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A Series of Studies on the Training of High-Intensity Muscle Power in Rugby League Football Players

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ABSTRACT

Maximal power (Pmax) levels and the effects of the manipulation of training variables on power output in rugby league football players were investigated in 5 studies. In study 1, players of 3 different ability levels were assessed for Pmax during explosive bench press throws. Pmax levels were a significant descriptor of playing ability within the sport. In study 2, the effect of contrast loading was investigated during jump squats. The result was a significant ($p < 0.05$) increase in power output in the investigated load. In study 3, the effect of an ascending vs. descending order of loads during explosive bench press throws was investigated. An ascending order resulted in a significantly higher power output for the heaviest load, whereas the descending order resulted in a significantly higher power output for the lightest load. In study 4, the relationship between measures of upper-body strength, power, and speed was investigated in athletes from 3 different levels of playing ability. Strength, power, and speed were significantly correlated overall; however, the relationships were greater in the more experienced training group. In study 5, it was found that stronger athletes utilized a lower percentage of 1 repetition maximum (1RM; 46–51%) to attain Pmax than less strong athletes (58–69%).

Key Words: bench throw, jump squat, strength, speed

Reference Data: Baker, D. A series of studies on the training of high-intensity muscle power in rugby league football players. *J. Strength Cond. Res. 15(2):198–209. 2001.*

Introduction

Enhanced muscular power is often the desired result of resistance-training programs designed for increasing sport performance. However, power entails both a speed and strength component, and strength coaches have traditionally concentrated on developing strength with the hope that to some degree it will transfer into power. However, recent advances in technology have enabled the direct measure of power output during certain training exercises. The collation and analysis of this type of data can be used effectively to gauge the effects of various training variable manipulations on muscle power.

Recently, Kraemer (14) reported a series of strength-training studies with the aim of using facts and test results to overcome the popular myths in training theory related to American football. It is the intention of this paper to similarly report the facts and test results from a series of short applied studies of rugby-league style football players in order to overcome the popular myths in training theory as related to the development of high-intensity muscular power.

Experiment 1: Can Muscle Power Levels Distinguish Between Athletes of Different Ability Levels?

Previously, Baker et al. (7) reported that semiprofessional and professional rugby league players exhibited similar maximum power (Pmax) and strength levels. However, in a follow-up study, Baker (4) reported that professional players were significantly more powerful and stronger than college-aged rugby league players, despite a lack of differences in body mass and height ($p < 0.05$). These latter results suggest that power output could be a significant descriptor of athletic success in rugby league football.

The purpose of this study was to compare the results of a number of tests of upper-body power output for national league professionals (NL), state league semiprofessionals (SL) and younger, college-aged players participating in the city league (CL) to ascertain if differences in maximum power output (Pmax) differentiated between the athletes of different levels of ability.

Methods

A total of 19 NL, 23 SL, and 17 CL rugby league players with a mean ± *SD* for body mass, height, and age of 94.8 ± 10.1, 91.8 ± 7.0, and 91.8 ± 10.1 kg; 182.2 ± 7.2, 183.6 ± 5.1, and 181.3 ± 5.2 cm; 25.1 ± 3.4, 19.7

± 2.0, and 17.6 ± 0.9 years, respectively, agreed to testing as part of the conditioning requirements for their sport. All groups were different from each other in age, but not in body mass or height ($p < 0.05$).

Testing of upper-body Pmax and power with a battery of barbell loads was performed using the Plyometric Power System (Plyopower Technologies, Lismore, Australia) and the methods previously described (4, 7) 3–4 times at the completion of training cycles throughout the season. Specifically, bench press throw power (BT P) with 40, 50, 60, 70, and 80 kg (BT P40, BT P50, BT P60, BT P70, and BT P80) were used to determine the highest average power output of the concentric phase of the lift and to generate the individual's load-power profile. Bench press throws in a smith machine weight-training device resulted in much higher power outputs than traditionally performed bench presses (18, 19). The highest power output for any resistance for each individual was deemed the BT Pmax. The best effort at every load was recorded for each individual at each test occasion. From these 3 or 4 test occasions, only the single-best test result for each individual was chosen for this analysis. Therefore, this analysis included the personal best BT Pmax and load-power profile (BT P40 to BT P80) for each athlete from the entire year.

Analyses of variance (ANOVAs) were used to determine if differences existed between the groups in BT Pmax or at any of the investigated loads. In the event of a significant *F*-ratio, Fisher post least square difference (PLSD) post hoc comparisons were used to determine where these differences existed. Pearsons moment correlations were also calculated between an individual's BT Pmax and placement into the 3 ranked teams. Significance was accepted at an alpha level of $p \leq 0.05$.

Results

The BT Pmax level of 635 ± 87 W for the NL group was significantly greater than the scores of 561 ± 57 and 499 ± 81 for the SL and CL groups, respectively. Furthermore, the SL group was also significantly different from the CL group in BT Pmax levels. Differences in power output with different barbell loads is graphically displayed in Figure 1. The NL group was significantly more powerful than the CL group in every investigated load, but only significantly more powerful than the SL group in the BT P70 and BT P80. The SL group was also significantly different to the CL group in every investigated load.

Discussion

Levels of upper-body maximal power appear to be potent discriminators of level of playing ability. A correlation of $r = 0.58$ ($p \leq 0.05$) existed between each individual's Pmax and his selection into the 3 differently ranked teams, irrespective of playing position.

