The NSCA's Position Statement on explosive exercises and training on pages 6 through 19 is in two parts. The first part - Explosive Exercises and Training - focuses on the underlying mechanisms of explosive exercise, injury potential and on the Olympic lifts, and begins on page 6. The second part - Explosive/Plyometric Exercises - begins on page 16.

Explosive exercises refer to the use of maximum or near maximum rates of force development (56). The ability to achieve high maximum rates of force development is associated with the ability to achieve high accelerations (56). During maximum efforts the maximum rate of force development is approximately equal at all resistances above 25 percent of maximum isometric force production (56). Almost any exercise can be performed explosively. Depending upon the resistance used, a high acceleration or a high rate of force development or both may be achieved. The usefulness of explosive exercises in improving performance depends upon a number of factors, including the sport's movement patterns and velocity requirements, and the training state of the participants.

Specificity of Training
Several studies and reviews have presented evidence and logical arguments for the necessity of using high force, high velocity, movement-specific training exercises in order to produce superior performance gains in strength and power oriented sports (12, 20, 22, 32, 53, 59). In order to better understand the apparent usefulness of explosive exercises, a brief discussion of definitions and underlying mechanisms is necessary.

Strength is the ability to produce force (64). Force production can occur at zero velocity (isometric strength) or result in a variety of velocities of contraction, depending upon the resistance being overcome (dynamic strength). Thus, maximum strength can be measured isometrically or dynamically. Dynamic strength can be measured eccentrically, concentrically or plyometrically. Speed strength is the ability of the neuromuscular system to produce the greatest possible velocity of movement as a result of applied force against a given resistance (55). Explosive exercises are defined, for this discussion, as those exercises in which the initial rate of concentric force production is maximal, or near maximal, and maximal or near maximal force production is maintained throughout a specified range of motion in keeping with the exercise technique involved. Thus, explosive exercises are movements in which rapid initiation of force production and the ability to accelerate are of primary importance. Because of the force production characteristics, the velocity of movement will be maximum or near maximum for a given resistance. Thus, a continuum of explosive exercise movements can be conceptualized, ranging from high force, slow movements (very heavy weights) to very fast movements performed with relatively light weights (see references 55 and 56 for additional information on definitions). However, actual exercise velocity in large part reflects the muscle length-tension curve, muscle force-velocity curve, body morphology, neuromuscular coordination and reflex activity and the storage and use of elastic energy.

Neuromuscular Considerations for Strength Production
It is apparent that in performing daily movements, and especially athletic movements, a large range of forces may be applied; gradation of strength is an important consideration in making these movements. The following factors and mechanisms are involved in force production (46, 47, 64):
1. Motor unit recruitment.
2. Rate coding (rate of electrical impulses to the motor unit resulting in contraction).
3. Synchronization.
4. Motor unit activation pattern.
5. Whole muscle contraction pattern and stretch shortening.
7. Cross-sectional area of muscle.
8. Motor unit type.

Motor Unit Recruitment and Rate Coding
Neural mechanism (1-6), with the possible exception of synchronization (39, 46) are especially important in strength gradation and in learning to exert maximum isometric or dynamic strength (36, 45, 53). During the contraction of an isolated or single muscle the two most important factors regulating the gradation of force are the motor unit recruitment and rate coding (12). Additionally, the relative importance of recruitment versus rate coding may be determined by the size of the muscle (3,
10, 11, 12, 38). In small muscles, such as the adductor pollicis (80 percent Type I fibers), approximately 86 percent of the motor units are recruited at 30 percent of maximum isometric voluntary contraction (MVIC) and 100 percent recruitment occurs by 50 percent MVIC (38). Further increases in tension are produced by increased rate coding (38).

