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The Load That Maximizes the Average Mechanical Power Output During Jump Squats in Power-Trained Athletes

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ABSTRACT

Three studies that used rugby league players experienced in power training methods as subjects were performed to investigate the resistance (percentage of 1 repetition maximum [1RM]) that maximized the average mechanical power output (Pmax) during the jump squat exercise. Maximum strength was assessed via 1RM (studies 2 and 3) or 3RM (study 1) during the full-squat exercise. Pmax was assessed during barbell jump squats, using resistances of 40, 60, 80, and 100 kg within the Plyometric Power System. All studies found that power output was maximized by resistances averaging circa 85–95 kg, representing 55–59% of 1RM full-squat strength. However, loads in the range of 47–63% of 1RM were often similarly effective in maximizing power output. The results of this investigation suggest that athletes specifically trained via both maximal strength and power training methods may generate their maximal power outputs at higher percentages of 1RM than those previously reported for solely strength-trained athletes and that there would appear to be an effective range of resistances for maximizing power output.

Key Words: explosive, squat, athlete

Reference Data: Baker, D., S. Nance, and M. Moore. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *J. Strength Cond. Res. 15(1):92–97. 2001.*

Introduction

A number of sports require a high degree of lower-body power for successful completion of various sport tasks. Consequently, the muscular power output of the lower body and methods to develop it are of considerable concern to sport coaches and researchers.

Considerable debate exists concerning which range of training resistances (percentage of 1 repetition maximum [1RM]) or loads brings about the most favorable adaptations in power development during explosive resistance training (1, 22). Some authors have suggested the low-resistance (circa 30% of 1RM) method (10) and others the high-resistance (>80–90% of 1RM) method to produce favorable speed-strength and power training adaptations (6, 17). In the instances listed above, these apparent anomalous results were both ascribed as due to the favorable neural adaptations that occur as a result of a specific resistance and associated training method. It was rationalized that increased firing rates and possibly enhanced recruitment patterns could account for the superiority of one loading method over another.

More recently, it was argued that to increase power and performance in explosive sport tasks it may be best to train with the resistance that maximizes the mechanical power output (Pmax) (21). It was argued that by using the load or resistance that generated the Pmax during the training exercise various specific neuromuscular adaptations may occur, which in turn may transfer more readily to explosive sport tasks. It has been shown, for example, that adaptations to heavy resistance training leads mainly to improvements in the concentric force and rate of force production capabilities (20). Conversely, low-load, high-velocity plyometric training leads mainly to an increase in the eccentric rate of force development capabilities (20). Theoretically, maximal power training methods may lead to an improvement in power or power training adaptations through a combination of these separate concentric and eccentric capabilities. This may be rationalized as due to both favorable neural and muscle fiber adaptations that result from the specific stresses placed on the neuromuscular system during training with resistances that maximize power output (21).

Of interest is the resistance or load of Pmax during various resistance training exercises, because currently there is some discrepancy between some researchers and strength practitioners.

Based on research that investigated loads across a broad spectrum of resistances (5, 10, 11, 13, 14), it has

been generally recommended that loads of 30–45% of 1RM would provide the optimal load for maximizing power output during resistance training exercises. Also, Wilson et al. (21) estimated resistances in the order of 30% of 1RM allowed for Pmax; however, they did not directly ascertain this figure.

However, strength practitioners and some investigators have postulated that loads of around 60% of 1RM would allow for maximal power output. Poprawski (16) stated that stronger athletes use loads that are a higher percentage of 1RM (70%) and conversely less strong athletes use loads that represent a lower percentage of 1RM (50%) to maximize power training adaptations. Tidow (18), reviewing a number of non–English-language research papers, stated that most research supported the use of loads within the range of 30–70% of 1RM. He further recommended the use of 40–60% of 1RM for the development of explosive ''speed-strength'' (power). Furthermore, in a review, Baker (1) suggested the load that maximized power output would depend on the nature of the exercise and the training level of the athlete.

More recently, Baker et al. (4) assessed the Pmax with loads equivalent to 23, 31, 39, 47, 55, and 63% of 1RM with power athletes specifically trained in the bench press throw. They reported that a resistance of 55 ± 5% of 1RM bench press maximized power output, although resistances of 46–62% were fairly equivalent. This would appear to be a slightly higher range of resistances than the 30–45% recommended by previous authors who investigated strength-trained, although not specifically power-trained, athletes.

