Developing Explosive Muscular Power: Implications for a Mixed Methods Training Strategy

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POWER CAN BE DEFINED AS the force applied multiplied by the velocity of movement (37). As the work done is equal to the force times the distance moved (21), and velocity is the distance moved divided by the time taken, power can also be expressed as work done per unit time (i.e., the rate of doing work) (21).

work = force \times distance

velocity = \frac{distance}{time}

power = force \times velocity

therefore:

power = \frac{work}{time} = \frac{force \times distance}{time}

Power output for the athlete can range from 50 to 60 watts produced during light cycling or jogging, to around 7,000 watts produced during the second phase of the pull for the Olympic clean (21). This review examines the higher levels of power output produced during a single, maximum effort muscle action, which we will term "explosive muscular power."

Explosive power output is the main determinant of performance in activities requiring one movement sequence to produce a high velocity at release or impact. Explosive muscle actions are required in throwing, jumping, and striking activities. In addition, sudden bursts of power are needed when rapidly changing direction or accelerating during various sports or athletic events (e.g., football, basketball, soccer, baseball, and gymnastics).

For example, the height to which an athlete jumps when rebounding in basketball is determined purely by the velocity with which he or she leaves the floor. At the bottom of the movement the body stops momentarily (Figure 1). Then as the athlete extends the trunk, hips, knees, and ankles, the body is accelerated upward to a maximum takeoff velocity as he or she leaves the floor. This takeoff velocity is determined by the force the muscles can generate against the floor, multiplied by the time during which the forces are applied.

Once the athlete has left the floor he or she can no longer apply the force, and the faster the acceleration, the shorter the time between the bottom of the movement and takeoff (shown in Figure 1 as 0.268 sec). It is here that we encounter the crucial importance of explosive muscular power. As an athlete attempts to maximize his or her explosive performance, the time over which he or she can apply force and accelerate the body decreases. Therefore two mechanical properties of muscle are paramount:

1. The ability to develop much force in a short period of time, termed the rate of force development;
2. The muscle’s ability to continue producing high force output as its velocity of shortening increases.

A number of factors enhance these two properties. The discus-
sion of each factor will help us understand the effects of different training strategies and how to maximize training efficiency.

Factors Contributing to Explosive Muscular Power

Muscular Strength and Heavy Resistance Training

Strength is the ability of the muscle to exert maximal force, or torque, at a specified velocity (37); it varies for different muscle actions such as eccentric, concentric, and isometric (41). Often coaches and athletes associate the term strength only with the force that can be exerted during slow speed or even during isometric muscle actions. This is often determined using a one-repetition maximum (1-RM) test in which strength is assessed as the maximum weight the athlete can lift once through the complete movement.

The development and assessment of 1-RM strength has received a great deal of research attention (3, 6, 29, 52). Pure 1-RM strength, however, is required by only a few athletic endeavors, such as powerlifting. Most sports require strength at faster velocities of movement.

From an athletic perspective we should think of strength as the force capability of the muscle for actions ranging from the fastest eccentric to the fastest concentric. The force velocity relationship for muscle, shown in Figure 2, dictates that the faster the velocity of concentric muscle action, the lower the force that can be produced (33). Yet maximal power is produced at intermediate velocities of movement, that is, at approximately 30% of maximum shortening velocity (37).

Pure 1-RM strength is required in the sport of powerlifting—we feel the name of the sport is inap-

Figure 1 Force, velocity, and power output during a vertical jump with counter movement. The concentric muscle action is only 268 ms long. The resulting takeoff velocity is determined by the sum of the forces that can be produced during this short period.

Figure 2 Force velocity power relationship for skeletal muscle. Vm, Pm, and Fm are maximum movement velocity, maximum power output, and maximum isometric force output, respectively (adapted from Ref. 20).
appropriate—because there is no requirement for the weight to be moved quickly (i.e., low power demands); the athlete is merely attempting to lift the maximum amount of weight. This requires movement velocities just higher than zero. Thus one exhibits maximal concentric force but very low levels of power in the 1-RM lifts.