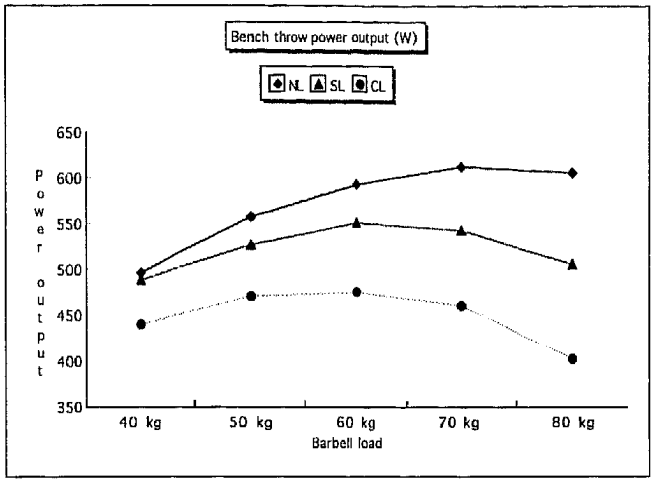

Figure 1. The power output profile during bench press throws with different barbell loads for rugby league players of differing abilities. *SD* bars were omitted for clarity.

The ability to generate maximal power and, more specifically, power against large resistances (in this case 70 and 80 kg) seems to be a significant descriptor of playing level within a sport. This would indicate that upper-body maximal power and power generated against large external resistances, along with maximal strength, would be important factors determining the success of rugby league football players.

Certainly maximal strength was different between players from the 3 teams of different ability levels (1RM bench press = 140.1 ± 13.8, 121.1 ± 13.2, and 108.7 ± 16.0 kg, respectively). Therefore, it could be rationalized that the difference in maximal strength largely, although not exclusively, accounted for differences in maximal power output between the 3 different teams. The regression analysis developed from the pooled data ($n = 59$) suggested that the bench throw power output could be predicted by the equation Pmax = 4.11 (1RM) + 60.16, with $r = 0.85$. Consequently, explosive bench throw power output was largely, although not exclusively, predicted from maximal strength. However, the extent of this relationship still suggests that other factors would also impact maximal power output. This would mean that training for maximal power would still need to deviate from that which is required for maximal strength training to some degree, especially with increased training experience.

Certainly a high level of maximal strength is needed to overcome large external resistances; however, speed of overcoming these resistances is also important. In the professional NL group, 3 of the faster (running speed) back-line players had power outputs of over 700 W, despite 1RM bench presses of 140–145 kg. In comparison, 2 forward-line players (slower running speed) had similar power outputs despite being 10–15 kg heavier and being able to bench press 160 kg. Thus a resistance of 80 kg may represent a minimal differ-

Table 1. Effect on power output (mean ± *SD*) of the intervention of a heavier contrast load set (jump squats with 60 kg) on the performance of jump squats with 40 kg (JS P40) in 6 professional rugby league players.

Method	Power output (W)	
	Set 1 (JS P40)	Set 2 (JS P40)
Control (straight sets)	1,365 ± 220	1,380 ± 215
Experimental (contrast load)	1,406 ± 214	1,482 ± 228*

* Denotes significantly different to all other occasions, $p < 0.05$.

ence between these 2 stronger groups of players (57 vs. 50% 1RM), as compared with less strong players whose 1RM may only be 100 kg (80 kg = 80% 1RM).

Therefore, these results indicate that the difference in power output between teams of different playing levels may depend largely on differences in maximal strength. However, other factors (e.g., pertaining to movement speed and specific neural patterning) must also contribute to power output, and these factors should not be neglected in the training of athletes.

Practical Applications

Rugby league football players appear to depend on high levels of muscular power for athletic success. Furthermore, the most successful players appear to be able to generate more power against larger external resistances than less successful players. Therefore, training should be directed at increasing muscular power levels, particularly against large resistances. Initially this may entail more maximal strength training, rather than maximal power training, to develop an adequate strength base. As strength levels begin to plateau, more emphasis should be placed on training to enhance muscular power. This would entail maintaining maximal strength as well as performing explosive power training aimed at lifting large loads with speed.

Experiment 2: Comparison of Contrast Loading vs. Straight Sets on Power Output

The acute effect of training variable manipulation on subsequent power output has received scant scientific regard despite training recommendations and prescriptions dating back over 10 years (11). Fleck and Kontor (11) reported a Russian method of training that they called complex training, which in reality was the use of contrasting loads and/or exercises to bring about short-term enhancement of power output. Typically this approach has entailed the alternating of sets of a strength exercise and load (>85% 1RM) with sets of a power exercise and/or load (30–45% 1RM). The rationale for this is that by alternating the heavy and light load from set to set, the neural system is 'super stimulated,' making the lighter power load 'feel lighter.' The presumed effect of this is that more power may be generated with this lighter load than would normally be the case.

Examples of this type of training have been the grouping of heavy squats and jump squats (or other types of jumps), clean pulls and power cleans, and bench presses and bench press throws (2). It is also widely seen in baseball where bat donuts and weighted balls are commonly used in training and sport warm-up with the aim of increasing speed and power. However, contrasting loading could possibly be made more specific by using light and heavy loads from within the power-training spectrum (30–60% 1RM), rather than using a strength load of >85% 1RM and a power load of 30–45% 1RM.

The purpose of this investigation was to determine the effects of the use of single heavier contrasting power loads on power output in professional rugby league players.

Methods

Six professional rugby league players with a mean ± *SD* body mass, height, and age of 84.8 ± 5.8 kg, 175.7 ± 7.5 cm, and 25.7 ± 4.8 years, respectively, participated in this experiment. All subjects were familiar with the jump squat exercise, which they had been performing regularly in their training for 2 to 3 years.