In larger muscles of more heterogeneous fiber composition, such as the biceps brachii, a different pattern of motor unit recruitment and rate coding has been observed (10, 11, 38). As these larger muscles increase force production, initially there is an increase in the rate coding for low threshold motor units (10, 11, 38). Although some overlap exists, these lower threshold motor units are made up of predominantly Type I fibers (8, 9). From approximately 30 to 90 percent of MVIC, tension is largely increased by recruitment, thereafter, an increased rate coding effects 100 percent MVIC (10, 38, 43). It should be noted that low threshold motor units (Type I) can operate through a larger range of frequencies than high threshold motor units (3, 10, 11). This suggests that during gradual increases in muscle tension or during relatively low tension outputs, low threshold motor units are responsible for a greater proportion of the MVIC than high threshold motor units. However, in order to reach maximum force levels the high threshold units (largely Type II) must be recruited (13). This suggests that purposeful slow movements, which do not produce as much force as explosive movements, may be less effective for strength development because they do not adequately recruit high threshold motor units necessary for maximum force production.

Motor Unit and Whole Muscle Contraction Patterns

Evidence suggests that specific motor units are preferentially recruited when a muscle is engaged in a specific task (12, 13, 44, 49, 54, 66, 67). Different recruitment patterns within a muscle are strongly related to commands from higher central nervous system centers (central command) (66) but may be modified to some extent by sensory feedback such as changes in joint angle (70). Thus, different parts of a muscle (i.e., different groups of motor units) may be active during different tasks or during changes in joint angles as muscle contraction causes movement about a joint (54).

Furthermore, there are task specific interactions among muscles (66). The activation of parts of muscles or whole muscles and their coordinated activity during movement is task specific (53, 54, 64, 66). For example, the activity of various muscles can change depending upon the type of muscle action (dynamic versus isometric), multi-joint versus single joint activities or because of differences in joint angle (54, 64, 70).

A great deal of evidence indicates that during gradation of contraction a preferential sequence of motor unit recruitment occurs. Several studies (9, 33) have noted that recruitment occurs from the smaller motor neurons to the larger neurons. This is termed the "size principle" and evidence suggests that this sequence holds during both ramp (gradual) and ballistic (explosive) voluntary and reflex contractions (8). This recruitment sequence is logical from two perspectives. First, the larger, more powerful motor units are recruited only when high force or high power outputs are necessary and second, lower intensity or graded intensity exercises can be accomplished with greater metabolic efficiency. This recruitment sequence suggests that in order to train Type II fibers, which typically make up the larger motor units, very high force contractions must be used.

The size principle is predicated on the concept that all motor neurons within a pool receive the same amount and type of stimulus (at a given moment in time). While this may be true for some muscles when they are performing a specific task, more recent evidence suggests that the size principle may not hold for all conditions. Afferent input from cutaneous tissue (15, 23) or change of position (49) of a specific multifunctional muscle may alter the recruitment sequence. Furthermore, evidence suggests that very high speed contractions (compared to slow speed contractions) may alter the recruitment sequence and allow higher threshold motor neurons to begin contracting before or simultaneously with low threshold motor units (13, 44, 67). Additionally, the manner in which the brain organizes the initiation of fast versus slow contractions may be different (14). These data suggest that recruitment order may be altered if the movement pattern or velocity is altered, thus recruitment patterns may be specific for specific types of movements. There is also data suggesting that high velocity training may affect the contractile properties of the muscle differently than slow velocity or isometric training (17).

These observations may help explain the high degree of specificity observed as a result of strength training in relation to velocity (34), differences in 1 RM strength as a result of position or exercise changes (50, 52), and differences in strength-endurance as a result of position or exercise changes (41).