Many strength and conditioning specialists believe that if the athlete’s slow velocity strength increases, then power output and dynamic performance will also improve. To a certain extent this is true, since maximum strength, even at slow velocities, is a contributing factor in explosive power. All explosive movements start from zero or from slow velocities, and it is at these phases of the movement that slow velocity strength can contribute to power development.

However, as the muscles begin to achieve high velocities of shortening, slow velocity strength capacity has less impact on the muscle’s ability to produce high force at rapid shortening velocities (16, 35, 36). This fact becomes increasingly important when the athlete begins to train specifically for optimal power development.

In terms of training, several studies have shown improved performance in power activities (e.g., vertical jump) following a strength training program (1, 4, 14, 59). Research by Häkkinen and Komi (27) showed a 7% improvement in vertical jump following 24 weeks of intense weight training.

In a related study (28), a group of subjects performed explosive jumps with a lighter resistance and averaged a 21% increase in vertical jump. The results indicated there may be specific training adaptations to heavy resistance versus power-type training. Heavy resistance strength training using high resistance and slow velocities of concentric muscle action leads primarily to improvements in maximal strength (i.e., the high force/low velocity portion of the force-velocity curve in Figure 2), and the improvements are reduced at higher velocities. Power training, which utilizes lighter resistances and higher velocities of muscle action, results in increases in force output at the higher velocities and in the rate of force development (28).

Although velocity specific training adaptations do occur, performance changes with training are not always consistent with this principle. This is due to the complex nature of explosive muscle actions and the integration of slow and fast force production requirements within the context of a complete movement.

Another reason it is difficult to observe clear, specific training adaptations is that in untrained persons, a variety of training interventions will produce increases in strength and power. Komi and Häkkinen (39) suggest that, depending on the person’s training status, the response may not always follow the velocity specific training principle. Individuals with low strength may see improvements throughout the force velocity spectrum regardless of the training resistance or style used (39).

It appears that training adaptations of single factors (high force, high power) occur only after a base level of strength and power training has been undertaken. In other words, if the athlete already has an adequate level of strength, then the increases in explosive power performance in response to traditional strength training will be poor and more specific training interventions will be needed to improve the power function (26). Thus, improvement of power performance in trained athletes may require more complex training strategies than was previously thought (59).

A Need for Training Integration
The rationale for slow velocity, heavy resistance training to develop explosive power is often based on the fact that power is equal to force times the velocity of the muscle action. It has been reasoned that if the athlete increases his or her 1-RM strength, nothing more is required from a resistance training program.

This situation is analogous to the evolution of aerobic endurance training methods. There was a time when only continuous training techniques were used, which increased maximum oxygen uptake and resulted in improved endurance performance. Later, exercise scientists determined that anaerobic threshold, exercise efficiency, and critical power abilities were also significant factors, and therefore interval training became an integral part of endurance athletes’ training regimens.

If we are to maximize improvements in power performance, then, we must train both the force and velocity components. This concept is summarized in Figure 3. Because the movement distance is limited by the athlete’s joint ranges of motion, velocity is determined by the time taken to complete the movement. Therefore, if we train using methods that will decrease the time needed for the movement, we increase the power output. Intimately linked to this concept is the rate of force development.

Rate of Force Development
Because time is limited during powerful muscle actions, the muscle must exert as much force as possible in a short time. One contributing factor is the rate of
force development (RFD) (Figure 4), which may help explain why heavy resistance training has been ineffective for increasing power performance (46).

Squat training with heavy resistances (70 to 120% of 1-RM) has been shown to improve maximum isometric strength. However, it does not improve the maximum rate of force development (30) and may even reduce the muscle's ability to develop force rapidly (26). On the contrary, activities during which the athlete attempts to develop force rapidly, such as explosive jump training with resistances of 30 to 60% 1-RM, increase his or her ability to rapidly develop force (5, 30).

Specifically, explosive resistance training increases the slope of the early portion of the force time curve, termed the maximum rate of force development (maxRFD). Figure 4 compares the effects of heavy resistance training versus explosive training on the isometric RFD curve.

