When designing resistance training programs for athletes, variables such as exercise selection, the number of sets and repetitions and frequency of training are given serious consideration. However, one variable frequently neglected is the speed of movement achieved during training. The following is an analysis of the effects of explosive strength training on the ability to generate high-speed strength. Explosive training has been defined as the use of maximum or near maximum rates of force development (46).

In sports science there are conflicting opinions about the optimal speeds of weight training movements (41, 44). One theory holds that strength training exercises should simulate the specific sport movements as closely as possible in terms of anatomical movement pattern, velocity, contraction type and force. According to the opposing theory, it is only necessary to strengthen the appropriate muscle groups and that by practicing the skills of the sport the strength gained in non-specific training enhance performance.

A slow contracting muscle can exert a greater amount of force than the same muscle contracting at a faster rate. Thus, training slowly with high resistance will develop a stronger contraction than contracting a muscle quickly with less force (38). A stronger contraction of the muscle will develop greater contractile properties, enabling it to contract faster. However, some studies have shown that subjects training at a fast repetition speed are able to produce significantly more force at fast velocity than those training at a slow repetition speed (38).

There is evidence to suggest that the ability to generate tension at different speeds of movement is somewhat specific to the velocity at which training occurs (15, 44). According to Sharp and Costill (47), the principle of specificity states simply that the effects of training are specific, or confined, not only to the muscle groups being used but also to the way in which those muscle groups are being used.

Behm (5) is in agreement, noting that "the most effective means of training may be ones that mimic the speed of performance." According to Counsilman (9) the use of weight lifting exercises with heavy weights at slow speed has limited merit for swimmers, basketball and football players, sprinters or any other athletes interested in acquiring speed, because this type of exercise builds big but slow muscles. In sports events requiring a high level of force and speed, the ability to develop high speed strength is of particular importance (25).

Power in Athletics

Power is the amount of work produced by the body per unit of time and can be calculated as the product of force and velocity. According to Kaneko et al. (25), power is affected not only by the amount of energy resources but also the speed of energy liberation. Increasing power in athletes involved in speed-strength sports enhances the opportunity for improved performance. Power is increased only if (a) the same amount of work is accomplished in a shorter period of time or, (b) an increased amount of work is accomplished in the same amount of time (49). In most athletic events, power is more important than static strength in achieving optimal performance. Komi (26) points out that the generation of force in a very short period of time is characteristic of most normal movements. The importance of muscular power is also supported by Adams et al. (1), Mayhew et al. (31) and Moffroid (34) who suggest that muscular power is a fundamental aspect of almost every sport. This concept was supported by Kanehisa and Miyashita (24), who said the important factor is how much power an athlete can exert, rather than how much muscular strength the athlete possesses. As suggested by Palmieri (38), because most sport activities are performed at high velocities, a stronger muscle is useless if it cannot produce sufficient levels of strength at the velocity required in the activity. This evidence indicates that because most athletic events involve high-speed movements, the athlete should train at speeds equal to or greater than those speeds used during competition (53). Thus, it can be stated that the ability to exert great force in a short time often dictates success. However, the usefulness of explosive resistance training in improving performance depends on the specific requirements of the sport, in terms of movement patterns and velocity requirements. In addition, the training state of the athlete's also requires consideration (50).

Many athletes and coaches, unaware of the relationship between low-
high-speed strength, assume they are the same thing (9, 49). While high-speed strength is related to low-speed strength, high-speed strength also involves the factor of speed.

The force/velocity curve is one method commonly used to describe the mechanical characteristics of the muscle. The force/velocity diagram demonstrates the relationship between the force and speed of single maximal contractions. Gambetta (16) stated that in the majority of athletic resistance training programs, most of the time and effort is spent on the upper left (high force, slow velocity area) of the force velocity curve (Figure 1). However, most athletic performances occur on the lower right of the curve (low force, high velocity) where the expression of force with velocity is the main consideration.

Optimal Strength
According to Gambetta (16), the critical factor is to emphasize optimum rather than maximal strength. While slow-speed strength is simply the ability to produce force (37), optimum (or high speed) strength improves performance. In a study conducted by Poprawski (42), Edward Sarul, 1983 World Champion in the shotput, was compared to a group of nine well-trained shot-putters. While Sarul was slightly stronger than the group average in the bench press, snatch, power clean and squat, the major difference occurred in tests for speed and power. For example, in the snatch Sarul’s velocity ranged from 4.13 percent faster than the average to 22.43 percent faster at the heaviest test weight (80 kg). Similar results occurred in the squat and Margaria-Kalamata test of leg power. This supports the concept of the importance of optimal strength over maximal stress.

