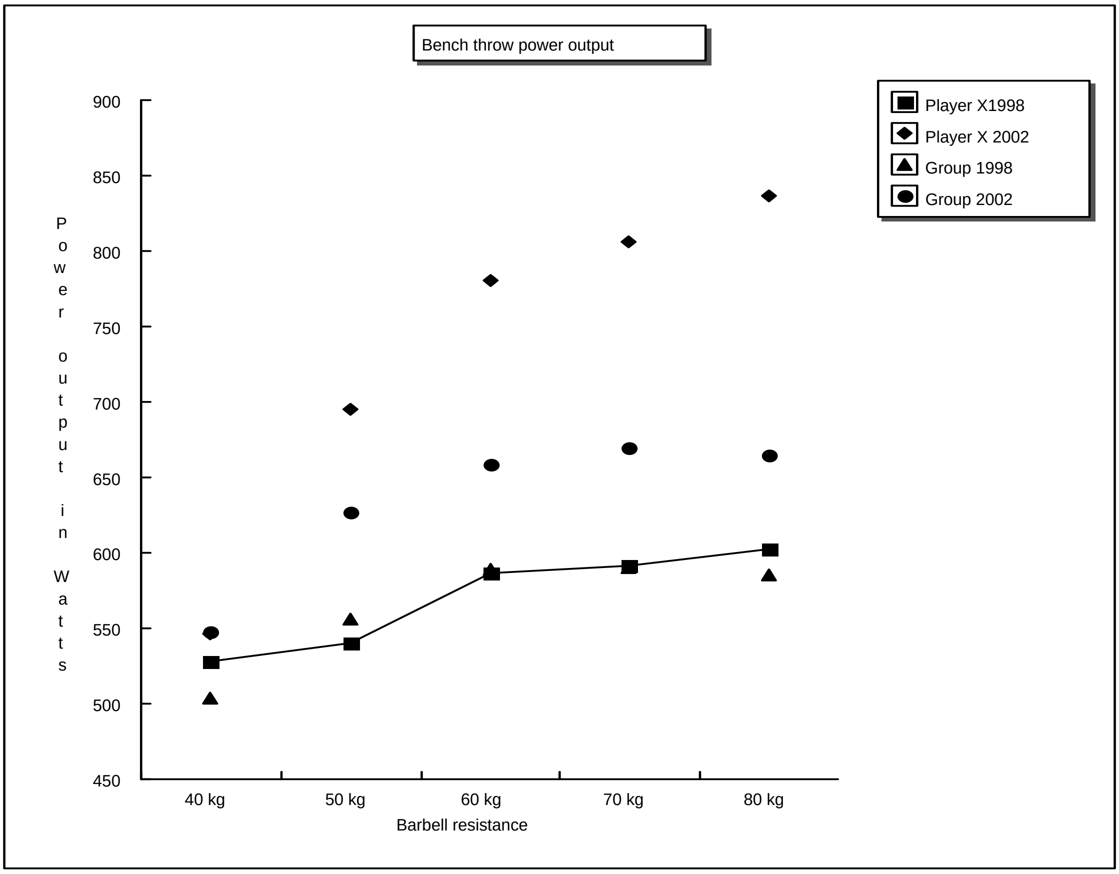
Maximal power (Pmax) for the purpose of this paper is defined as the maximal power output for the entire concentric range of movement/contraction. Peak power refers to the highest instantaneous power output for a 1-msec period within a movement. Pmax is usually determined by measuring power output during the lifting of a number of different barbell resistances in a designated exercise (eg. bench press, BP or bench throws, BT, in a Smith machine or during jump squats or power cleans) using some measurement system such as force plates or the Plyometric Power System (PPS, see Wilson et al., 1993, Newton et al., 1996, 1997, Baker, 2001a, b, c, d). The load-power curve or profile (see Figures 1 and 2) that is generated for each individual from this testing can aid in prescribing training (Newton and Kraemer, 1994, Baker 2001d). The classic work by Hakkinen and colleagues using jump squats with resistances ranging from 20 to 140 kg, illustrated that very heavy strength training or lighter, maximal power-oriented training affected the load-power curve in different areas (Hakkinen et al., 1985a, b). Specifically heavy strength training caused athletes to be able to produce more power with heavy resistances (>60-80 kg) but with little change in how much power they produced against light resistances (BM to 60 kg). Thus power was increased through increasing force/strength but not through any change in unloaded speed (the "power through strength" training approach). Lighter power-oriented training (the "power through speed" training approach, Baker, 1996, 2001a) had the opposite effect upon power output produced against the range of resistances, with power being increased markedly with lighter resistances and minimal change occurring against the very heavy resistances. Therefore training prescription may depend not only upon sport-specific objectives but also upon the results of the load-power curve testing.

Figure 1. Load-power curves (average concentric power) for rugby league players participating in the professional National Rugby League (NL), State league (SL) or intra-city based leagues (CL). From Baker, 2001d.