Power output was assessed during jump squats with a 40 kg barbell (JS P40) using the plyometric power system during 2 conditions. For the experimental condition, the subjects performed 2 sets of 6 repetitions with JS P40, with 1 set of 3 repetitions with 60 kg performed between the 2 JS P40 sets. This intervention of a set of jump squats with 60 kg was to provide a contrast in load and tension as compared with the JS P40 sets. For the control condition, the same group performed 2 sets of JS P40. Two to 3 minutes rest was allowed between sets. Only the single-highest average power output for the concentric flight phase of each set was recorded and compared. Therefore, if any differences existed between the JS P40 set performed after the heavier contrast load set in the experimental condition and the other JS P40 sets, it must be attributed to the acute effects of the heavier 60 kg set.

The data were analyzed by repeated-measures ANOVA to determine if differences existed in JS P40 power output consequent to the intervention of the heavier contrast set. In the event of a significant *F*-ratio, Fisher PLSD was used for post hoc comparisons to see where the differences occurred. Significance was accepted at an alpha level of $p \leq 0.05$.

Results

The results for the jump squat performance with 40 kg are contained in Table 1. The power output in the sec-

ond set of JS P40 in the experimental condition, which followed the intervention of the 60-kg jump squat set, was statistically different ($p \leq 0.05$) to the power output before the intervention and also different to the JS P40 scores in the control condition. There were no other differences in JS P40 scores within or between conditions.

Discussion

The 5.4% increase in JS P40 power output consequent to the intervention of a heavier contrast load illustrated that the alternating of light and heavy resistances during power-training exercises had the effect of increasing the power output developed with the lighter resistance. There was no augmentation of power output when the athletes performed the traditional straight-sets manner as a control condition. Therefore, the augmentation to the highest power output of the second JS P40 in the experimental condition must have been due to the acute intervention of the heavier, 60-kg jump squat set, which is in line with previous research (1, 3, 12, 25). Although this intervention load was not as heavy as some previously investigated loads (5–8RM or maximal isometric contractions; 1, 12, 25), it still resulted in an increase in power output similar to a previous finding (3). There are a number of theories (1, 3, 11, 12, 25) on what neural or biomechanical mechanisms might account for this acute augmentation in power output brought about by the use of contrasting heavier and lighter loads in power training.

The exact neural mechanism(s) have yet to be determined, but it has been theorized as possibly due to a number of mechanisms such as increased descending activity from the higher motor centers, direct myoelectrical potentiation, increased synchronization of motor-unit firing, reduced peripheral inhibition from the Golgi tendon organ (GTO), reduced central inhibition from the Renshaw cell, and enhanced reciprocal inhibition of the antagonist musculature (2). As the intervention mechanism is load related, then some tension-sensitive mechanism of the neuromuscular system that is affected by load must be at least partly responsible (11). Tension-sensitive receptors such as the GTO and Renshaw cell could possibly account for this consequent change in power output by reducing their negative inhibitory feedback. Therefore, the heavier set probably enables the athlete to be better able to process and override the inhibitory signals that would occur when lifting resistances at high speeds during power training, resulting in greater power output.

An effective relaxation of the antagonist muscles to prevent excessive cocontraction must also be considered an option available to the neuromuscular system to enhance the neural drive to the targeted muscles.

Gulich and Schmidtbleicher (12) and Young et al. (25) also rationalized that the high-intensity strength stimulus may increase motor unit activation, leading to a greater power output in the lighter jump sets; however, similar to this study no EMG data was collected in their studies. Young et al. (25) found the greatest augmentation in the strongest athletes using the heaviest 5RM loads. This would tend to support the fact that some tension-sensitive mechanisms, such as the GTO, were at least partially responsible.

Strength coaches may need to decide between the positive contribution of higher tension (brought about through a very heavy load) on disinhibition vs. the negative effect that such a heavy, slow load could have on the timing of the neural patterning during the following power set (discussed in detail below). This is the reason that in this investigation 2 loads from within the power-training zone itself, rather than a strength and power load, were used. For particularly finite sports skills, such as in baseball, it may be disadvantageous to use a much heavier contrast resistance if this load disrupted the fine patterning of the following sport skill. A slightly heavier version of the sport skill may suffice. Clearly more research needs to be done in this area, especially to discover if this acute augmentation has a positive accumulative effect on power output over time.

Practical Applications

The use of heavier and lighter contrasting resistances has an acute effect of increasing power output. These heavier resistances have been shown to be effective for the lower body whether they are maximal isometric contractions, squats, half squats, or even heavier jump squats.

Combinations of exercises for the development of power may be squats and jump squats, pulls (clean or snatch), power cleans or snatches, bench presses, and bench throws. However, contrasting resistances with the same power exercise may prove even more effective (e.g., alternating heavy and light sets of jump squats, power cleans, bench throws, and so on).

Other sports have used a variety of methods to apply resistances during sport movement, such as bat donuts, weighted balls and implements, sprint sleds and parachutes, power bands, towing, etc. These are all forms of providing sport-specific contrast loading.

Experiment 3: Comparison of Ascending Set Order vs. Descending Set Order on Power Output

Typically, power-training loads have been presented in an ascending order (working up in weight from lightest to heaviest weight), which probably had its origins in Olympic weightlifting–style training. However, Spassov (20) presented a method of loading, which after warming up and performing heavy strength loads was characterized by a descending order of pre-

Table 2. The effect of an ascending or descending order on power output with resistances of 40, 50, and 60 kg (P40, P50, P60) during bench press throws in 8 professional rugby league players.