High Velocity Training
Numerous studies have been conducted to investigate “fast” and “slow” speeds of movement during resistance training. In part, this interest has been stimulated by the development of isokinetic devices that permit the control of the rate of contraction. In addition, there is a widespread conviction that strength training exercises should closely simulate the athlete’s specific skill(s) (23). The majority of the investigations which studied the role of “fast” and “slow” contractions during weight training used isokinetic devices in both the training and testing of subjects. The primary reason for this is that the rate of joint movement can be predetermined by setting the isokinetic device at the desired speed. However, it is recognized that the majority of athletic training programs utilize weight equipment, not isokinetic. Thus, it could be argued that the applicability of these studies to most athletic training programs is limited because of the dissimilarity of training devices. However, athletes involved in events with a very high-speed strength component (i.e., throwing events in track and field) typically emphasize Olympic lifts (i.e., snatches, jerks) in their training programs. For example, Chernyak and Charkeyev (7) noted that in a typical weight training program for throwers (shot-putters and discus throwers) nearly 60 percent of their lifts were Olympic lifts or associated training exercises. These lifts are executed at velocities much higher than typical weight training movements and thus can be considered explosive by nature. While this does not necessarily demonstrate that high-velocity training is the best way to increase high-speed strength, it does imply a fact that critical factor may be the speed of contraction, regardless of whether or not isotonic or isokinetic equipment is utilized.

As previously mentioned, a number of investigators (6, 10, 21, 34, 40) have examined the role of speed of movement during isokinetic movements and the resulting performance and/or physiological adaptations that occur due to training. While there are conflicting results from these studies, there is a general consensus that those subjects who strength train at fast speeds perform better in tests at fast speeds than do subjects who train at slow speeds. It has also been demonstrated that an intermediate training velocity may exist which can enhance muscular output over a wide range of contraction velocities (15).

Fast vs. Slow
The primary area of disagreement among researchers is: (a) Does training at fast speeds optimally improve performance at both slow and fast speeds? and (b) Is slow training more effective than fast training at improving slow-speed strength, while fast training is more effective at improving high-speed strength. What authors label as fast-speed training in some studies could actually be best described as moderate speed.

Figure 1. Area of emphasis vs. area of need

![Diagram](Adapted from Gambetta, 1987)
Support for the superiority of high-speed training as a means of improving performance at and below training speeds was provided by Adeyanju, et al. (2) and Moffroid and Whipple (34). Based on the results of their study, Moffroid and Whipple concluded that low-speed, high resistance training produces greater increases in muscular force at low speeds only. In contrast, high speed, low resistance training results in improvements in muscular force at all speeds of contraction at and below training speeds. Adeyanju, et al. (2) came to a similar conclusion, suggesting that:

1. Isokinetic training is effective in developing low-speed strength, high speed strength and endurance.

2. Low power (low-speed, high-load) exercises produce greater increases in muscular force only at slow speeds.

3. High power (high speed, low load) exercises produce increases in muscular force at all speeds of contraction at and below the training speed.

4. Isokinetic fast-speed training is superior to slow speed training in the development of high-speed strength.

Mastropaolo and Takei (29) lend further support to the superiority of high velocity training in producing increases in both slow and high speed strength. These researchers found that after training, both the slow and fast groups improved in slow strength. Additionally, the fast group improved in high speed strength and velocity (the five heaviest loads) while the slow group did not.

**Speed Specific**

In contrast, other investigations have found training to be more speed specific. That is, training at slow speeds improves test results at slow speeds but not fast speeds, while training at fast speeds improves test results at fast speeds but not slow speeds. Coyle et al. (11) found training to be more speed specific. The study required subjects to perform maximal isokinetic knee extensions at 60 degrees per second (slow), 300 degrees per second (fast), or both 60 and 300 degrees per second (mixed). Investigators concluded that performance in a slow-velocity event (of which there are very few in athletics) that depends on maximal muscular tension is best improved through high tension, slow velocity training. As Coyle et al. (11) pointed out, "this slow training, however, will not improve fast-velocity performance, at least during the initial stages of training. Muscular power is enhanced through high-velocity training that may also improve output at slower velocities." These results are similar to the conclusions of the Coyle and Feiring (10) study in which subjects trained on a isokinetic leg extension device at velocities of either 60 (slow) or 300 (fast) degrees/sec, or a mixture of both 60 and 300 degree/sec (mixed).