For example, an individual whose load-power curve was characterized by high power outputs with light resistances but also exhibited pronounced reductions in power output with heavier resistances would be prescribed more maximal power-oriented and especially, heavy resistance strength training. An athlete whose load-power curve was characterized by low power outputs with light resistances but higher power outputs with very heavy resistances would be diagnosed as probably possessing enough strength but being deficient in speed. They would be prescribed slightly more ballistic power and speed training and slightly less maximal strength training.

Figure 2. Change in the upper body bench throw load-power curve (average concentric power) across a four-year period in a group of twelve professional rugby league players as well as for one individual who made considerable progress (player X). The change in 1RM BP appears to underpin the change in BT Pmax during this time. From reference Baker and Newton, 2005c.



Relationship of Pmax to maximal strength

Maximal strength has been shown to be highly correlated to Pmax in both the upper- (Moss et al., 1997, Baker and Nance, 1999, Baker et al., 2001a, b, Baker, 2001c, d,) and lower-body (Baker and Nance, 1999a, Baker et al., 2001b) for both elite and less experienced athletes. Running speed is also heavily dependant upon Pmax and strength, relative to body mass (Baker and Nance, 1999b).

Long-term studies across one season (Baker, 2001c) or four years (Baker and Newton, 2005b) show that changes in Pmax are heavily dependant upon changes in maximal strength. As maximum strength is the physical quality that most appears to underpin Pmax, it is advisable that athletes who wish to attain high Pmax levels develop and/or maintain very high levels of strength in both agonist and antagonist muscle groups (Baker and Newton, 2005a). The strength of the antagonists should not be neglected for athletes who require rapid limb movements as research has shown that strengthening of antagonists increases both limb speed and accuracy of movement due to favourable alterations in the neural firing pattern (Jaric et al., 1995).

It has also been shown that some power training practices described below are only effective for stronger, more experienced athletes (Young et al. 1998, Duthie et al. 2002, Chu et al. 2003). It is only when a good strength and muscle-conditioning base has been established will the following practices be most useful.

Practical methods to increase the effectiveness of maximal power training.

1. Include full acceleration exercises as power exercises

It is important to differentiate exercises as being used primarily for the development of **strength** (or related qualities such as hypertrophy, stability/control etc depending on sets, reps, rest periods etc) or **power** (Baker, 1995a, Baker, 1998a-c, Baker and Newton, 2005b). What differentiates between these two classifications of strength or power exercises is **whether the performance of the exercise entails acceleration throughout the range**

of movement, resulting in faster movement speeds and hence higher power outputs (Wilson et al., 1993, Baker, 1995a, Newton et al., 1996, Keogh et al., 1999). Power exercises are those exercises that entail acceleration for the full range of movement with resultant high lifting velocities and power outputs. Strength exercises are those exercises that entail heavy resistances and high force outputs but also pronounced periods of deceleration resulting in lower lifting velocities and reduced power outputs (Newton et al., 1997) (see Table 1 for examples). Performing an exercise whereby acceleration can occur throughout the entire range of movement (such as a bench throw or jump squat in a Smith machine, see Photos 1-6, medicine ball throws, power pushups etc) allows for higher lifting speeds and power outputs (Wilson et al., 1993, Newton et al., 1995, 1996) (see Table 2).

Photos 1 and 2 show the bench throw exercise in a Smith machine. The loss of hand contact with the barbell in Photo 2 allows for full acceleration throughout the entire range of movement, making this exercise more conducive to power training.

If athletes attempt to lift light resistances explosively in traditional exercises such as bench press and squats, large deceleration phases occur in the second half of the movement, resulting in lower power outputs as compared to power versions of bench throw and jump squats (Wilson et al., 1988, Wilson et al., 1993, Newton et al., 1995, 1996). Thus heavy resistance exercises such as bench press, squat and deadlifts are considered strength exercises whereas bench throws, jump squats and power cleans are considered power exercises (Baker, 1995a).

Table 1. Example of exercises categorized as strength or power exercises. If an exercise entails acceleration throughout the entire range of movement, then it is classified as a power training exercise.

Strength	**Power**
Squat	Jump squat
Split squat	Alternating leg jump squat
One-leg squat	One-leg hop/jump
Deadlift	Power clean/snatch/pull
Bench press	Bench throw
Seated row	Bench pull
Military press	Push jerk
Push up	Clap push up

Training to maximize power output should entail both heavy resistance, slower speed exercises for strength development and exercises that entail higher velocities and acceleration for the entire range of movement for rapid power development (Newton and Kraemer, 1994, Baker, 1995a, 2001d). This two-sided approach should result in the musculature being able to contract both forcefully and rapidly, the basis of power production. It may merely be the dosages of each exercise type that varies depending upon the athletes experience and strength levels, sport requirements, stage of the training year and so on Baker (1995a).

Table 2. Estimated power output during a 100% 1RM and 100% Pmax effort for different exercises for a theoretical athlete with a body mass of 75 kg (modified from reference Baker, 1995a). However, please note that lifting at less than 100% 1RM will result in higher outputs for the strength exercises.