Order	P60 (W)	P50 (W)	P40 (W)
Ascending	540 ± 27	486 ± 21	439 ± 22
Descending	487 ± 65*	499 ± 40	486 ± 42*

*$p \leq 0.05$.

sentation of the training loads (i.e., the Bulgarian speed-strength method; 2). No data have been found that directly compares the effect of ascending or descending order on power output. The purpose of this study was to compare ascending vs. descending loading on bench press throw power output with typical power-training loads in professional rugby league players.

Methods

Eight professional rugby league players with a mean ± *SD* 1RM bench press, bench throw Pmax, body mass, height, and age of 134.3 ± 10.5 kg, 576 ± 64 W, 94.8 ± 6.0 kg, 182.0 ± 73.9 cm, and 23.3 ± 3.0 years, respectively, served as subjects for this investigation. All subjects were experienced in the bench press throw exercise, which they had been performing regularly in training for 1–2 years.

After performing 3 sets of 3–6 repetitions with loads of 75–85% 1RM in the bench press exercise, the athletes performed bench press throws with 40, 50, and 60 kg for 6, 5, and 4 repetitions, respectively, in either an ascending (Asc P40, Asc P50, Asc P60) or descending (Dsc P60, Dsc P50, Dsc P40) order using the plyometric power system to measure power output. Each athlete performed the descending order on the first day and the ascending order 48 hours later. The single-highest power output during the concentric phase of each set was recorded and used for analysis.

The data was analyzed by repeated-measures ANOVA to determine if differences existed in power output consequent to the manipulation of the exercise order. In the event of a significant *F*-ratio, Fisher PLSD was used for post hoc comparisons to see where the differences occurred. Significance was accepted at an alpha level of $p \leq 0.05$.

Results

The results contained in Table 2 indicate that the order of the presentation of power loads has an effect on power output during the performance of these sets. Specifically, the highest power output within the workouts was achieved with an ascending order of presentation. The power output achieved with 40 and 60 kg were significantly affected by exercise order. The power output with 50 kg was not affected by exercise order.

Discussion

The data presented indicate that power output was acutely affected by the manipulation of the order in which the loads were presented to the athlete. Basically, the highest output with 60 kg was significantly lower by a mean of 10% when a descending order of sets was performed. Power output with the middle load (50 kg) was, as expected, similar in ascending or descending order because it was performed second in both orders. However, power output with the lighter load was significantly enhanced by the descending-order method by a mean of 10.7%.

These results imply that the order in which the loads are presented is of importance to the training of power output. Given that the highest power output was reduced significantly by about 10% by the descending-order method, this method is not recommended for enhancing Pmax. All athletes experienced the same prior 'strength stimulus' by performing heavy bench presses, and it may be argued that by then performing the bench throw power sets in an ascending order, the athletes are training the speed stimulus during the first lighter set. Thus by the time they reach the heaviest load during the bench throws, they have stimulated the neural system with both strength and speed stimuli, creating a favorable situation for power to be maximized for that third set. Loads of 60–70 kg in the bench press throw were indeed the range of loads that maximized power output for all but 1 of the athletes in this experiment. Therefore, for maximizing power output the combination of the strength stimulus of the heavy bench presses and the speed stimulus of the first set of lighter resistance bench throws appeared to be fruitful. If athletes are already strong, then the speed effect may provide a potent stimulus for enhancing power in ensuing sets. That is, athletes attempt to use the speed they developed with the first lighter sets during the performance of the heavier second and third sets.

The descending-order method tends to allow significantly more power to be developed with lighter loads. In reality this result should be expected, as the effects would be similar to the contrast load experiment discussed above. The prior heavier power loads of 60 and 50 kg could super-stimulate the neural system, such that the lighter loads can be lifted with more power than usually possible. If contrast loads needed to be very heavy strength loads, one would presume that the power output during bench press throws with 40 kg would have been higher by performing heavy sets of bench press and then, immediately after a 3-minutes rest, bench press throws with 40 kg (the first set of ascending order). However, this was not the case as the power output with 40 kg was higher in the de-

scending order. Presumably the effect of speed of movement must play some role, and slightly heavier versions of the basic power movement may provide a more potent, specific stimulus than heavy strength-oriented loads, as these slightly heavier power loads still allow for considerable speed to be developed.

The reason that the power output would be highest when using an ascending order and that the power output with lighter resistances would be higher when using a descending order may be partially explained by the speed-control neural mechanisms that were detected by Enoka (10) in Olympic-style weightlifters. In that study (10), it was demonstrated that highly skilled Olympic lifters utilized speed of movement to control neural output during a power exercise. Thus there was a patterning of neural output based on the time of the contraction and where the barbell was in relation to the lifter. In the present case it could be argued that the neuromuscular system has a 'timing' of neural output established after the heavy bench presses, which when performing the first set of bench throws with either 40 or 60 kg is too slow to achieve the best power possible with these resistances. However, with more bench throws (sets and repetitions), the neuromuscular system becomes more attuned to the speed of this faster exercise, rather than that of the slower, heavy bench presses, and modifies the neural output and pattern accordingly. Hence speed of movement, and consequently power, increases with ensuing sets. This is not a warm-up effect per se, but probably an efficient neural fine-tuning of the speed of movement. The concept is analogous to 'warming up' of strength, except in this case it is warming up speed by recruiting the necessary motor units that fire at faster speeds and in the specific patterns of the movement.