Consequently, an investigation into which resistance allowed for the maximal power output during a typical lower-body power training exercise would be of considerable interest.

The barbell jump squat is a common lower-body power training and testing exercise (1, 7, 8, 21) that could lend itself readily to the investigation of which resistance maximized power output. However, the authors know of no research published as yet that has determined at which load (percentage of 1RM) the Pmax occurred during an explosive jump squat. The purpose of this article is to report on investigations into the load that maximizes the average mechanical power output in athletes specifically trained in the explosive jump squat exercise.

Methods

Subjects

All the subjects were competitive male rugby league players from the same football club and provided informed consent to be tested as part of their athletic conditioning program.

In study 1, 32 professional and semiprofessional rugby league players with a mean (±*SD*) age, height, and body mass of 22.4 (3.8) years, 181.3 (7.9) cm, and 91.7 (11.8) kg, respectively, participated in this study.

In study 2, 24 college-aged rugby league players with a mean (±*SD*) age, height, and body mass of 18.1 (1.1) years, 181.3 (6.1) cm, and 91.4 (9.8) kg, respectively, participated in this study.

In study 3, 17 professional rugby league players with a mean (±*SD*) age, height, and body mass of 24.3 (3.7) years, 181.7 (6.9) cm, and 93.4 (9.6) kg, respectively, participated in this study.

All subjects were in current training, which entailed the full-squat and explosive jump squat exercises for a period of at least 2 months in the training cycle before testing. The subjects in study 1 and study 3 had been performing these exercises regularly for at least 1 year.

Strength Testing

The full squat was selected to provide data pertinent to the maximum strength through the full range of motion of the muscles involved.

In study 1, maximum strength was assessed by a 3RM full-squat exercise performed with a free-weight Olympic-style barbell using the methods previously detailed (3). From this figure, a 1RM was to be determined by multiplying the 3RM by a standard correction factor of 1.08 (2).

In studies 2 and 3, maximum strength was assessed directly by a 1RM full-squat exercise performed using a free-weight Olympic-style barbell using the same methods as above.

In all studies, squat depth had to descend to a level of upper thigh below parallel with the floor per International Powerlifting Federation rules (9). This depth of squat was visually assessed by the strength coach, who was an accredited powerlifting coach. After warming up with progressively heavier loads, the athletes attempted a 3RM (study 1) or 1RM (studies 2 and 3) load that had been predetermined by their strength coach, based on recent training history and previous maximum test results. If the athlete was successful with this load, he was allowed to attempt another load(s) until both the athlete and the strength coach were confident that 3RM (study 1) or 1RM (studies 2 and 3) had been attained. A powerlifting belt was worn around the waist for support and safety, but no other supportive apparel, such as knee wraps or lifting suit, could be worn.

Power Testing

Power output during jump squats was assessed using the Plyometric Power System, which has been described elsewhere (3, 14, 15, 20, 21). The body mass of the athlete was added to the barbell mass to ascertain the system mass. Using this system mass, the average mechanical power output for the concentric flight phase of each jump squat for each load was deter-

Table 1. The mean (±*SD*) maximum average mechanical power output (Pmax) and the average mechanical power output during jump squats executed with different barbell loads.*

	Power output (W)		
	Study 1	Study 2	Study 3
Pmax	1851 (210)	1726 (187)	1740 (205)
P40	1587 (242)	1574 (150)	1557 (224)
P60	1711 (206)	1666 (170)	1645 (197)
P80	1796 (218)	1675 (187)	1689 (203)
P100	1823 (230)	1702 (202)	1691 (212)
P120			1658 (224)

* P40, P60, P80, P100, and P120 indicate mechanical power output with barbell loads of 40, 60, 80, 100, and 120 kg, respectively.

mined by the software of the Plyometric Power System, and the highest score for each load was recorded. The highest power output attained with the investigated loads was deemed the Pmax. Specifically, the athletes performed 3 consecutive countermovement jumps against absolute barbell loads of 40, 60, 80, and 100 kg (P40, P60, P80, P100). Pilot work had shown that the highest power output for any given load did not always occur on the first repetition but did occur within the first 3 repetitions. During study 3, the athletes also used a load of 120 kg (P120). These absolute loads represented an equivalent mean resistance of 24, 36, 48, and 60% of 1RM for study 1; 26, 40, 54, and 68% of 1RM for study 2; and 25, 37, 50, 62, and 75% of 1RM for study 3.