Exercise	Mass x (kg) x	Gravity x 9.81 x	Height m	= Work / = J /	Time s	= Power = W
Bench press	100 x	9.81 x	.4	= 392 /	2	= 196
Bench throw	50 x	9.81 x	.6	= 294/	.7	= 420
Full squat	140 (75) x	9.81 x	.65	= 1370/	2.75	= 499
Jump squat	45 (75) x	9.81 x	.85	= 1000/	.6	= 1668
Deadlift	170 (75)* x	9.81 x	.5	= 1202 /	3	= 400
Power clean	90 (75) x	9.81 x	.85	= 1375/	.8	= 1719

All lifts except the bench press also require the lifting of the body mass (75 kg). The barbell mass and the body mass become the system mass and this combined mass is used to calculate power output. Concentric portion only.

Photo 3. The 1-arm bench throw on an incline bench is a power exercise especially suited for athletes who have to fend off (all collision types of football), punch (boxers/martial artists) or throw (Shot-putt, cricket, baseball)).

Photos 4, 5 and 6. The jump squat exercise in a Smith machine is a power exercise because the loss of foot contact from the floor allows the athlete to generate both high forces and high speeds late in the movement range. It can be performed in a parallel (P4 & 5) or split/alternating stance (P6).



Photos 7, 8 and 9. The deadlift exercise is a strength-oriented exercise where heavy resistances can be lifted, but at slower movements speeds.



Photos 10, 11 and 12. The power clean (from the hang in this instance) is a more power-oriented exercise because of the faster lifting speeds. Both cleans and deadlifts have application to the wrestling/grappling demands in **Photo 13** (deadlifts for the strength component and power cleans for the power component). Note the angles of the legs and back in these photos.



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2. Alter the kinetics of some strength exercises to more favorably affect rapid-force or power output

Because heavy resistance strength exercises such as bench press or squat typically entail slower movement speeds and lower power outputs as discussed above, these exercises **alone** are not specifically suited to developing Pmax in athletes past the intermediate stages of adaptation. As explained above, faster, more power-oriented exercises must also be performed in training (Baker, 1994, 2001a). This phenomenon has been the subject of considerable research attention. There are power specific adaptations in terms of the neural activation, muscle fiber/contractile protein characteristics and muscle architecture (Blazevich et al., 2003) that must be considered when choosing power-training exercises. As discussed above, attempting to lift light resistance bench presses explosively results in large deceleration periods (Wilson et al., 1989, 1993, Newton et al., 1996, 1997) whereas for power development acceleration throughout the entire movement is the key.

However, there are a number of strategies that the strength coach can implement to alter the force profile or lifting speeds of strength exercises to make them more suitable to rapid-force development and hence play a key role in Pmax training. In effect we can alter traditional strength exercises to make their force and velocity characteristics much more like power exercises (faster lifting speeds, acceleration and high force levels late in the movement).

For example, the performance of the bench press can be modified by adding chains to the end of the barbell to alter the kinetics of the exercise so that the acceleration phase can be extended further into the range of movement. When the barbell is lowered to the chest, the chains are furled on the floor and only provide minimal resistance (Baker and Newton, 2005b, see Photo 14). As the barbell is lifted, the chains unfurl and steadily increase resistance throughout the range of motion (see Photo 15). This method means that a lighter resistance (eg. 50-75% 1RM) can be lifted explosively off the chest but as the additional resistance (+10-15% 1RM in chains) is added by the constant unfurling of the chain links off the floor, the athlete can continue attempting to accelerate the bar. The bar speed will slow down but this will be due to the increasing mass, rather than the athlete consciously reducing the push against the barbell. This alters the kinetic profile of the strength exercise to become more like a power exercise (acceleration lasts longer into the range of motion and higher force late in the movement).

Photos 14 and15. The bench press exercise kinetically modified to make it more closely resemble a power exercise by adding chains to the sleeves of the barbell. When the chains are furled upon the floor as the barbell is on the chest as in Photo 14 they add no extra weight to the barbell: however the unfurling of the chain links adds extra weight to the barbell as it progresses throughout its range of motion (P15). In this case the resistance is 60 kg (barbell only) when at the chest but 75 kg when the chains (7.5 kg of chains on each side) have cleared the floor (before the lockout position).

A similar strategy is to use rubber-tubing resistance (power bands) on the ends of the barbell to increase resistance throughout the range of motion. In this case the athlete pushes upward in the bench press or squat and stretches the large rubber bands attached to each end of the barbell (see Photos 16). The higher into the range, the more stretch and so the greater the elastic resistance. Similar to the chains example, this allows the athlete to explode upwards and continue to apply high force much later into the movement.

Photos 16 and 17. Kinetically modified squat (from hip height within the racks) with additional rubber-tubing resistance (P16) or as a functional isometric (FI) squat (P17). As the elastic bands stretch they add increasing amounts of resistance to the barbell, but at higher points in the range of movement (P16). In the FI squat (P17), the athlete pushes hard the barbell hard against the transverse pins for 2-10 s, allowing for the generation of very high forces in this range of the movement. Both exercises have application to the wrestling/grappling demands illustrated in **Photo 18** or to tackling or scrummaging demands for rugby league and union.