Given that most athletes would be required to be powerful across a spectrum of resistances, then the simple method of using the ascending set order with a lighter 'down set' could be recommended. This style of loading is common in the training of competitive weightlifters and powerlifters.

Practical Applications

The basic finding of this study is that the absolute power output for the workout is highest when using an ascending order, but that power output developed during the lifting of lighter resistances is higher using a descending order, at least when a strength exercise precedes the power exercise. For sports where movement speed and power output against lighter external resistances is more important than overall maximal power, then the descending order may prove a better method of presenting loads during power training. In sports where maximal power output and the power developed against large resistances is more important, as in rugby and American-style football, then the ascending order may be more beneficial.

If a coach is seeking to train power across the spectrum of resistances, then performing sets in ascending order with a lighter down set at the end could be a simple method of attaining these goals.

Experiment 4: Relationship Between Measures of Upper-Body Strength, Power, and Speed

Recently, Baker and Nance (6) reported strong relationships between measures of lower-body strength and power (relative to body mass) and running speed across 10 and 40 m in professional rugby league players. Their data illustrated that running speed was more highly correlated to power ($r = -0.76$, $p \leq 0.05$) than strength ($r = -0.66$, $p \leq 0.05$). Based on this research, the 3 qualities of strength, power, and speed appear fairly interrelated, at least as far as the lower body is concerned.

In regard to the upper body, a paucity of data exists concerning the relationship between strength, power, and speed. This may be due to the difficulty in establishing a general upper-body speed test that is as widely accepted as sprinting is for the lower body. However, throwing of various weighted implements has been widely used to ascertain upper-body speed. The purpose of this study was to investigate the relationships between the qualities of upper-body strength, speed, and power in rugby league football players during the lifting of a number of resistances across the speed-power-strength spectrum.

Methods

Thirty-six rugby league players (15 NL, 12 SL, and 9 CL), with a mean ± *SD* body mass, height, and age of 91.7 ± 9.3 kg, 181.6 ± 6.6 cm, and 20.9 ± 3.3 years, respectively, were tested as part of the conditioning requirements for their sport. Strength was measured on the first day of the investigation, and power testing was conducted 48 hours later.

Strength was assessed by a 3RM free-weight bench press using the methods described previously (5). Speed and power tests were performed during incline bench press throws using the plyometric power system and the methods described previously (5). These tests isolated the upper body during explosive movements that were familiar to all subjects. The power output (Inc P20) produced while throwing the empty barbell (20 kg) within the plyometric power system was deemed to indicate the upper-body speed capabilities. Incline bench throws with 40 and 60 kg (Inc P40 and Inc P60) were also chosen for investigation, as they represented commonly tested loads along the speed-power-strength spectrum. Each athlete's maximum power generated during incline throws (Inc Pmax) was also used for comparison. Thus the 3RM bench press was the measure of strength, the Inc Pmax was the

Table 3. Correlations between measures of upper-body speed, power, and strength in 36 rugby league football players ranging from college-aged to elite professionals.†

	Speed (Inc P20)	Power (Inc Pmax)	Strength (3RM BP)
Inc P20	—	0.46*	0.34*
Inc P40	0.5*	0.87*	0.82*
Inc P60	0.42*	0.92*	0.8*
Inc Pmax	0.46*	—	0.87*
3RM BP	0.34*	0.87*	—

* $p \leq 0.05$.

† Inc P20 = incline throws with 20 kg; Inc Pmax = incline throws with maximal power; 3RM BP = 3 repetitions maximum bench press.

Table 4. Correlations between measures of upper-body speed, power, and strength according to team status (reflecting playing ability and training experience).†

	Speed measure Inc P20 (W)	Power measure Inc Pmax (W)	Strength measure 3 RM BP (kg)
NL	311 ± 15	583 ± 72*	125.3 ± 13.9**
SL	308 ± 14	565 ± 67	112.1 ± 15.2
CL	304 ± 11	506 ± 64	105.0 ± 10.6
	Speed vs. strength	Speed vs. power	Strength vs. power
NL	0.5***	0.71***	0.88***
SL	0.18	0.23	0.86***
CL	−0.01	−0.19	0.94***

† Inc P20 = incline throw with 20 kg; Inc Pmax = incline throw with maximal power; 3 RM BP = 3 repetition maximum bench press; NL = national league professionals; SL = state league semiprofessionals; CL = college-age city league players.

* Denotes NL group different to CL group, but not SL group, $p \leq 0.05$.

** Denotes NL group different to both SL and CL groups, $p \leq 0.05$.

*** Denotes relationships were significant, $p \leq 0.05$.

measure of power, and the Inc P20 was the measure of speed. The Inc P40 and Inc P60 were chosen as typical training loads for these athletes and also provided additional points for comparison along the speed-power-strength spectrum.

Pearsons moment correlations were performed to determine the extent of relationships between variables. Significance was accepted at $p \leq 0.05$.

Results

The relationships between the various measures of upper-body strength, power, and speed are in Table 3 for the pooled data. All the relationships were positive and significant. Performance between the Inc P20, Inc P40, and Inc P60 were all significantly different to each other. The Inc Pmax was significantly different to the Inc P20 and Inc P40, but not the Inc P60.

Table 4 contains a summary of the key performance data and relationships between speed, strength, and power according to team affiliation (training experience). Only the NL group exhibited positive relationships between speed and the other variables of strength and power.