During post-testing at 60 degrees/sec the slow, mixed and fast group significantly improved peak torque, with the slow group showing the best results. Although the fast group significantly improved their post-test at 60 degrees/sec, it was not a significant improvement when compared to the placebo group. In contrast, peak torque at 300 degrees/sec improved only in the two groups that trained at that speed (mixed and fast). Thus, as noted by Coyle and Feiring (10), "physiological significant improvements (>placebo) in slow muscle power were obtained only through slow training, while fast muscular power was improved only by including fast training."

Kanehisa and Miyashita (24) also used an isokinetic leg extension device to evaluate the effect of various speeds of training. Subjects were pre- and post-tested for maximal knee extension high-speed strength at five specific speeds. Subjects were randomly assigned to one of three training groups, slow (60 deg/sec), intermediate (180 deg/sec) or fast (300 deg/sec). During post-testing the slow group showed significant increases in high-speed strength at all test speeds, with smaller percent improvements as test speeds increased (24.8 percent at 60 deg/sec to 8.6 percent at 300 deg/sec). The intermediate group demonstrated similar increases in high speed strength at all speeds, from 15.4 to 22.4 percent. Unlike the slow and intermediate groups, the fast group improved high-speed strength significantly only at the faster test speeds (23.9 percent at 240 deg/sec and 22.8 percent at 300 deg/sec). Similar results were derived from a study by Caozzo et al. (6). This investigation involved training and testing on an isokinetic leg extension machine. Subjects were randomly assigned to either a control group, training at 96 deg/sec or training at 240 deg/sec. During post-testing, subjects who trained at 96 deg/sec showed a mean improvement of 14.7 percent at 0 deg/sec, but only 0.5 percent at 288 deg/sec. On the other hand, subjects that trained at 240 deg/sec showed a similar but opposite trend. "This evidence indicates that velocity-specific strength training programs can produce alterations in the in vivo force-velocity relationship which are related to the training velocity" (40).

**Limited Benefits**

A similar conclusion was drawn by Lesmes et al. (27) who found that strength training benefits may, in part, be limited to speeds at and below training speeds. This suggests that the athlete should train at speeds approximating or exceeding those used during competition. Another study supporting the concept of velocity specificity in training was conducted by Ewing et al. (15). Subjects performed repetitions at a rate of either 60 deg/sec or 240 deg/sec. Subjects were pre- and post-tested for peak torque and high-speed strength on an isokinetic dynamometer at 60, 180, and 240 deg/sec. In testing at slow velocity (60 deg/sec), only the group that trained at that rate showed a significant increase of peak torque. At the intermediate test speed (180 deg/sec), both groups increased torque and high speed strength with no difference between groups. When tested at 240 deg/sec, only the group that had trained at that velocity demonstrated an increase in peak torque.

The specificity observed in this study was greater than reported in other
studies (27, 34). The results are in concurrence with previous findings that isokinetic training is effective in enhancing peak torque (11) and high-speed strength (24) but the gains that can be expected are affected by velocity of training and testing (5).

Based on the available evidence, Sale and MacDougall (44) stated that there is a specificity of velocity. Training at low velocities substantially increases low velocity strength but has little effect on high velocity strength. In contrast, training at high velocity causes a greater improvement in strength at high velocities than at low velocities. Sale and MacDougall also noted that it is easier to increase low velocity strength with specific training than high velocity strength with specific training. Mixed training produces intermediate results. In addition, it has also been demonstrated that an intermediate velocity exists which can enhance both low and high velocity strength (41, 44).

It also is important to note that other studies have demonstrated no significant differences when training either at fast or slow speeds. For example, Palmieri (38) conducted a training study in which subjects trained at either fast or slow speeds or a combination of both (fast was defined as performing concentric contraction in .75 second or less, slow was defined as concentric contractions performed in two or more seconds). It was found that while all three groups significantly improved leg high-speed strength (p < 0.05), none of the groups gained significantly more than the other. Based on these results, Palmieri concluded that slow, fast and mixed training results in significant gains in high-speed strength, but no significant differences occurred because of the various training methods.

To summarize, some investigations have found that fast training is more effective than slow training at increasing high-speed strength at both slow and fast test speeds. In contrast, other studies indicate that there are velocity-specific training effects derived from slow or fast contractions. Accordingly, fast training best improves test results at fast speeds, while slow training best improves slow test results. In addition, some studies have shown that, regardless of training speed, no significant differences occur in terms of improving high-speed strength.