Specificity of Strength/Power Training

Cross-sectional studies of athletes training with different resistance training programs for long periods appear to show differential training effects in the ability to exert strength and power. Wrestlers training with high force/fast movements, compared to powerlifters training with high force/slow movements (heavy resistance training), showed greater rates of increase in isometric force of the leg resistance (31). Similar results have been observed when comparing weightlifters (high force/fast movements) to bodybuilders and powerlifters (30). Some longitudinal studies using relatively untrained or...
moderately trained subjects support this observation among well-trained strength/power athletes. Hakkinen and Komi (27) demonstrated that 24 weeks of heavy resistance training (low volume/high resistance) produced marked improvements in maximum squatting ability. However, improvements in the weighted squat jump were marked at 100 kg but diminished as the resistance decreased to 0 kg. This observation suggests that heavy resistance training produces its greatest effects (improvements) at the high force/low velocity end of the concentric force velocity curve (32). Training with low resistances and relatively fast muscle actions produce little change in the high force end of the force velocity curve but produces greater increases in the high velocity end (28). Differential adaptations for high force/low velocity (near maximal or maximal force exerted but speed limited by heavy weight) training versus high velocity (light weight) training are also apparent in force time curves. High force/low speed resistance training results primarily in an increase in maximal force at the low speed end of the force velocity curve, while high speed training results in a faster rate of isometric force development but little change in maximum isometric force (27, 28, 32).

Neural Vs. Hypertrophic Factors

Differences in hypertrophy have also been noted when comparing athletes from different resistance training backgrounds. Bodybuilders generally show greater hypertrophy compared to weightlifters (30); while this may be partially or wholly due to differences in training volume, inter-set rest periods and exercise selection, it also may be due to differences in contraction type. A longitudinal study (24 weeks) using moderately trained subjects and comparing the hypertrophic adaptation of heavy resistance training to explosive strength training (high power training), suggests that heavy strength training produces a greater increase in muscle fiber area than explosive training. Additionally, the hypertrophy from explosive training is largely confined to the Type II fibers (32). The hypertrophy adaptation from heavy resistance training takes place in both fiber types, although the Type II fibers hypertrophy at a faster rate (28, 32, 40). However, explosive or high power training results in greater increases in neural activation (as measured by IEMG and rate of isometric force production) than typical heavy resistance training (30, 32). Thus, changes in maximum strength may be strongly related to the hypertrophic adaptation and changes in rate of increase in muscular force may be strongly related to changes in neural activation (32, 53). However, it is also possible that the hypertrophy of the Type II fibers, although relatively small, may contribute to the increased rate of isometric force production (30). This does not mean that hypertrophy is solely responsible for gains in maximum strength or that neural adaptation is solely responsible for gains in explosiveness or maximum power. The time course of strength and power gains due to neural and hypertrophic adaptations vary according to the training history of the individual (32, 53).

Untrained subjects show rapid gains in maximum strength, largely attributable to neural adaptations during the first two or three months of training (32, 45, 53), with hypertrophy largely accounting for subsequent gains in strength (53). As an example, previously untrained 13 to 15-year-old boys showed parallel increases of maximum isometric strength and integrated electromyograms (IEMG) during 12 weeks of strength training (36). Continued training resulted in a plateau of maximum strength accompanied by a decrease in IEMG (25). Hypertrophic adaptation was probably responsible for the maintenance of maximum strength despite the decreased IEMG. Detraining caused both force and IEMG to decrease across eight weeks.

Strength/Power Relationships

It is clear from a variety of sources that stronger subjects generally produce greater maximum power outputs. For example, cross-sectional data shows that strength trained athletes with high maximum leg and hip strength measures (i.e. squat, front squat, etc.) have markedly superior maximum power outputs as calculated from counter movement and static vertical jumps (typical measures of explosiveness) when compared to untrained subjects or subjects in non-strength/power sports (30, 58, 60, 62). Longitudinal data assessing increases in the 1 RM squat and power from the vertical jump and stair climbing support this relationship (62, 65). While the exact nature of the relation between maximum strength and power is not clear, the following arguments seem reasonable:

1) Heavy strength training can increase maximum strength and power. However, heavy strength training which is continued for relatively long periods (several months) may result in a diminished rate of isometric force production and power performance (24 and unpublished data). Thus, the positive association between increases in maximum strength and maximum power output are largely restricted to the early phases of training (32). This suggests that in sports that require high power output during performance, the early emphasis of training can be on maximum strength development, with the emphasis shifting to power and speed development later in the training program.