Discussion

In line with previous studies (6, 16), there was a strong relationship between maximum power and strength for the pooled data ($r = 0.87$). However, the relationships between the upper-body speed measure and the maximum strength and power measures were considerably less strong. Upper-body strength and speed, as measured in this study, exhibited a statistically significant relationship of $r = 0.34$, a figure that suggests only 11% of the speed performance could be predicted from the strength performance. Similar to the previous evidence cited for the lower body, the relationship between power and speed was slightly higher ($r = 0.46$, $p \leq 0.05$), suggesting 21% of the power performance could be predicted from the speed performance.

As the Inc P40 exhibited a slightly higher relationship ($r = 0.5$, $p \leq 0.05$) to the speed measure, this would tend to suggest that a spectrum of speed-power-strength does exist, but that there is a diminishing relationship between speed and strength as resistances become larger. Most importantly, it suggests that strength measures are more highly related to power performances than are speed measures. The 3RM bench press strength correlated highly with all power measures ($r \geq 0.8$), whereas the speed score exhibited correlations ranging from $r = 0.42$ to 0.5 ($p \leq 0.05$) with the power measures of Inc P40, Inc P60, and Inc Pmax. Therefore, the training of strength may be more important to the development of power than the training of movement speed. However, given that speed is still related to power output and the extent of that relationship, it would be remiss of strength and conditioning specialists to believe that this would not be an area for exploitation in order to improve power performance, especially in athletes who have reached a plateau in strength.

Thus early in the training career of athletes, improving upper-body strength will probably increase power more than increasing upper-body speed. This can be easily seen when the performances of the 12 NL and 9 CL players are compared.

Figure 2 graphically depicts the increasing difference between these 2 groups in regard to increasing resistance, with the P40, P60, and 3RM all being significantly different. However, of most importance is that the Inc P20, which designated the speed qualities

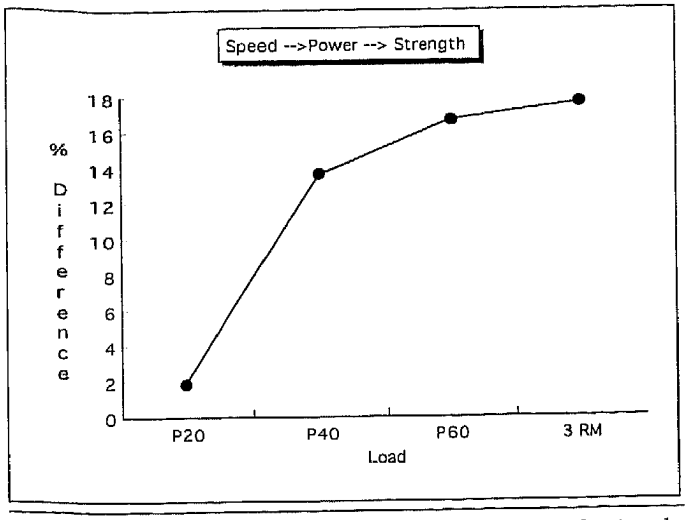

Figure 2. The percentage difference between professional (NL) and college-aged (CL) rugby league players in 4 loads of the speed-power-strength spectrum during upper-body exercises (study 4). The difference in the Inc P20, representing the speed end of the spectrum, was not significantly different, whereas differences in the other 3 loads were.

of the upper-body musculature, was not different between the groups. Thus speed is the same for these 2 groups, but the 3RM strength was different between the groups, and it is this difference in strength that must account for the increasing differences in power output that occur with increasing loads along the spectrum. Therefore, the greater maximal strength of the NL group ensured that they exhibited markedly higher power outputs at all the absolute loads, despite possessing the same speed as the younger CL group with the absolute load of 20 kg.

The NL possessed greater strength, which enabled them to lift the resistances of 40 and 60 kg with more speed, resulting in significantly higher power output. An observation could also be that more advanced or powerful athletes are better able to utilize their speed with increasing loads during power exercises. Increased eccentric strength and eccentric rate of force development, stemming from the plyometric training effect (23), appears to allow these athletes to garner greater augmentation from their use of the stretch-shorten cycle during power exercises. There is some evidence in support of this theory when the correlations between the variables for the 3 distinct groups are further analyzed (Table 4).

The CL group exhibited no significant relationships between their speed score or any other measure (r = −0.01 – −0.19), whereas the professional NL group exhibited a relationship of r = 0.5 ($p \leq 0.05$) between speed and strength (much higher than for the pooled data) and r = 0.71 ($p \leq 0.05$) between speed and maximum power (also much higher than for the pooled data). The younger CL exhibited a relationship of r = 0.94 between strength and power, similar to that of the NL group (r = 0.88). It appears that the CL group, with less power-training experience, cannot harness the speed that they are capable of with lighter resistances and transfer it to the execution of heavier resistances. They rely more on maximal strength to achieve maximal power. The NL group, with many more years of power-training experience, have a similar relationship between maximum strength and maximum power, but appear to be better able to use their speed capabilities with any load and thus exhibit stronger relationships between strength and speed measures in the upper body (Table 4). The semiprofessional SL data supports this fact as the relationships between the speed measure and other measures tends to fall between those of the CL and NL groups (r = 0.18–0.23), similar to that of their upper-body power-training experiences. However, they also exhibited the same high relationship between strength and power (r = 0.86) as the other groups.

Although the pooled data suggests that an upper-body speed measure exhibited a moderate correlation with maximum upper-body power, this further analysis illustrated that the upper-body training experiences may impact the extent of the relationship. The athletes with greater upper-body power-training histories possessed a much higher relationship, whereas those with less experience exhibited diminished correlations, becoming virtually nonexistent with the CL group. Thus a key aspect of prolonged exposure to upper-body combined strength and power training is that it appears to train the athletes to better utilize their speed with increasing resistances. This may also represent a strategy that the neuromuscular system adopts to increase power when strength levels have plateaued, and hence cannot be relied on to account for increasing power output. In these cases, the neuromuscular system of experienced athletes may increase power output against larger resistances through increases in the speed of lifting of these resistances.