Although heavy resistance training increases maximum strength, the highest point of the force-time curve, this type of training does not improve power performance appreciably, especially in athletes who have already developed a strength training base (i.e., more than 6 months of training). This is because the movement time during explosive activities is typically less than 300 ms and most of the force increases cannot be realized over such a short time. The athlete does not have the time to utilize his or her developed slow velocity strength.

**The Controversy of Velocity Specific Training**

Velocity specificity of resistance training is one of the most contentious issues in the theory of muscle strength and power. Studies on isokinetic testing and training methods have found that strength increases are specific to the velocity at which one trains (44). If you train at a slow movement velocity, you tend to increase strength at that velocity, thus the improvements in strength at higher velocities, which are more common in sport, are usually not of the same magnitude. Based on this, it has been recommended that resistance training be performed at a high speed if the purpose of the training is to increase power.

Behm and Sale (5) have presented evidence that it is the intention to move quickly which determines the velocity specific response, and that heavy resistance weight training may be effective if the athlete attempts to move the resistance as quickly as possible.

This theory was tested by Young and Bilby (61), who compared the effects of slow and fast weight training on vertical jump and rate of force development. Their study failed to find a velocity specific effect on rate of force development, and the slow weight training was more effective for increasing vertical jump performance. The subjects had no prior weight training experience and this may have influenced the results.

Kaneko et al. (36) found velocity specific effects for a task that involved lifting a weight as quickly as possible. Subjects trained with a resistance of either 0, 30, 60, or 100% of maximum isometric strength. The results demonstrated a classic resistance-specific training effect. The groups training with the heavier resistances produced the greatest increases in isometric strength while the group training with 0% resistance produced the greatest increase in unloaded movement velocity.

Perhaps the most interesting finding was that the 30% resistance produced the greatest increase in force and power over the entire concentric velocity range and also resulted in the greatest
increase in maximum mechanical power.

Certainly, further research is required. Based on studies of muscle fiber contractile characteristics (20, 25), there appears to be a great range of adaptations within the cell that alter its maximum velocity of shortening and force output at specific velocities. In particular, there is a considerable difference in the power capacity of fast twitch (Type II) versus slow twitch (Type I) muscle fibers (20).

One study by Duchateau and Hainaut (16) removed the confounding variable of neural innervation and only considered contractile changes within the muscle. Subjects completed 12 weeks of training using either dynamic contractions with a resistance of 30% of maximum voluntary contraction (MVC) or isometric training. The dynamically trained group produced increases in maximum contractile speed whereas the isometrically trained group did not. It is not known whether the actual shortening velocity of the muscle fiber or the frequency of neural input is the stimulus to adaptations in force production at specific velocities.

**The Optimal Resistance**

Several studies (36, 45, 59) have shown that to increase explosive power output, athletes should train at the velocity and use the resistance that maximizes mechanical power output. As shown in Figure 2, the force and velocity capabilities of muscle are intimately linked. Maximal mechanical power is produced at a resistance of 30% of maximum isometric strength, which corresponds to a velocity of muscle shortening of approximately 30% of maximum (20).

Wilson et al. (59) compared the effects of 10 weeks of training on vertical jump performance using traditional back squats, explosive jump squats, or plyometrics in the form of drop jumps. The explosive jump squats involved a resistance that allowed the subjects to produce the greatest mechanical power output, approximately 30% of 1-RM. All training groups produced increases in vertical jump performance, but the maximal power group had significantly greater increases (18%) than the other two groups (heavy resistance training, 5%; drop jump training, 10%).

These results were similar to those obtained by Berger (7), who also found that jump squats performed with a resistance of 30% of maximum led to greater increases in vertical jump as compared to traditional weight training, plyometric training, or isometric training.

The studies by Wilson et al. (59) and Berger (7) found superior improvements in power performance due to jump squat training using a 30% resistance as compared to heavy squat lifting. This may not have been a reflection of the resistance used but rather the more specific training movement of jump squats and the disadvantages of traditional weight training movements, which will be discussed next.

Heavy resistance training will increase power output at low velocities and heavy resistances, while light resistance training (e.g., 30% MVC) will increase power output for light resistances (16). Furthermore, heavy resistance training tends to shift the optimal resistance for power output toward the heavier resistances, that is, maximum power output is produced at a heavier resistance.