2) However, it is also apparent that maximum strength levels have greater effects on power output as the resistance increases (27, 55). Therefore, in activities in which implements or equipment are used during performance, and in which maximum power outputs are necessary, maximum strength may be of primary importance. Speculation suggests that maximum strength would have its greatest effects at the beginning of movements in overcoming the inertia of the mass to be
moved; as the mass becomes larger a greater initial force would be necessary to produce a greater rate of initial acceleration (F = ma). After initiation of movement, the ability to continue to move a mass at a high velocity or further accelerate a mass can depend upon specific power training as well as maximum strength levels. Thus, athletes such as weightlifters training primarily with high power outputs, but also using heavy strength training, may show excellent adaptation to both.

Comparisons of weightlifters to bodybuilders showed that weightlifters possessed slightly greater maximum strength, faster rates of isometric force production and superior weighted and unweighted vertical jumps despite a smaller body mass (30). Additionally, weightlifters possess superior maximum power outputs as estimated from vertical jumps when compared to other strength athletes, such as football and basketball players (60). While some of these differences between weightlifters and other athletes may be due to genetic differences, some are likely due to training differences.

Strong relationships have been noted between IEMG and the relative intensity of weight training (27). The relative intensity of training (percent 1 RM) is known to be a primary factor in eliciting performance adaptations among weightlifters (31, 32) as well as other strength/power athletes. Thus, intensity of both high force and high power movements is an important factor in eliciting maximal strength gains and power gains.

3) Well-trained adult strength/power athletes have a decreased potential for maximum strength and power increases compared to untrained individuals. Results from relatively long-term observations of elite athletes suggest that their neural and hypertrophic adaptations are both smaller and have a somewhat different time course than those for untrained subjects (31, 32).

4) The preceding discussion suggests that considerable variation may be necessary in the training of advanced strength/power athletes in order to maximize both strength and power (32, 59).

Periodized strength/power training programs appear to offer a superior form of training for increasing strength and power (32, 59).

These data suggest that in order to appropriately train for very high force or high velocity performance movements, high force/high velocity training should be used with exercises similar in movement patterns to the performance. This agrees with the observation of many strength coaches that the closer the movement pattern and velocity of the training exercise is to actual performance movement patterns (biomechanical specificity) the greater the carry-over (46, 47). Furthermore, these data may explain the necessity of using a variety of movements in order to fully develop (hypertrophy) a muscle (46, 47).

**Effects of Fatigue**

Fatigue can reduce muscular force, decrease the rate of isometric force production (68, 71) and interfere with movement patterns, especially during high power technique-oriented activities such as the snatch (2). Thus, during high volume training, when fatigue levels are high, care should be taken to reduce the number of highly technique-oriented power exercises. Performing these exercises during a fatigued state may interfere with learning or stabilizing proper technique and results in diminished adaptations for maximum strength and power (2, 59).

**Categories of Exercise**

From a practical standpoint two broad categories of exercises can be defined as shown in Table 1.

It should be noted that within each category, slow and fast movements can be made. Slow movement speed does not necessarily mean that an exercise is not explosive. A slow movement may be considered explosive if the athlete applies maximal force as rapidly as possible, although the weight moves slowly due to its inertia. (Note: Explosive slow movements are not intentionally performed in a slow manner and can be considered explosive in that explosive strength is used in making an effort to accelerate the weight.)

In all power-oriented exercises the speed of movement should be as fast as possible for the weight used, rather than intentionally slow. An explosive slow movement requires a high level of neural activation, and is beneficial as long as reasonable resistance is used and good technique is maintained.

As previously pointed out, a stretch shortening cycle may modify the neural input to muscle and effect other changes which can potentiate concentric strength. Counter movement (plyometric) exercises use an eccentric muscle action followed by a concentric muscle action. The advantage of this type of movement is that the force of the eccentric contraction may be augmented by: 1) the storage of elastic energy by the agonist as a result of pre-stretch (1.5, 20); 2) causing a myotatic reflex (16, 42); and 3) potentiation of the muscle contractile machinery by pre-loading (4, 69). The exact mechanism of force enhancement as a result of counter movement is not completely understood (4).