Practical Applications

Maximal upper-body power is more dependent on strength than speed, irrespective of training history. However, with increasing upper-body power-training experiences, the extent of the relationship between speed and power does increase markedly, but are still less than that for strength and power.

Lower-level athletes appear to rely heavily on maximal strength to increase power, and therefore their training should be directed mainly, although not exclusively, in that regard. With an increased power-training history, athletes may rely more on increases in speed to increase power output (because strength may reach a plateu).

There was no difference in the speed measure (Inc P20) between any of the groups. The differences between the groups of athletes in this investigation were

due to maximal strength and the apparent ability to lift larger resistances with increased speed because these absolute resistances equated to lower relative percentages of the maximum strength, rather than speed itself. The more elite athletes also possessed higher relationships between speed and strength and power.

Based on these results, increasing maximal strength should take priority in early training stages to maximize power output. However, speed of movement should not be neglected, even at the early stages of training, and it should play an increasing role with greater training experience.

Experiment 5: The Percentage of 1RM That Maximizes Power Output

Based on the earlier work of Kaneko et al. (13), Wilson et al. (24) postulated 30% 1RM was the load that allowed for the attainment of the Pmax. This work was supported by the more recent work of Newton et al. (19), who found that loads of 30 and 45% 1RM allowed athletes to attain their highest power outputs during bench throws. However, they also reported that power output with a resistance of 60% 1RM was also not much different to 30 and 45% 1RM.

Other researchers have recommended resistances in the range of 40–60% 1RM to maximize power, although this could be dependent on the nature of the exercise and the experience of the athlete (2, 21). More recent studies have supported the use of loads circa 50% 1RM to maximize power output (15, 16).

Recent studies and training observations by Baker (4) and Baker et al. (5, 7, 8) have been gathered on a number of athletes, ranging from college-aged to elite professionals, in both the jump squat and bench throw exercise. In every instance the mean load that allowed for the attainment of the Pmax in a group was 50–60% 1RM, with 55% 1RM the closest resistance in most cases. In Baker et al. (8), 3 investigations were carried out comparing the Pmax load for jump squats with the 1RM full squat. Resistances of 58.8, 57.1, and 55.2% 1RM allowed for the attainment of the Pmax for the combined NL and SL (study 1), SL and CL (study 2), and NL (study 3) groups, respectively. During bench press throws, similar results have been achieved, with Baker et al. (7) reporting 55% of the 1RM bench press brought about the Pmax in both professional NL and semiprofessional SL rugby league players. The most recent testing also confirms these results with mean resistances of 51.1, 50.3, and 52.8% for professional and 54.9, 53.9, and 54.1 of the 1RM bench press for college-aged rugby league players, respectively, maximizing power output (4, 7).

Although a mean resistance of circa 55% 1RM will allow for the attainment of the Pmax during testing, previous testing data collected by the author with these athletes suggest that stronger athletes generally use lower-percentage 1RM resistances than the less strong athletes in order to attain Pmax outputs during testing. The purpose of this study was to determine if stronger athletes tended to use lower-percentage 1RM resistance to attain Pmax than less strong athletes.

Method

The data from a number of studies was reanalyzed to determine whether the 5–6 strongest individuals within a group were significantly different than the 5–6 less-strong individuals in regard to the resistance that allows for Pmax attainment. To determine whether an athlete was strong or less strong, his 1RM was multiplied by the respective correction factor for his body mass, as is used in international powerlifting (22). Overall, 6 testing sessions were reanalyzed in this manner, and the seventh analysis included comparing strong NL players overall to less-strong CL players.

A 1-way factorial ANOVA was performed to determine that these groups were different in regard to their Pmax levels and corrected-strength scores, but not in regard to body mass. A 1-way factorial ANOVA was then performed to determine whether these groups were different in regard to the percentage 1RM at which the Pmax was attained. Significance was accepted at $p \leq 0.05$.

Results

Four of the 6 analyses of small groups (5–6 subjects) illustrated that the strongest athletes tended to attain Pmax levels with a significantly lower percentage of 1RM (see Table 5). Also, the stronger NL professional group ($n = 22$) overall used a significantly lower resistance of 51% 1RM compared with 55% 1RM for the less-strong college-aged CL players ($n = 27$).

Discussion

The majority of the data suggests that stronger athletes used lower-percentage 1RM than less strong athletes to attain Pmax. For example, data from 2 of the recent studies (8) illustrated that the strongest athletes utilized a mean resistance of 46 and 49% 1RM, compared with 64 and 69% 1RM for the less-strong athletes, to attain the Pmax during jump squats.

Reanalyzed data from Baker et al. (7) also illustrated that during bench press throws, the strongest NL players utilized statistically lower resistances of 47% compared with 54% for the less-strong NL players. Similarly, the strongest college-aged rugby league players utilized resistances of 51% compared with 58% for the less-strong college-aged rugby league players.