Therefore, increases in power are specific to the training resis-
tance and velocity used. This may be the rationale behind the recommendation of a 30% MVC resistance. Since this is the resistance at which power is maximized, training at this resistance will produce the greatest increases in maximum power. The degree to which this increase in power output will transfer to athletic performance, however, may depend on whether the mass being moved represents a similar resistance to 30% MVC. Throwing a baseball or accelerating the leg to kick a football represents a much lighter resistance than 30%. Similarly, performing an Olympic-style lift involves a much heavier resistance.

Further research is needed, but it may be prudent to continuously adjust the resistance used in training to ensure increased power output in the specific activity and thus maximize performance gains.

**Traditional Weight Training**

The results of some studies (7, 59, 61) highlight a further problem with traditional weight training and power development. It has been observed that when lifting a 1-RM weight, the bar is decelerating for as much as 24% of the concentric movement (18). The deceleration phase increases to 52% when performing the lift with a lighter resistance, for example, 81% of 1-RM (18).

In an effort to train at a faster velocity more specific to sport activity, athletes may attempt to move the bar rapidly during the lift. This also increases the duration of the deceleration phase (49), as the athlete must slow the bar to a complete stop at the end of the range.

Plyometric training and weighted jump squats avoid this problem by allowing the athlete to explode all the way through the movement to the point of projection of the resistance (e.g., takeoff in jumping, ball release in throwing, or impact in striking activities). It could be argued that traditional weight training may promote the development of this undesirable deceleration movement pattern. The deceleration results from a decreased activation of the agonists during the latter phase of the lift and may be accompanied by considerable activation of the antagonists, particularly when using lighter resistances and trying to lift the weight quickly (47).

This obviously is a very undesirable movement to develop when attempting to maximize explosive performance. Thus, to offset this, the lifter must employ "ballistic" resistance training.

**Ballistic Resistance Training**

The problem of the deceleration phase can be overcome if the athlete actually throws or jumps with the weight. This has been termed "dynamic" or "explosive" resistance training but is probably best described as ballistic resistance training.

The term dynamic is not really applicable because all training which involves movement (i.e., not static or isometric) would be classified as dynamic. The term explosive is too general, as one can be explosive from the bottom of a traditional squat but reduce the effort near the top of the range of motion and never leave the ground, as in the study by Young and Bilby (61). Similarly, the training study by Behm and Sale (5) could be said to involve explosive muscle action but the joint movement was actually isometric.

Ballistic infers accelerative, of high velocity, and with actual projection into free space. This type of training is perhaps best described as ballistic resistance training (32, 49).

**Heavy Versus Light Resistance**

Whether performing traditional or ballistic resistance training, there is considerable controversy over the resistance to be used for developing explosive power performance (59, 60). If you are limited to traditional resistance training techniques, heavy (>80%) resistances are preferable because you simply cannot overload the muscle enough using light resistances while stopping the weight at the top of the range of motion (47). With ballistic resistance there is perhaps no optimal intensity or resistance.

Both heavy (>80%) and light (<60%) resistances can be used in the training of muscular power, with each affecting different components of explosive muscle action. If one has to choose a single resistance, the one that produces maximum power output, 30% MVC, has been found optimal for increasing maximal mechanical power (36, 59). There is a wide selection of resistances, and the greatest training adaptations will result when athletes train with resistances that span the concentric force velocity capability.

Although ballistic resistance training improves power performance, it does exert high eccentric forces on the athlete when landing from the jump or catching the falling weight (48). However, weight training equipment can be adapted to reduce the eccentric resistance (48). In addition, ballistic weight training should progress gradually from light resistance (15 to 45% 1-RM) to heavy resistance (60 to 90% 1-RM) conditions when the athlete has completed a strength training program. Therefore, preparatory phases for developing basic strength levels are vital when progressing to ballistic training techniques.
Stretch Shortening Cycle

Most explosive activities involve a counter movement during which the muscles are first stretched and then shortened to accelerate the body or limb. This action of the muscle, called a stretch shortening cycle (SSC) (38), involves neural and mechanical processes. A lot of research has been directed toward the study of the stretch shortening cycle (11, 12, 19, 24, 26, 40, 52, 57) because it has been observed that performance is potentiated by the amount of prestretch during the counter movement (11).