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Another strategy is the use of Functional Isometric (FI) training. A FI exercise can be performed for the top half of a movement in a power rack or Smith machine, altering the force characteristics considerably (Keogh et al., 1999) (See Photos 17). In FI training high force is generated late in the movement range, typically where force may decrease in traditional strength exercises. For example the lockout portions of squats and bench presses are relatively easy when sub-maximal resistances are being used. Placing a FI stop (via the use of the transverse pin in a power rack) the lockout portion of either of these exercises allow the athlete to develop high forces in this area of the range of movement.

Another method of altering the kinetic profile similar to FI is to merely include some partial repetitions in the top half of the lift (Moorkejee and Ratamess, 1999). Again the idea here is to increase force output at the end of the range of movement, similar to what actually happens in most sports (and power training) movements, but opposite to traditional weight-training kinetics.

Weighted adjustable hooks (periscope type design) that are constructed to fall off the barbell when the base of the apparatus contacts the floor during the lowest portion of the bench press, deadlift or squat can also alter barbell kinetics within a repetition (Brandon et al., 2002). Their use allows for heavier eccentric and lighter concentric phases, conceivably resulting in enhanced concentric lifting velocities.

The use of chains, power bands, FI, partials, hooks and other devices to alter the resistance/force production (and acceleration) throughout the barbell trajectory and particularly the end of the range of movement (so that it more closely mimics power exercises) can be basically applied to any free weight barbell exercise used in power training.

3. Use complexes of contrasting resistances or exercises

A method of training where sets of a heavy resistance strength exercise are alternated with sets of lighter resistance power exercises are known as a complex (Fleck and Kontor, 1986, Ebben and Watts, 1998, Ebben et al., 2000, Young et al., 1998) or contrast training (Baker, 2001a, 2003a, Duthie et al., 2003). Examples of such training may be alternating sets of heavy squats and bench presses with sets of lighter jump squats and bench throws, respectively. This type of training has been shown to acutely increase explosive force production or jumping ability when implemented for lower body power training (Gulich and Schmidtbleicher, 1996, Young et al., 1998, Baker , 2001a, d, Duthie et al., 2002,), presumably through stimulating the neuro- or musculo-mechanical system (s) (Gulich and Schmidtbleicher, 1996, Young et al., 1998)

Recent research further illustrates it is an effective method for acutely increasing upper body power output (Baker, 2003a). For example, research found that bench presses with 65% 1RM alternated with bench throws (30-45% 1RM) resulted in an acute increase in power output (Baker, 2003a). Some lower body research has alternated resistances of 90% 1RM with 30-45% with mixed results (Duthie et al., 2002, Chiu et al., 2003). It is also important to note that this method appears to only work well with experienced or strong athletes, with the less experienced athletes not improving or actually exhibiting an acute decrease in power output (Duthie et al., 2002, Chiu et al., 2003). It could well be that very heavy resistances are to great to handle for the less experienced athletes. But very heavy resistances may not be necessary for contrast loading to be an effective power training strategy as alternating jump squats of 60 kg with 40 kg was found to have a significant effect upon power output (Baker, 2001d).

An agonist-antagonist complex (contrasting exercises) may also warrant consideration from the coach as speed of agonist movement may be improved in these situations, possibly through some reciprocal neural inhibition (Burke et al., 1999, Baker and Newton, 2005a). Recent research illustrated a 4.6% increase in bench throw power output if a set of antagonist bench pulls was performed as the contrast partner exercise (Baker and Newton, 2005a). Based upon the current research, this method may be of most benefit to rapid upper limb movements.

Thus a strength coach has a choice of implementing agonist strength and power exercises or antagonist and agonist strength and power exercises in a complex to increase power output.

It is recommended that if, for example, upper body resistance training is performed twice per week during the strength-power phase of a training cycle, then one day of the training week could emphasize strength development with heavy resistance training (>80%1RM) and another training day emphasize power development with training complexes alternating contrasting sets of light resistances (30-45% 1RM during bench throws) and medium-heavy resistances (60-75% 1RM during bench presses) (Baker, 1995a, 2001d). But as stated above the contrast method appears to work best with stronger, more experienced athletes.

4. Periodize the presentation of power exercises and resistances

Many authors have suggested the periodization of resistance training exercises to enhance power output (Baker, 2001d, Haff et al., 2001). While prescribing resistances in a periodized manner is not a novel idea in relation to training for power as has traditionally been used with Olympic weightlifting style exercises, it has not been fully utilized for simpler, power exercises such as the bench throw or jump squat. It has been suggested that the resistances and exercises be periodized to effectively stress the multi-faceted nature of muscle power (Newton and Kramer, 1994). Four power-training intensity-zones and their analogous strength training intensity-zones are outlined in Table 3 (Baker, 2001d). Across a training cycle the power training resistances can progress from lighter resistances where technique and ballistic speed are emphasized to the heavier resistances that maximize power output (about 50% 1RM = 100% Pmax).

