Volume 23, Number 3, pages 13–20

A Brief Review: Explosive Exercises and Sports Performance

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Keywords: weightlifting; motor unit recruitment; rate coding; power; injuries.

Introduction

The ability to generate high power outputs in sport is often a determinant of athletic success (43). In fact, it is believed that power output-generating capabilities are among the most important factors in sports performance, especially those that involve jumping and sprinting (31). The use of resistance training modes and methods that have explosive exercise components may enhance an athlete's ability to generate high power outputs. Explosive exercises generally utilize rates of force development that approach near maximal or maximal values and potentiate an athlete's ability to generate high rates of acceleration (40). The highest recorded rates of force development have been demonstrated in male power athletes who employ explosive exercises of varying loads in their training regimes (18, 25). It appears that explosive exercises tend to enhance an athlete's ability to generate high rates of force development (18, 22, 25, 54), whereas slow exercises tend to impair this ability (24, 25, 50). Almost any exercise can be performed explosively depending upon the resistance used.

Several studies and review articles have reported evidence and logical arguments for the use of explosive exercises. These types of exercises are marked by high-force, high-velocity movements and are used by athletes who participate in strength and power sports (9, 15, 16, 24, 39, 42). Generally, we can define an explosive exercise as having a maximal or near maximal initial rate of force development that is maintained throughout a specified range of motion. These types of exercises are marked by a rapid initiation of force production and focus on movement accelerations, which result in near maximal or maximal movement velocities at a given resistance. Therefore, a conceptual continuum of explosive exercise can be created (Figure 1). The type of explosive exercise employed in the training program will then dictate the adaptive response of the athlete and will ultimately affect the sports performance. It is likely that improvements in sports performance through the use of explosive exercises may be partially dependent upon the movement and velocity patterns required by the sport and upon the training status of the athlete.

Neuromuscular Factors

When examining strength and the factors that are involved in the production of muscular force, sev-

Figure 1. **Conceptual continuum of explosive exercises.**

eral factors can be delineated (Table 1). The effectiveness of explosive exercises as training tools may be related to their ability to affect these factors. Specifically, when examining these factors, the body's ability to recruit motor units or to stimulate the rate coding mechanism is of critical importance to understanding the effectiveness of explosive exercises in sports performance. Additionally, the hypertrophic response to explosive exercises may add further evidence to the effectiveness of explosive exercises as a training modality.

Motor Unit Recruitment and Rate Coding

When examining the neuromuscular system, the motor unit is described as being composed of a motor neuron and all the muscle fibers it innervates (32). Motor units are generally composed of between 9 and 1,934 muscle fibers per motor neuron (13, 30). Muscle fibers that have a lower muscle fiber to motor neuron ratio (9:1) are used to control fine movements, whereas muscle with large ratios (1,934:1) are used in the performance of gross physical movements (30, 51). The ability to regulate the amount of tension produced by a muscle is clearly related either to the ability to recruit or to rate coding of motor units (10, 11, 33, 35).

Several investigations have suggested that there is a sequential gradation of motor unit recruitment that results in a recruitment of smaller to larger motor units (6, 27). Often this concept is termed the *size principle.* This principle appears to hold true for both ramp and ballistic or explosive voluntary and reflex contraction (5). Generally, it is believed that small motor units, which tend to have lower thresholds and are predominantly composed of Type I fibers, are recruited in response to lower force demands. When higher forces are demanded, the higher-threshold motor units, which typically are made up of Type II muscle fibers, are recruited (9). The fact that larger, more powerful motor units are recruited only when high force or high power outputs are demanded by the activity is of particular interest to understanding the effectiveness of explosive exercises (43). Thus, in order to activate the larger motor units, explosive exercises--which generally require high force and high power outputs--are needed. In addition to stimulating the recruitment of higher-threshold motor units, explosive exercises, which require high contraction speeds, have the potential to alter the motor unit recruitment pattern. These exercises may train higher-threshold motor units to contract before or in concert with low-threshold motor units (10, 36, 49). Therefore, the use of explosive exercises in a training program may result in adaptations that allow the athlete to be able to recruit larger motor units sooner or more efficiently. These findings may partially explain why there is a high degree of velocity specificity in resistance training (28).

Another strategy for increasing the amount of force generated is the activation of the rate coding mechanism (34). *Rate coding* is often defined as occurring when the frequency of neural impulses sent to motor neurons already activated is increased (4). The rate coding process is unique in that the force generated increases without additional motor units being recruited. The high force and high power output demand of explosive exercises may also result in changes in the muscles' ability to rate code because of the ability

Table 1
Factors Related to Force Generating Capabilities

Factors

1. Motor unit recruitment and activation patterns
2. Rate coding
3. Synchronization
4. Neural inhibition
5. Muscle cross-sectional area
6. Motor unit type

Note: Modified from Stone (43).

of this type of exercise to increase the frequency of stimulation of higher-threshold motor units (9).