In a cross-sectional study, Bosco et al. (12) observed height differences of 18 to 20% between the squat jump, a purely concentric jump initiated from a crouch position, and the counter movement jump, which is initiated from a standing position with the athlete making a preparatory dip and then jumping upward.

The latter jump is higher because as the jumper approaches the end of the preparatory descent, the muscle begins to act eccentrically to slow the body and initiate the upward movement. As the muscle is activated, force is increased in the tendomuscular complex, increasing its stiffness or resistance to stretching. The resultant storage of elastic energy in the muscle and tendon that is recovered during the subsequent concentric phase, making it more powerful (11). Also contributing to the concentric muscle action is a reflex increase in neural stimulation to the muscle, brought about by the sudden stretch stimulus (24, 55).

Studies by Bosco and Komi (11) demonstrate that performance increases when increasing stretch forces are applied. For example, during drop jumping the height of the subsequent jump increases with increases in drop height. But this occurs only up to a point. There is a threshold at which the stretch force is too great and the Golgi tendon organ reflex inhibits muscle action, reducing the jump height attained (24, 55).

Athletes who are not used to intense SSC forces may produce their best performance during a counter movement jump, and drop jump heights will be even lower than those of the squat jump (53). This is due to the strong inhibition effect of the Golgi tendon organ reflex, which has not been modified through prior SSC training (53).

Explosive power performance responds to training in which athletes perform SSC movements with a stretch force greater and more rapid than that to which they are accustomed. These activities, called plyometrics, have been found effective for increasing jumping ability (1, 14, 55, 59). Plyometric training increases the overall neural stimulation of the muscle, and thus force output, but qualitative changes are also apparent.

In persons who are not used to intense SSC forces, there is a reduction in EMG activity beginning 50 to 100 ms before ground contact and lasting for 100 to 200 ms (55). Gollhofer (23) has attributed this to a protective mechanism by the Golgi tendon organ reflex acting during sudden, intense stretch forces to reduce the tension in the tendomuscular unit during the force peak of the SSC. After a period of plyometric training, the inhibitory effects are reduced (termed disinhibition) and SSC performance improves (54).

Plyometric training places considerable forces on the musculoskeletal system, thus the athlete should have a preliminary strength training base before beginning a plyometric training program (e.g., squat 1.5 x body weight). Similar to other forms of training, the plyometric overload should involve a gradual progression from ground level, double limb contacts, to exercises involving single limb landings or possibly drop jumps from increasing heights. However, the latter exercises are also thought to have a higher risk for injury (53).

Coordination of Movement Pattern and Skill

Power performance is affected by the interaction between agonists, antagonists, and synergists involved in the joint movement. A fast movement velocity requires low resistance. Although the agonist muscle may be able to apply great force in a short time, there must be a complementary relaxation of the antagonists (43).

Specific training movements will reduce the co-contraction of antagonists and increase the coordination of agonist and synergist activity (53, 60), but the movement must be specific to the activity in terms of pattern and speed. Furthermore, the improvements are not transferable to other movements. This method may be better described as coordination training rather than strength or power training (53). Thus, specific skill and coordination of force application are important contributors to powerful movements.

The Bilateral Deficit

Neural activation patterns and skill are intrinsic to the powerful performance of a movement. Most activities are unilateral in that they involve one arm or leg producing the movement while the other undergoes recovery or stabi-
lizing movements. Sale (51) described the phenomenon of bilateral deficit as the difference between the force output when the left and right sides act simultaneously and the sum of the forces produced by the left and right limbs acting alone.

Training may increase or reduce the deficit, as demonstrated by tests on rowers who were found to be stronger in bilateral leg press than in the sum of single leg press, and on cyclists who normally alternate leg actions and displayed a large deficit (51). Therefore, when training for specific unilateral activities (e.g., kicking), it may be best to train using single-leg presses and knee extensions rather than exercising both legs simultaneously.