It is important to note, however, that the results of 2 analyses were not significant (jump squat study 3, 52.5 vs. 56.8% 1RM; bench throw study 3, 54.5 vs. 56.5% 1RM). It is not possible to discern the exact reasons for this, although the small number of subjects

Table 5. The differences in the resistance (percent 1RM) that evokes the Pmax in strong and less-strong athletes from different groups in 2 standard power exercises.†

Group	Subjects	Percent 1RM	1RM	Pmax
Bench press throws				
Study 1‡	Strong = 5	51.4 ± 3.9*	152.0 ± 8.4*	715 ± 37**
	Less strong = 5	57.9 ± 3.9	124.0 ± 6.5	645 ± 74
Study 2§	Strong = 6	46.9 ± 60*	153.3 ± 8.8*	652 ± 58*
	Less strong = 6	54.1 ± 2.9	120.0 ± 7.1	551 ± 50
Study 3§	Strong = 6	54.5 ± 5.6	131.7 ± 4.1*	606 ± 47*
	Less strong = 6	56.5 ± 4.0	91.7 ± 6.8	438 ± 46
Jump squats‖				
Study 1	Strong = 5	45.8 ± 6.4*	201.0 ± 8.9*	2,146 ± 162*
	Less strong = 5	69.0 ± 2.4	145.0 ± 5.0	1,696 ± 143
Study 2	Strong = 5	48.9 ± 10.8**	181.0 ± 17.8*	1,907 ± 240*
	Less strong = 5	63.7 ± 13.2	118.0 ± 13.0	1,604 ± 177
Study 3	Strong = 5	52.5 ± 8.2	178.0 ± 11.5*	1,831 ± 180*
	Less strong = 5	56.8 ± 11.9	142.0 ± 9.1	1,503 ± 161

† Pmax = maximal power; 1RM = 1 repetition maximum.
‡ Data reanalyzed from Baker et al. (7).
§ Data reanalyzed from Baker (4).
‖ Data from studies 1, 2, and 3 from Baker et al. (8).

used in this type of analysis does tend to reduce the chance of statistical significance being attained.

The authors' observations are that although generally the resistance of circa 55% 1RM would allow for the Pmax to be attained during a testing session when an athlete is fresh and not fatigued, this level of resistance may be slightly above the Pmax resistance during a training session or during times of fatiguing loading, especially with the stronger athletes.

Accordingly, although our results suggest that loads of 30–45% 1RM invariably do not allow for the Pmax to be attained during a testing session, they are often the most suitable loads for training with, especially when athletes are residually fatigued (e.g., during 'over-reaching' training phases). Thus the presentation of loads circa 46–63% of 1RM to maximize power output should be reserved to the last few weeks of a training cycle (and testing sessions) when the volume of training is decreased and the athlete is better able to exert quickly and forcefully against loads of this magnitude. It would be remiss of strength and conditioning coaches to believe that the dogmatic presentation of 1 'optimal power' resistance would effectively train power output, as was once believed in maximal strength training (9).

Practical Applications

A resistance of 55% 1RM usually allows for the attainment of Pmax during jump squat and bench throw power testing. However, the strongest athletes (corrected for body mass) usually attain their Pmax with significantly lower resistances in the range of 46–51% 1RM compared with the less strong (corrected for body mass), who tend to utilize resistances of 58–69% 1RM. Therefore, stronger and more experienced athletes tend to use lower percentages of 1RM (although the absolute magnitude of the load in kilograms lifted is higher) than less-strong or experienced athletes.

Although resistances of 55% 1RM may allow for the attainment of Pmax during testing, practical experience has shown that it may be more beneficial to utilize lower resistances (20–45% 1RM) during hard training sessions or weeks when athletes are residually fatigued. Resistances of 46–63% 1RM should be reserved until the last few weeks of a training cycle when volume is reduced and the athletes are less fatigued (peaking weeks).

Practical Applications

Training Recommendations Based on the Results of the Five Studies

Power levels appear to be significant descriptors of playing ability in rugby league football. Maximum power is highly related to maximum strength. Maximum power in the upper body is less related to speed than strength, but this relationship appears to increase with greater specific power-training experience. Power appears to be affected by acute strategies that affect power output within the workout and broad strategies that affect the long-term development of power.

Acute strategies affect power by the specific manipulation of training variables such as volume, intensity, exercise order, and load. For maximizing power output, an ascending presentation of loads is recommended. For increasing power output against light re-

Table 6. Zones of intensity for strength and power training.

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

* Percentage of maximum refers to maximum resistance. For strength, 100% = 1 repetition maximum (1RM) resistance. For power, 100% = maximal power (Pmax) resistance (circa 55% 1RM if exact Pmax resistance is not known).

sistances, a descending order is recommended. For increasing power output across a spectrum of loads, an ascending order with a lighter 'down' set at the end is recommended. Contrast loading has also shown to be effective in acutely increasing power output.

Broad strategies to increase power may depend on the training status of the athlete. Methods to increase power may entail primarily methods that increase maximal strength in less-strong athletes. Athletes who already possess an adequate strength base appear able to lift large resistances with greater speed than less strong individuals. These athletes may require a combination of training methods entailing maximal strength training, ballistic power training with very light to medium resistances to emphasize speed of movement, and power training with larger resistances to maximize power output.

The presentation of acute strategies within the overall broad strategy may entail the use of different zones of intensity for power training. It is posited that power training itself should be recognized as having zones of intensity, which are analogous to the zones of intensity for strength training (see Table 6). Training in a periodized manner in these different zones may methodically develop the many factors (17) that contribute to explosive power output. For example, strong athletes who possess low Pmax may need to perform more of their power training in the general neural training zone (zone 1, velocity-oriented training) or in the ballistic speed-training zone (zone 2) to increase their Pmax.

Strength and conditioning coaches may need to be aware of these zones of intensity and tendencies so as to plan power training accordingly.

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