Table 3. Zones of intensity for strength and power training, modified from

Baker, 2001d. Each zone provides a foundation for progress into the next training zone.

Type and / or goal of training of each intensity zone*		
	Strength	**Power**
Zone 1: (< 50%)	General muscle & technical	General neural & technical (<25 % 1RM)
Zone 2: 50-75%	Hypertrophy training	Ballistic speed training (25 - 37.5 % 1RM)
Zone 3: 75-90%	Basic strength training	Basic power training (37.5 - 45 % 1RM)
Zone 4: 90-100%	Maximal strength training	Maximal power training (45 - 55 % 1RM)

For strength, percentage of maximum refers to 1RM (100%). For power, 100% = Pmax resistance (circa 45-55% 1RM if exact Pmax resistance not known). Equivalent percentage ranges based upon 1RM are included in brackets for cases where exact Pmax resistance is not known.

Table 4 details the last four weeks of an elite athletes bench press and bench throw training cycle aimed at simultaneously maximizing strength and power output. The progression in power training resistances (from 40 to 80 kg in bench throws) and concomitant increase in power output from 573 to 755 W can be seen. If coaches don't have access to technologies that can measure the actual power outputs and Pmax and the resistance at which it occurred, it is recommended assuming 50-55% 1RM for most athletes, 45%1RM for very strong athletes (eg. 1RM BP = >150 kg) and greater than 55 % 1RM for less experienced or strong athletes (Baker, 2001d). This means that a resistance of 50% 1RM equals 100% Pmax (and hence this resistance is the Pmax resistance). For example, an athlete with a 1RM BP of 100 kg, the 100% BT

Pmax resistance = 50 kg. Training at a resistance of 90% BT Pmax resistance would mean 45 kg for this athlete during bench throws.

It is important to note that, for example, training with a 50% Pmax resistance does not mean the athlete will attain only 50% of their maximal power output. For example, from Table 5 it can be seen that the athletes Pmax resistance is 80 kg for bench throws, but that 40 kg, representing 50% Pmax resistance, actually allows for the athlete to attain a power output of 76-78% of the maximum. During week 2, training with a resistance of 50 kg (representing 63% of his Pmax resistance of 80 kg) allowed the athlete to attain power outputs of around 600 w or 80% of maximum. Therefore an athlete can attain very high power outputs at lower percentages of the Pmax resistance. Because of the plateauing of power output around the Pmax (see Figure 1), it can be seen that the use of resistances of around 85% or more of the resistance used to attain Pmax will usually result in the athlete training at or very close to Pmax (eg. 70 kg in Table 2 = 84 % Pmax resistance but results in power outputs of up to 96% Pmax).

5. Use low repetitions when maximizing power output

Low repetitions are necessary to maximize power output. High repetition, high workload, hypertrophy-oriented training acutely decreases power output (Baker, 2003b) and should not precede or be combined with maximal power training. It would appear important to avoid fatigue when attempting to maximize power output and a simple method for achieving this is by using low repetitions for power exercises (and obviously ensuring the appropriate rest period is utilized).

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Table 4. Actual training content for bench press and bench throws across the

last 4-weeks of a pre-season strength-power training cycle for an elite professional rugby league player. Testing occurred in week 5 (from Baker and Newton, 2005b).

		Weeks				
		1	2	3	4	5
Bench throws						
						TEST
D1	Power	573 w	599 w	696 w	683 w	=755
	Wt	@ 40 kg	@ 50 kg	@ 70 kg	@ 70 kg	@80kg
%BT Pmax		76	79	92	91	=100%
D2	Power	588 w	605 w	722 w	746 w	
	Wt	@ 40 kg	@ 50 kg	@ 70 kg	@ 80 kg	
%BT Pmax		78	80	96	99	
Bench press						
						TEST
D1	Wt	130 kg	135 kg	140 kg	150 kg	=170kg
	SxR	3x5	3x5	3x5	3 x 3	=100%
% 1RM		76.5	79.4	82.4	88.2	
D2	Wt	105 kg	110 kg	125 kg*	125 kg*	
	SxR	3x5	3x5	5 x 3	5 x 3	
% 1RM		61.8	64.7	73.5	73.5	

W = power output in watts, Wt = resistance in kilograms, SxR = Sets x Repetitions, D1 = Heavier, strength-oriented training day with BP performed before BT.D2 = Medium-heavy, power-oriented training day consisting of contrasting resistance complexes (alternating sets of BP & BT, same sets and repetitions). *Denotes 110 kg barbell load plus 15 kg in chains .

Anecdotal evidence from training hundreds of athletes with the PPS shows that power output markedly decreases after three to five repetitions when using resistances that maximize power output (90-100% Pmax = around 45-50% 1RM) during the BT or JS exercise.