Generally, it is believed that there is an interplay between rate coding and motor unit recruitment in the body's ability to generate force (9). The interplay of these 2 force-generating mechanisms may be related to the size and fiber-type composition of the muscle (9). Research evidence suggests that homogeneous muscles such as the adductor pollicis (72-91% Type I fibers) rely primarily on motor unit recruitment from 0-50% of their maximal voluntary contraction (MVC) (29). Rate coding becomes the primary mechanism for increasing force production in this muscle at intensities greater than 50% of its MVC (29). A different pattern of recruitment and rate coding may be experienced with larger heterogeneous (both Type II and Type I fibers) muscles, such as the deltoid and biceps brachii (7, 8, 29). With these larger muscle groups, there is an initial reliance on rate coding of the low-threshold motor units, which are primarily composed of Type I fibers and small motor neurons (5, 6). Tension development between 30 and 90% of MVC is primarily determined by the increased recruitment of motor units (8, 29, 35). During this period of increased motor unit recruitment, it is important to note that the low-threshold units are the first to be recruited, but as the tension (force and power output) increases, any additional force is generated by recruiting higher-threshold motor units (4, 7, 8, 29). Increased rate coding of these higher-threshold motor units is then needed to generate forces that approach 100% of MVC. Therefore, it is important to note that maximal or near maximal forces can only be generated through the increased recruitment or rate coding of higher-threshold motor units. Because of their high force- and power output-generating capabilities, explosive exercises appear to be the optimal mechanism for inducing sport-specific changes in motor unit recruitment and rate coding.

Hypertrophic Factors

When examining the hypertrophic effects of explosive resistance exercise training, it appears that hypertrophy is associated with Type II muscle fibers (24). This may be related to the preferential activation of higher-threshold motor units, which are predominantly composed of Type II muscle fibers (10, 36, 49). Explosive exercise training will lead to greater increases in neural activation during integrated electromyographic activity and rate of isometric force production when compared to heavy resistance training (21, 24). Conversely, heavy resistance training appears to stimulate the hypertrophy of both Type I and Type II fibers, with type II fibers experiencing a greater rate of hypertrophy (20, 24). Thus, it is likely that alterations in maximal strength are probably related to the combined effects of hypertrophic factors, whereas rate of force development may be associated with alterations in neural activation (24, 39). However, it is likely that hypertrophy of Type II fibers can result in some alterations in the rate of force development (21).

It is also likely that the training experience or status of the athlete will exhibit a significant effect on the hypertrophic and neural adaptation to explosive exercises (24, 39). Generally, it is believed that untrained subjects will experience rapid gains in strength during the first 2-3 months (39). These gains are largely associated with neural adaptations to a training program (39). After this 2- to 3-month period, additional strength gains will be related to hypertrophic factors (39).

Explosive Exercise and Power

Häkkinen and Komi (20) have defined *power* as an explosive production of force. Generally, explosive strength is related to maximal power output, which is best characterized by brief muscle actions, which result in high-velocity movements (31, 37). Maximal power output is generally related to strength or maximal force production but is somewhat different and not completely dependent upon this variable (31). Cross-sectional data clearly suggest that high levels of leg and hip strength are present in athletes who possess superior maximal power outputs as assessed by vertical jumping (21, 45, 47). This relationship is strengthened by longitudinal studies, which assess increases in 1 repetition maximum squat and vertical jump performance (45, 48).

It has been suggested that a continuum of explosive exercise modalities exists (Figure 1) and that depending upon the mode selected and method of application, different adaptations may occur. Typically, low-speed/high-force resistance training, which is usually undertaken at relative intensities of 80% or greater, can markedly increase maximum strength (3, 19), power, and speed gains when compared to training with light weights (41, 53). These adaptations may be potentiated when high levels of muscular force are required and when there is a conscious intention to create fast movements (2). This type of heavy strength training is typically un-

Table 2
Exercise Power Outputs

Exercise	Absolute Power (W) 100-kg male	Absolute Power (W) 75-kg female
Jerk	5,400	2,600
Snatch	3,000	1,750
Clean	2,950	1,750
Deadlift	1,100	
Squat	1,100	
Bench press	300	

Note: Modified from Stone (43).

dertaken by power lifters (bench, squat, and deadlift) and can result in high-power outputs when compared to nonlifting controls (9). However, if heavy strength training is maintained for long periods of time (months to years), the rate of isometric force and power production can be impaired (26, 43).