### Muscle Hypertrophy and Power

As noted above, high muscle force is a component of power. This ability for high force production or strength can be increased by the muscle growing larger (hypertrophy) and/or through improved neural innervation of the muscle (54).

One long held belief is that excessive hypertrophy may be a disadvantage to power athletes who must work against their body weight, for example jumpers and sprinters. However, increases in muscle size are always accompanied by increases in muscle strength (53). If appropriate power training is included, the power : weight ratio, so crucial in jumping events especially, is increased rather than decreased.

At the extreme of muscle hypertrophy, as seen in elite bodybuilders, there may be decreased range of motion and alteration in pennation angle of the muscle fibers. This would be detrimental to muscle speed of contraction and thus reduce the power potential.

We do not know at what level of hypertrophy this occurs, but it is certain to be near the limit of one’s genetic potential.

The type of high volume training (e.g., 6 to 14 sets of 10-RM using isolated joint movements) needed for dramatic muscle hypertrophy would require considerable time in terms of training and recovery. This would dramatically reduce the time available for other forms of sport training. It is here that training specificity dramatically separates itself between power sports and body building. Nevertheless, hypertrophy training may be needed at some point in the athlete’s career to maintain optimal upper limits for muscle size.

### The Window of Adaptation

Several studies have compared the effectiveness of plyometrics, resistance training, and a combination of both. Although specific training protocols vary, in general plyometric training alone has been found effective for increasing power performance in both trained and untrained individuals (1, 14, 15, 17, 34, 55, 59). Traditional resistance training led to increases in power output in most of the research (1, 4, 50, 58, 59, 61), while a few studies found no change in subjects who were already strength trained (27, 40).

When resistance training is combined with plyometrics, power output is increased (4, 8,
14), and this is perhaps a greater stimulus to explosive power performance than either weight or plyometric training alone (1). These findings highlight the multifaceted nature of power performance, with a mixed training methods approach being most effective because it develops more components of explosive power.

Furthermore, the findings of Häkkinen and Komi (27, 28) demonstrate that as an athlete develops one component to a high level (e.g., strength), the potential for that component to contribute to further increases in power output diminish. Thus each component can be thought of as a "window of adaptation" to the larger window of adaptation in explosive power.

This concept is summarized in Figure 5. Training must be targeted to optimize the variables within this five-factor paradigm. Optimal power can be achieved only if each factor is addressed in the training program.

**Exercises That May Not be Optimal**

Many strength and conditioning coaches believe strength is a quality of muscle that can be expressed across all movements involving that muscle. Therefore training programs often focus on single joint exercises with low movement speeds, in the expectation that power output will be increased for the movement trained and that this will carry over to more functional multijoint movements.

It is well known that strength development is specific to the movement pattern, speed, and type of muscle action used in the training (16, 35, 36, 44). This is perhaps even more evident when training for increased power. The only chances for muscle power to be generalized across different movements are as follows:

1. Hypertrophy can result from a wide range of exercises involving the muscle, and as cross-sectional area is increased, the force capability of the muscle is greater regardless of the movement. However, hypertrophy is a result of training involving high volume (about 10-RM resistance) and short rest periods between sets and exercises; it is not generally a result of power training involving low volume and long rests (42).

2. Contractile changes within the muscle toward faster and more powerful characteristics could conceivably contribute to other movements, even multijoint, involving the muscle (56).

As noted, much of the muscle's adaptation toward greater power development is neural in terms of better intramuscular and intermuscular coordination. As such, even if the above alterations are achieved through resistance training using movements that are not specific, it is doubtful they can be effectively utilized in the specific movement.

In periodized training, athletes often perform resistance training that is not specific to their sport but rather aims at overall increases in muscle size and strength; then they progress to more specific power training as they approach their competitive peak. Further research may reveal whether the gains from the previous, more general strength training contribute to the performance developed during movement-specific power training. That is, does the improved neural recruitment that results from power training allow athletes to take advantage of the local changes induced in the muscle during the preparatory phases?