Figure 3. Change in BT P60 power output across a set of ten repetitions in 24 professional rugby league players. Note the sharp drop in power output after the fifth repetition. The decline in power (from the maximal level on the 3rd repetition) till the last repetition is almost 20%.

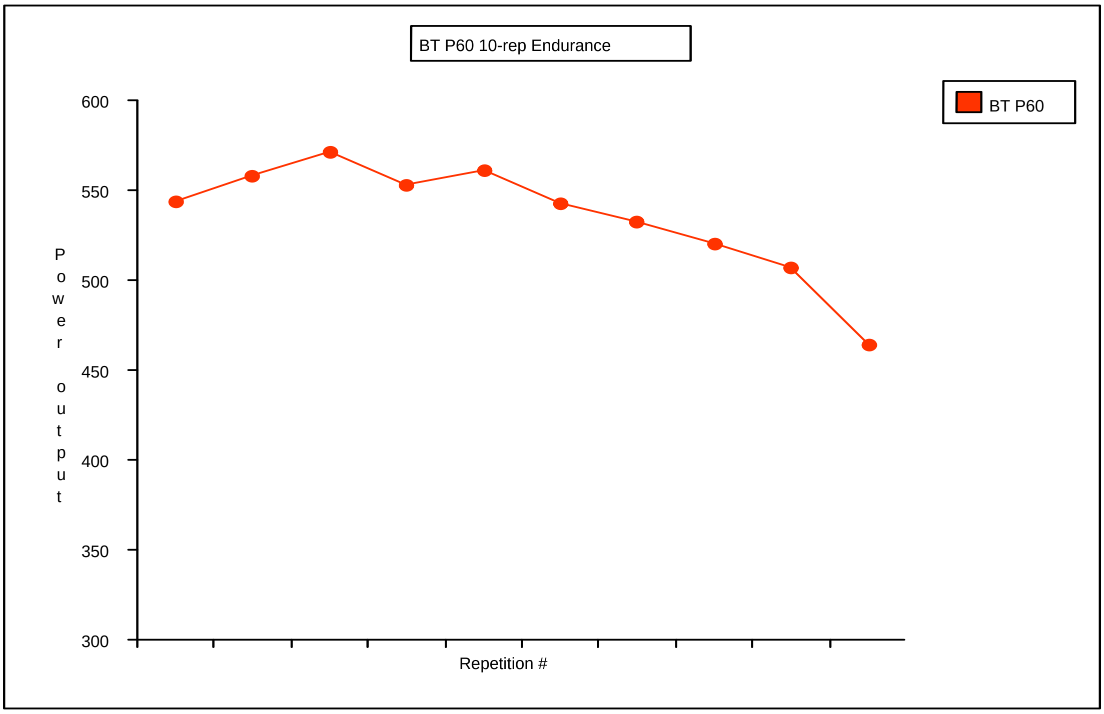

Figure 3 depicts the power output for 10 consecutively performed repetitions during bench throws with a resistance of 60 kg (about 45% 1RM BP) for 24 professional rugby league players. The decline from the highest power level (occurring on the third repetition) till the last repetition is almost 20%. The decline of the average of the power of the first three repetitions compared to the average of the power of the last three repetitions is also over 10%. It must be remembered also that this is a one-off test , not a training set that needed to be repeated for 3 or more sets, which would further erode power output. So if the aim of the set or training session is build or maintain maximum power, use lower repetitions of 5-6 or less. More repetitions (eg. 8-10) can be used when the resistances are lighter (eg. 20% 1RM), but the set should cease when power output drops by 10% if maximum power is the goal (Tidow, 1990).

Based on this evidence, for power exercises it is usually recommended that only 2-3 repetitions be performed when training in the maximal power zone, 3-5 in the general power and ballistic power zone and higher repetitions (eg. 8-10) are only performed when using lighter resistances in the technical/neural zone (learning technique or warming up). See Table 3 for the approximate % resistances for these intensity zones described above.

6. Use "clusters", "rest-pause" or "breakdown" techniques for some strength or power exercises

To increase force output and velocity and reduce fatigue within a set, some specific methods have evolved over the years (Keogh et al., 1999). Recent research indicates that, compared to the traditional manner of performing repetitions, force or velocity can be increased when repetitions are presented in clusters (Haff et al., 2003) or by using the "rest-pause" or "breakdown" methods (Keogh et al., 1999). Clusters are a method whereby a set of higher repetitions is broken down into smaller "clusters" of repetitions that allow a brief pause between performances of these clusters. For example, eight repetitions can be performed as four clusters of two repetitions with a 10-second rest between clusters. The rest-pause system is essentially similar but typically entails the breakdown of a lower repetition set (for example, 5RM) into single repetitions with a short pause (for example, 2-15 s) between repetitions. A "breakdown" (aka "stripping") set consists of small amounts of resistance being taken from the barbell during short pauses between repetitions (or taking the pin down when using a weight stack exercise like lat pulldowns). This reduction in resistance to accommodate the cumulative effects of fatigue results in a decreased degree of deterioration in power output across the set as well as increased force in the initial repetitions as compared to the traditional manner of lifting a heavy resistance (Keogh et al., 1999). For example, if doing a seated row, the athlete may perform two repetitions at 90% 1RM, then has a short (<5 s) while the coach/partner reduces the resistance to 80% (for 3 repetitions) and again at 70% (for five repetitions). In total, the athlete has performed ten repetitions at an average of 77% 1RM, but they have all be explosive lifts in comparison to the traditional method of performing ten straight repetitions at