As can be seen from Table 1, counter movement exercises can be performed slowly or rapidly depending upon the resistance encountered. The enhancement of the concentric muscle action increases with the speed of the eccentric (pre-stretch) movement (18).

---

**Table 1: Categories of Explosive Exercises**

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Counter Movement</td>
<td>Typical squats</td>
</tr>
<tr>
<td>a) Slow</td>
<td>Vertical jumps</td>
</tr>
<tr>
<td>b) Fast</td>
<td></td>
</tr>
<tr>
<td>2. Dead stop start</td>
<td>Dead-stop squats,</td>
</tr>
<tr>
<td>a) Slow</td>
<td>deadlifts</td>
</tr>
<tr>
<td>b) Fast</td>
<td>Static vertical</td>
</tr>
<tr>
<td></td>
<td>jumps, power</td>
</tr>
<tr>
<td></td>
<td>clean*, power</td>
</tr>
<tr>
<td></td>
<td>snatch*</td>
</tr>
</tbody>
</table>

*Correct technique requires a counter movement prior to the second pull.
and decreases with the time elapsed after the pre-stretch until the concentric muscle action (7, 18). The magnitude of the pre-stretch also can influence subsequent performance (4). A special category of a counter movement exercise entails starting the movement by encountering a sudden impulse, i.e. drop jumps. According to Komi and Bosco (36) and Bosco and Komi (5), this sudden impulse enhances the storage of elastic energy and the myotatic reflex (see Plyometric Exercises Position Statement on page 80).

A movement that starts from a dead stop does not allow the potentiation mechanisms at the beginning of the concentric muscle action to occur; this diminishes the force which can be exerted in the concentric muscle action. A dead stop initiation can be accomplished in two ways: 1) actually starting with the weight supported, such as doing squats in a rack or lifting from the floor, or 2) holding a dead-stop position after going through the eccentric portion of a movement. These exercises may be particularly useful for sport movements initiated from a dead-stop, such as the starting movements of a football lineman, sprinter or weightlifter.

Both categories of movements may be used advantageously in training, depending upon the basic movement characteristics needed.

**Speed-Strength Exercises**

Strength training exercises involving fast movements are sometimes termed speed-strength exercises. These exercises can produce very high power outputs, which is important for performance gains in power sports. Although most exercises can be performed as speed-strength exercises, more typical speed-strength exercises include snatches, cleans and pulls and various jerking movements. A comparison in Table 2 shows the estimated average power outputs of speed-strength exercises versus typical strength exercises among athletes of similar body mass in competition (modified from 19, 21, 22):

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Absolute Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench press</td>
<td>300</td>
</tr>
<tr>
<td>Squat</td>
<td>1100</td>
</tr>
<tr>
<td>Deadlift</td>
<td>1100</td>
</tr>
<tr>
<td>Snatch*</td>
<td>3000</td>
</tr>
<tr>
<td>2nd pull**</td>
<td>5500</td>
</tr>
<tr>
<td>Clean*</td>
<td>2950</td>
</tr>
<tr>
<td>2nd pull**</td>
<td>5500</td>
</tr>
<tr>
<td>Jerk</td>
<td>5400</td>
</tr>
<tr>
<td></td>
<td>75 kg Female</td>
</tr>
</tbody>
</table>

*Total pull: lift-off until maximum vertical velocity
**2nd pull: transition until maximum barbell velocity

It can be seen that using typical high force-low velocity exercises does not produce the highest power outputs. In addition, the highest average human power outputs recorded have occurred during the performance of weightlifting movements, (19, 21, 22). Using these high power exercises in training may explain the differences in power output when comparing weightlifters to bodybuilders and powerlifters.