The major problem is that isolated joint exercises, while contributing to one factor in power development—increased muscle cross-sectional area—cannot influence the neural coordination needed for their use in multijoint movements. Thus total body power is only promoted via a few local changes in joint musculature and is not integrated across joints for multijoint sport movements such as tackling in football, jumping in basketball and volleyball, or takedowns in wrestling.

A further problem when trying to perform rapid single-joint resistance training movements is the risk of injury. When the athlete rapidly accelerates the mass through the range of movement, considerable kinetic energy is stored in the form of motion of the implement or limb. If the mass must stop at the end of the range, this energy must be absorbed by the muscles and joint structures very quickly, resulting in high forces being applied and more chance of injury.

In ballistic resistance multijoint training, such as explosive jump squats, the mass is released with high kinetic energy that is subsequently absorbed by the external environment as the velocity is reduced under the action of gravity. Therefore the momentum of the mass does not affect the involved joints and muscles to the same extent.

**The Olympic-Style Lifts**

The Olympic-style lifts (snatch, clean and jerk) and related lifts (hang pulls, hang cleans, power snatch, power clean, push press, power jerk) have been proposed as effective exercises for developing explosive power (2, 21, 22). Upper and lower body power development is specific to the exercise movements (e.g., push press—upper body; hang pulls—lower
body). This training method is widely accepted, partly because of the many Olympic-style weightlifters and coaches in general strength and conditioning positions in high schools and colleges. In addition, the fact that weightlifters usually exhibit exceptional power during vertical jump and sprinting has promoted the use of this style of training. Nevertheless, it has not been determined whether this is a result of genetic predisposition or Olympic-style training per se, yet there are several aspects to Olympic-style lifting that make it suitable for power development.

During weightlifting, power output is extremely high and the speed of movement is fast. Further, such lifts have an explosive, accelerative velocity profile, making them much more specific than traditional resistance training exercises to explosive power performance in other sport activities (21, 22). However, for power sports involving rotational and unilateral movements, which are not replicated in the Olympic-style lifts, other explosive power training exercises that are more similar in movement pattern should be prescribed.

Although the effect of an Olympic lifting program on Olympic weightlifters has been investigated (29), there is no data on the effect of a controlled Olympic-style training program on power performance in athletes who are not Olympic weightlifters. Many have argued, inappropriately, that such lifts are inherently more dangerous and that single-joint exercises can accomplish the same effect. From what we have shown, both the injury (31) and effectiveness arguments fall short. In addition, multifaceted training demands all types of training to optimize all functions. Even Olympic-style weightlifting exercise alone may have limitations as to what can be produced (e.g., hypertrophy, rotational power) in a training program.

**Motivation and Power Training**

One problem with power training using plyometrics or light resistance weight training is that of producing maximal effort. Young (60) has pointed out that it is necessary to produce maximal effort to lift a 90 to 100% 1-RM resistance but it is not required during lighter resistance training and thus the athlete may reduce intensity and subsequent training effect. This can be overcome through performance feedback in the form of target jump heights, or feedback of power output using force plate or contact mat systems.

**Power Training and Fatigue State**

Power training aims at increasing the ability of the neural system to innervate the muscles and develop the skill to coordinate the movement for greatest effectiveness. For maximum benefit, this type of training should be performed in a rested state. In scheduling training sessions, it is important not to fatigue the athlete with endurance or strength training prior to power training. Thus power training should be performed at the beginning of an exercise session or on separate training days.

**Summary**

This paper has provided the theoretical framework for a training strategy. In planning a training program to optimize explosive power, one should consider a number of points. Explosive power performance is a multifaceted phenomenon that represents many training factors. Of particular importance is the individual’s muscular strength in both fast and slow muscle actions, rate of force development capability, stretch shorten cycle ability, and intermuscular coordination and skill.

Explosive power performance will see its greatest improvement if a range of training methodologies are implemented that address each component. If a component is already highly developed, however, then greater attention to other components will be more beneficial. This highlights the need to implement an assessment program that can isolate those components in which the athlete is relatively weak.

For examples of appropriate testing protocols, see Bosco et al. (9, 10, 11). Shifting the emphasis of the training program to target these components should result in the greatest improvements in explosive power performance.

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