77% 1RM. Thus this method allows the athlete to perform more repetitions at slightly higher % 1RM than traditionally performed sets (affecting strength) and the short rest pauses also allows for the repetitions to be lifted with greater speed, positively affecting power.

7. Use an ascending order of resistances when maximizing power output

Whether the resistances are presented in an ascending (working up in resistance, for example sets of bench throws with 40kg, then 50 kg, then 60 kg) or descending (working down in resistance, sets of bench throws with 60kg, then 50 kg, then 40 kg) order during power training has been cause of some debate (Baker, 2001d). A recent study examining the effects of ascending or descending order on power output during bench throws reported that an ascending order resulted in the highest power output during BT (Baker, 2001d). However power output with the lightest resistance was higher when using the descending method. It was also recommended that if increasing Pmax was the goal of training, then an ascending order of resistances was the best method. However, for sports where Pmax is not the main objective, but increasing the power output that is generated against light resistances is, then the descending order may be warranted. It was also recommended that the ascending method with the inclusion of a lighter "down set" might be an effective method of presenting power-training resistances (eg. jump squats 40 kg, 60 kg, 80 kg, then finish with 40 kg). The "down" set in effect becomes a contrast load method.

Rest periods

The rest period between sets or even repetitions will depend upon the objective of that set, the number of repetitions being performed, the intensity of the resistance, the type of exercise, the training state of the athlete and the periodization phase. When the objective of the set is maximize the power output that can be generated with the selected resistance, the rest period between sets of a power exercise should be one to two-minutes or as is long enough to ensure that the objective is met. Shorter rest periods (eg. < 1-minute between sets of a power exercise or < 3-minutes for a complex) result in reduced power outputs, diminishing the effectiveness of the maximal power training process. When performing a complex of a strength and power exercise, anecdotal evidence suggests a four-minute turn-around period (eg. set of bench press then 90 s rest, set of bench throw then 120 s rest before repeating complex) has been shown to be adequate as evidenced by the power outputs measured by the PPS. If power-endurance is the goal of training, then rest periods may be much shorter than in Pmax training. Reductions in power output of >15% are evidenced when high repetitions and short rest periods occur during combined strength/power training (Baker, 2003b). The coach must distinguish between the objective of the exercise/complex/session: Is the objective of training to increase Pmax, requiring longer rests and lower repetitions to avoid fatigue-induced reductions in speed and hence power output? Or is the objective power-endurance, requiring higher repetitions and shorter rest periods? The astute coach will realize the implications that the rest period length and number of repetitions has upon power output and program accordingly in line with their objectives.

Long-term progress

Initially in novice weight trainers power is easily improved by basic methods and general exercises (Baker, 1996). With increased training experience improvement in power output become more difficult to attain (Hakkinen, 1985, Hakkinen et al., 1988). However, maximal power can still be quite readily increased over the long term even in advanced trainers, although there will be diminished scope for improvement with experienced elite athletes. Changes in the load-power curve for a group of twelve professional rugby league players as well as the individual progression of one young rugby league player (player X) across a four year period is depicted in Figure 2 (Baker and Newton, 2005c). It is clear that even for advanced trainers (all 12 were NRL professionals, 8 Played International Tests for Australia and 9 Played State of Origin during this time period) such as this group that progression can still be quite pronounced, especially in power output against heavier resistances. The load-power curve for the group as a whole as well as for player X has shifted upwards and slightly towards the left. From the graph it is visible that while power output generated while lifting a resistance of 40 kg (BT P40) changes only slightly, power outputs with heavier resistances of 60-80 kg increased markedly, a favourable situation considering the strong relation between high power outputs generated while lifting 70 and 80 kg in the bench throw exercise and progress into the elite professional rugby league ranks (Baker, 2001d). As power output with lighter resistances improved relatively less than power output with heavier resistances, it is obvious that increases in strength rather than speed accounted for the majority of change. Statistically Pmax is more related to maximal strength rather than speed in these athletes (Baker, 2000a-d, 2001d, Baker et al., 2001a, b) or other athletes (Moss et al., 1997).

During this time player X progressed from playing in the city-based leagues into the ranks of the full-time professional national rugby league. His BT Pmax increased 39%, from 603 w to 836 w while his 1RM BP increased from 135 to 180 kg (33%) at a relatively constant body mass of 110 kg. For the group of twelve subjects as a whole, the BT Pmax increased from 611 w to 696 w. This 14% increase appears to be underpinned by a similar change of 14.3 % in 1RM BP (from 129.6 to 148.1 kg) (Baker and Newton, 2005c). While these figures do show that experienced athletes can still progress in Pmax across long-term training periods, more detailed analyses of the data revealed a diminishing scope for improvement with increased strength and power levels.