Statistical Analysis

The mean and *SD* were determined for each load and for the Pmax. The results for each load and the Pmax were compared using a 1-way analysis of variance. If a significant effect of load was found, Fisher Post Least Squares Difference (PLSD) comparisons were performed to determine which loads produced significantly different power outputs. Statistical significance was accepted at an α level of $p \leq 0.05$.

Results

In study 1, the mean 3RM full squat was 152.9 kg (±17.1 kg), which extrapolated to a 1RM of 165.1 kg (±19.1 kg). The Pmax was 1851 W (±210 W), which occurred at a mean load of 95.6 kg, representing 58.8 ± 11% of the extrapolated 1RM full squat. The results for P40, P60, P80, and P100 are contained in Table 1. The Pmax was significantly different to P40, P60, and P80 but not P100. The power produced at all other loads was significantly different to each other, except for between P80 and P100.

In study 2, the mean 1RM full squat and Pmax were 147.6 kg (±25.2 kg) and 1726 W (±187 W), respectively. The Pmax load of 84.8 kg (±18.5 kg) was equivalent to 57.1 ± 12.6% of the 1RM. The results for the power output produced against loads of P40, P60, P80, and P100 are contained in Table 1. The Pmax was significantly different to P40, P60, and P80 but not P100. There was no significant difference among the P60, P80, and P100.

In study 3, the mean 1RM full squat and Pmax were 161.2 kg (±16.9 kg) and 1740 W (±205 W), respectively. The Pmax load of 89.0 kg (±16.5 kg) was equivalent to 55.2 ± 9.9% of the 1RM. The results for P40, P60, P80, P100, and P120 are contained in Table 1. The Pmax was significantly different than P40, P60, and P120 but not P80 and P100. There was no significant difference among P60, P80, and P100.

There was a significant and strong relation between maximal strength and the Pmax in each study (Table 2).

Table 2. The relation between maximal strength and maximal power (Pmax) in each of the 3 studies.

Study	Correlation	Coefficient of determination (%)
1	0.79	63
2	0.81	65
3	0.86	74

Discussion

The results of all 3 studies suggest that loads of circa 85–95 kg, representing 55–59% of the full-squat 1RM, evoked the highest average mechanical power output during the concentric phase of the jump squat exercise in athletes expressly trained in both strength and power exercises. However, generally no statistical difference appeared to exist between the Pmax and the power produced against loads close to the Pmax load (P80 and P100). This can be seen as the peak of the load-power curve from study 1 displayed in Figure 1.

Thus, it should be noted that although a resistance of 55–59% generally maximizes power output, a range of loads generally within the zone of 48–63% of 1RM allowed for similarly high power outputs. Loads heavier than this level (>63% of 1RM) result in a greater proportional decrease in velocity than increase in mass and consequently power output decreases. Conversely, lighter loads (<47% of 1RM) that entail greater velocities also result in a decreased power output due to a greater proportional decrease in mass (14).

These results are in general agreement with the hypothesis of a number of researchers and strength practitioners who have suggested that for power athletes the load for maximal power training may be in the higher range of 40–60% of 1RM (1, 16, 18) as opposed

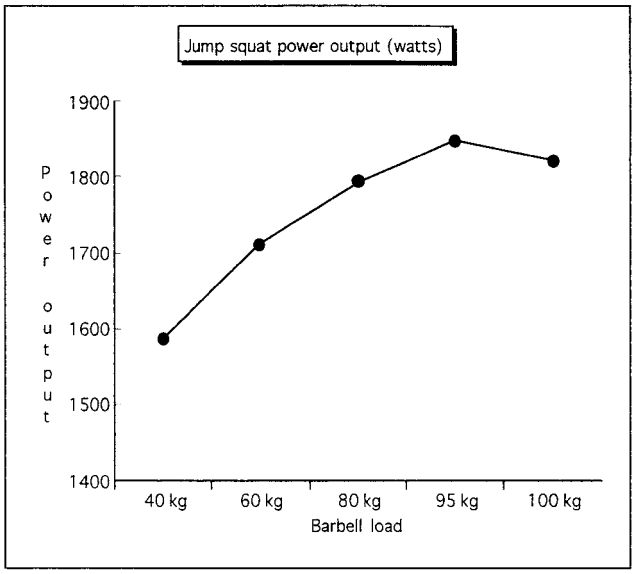

Figure 1. The nature of the power output vs barbell load relationship depicted

to the lower range of 30–45% of 1RM (10, 11, 14, 20). Furthermore, the figures of 59, 57, and 55% of 1RM, representing the Pmax load for jump squats, are in almost complete agreement with our recent finding of 55% of 1RM for the bench press throw exercise (4).