Considering the arguments concerning movement specificity and the relative power outputs of pulling movements (i.e. snatch pulls, snatches, clean pulls, cleans, etc.) it can be argued that these exercises should have considerable transfer of training effect to many strength-power sports. This is because the movement patterns, velocities and power outputs of these pulling movements are more similar to many sport performances than are typical high force slow movements.

**Injury Potential of Speed-Strength Exercises**

Few studies have been carried out examining the injury rate of speed-strength exercises such as the snatch or clean. A study of injury rates is difficult from a practical standpoint since these exercises are usually performed in conjunction with various other exercises during a typical training program. Studies of weight training which include a variety of speed-strength exercises may allow some insight into the relative safety of training that includes these exercises. A four-year longitudinal study of weight training related injuries among college football teams (American Injury Monitoring System) suggests that one percent of time-loss injuries were due to weight training as a result of football (72). Injuries resulting from weightlifting competition and weightlifting training do not appear to be excessive and may be less than from sports such as basketball, football and gymnastics (59).

Biomechanical techniques may provide some insight into the relative injury potential of various activities, including speed-strength exercises. Ground reaction forces measured using a force plate may be used as an estimate of the stresses on the lower extremity. Burkhardt et al. (6) examined the propulsive and impact forces of a counter movement vertical jump, drop jumps from 42 and 63 cm. and 80 and 90 percent of 1 RM power cleans. The results showed that peak propulsion forces (relative to body mass) of the power cleans were similar to those of the jumping movements, and impact forces were similar or smaller than landing after jumping. (The authors point out that these measures were made in controlled laboratory conditions and that athletic competition could result in higher forces; furthermore, landing from jumping often takes place on one leg which would increase the stress and shear forces on the joints.)

Biomechanical modeling using appropriate mathematical techniques can be useful in estimating the forces at a particular joint during an isometric contraction or a specific movement. For example, forces at the patellofemoral joint have been estimated for a number of activities and have been summarized by Kaufman et al. (35). Peak forces range from approximately 0.5 times body mass for walking to 20 - 25 times body mass for jumping impact forces (37) and the
eccentric portion of the jerk (73). Although patellar tendon or ligament rupture has occurred during weightlifting (73) and powerlifting movements, it is rare and may be a function of the use of anabolic steroids, corticosteroids or over-training, rather than the high forces encountered during rapid eccentric movements (59, 61). (See NSCA Position Statement on the Squat for the additional information on forces generated at different joints).

Considering the relatively low incidence of weight training and weightlifting injuries relative to the high forces generated during some movements, it is likely that a training adaptation has occurred which reduces injury potential. Weight training, including speed-strength exercises, can increase the tensile strength of visco-elastic tissue and particularly increases bone density and strength (59, 61). Speed-strength exercises may be of particular importance in stimulating bone remodeling and enhancing bone tensile strength (61). It is also important to realize that speed-strength exercises such as snatches, snatch pulls, cleans, clean pulls and jumping exercises are typically done in a controlled manner and, during training, should be performed under proper supervision. By using proper technique, both compressive and shear forces can be minimized.

Rutherford (51) and Palmitier et al. (48) point out that the concepts of movement and velocity specificity are often overlooked in both injury prevention and rehabilitation programs. Loading the joints in a manner consistent with daily task and sports performance is crucial to both the prevention and rehabilitation of injuries (48). It has been suggested that constant adherence to slow velocities or isolated weight training movements during training may not adequately prepare visco-elastic tissue for high velocity training exercises or competitive movements and, in fact, may increase injury potential (51). Because of the high forces which may be encountered in explosive movements used in training or competition for many sports, such as football, track and field and gymnastics, appropriate conditioning is necessary to reduce injuries. Conditioning programs can consist of a variety of speed and speed-strength exercises including the Olympic lifts and appropriate variations. It is essential that explosive exercises be taught by well qualified and experienced instructors who know the correct technique of the exercises, as well as the correct progression of activities leading up to the use of explosive exercises, thereby minimizing injury potential.

References


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