The use of high-speed/low-force movements can also result in increased gains in power output (3, 19). When this type of training is used with squatting and jumping motions at ~30% of maximal isometric force, superior performance gains have been noted in sports that rely on speed or power output (52). These enhancements have been hypothesized to result from improvements in intra- and intermuscular coordination during the performance of high-speed/low-force movements (9, 19, 41). Additionally, contractile speed has been suggested to be increased after short-term high-power training when compared to isometric training (12). Based upon these data, it appears that both neural and contractile mechanisms are affected by the use of high-speed/low-force exercises. However, if athletes use only high-speed/low-force movements, maximal strength levels will not be improved, which suggests that an alternate training model may be needed (26).

Several authors have suggested that the optimal adaptive explosive exercise stimulus for the muscle and nervous system must come from the combination of high-force/low-velocity, low-force/high-velocity, and high-force/high-velocity exercise movements (1, 26, 44). Harris et al. (26) suggest that the combination of training modalities will optimize performance gains. In this study, the utilization of a combination of high-force/low-velocity (5 weeks) and low-force/high-velocity training (4 weeks) produced optimal gains over a 9-week training period when compared to high-force/low-velocity and low-force/high-velocity training. These data suggest that maximum strength development can increase power production early in a training program and that a shift toward power development training is necessary during a training cycle in order to optimize power production. This type of training shift is one of the major tenets of the theory of periodized training (1, 46).

Additional cross sectional data suggest that Olympic-style weightlifters (snatch, clean and jerk) whose training programs are centered on the utilization of explosive exercises possess comparable maximal strength levels with power lifters (31). This also suggests that weightlifters are capable of jumping higher than power lifters and generally produce superior maximal power outputs (31). This relationship is not totally unexpected, because the highest power outputs are produced during the performance of weightlifting exercises (Table 2) (43). Traditionally, weightlifters use training techniques that utilize slow-velocity/high-force movements and explosive high-velocity/high-force movements during certain phase of training and that ultimately result in improved power output production (14, 23).

Explosive Exercises

Generally, explosive exercises or speed strength exercises result in the production of high power outputs (43). The exercises most typically employed in this capacity are the Olympic-style lifts—more specifically the snatch, clean, pulling motions, and various jerking movements (Table 3). The clean and jerk and snatch lifts have the potential to produce some of the highest average human power outputs (Table 2) (14, 16, 17). Clearly, when comparing the Olympic-style lifts to traditional high-force/low-velocity exercises, higher power outputs are encountered. Thus, the use of explosive lifts such as the Olympic-style lifts may partially explain the differences in power output capabilities of different strength power athletes (31, 43). Because these exercises stimulate improved power output-generating capabilities, many have suggested that they will produce a

Table 3 Types of Explosive Exercises
Exercise
Snatch (squat and power)
Clean (squat and power)
Pulls (clean and snatch)
Jump squats
Speed squats
Jerks (push and split)

significant carry-over to other strength power sports (43). This suggestion is generally based upon the belief that these exercises produce movement patterns, velocity characteristics, and power outputs that are similar to those needed in many sports performances.

Injuries and Explosive Exercises

Explosive exercises appear to be a safe means of maximizing sports performance. However, many sports medicine and exercise professionals express skepticism about the safety of this type of training. Recently, Pierce et al. (38) have reported that no injuries that required medical attention or that limited training occurred in a group of 15 girls and 55 boys who ranged in age from 7 to 16 years and participated in a structured weightlifting program. This training program consisted of 2.9 days of formal training over a 1-year period, and ~1,224 competitive lifts (snatch and clean and jerks) were performed over this time period. (38). Additionally, it appears that the injuries that result from weightlifting training and competition are not excessive and may be substantially fewer than the injuries incurred from sports such as gymnastics, football, or basketball (42).

Examination of the injury rates of athletes participating in training programs that require the performance of speed strength or explosive exercises indicates that apparently very few injuries occur. In fact, a longitudinal study that examined 4 years of weight training in college football teams (American Injury Monitoring System) reported that the time lost from injuries incurred during weight training amounted to 1% of the time lost from injuries that resulted from participation in football (55). It is important to note that the safety of speed strength exercises can be maximized by using proper lifting technique (43). Developing proper technique habits and following appropriate teaching progressions are essential during the learning and performance of explosive exercises. Proper lifting technique typically requires the athlete or participant to perform the exercises in a controlled fashion. Additionally, the safety of the exercise can be maximized through careful supervision by a knowledgeable strength and conditioning professional, who can correct technique and lead the athlete through appropriate learning progressions.

Conclusions

Explosive exercises can result in improvements in power production. It appears that the Olympic-style lifts have the greatest potential to affect power production. These lifts stimulate neuromuscular adaptations, which may potentially result in improved sports performance. Power production may also be maximized by using a combination of explosive exercise modalities in a periodized training program. Additionally, when these exercise are performed with appropriate technique and are supervised by a qualified strength professional, there is minimal risk of injury. ▲

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