Thus, the major finding of this study is that for power-trained athletes the mechanical power output is maximized with higher resistances than previously believed by some researchers. The fact that trained power athletes, such as those used in these and our previous investigations (4), maximized power with a similar resistance (circa 55% of 1RM), irrespective of the exercise affecting the upper or lower body, is of considerable interest. Why loads of 30–45% of 1RM, although generally recommended on the basis of research with athletes or students inexperienced in specialized power training, would appear to be less effective in maximizing power output in specifically trained power athletes may be due to a number of reasons.

First, discrepancies may exist in the measurement of maximum strength and power capabilities. In the current studies, strength and power were measured during variations of the basic exercise (i.e., squat and jump squat). Exercises such as jump squats and bench press throws (performed in a smith machine) do not entail a large deceleration period, as do their traditional strength training counterparts (squat and bench press) (15, 19, 21). Consequently, jump squats and bench press throws result in greater power outputs, velocities, and muscle activation levels compared with their traditional counterparts of squat and bench press (15, 21). Therefore, it is necessary to measure maximum strength during a squat and maximum power output during a jump squat.

In the present study, the athletes' strength was assessed by a full squat to assess strength through the full range of motion. However, when jumping, athletes tend to self-select a range of motion that allows for the most powerful execution of the jump. This range of motion varies for each individual but is usually only around 50% of the range required during the full-squat strength test. Because the strength capabilities from this reduced range exceed those of the full range of motion, a discrepancy may exist in the definition of strength (full-range strength vs. half-range strength). Thus, if strength is only measured with a half-squat exercise than the maximum strength score may be inflated over that of the full-range strength score. Therefore, a load that is equivalent to 55% of the full-squat 1RM may indeed be in the range of 30–45% of a half-squat 1RM.

It was felt that this is more useful to measure the full range of strength and let the athlete self-select the range of the countermovement during the jump squat. Indeed, some athletes did descend into a full-squat position for the jump squat. Also, tests of strength are usually performed through the full range of motion, and in comparison we are unaware of any testing, for example, of only the top half, or maximum strength, portion of the bench press. Therefore, it would appear most valid to measure the full-squat strength and let the experienced power athletes self-select the depth of movement during the jump squat.

Second, although a 1RM was not directly assessed in the preliminary study (study 1), we do not believe that this procedure would have greatly altered results, since the results of that study were corroborated by the results of studies 2 and 3, which did test 1RM strength. The use of a 3RM and a correction factor of 1.08 has been shown to a good predictor of 1RM squat and bench press strength (2). Indeed, the strong correlation between (r = 0.96) between the predicted 1RM, derived using the 3RM and correction factor of 1.08, and the previously measured 1RM squat performed by a subgrouping of 19 of the subjects from study 1, suggests that this estimation of 1RM would not be a large source of error. Also, during study 3, a predicted 1RM (3RM measured 1 week before the 1RM test and then multiplied by 1.08) correlated highly (r = 0.97, n = 17) with the actual 1RM. Furthermore, the results of our preliminary investigation were in complete agreement with the results of studies 2 and 3 and our previous investigations that used the bench press throw exercise.

If testing or methodological procedures cannot account for differences between the theories of light (30–45% of 1RM) and median (45–60% of 1RM) resistances in maximizing power output, then other factors must be examined.

First, specifically trained power athletes may exhibit distinct neural adaptations as a result of ballistic power training. This may include an increase in inte-

grated electromyographic (IEMG) activity brought about possibly through both increased firing rates and increased recruitment (8). Hakkinen and Komi (8) reported that the change in performance during countermovement jump squats with a 40-kg barbell correlated very strongly with the change in both concentric ($r = 0.95$) and eccentric ($r = 0.87$) IEMG after 24 weeks of power training.

This increase in IEMG may also be brought about through a reduction in inhibitory signals being feedback from the peripheral sensory receptors, such as the Golgi tendon organ and the central inhibitory feedback mechanism of the Renshaw cell. An effective relaxation of the antagonist muscles to prevent excessive co-contraction must also be considered an option available to the neuromuscular system to enhance the neural drive to the targeted muscles. Thus, power athletes may be better able to process and override the inhibitory signals that would occur when lifting large resistances at high speeds. This may then lead to an increase in the resistances that they can use for maximal power training and hence an increase in maximal power itself.