Table 5. Results for changes in body mass, 1RM SQ and JS Pmax between 1998 and 2002 expressed as mean (standard deviation) with effect size and percentage change 1998 to 2002 total and per annum (from Baker and Newton, 2005d).

	Body mass (kg) BM	Strength (kg) 1RM SQ	Power (watts) JS Pmax
1998	95.8 (9.8)	160.0 (25.9)	1805 (222)
2002	98.8 (9.5)	182.5 (30.0)*	2045 (362)*
total	3.1%	14.1%	13.3%
p.a.	0.8%	3.5%	3.3%

* denotes significantly different in 2002. + denotes approached significance (p = 0.09)

Table 5 depicts the change in lower body strength (1RM full squat) and jump squat maximum power (JS Pmax) for a group of six elite professional rugby league players across a 4-year period (Baker and Newton, 2005d). The 14% increase in strength and 13% increase in JS Pmax were highly correlated (r = 0.96), indicating that increasing strength levels plays an important role in increasing power levels in these athletes. However as the changes in strength and power were only in the order of 12-15% over 4-years, this observation tends to verify a more limited scope for strength and power gains in already experienced, resistance trainers as compared to novice resistance trainers. As all the athletes performed large amounts of conditioning training concurrently with resistance training throughout the 4-year observation, yet still made steady progress in strength and power, it also indicates that a high volume of endurance training does not prevent such adaptations from being realized from an appropriate concurrent resistance-training program.

It is important to note that the age that athletes commence combined strength and power training is also important. Table 6 depicts the strength and power results for two groups of six professional rugby league players form the same team (matched for playing position), the only difference being their ages, the number of NRL games played and most importantly the age they commenced regimented maximal power training. Clearly commencing maximal power training in the late teenage years affords a greater advantage in maximal power (and strength) as compared to starting in the mid-twenties.

Table 6. Strength and power testing results for NRL players who commenced power training at either a Younger or Older age (n = 6 each). Mean (standard deviation). From Baker, 2003a.

	1RM BP	1RM SQ	BT Pmax	JS Pmax
Younger	143.3 (15.4)	182.5 (23.6)	670 (78)	1881 (254)
Older	126.7 (7.5)*	153.3 (12.1)*	548 (48)*	1579 (197)*

* denotes statistically difference between groups

So despite no difference in body-weight or height, those six athletes who commenced power training between 16-19 years were >16-22% more powerful than the six who commenced in their early to mid-twenties. Thus long-term progress in power development also depends upon establishing good training systems and programs for strength and power when athletes are in their teenage years. From this evidence it would appear that the concept of combining maximum strength and power training can result in enhanced power output over long-term training periods, however, there appears to be a diminishing scope for power improvements with increased training experience, strength and power levels. As the athlete becomes more experienced and stronger, the practical methods outlined above play an increasing important role in stimulating the neuromuscular system to produce or maintain higher power outputs.

Practical applications

A number of practical methods used for increasing the effectiveness of power training have been presented. It is not necessary to use all of these methods at one time to effectively develop maximal power. However, it is not difficult to implement a number of these methods simultaneously either. For example, a bench press and bench throw workout to maximize pressing power that entails six methods: full acceleration exercise; kinetically altered strength exercise; contrasting resistance complex; low repetitions; ascending order of resistances for the power exercise; and clustered repetitions is detailed in Table 7 (also see Table 4). Variation and periodization should influence if, when and how, any of these strategies are implemented.

This paper has addressed mainly the training for maximal power production and especially may be of value for athletes who must overcome large external resistances such as the body mass of opponents (eg. football, rugby league and union, wrestling, judo, mixed martial arts). Athletes who require a greater speed contribution rather than pure strength contribution in their power production (eg. boxing and related martial arts, tennis, javelin) may need to modify their training accordingly and their load-power curves would reflect this by perhaps showing increased power output with lighter resistances of 10-40 kg. However, many of the methods described above would be applicable to many sporting situations and it is the job of the astute coach to modify and implement them accordingly.

Table 7. Sample workout for combined bench press and bench throws on a

power-oriented training day during the peaking maximum strength/power phase for an athlete possessing a 1RM BP of 130 kg (from Baker and Newton, 2005b).

	Sets	1	2	3	4
	Wt (kg)	40	50	60	70
1a. Bench throws (Smith machine)	Reps	5	4	3	3
	Wt (kg)	60	100*	100*	100*
1b. Bench press + chains*	Reps	5	1,1,1	1,1,1	1,1,1

1a, 1b. = Alternate exercises as a contrast resistance complex.
* = 85 kg barbell resistance + 15 kg in chains attached = 100 kg resistance at lockout.
1, 1, 1= 3-rep cluster sets, rest 15 s between each clustered repetition.

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