A second specific power training neural adaptation was also detected by Moritani et al. (12). These researchers reported that power training may result in the use of a premovement silent period about 50 ms before the onset of the concentric phase of an exercise. During this silent period, all of the motor units are brought into a nonrefractory state such that they are better prepared to fire synchronously during the first 60–100 ms of the concentric phase of the movement. The resultant summation of firing potentials and force outputs immediately after the commencement of the concentric phase would theoretically allow for enhanced power development during contractions of limited duration. They further reported that this occurrence appeared to be a learned response by the subjects that was not always readily duplicable. Thus, experience in power training may allow athletes to better use neural strategies that allow for the use of heavier resistances to maximize power output.

The fact that the Pmax load has shown to be around 30–45% of 1RM in athletes unaccustomed to specific power training and around 55–59% of 1RM in specifically power-trained athletes should be noted. Baker (1) has previously hypothesized that the Pmax load would depend on the nature of the exercise and the training experience of the athlete. For example, Olympic-style lifts (power clean, power snatch, jerks) and special power exercises (jump squats and bench press throws in a smith machine) may require distinctly disparate loads of 70–90% and 30–60% of the relevant 1RM, respectively, to maximize power output (1).

Furthermore, because the Pmax may be lower in nonspecialized athletes, the loads used to maximize the power output may also need to be lower. Consequently, although a resistance equivalent to 55–59% of 1RM maximized power output is used during explosive jump squats in experienced power athletes, it may be prudent to use a lower spectrum of loads during initial training phases with inexperienced athletes (1).

Based on this and previous research (13, 14), heavier resistance loads (>75% of 1RM) appear ineffective for maximizing power output during exercises such as jump squats and bench press throws. This is due to the far greater decrease in velocity as opposed to the smaller increase in force that results from the use of these loads (14). However, it has been rationalized that squats and bench presses may be performed with heavy resistances for strength development and the explosive variations of jump squats and bench press throws performed with light and median resistances for power development (1).

Indeed, the results from this series of studies concerning the relation between maximal strength and power are in agreement with previous research (3, 13). Because circa 65–75% of the Pmax performance could be related to maximal strength performance (see correlations in Table 2), it would be imprudent to preclude heavier load strength–oriented lifting from the regimen of power athletes on the basis that heavier loads do not maximize power output. If the strength training stimulus is reduced, given the strong relation between strength and power, then it is conceivable for power output to be reduced over time.

The purpose of this research was to determine which resistance(s) maximized power output during explosive jump squats, rather than make dogmatic recommendations on which resistance(s) to use for power training. The results of this study do not suggest that heavier or lighter resistances should not be used for power training. It has merely been determined that resistances of circa 55–59% of 1RM (range, 48–63% of 1RM) appear equally effective in maximizing power output. This does not preclude the use of a holistic approach to combined power and strength training.

Rather, it can be clearly delineated that heavier load lifting (>75% of 1RM) is suited to training strength with squats and bench presses and low (30–45% of 1RM) and median (45–65% of 1RM) load lifting suited for training power with jump squats and bench press throws. We believe that training with the resistances that maximize power should coincide with training with the resistances that maximize strength (>85% of 1RM). Thus, strength and power can be peaked or ''maximized'' together. This may be during the last few weeks of a training cycle. In the preceding weeks, we believe that jump squat power training should entail the lower-resistance range of 30–45% of 1RM, whereas squat training for strength would be aligned with resistances of 65–85% of 1RM. This would provide the basis of a periodized framework for strength and power development.

The percentages of 1RM that maximize power output might vary for the Olympic lifts. Indeed, future research might investigate whether power output during the entire pull phase of the power clean was different to a jump squat with the same external barbell load. Also of interest is what loads (percentage of 1RM) maximize power output during the pull phase of Olympic-style lifts for athletes other than competitive lifters.

Practical Applications

The average mechanical power output during explosive jump squats is maximized with a resistance of 55–59% of the free-weight full-squat 1RM. However, there is often little difference between the Pmax and the power generated with the resistances immediately below or above the Pmax load. Consequently, loads in the range of circa 48–63% of 1RM seem equally effective in maximizing power output during jump squats in power-trained athletes. Furthermore, these studies and our previous research suggest that specifically power-trained athletes may maximize their power outputs at slightly higher resistances (48–63% of 1RM) than previously recommended (30–45% of 1RM) during the jump squat and bench press throw exercises. However, this does not preclude these lower resistances from being effective for power training, because these lower resistances may provide a greater speed stimulus for athletes whose strength is high, but Pmax is relatively low in comparison. It is recommended that athletes perform most of their jump squat power training with resistances of 30–45% of 1RM and only use Pmax loads (48–63% of 1RM) for the last few weeks of a training cycle (i.e., the ''peaking'' weeks). In this way, the power and strength performance can be aligned and complementary. Less experienced athletes would need to start with lower resistances and progressively build up in intensity before attempting resistances of more than 50% of 1RM.

References

1. Baker D. Selecting the appropriate exercises and loads for speed-strength development. *Strength Cond. Coach* 3(2):8–16. 1995.
2. Baker D. The use of sub-maximal repetitions to predict maximal squat and bench press strength in trained athletes. *Strength Cond. Coach* 3(4):17–19. 1995.
3. Baker, D., and S. Nance. The relationship between strength and power in professional rugby league players. *J. Strength Cond. Res.* 13:224–229. 1999.
4. Baker, D., S. Nance, and M. Moore. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J. Strength Cond. Res.* 15:20–24. 2001.
5. Bemben, M., D. Rohrs, D. Bemben, and J. Ware. Effect of resistance training on upper body strength, power and performance [Abstract]. *J. Appl. Sport Sci. Res.* 5:162. 1991.
6. Buehrle, M., and D. Schmidtbleicher. The influence of maximal strength on movement speed [in German]. *Leistungssport* 7:3–10. 1977.
7. Hakkinen, K., and P.V. Komi. Changes in electrical and mechanical behaviour of leg extensor muscles during heavy resistance strength training. *Scand. J. Sport Sci.* 7:55–64. 1985.
8. Hakkinen, K., and P.V. Komi. Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening exercises. *Scand. J. Sport Sci.* 7:65–75. 1985.
9. International Powerlifting Federation. The rules for the squat. Available at: http// www.ipf.com. Accessed February 1997.
10. Kaneko, M., T. Fuchimoto, H. Toji, and K. Suei. Training effects of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scand. J. Sport Sci.* 5:50–55. 1983.
11. Mayhew, J., R. Johns, J. Ware, M. Bemben, and D. Bemben. Changes in absolute upper body power following resistance training in college males [Abstract]. *J. Appl. Sport Sci. Res.* 6:187. 1992.
12. Moritani, T., M. Muro, K. Ishida, and S. Taguchi. Electromyographic analyses of the effects of muscle power training [in Japanese]. *J. Sports Med. Sci.* 1:23–32. 1987.
13. Moss, B. M., P. E. Refsnes, A. Abildaard, K. Nicolaysen, and J. Jensen. Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *Eur. J. Appl. Physiol.* 75: 193–199. 1997.
14. Newton, R., W. Kraemer, K. Hakkinen, B. Humphries, and A. Murphy. Kinematics, kinetics and muscle activation during explosive upper body movements. *J. Appl. Biomech.* 12:31–43. 1996.
15. Newton, R., A. Murphy, B. Humphries, G. Wilson, W. Kraemer, and K. Hakkinen. Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive bench press throws. *Eur. J. Appl. Physiol.* 75:333–342. 1997.
16. Poprawski, B. Aspects of strength, power and speed in shot put training. *N. Stud. Athletics* 3:89–93. 1988.
17. Schmidtbleicher, D., and M. Buehrle. Neuronal adaptations and increase of cross-sectional area studying different strength training methods. In: *Biomechanics X-B*. B. Jonsson, ed. Champaign, IL: Human Kinetics, 1987. pp. 615–620.
18. Tidow, G. Muscular adaptations induced by training and detraining—A review of biopsy studies. *N. Stud. Athletics* 10:47–56. 1995.
19. Wilson, G., B. Elliott, and G. Kerr. Bar path and force profile characteristics for maximal and submaximal loads in the bench press. *Int. J. Sport Biomech.* 5:390–402. 1989.
20. Wilson, G., A. Murphy, and A. Giorgi. Weight and plyometric training: Effects on eccentric and concentric force production. *Can. J. Appl. Physiol.* 21:301–315. 1996.
21. Wilson, G., R. Newton, A. Murphy, and B. Humphries. The optimal training load for the development of dynamic athletic performance. *Med. Sci. Sports Exerc.* 23:1279–1286. 1993.
22. Young, W. Training for speed-strength: Heavy versus light loads. *NSCA J.* 15(5):34–42. 1993.