Adaptations

The majority of research investigating the physiological adaptations of the neuromuscular system to physical training have primarily utilized slow contraction velocities in their training and testing methodology (11). Although a limited number of studies have investigated the training effects derived from high-velocity contractions, it can be hypothesized that the physiological adaptations that occur as a result of such training differs from the adaptations that occur during slow-velocity contractions. A slow velocity of execution is associated with production of high forces, while high velocity movements favor high levels of neuromuscular output (41). It is therefore apparent that resistance which is light enough for high speed strength development is not heavy enough for optimal development of low speed strength.

Hakkinen, et al. (21), stated that training induced adaptations in low speed strength and isometric force-time or force-velocity curves are dependent on the type and/or duration of the training method. The magnitudes and time courses of the adaptations in the neuromuscular system give valuable information to those attempting to develop more effective and specific training regimens.

Adaptations

Muscles, like other organs in the body, adapt to stress (9). This adaptation allows the muscle to better tolerate the particular stress that is imposed. Muscles can change physiologically in many ways: by changing size, changing chemical composition, increasing the number of functional capillaries, increasing the number of mitochondria, etc.

A review of the adaptations that occur as a result of training at the muscular level, show that the power-generating contractile mass can be increased through hypertrophy and perhaps hyperplasia. A motor unit is comprised of a motoneuron which innervates specific groups of either fast or slow muscle fibers. A number of studies also have found that recruitment occurs in sequence, from the smaller to the larger motoneurons. This is called the size principle (50). Evidence suggests this recruitment pattern is consistent during both gradual and ballistic contractions (8). The highest threshold motor units possess the largest and fastest twitch contractions and may be the units that many untrained people cannot recruit or raise to the optimal firing rates (43).

Sale stated that during brief maximal velocity contractions, motor units will fire briefly at rates much higher than what occur during maximal force contractions. This very high firing rate increases the rate of force development, with the highest firing rates occurring during maximal ballistic contractions in which the subject attempts to contract as rapidly as possible (43). Thus, high speed training may increase the ability to fire motor units briefly at very high rates. Because of this, Sale suggested the rate of force development would, therefore, increase even if peak isometric force does not. “This adaptation might account for the specific effects of explosive training upon rate of force development . . .” (43).

It is commonly believed that strength training at low velocities recruits only slow twitch motor units, with hypertrophy occurring only in slow twitch muscle fibers. Similarly, it is believed that training at high velocity selectively recruits fast twitch fibers and causes hypertrophy of fast twitch muscle fibers. While the concept of selective recruitment based on speed of movement may be widespread among coaches and athletes, it is not in agreement with a considerable body of evidence. It is well accepted that high resistance low velocity training results in a greater degree of hypertrophy than does explosive training.
However, in both conventional slow velocity weight training and slow isokinetic training, hypertrophy of both fiber types occurs (28). In fact, it was found that fast twitch fibers are enlarged to a greater extent than slow twitch fibers in bodybuilders and power lifters (who train exclusively at slow velocities) (28). This suggests that type II fibers, which generally make up the larger motor units, respond optimally to very high force contractions (50). This is not meant to imply that fast twitch motor units were recruited more, but that fast twitch fibers are more adaptable in relation to hypertrophy. As additional evidence, Sale and MacDougall (44) noted that EMG studies have indicated that providing the degree of voluntary effort is maximal, motor unit activation is similar in type I and type II fibers, regardless of velocity of contraction (13, 30).

Indeed, there is evidence that fast twitch motor units are activated during isometric contractions (19, 44, 54). In addition, a positive correlation between isometric strength and percentage of fast twitch fibers within a muscle has been established (51). As pointed out by Sale and MacDougall, if fast twitch motor units were not recruited during ultra slow contractions, a positive correlation between isometric strength and fast twitch fibers would not be likely. Similarly, Ewing et al. (15), found in a study comparing fast and slow speed training that while there was an increase in both type I and type IIa fiber areas, there was no change in the type Iib fibers. It had been hypothesized that there would be greater hypertrophy of type I fibers in the slow training group and in the type II fibers in the fast training group. However, this was not the case. As suggested by Ewing et al., type I and IIa fibers are highly oxidative, and a possible explanation for this finding is that even though the fast speed training was four times faster than slow speed training, the former was still only 35 percent of the maximal velocity of unrestricted muscle (12). The finding that both fast twitch and slow twitch fiber areas increased during training is consistent with results of the MacDougal et al. study. In that study, heavy-resistance training increased the fast twitch fiber area by 39 percent and slow twitch fiber area by 31 percent. Ewing et al. noted further that isokinetic training appears to result in hypertrophy of type I and type IIa muscle fibers, but the extent of the hypertrophy does not seem to be altered by the speed at which the muscle is trained.

While adaptations within the muscle fibers may be partially responsible for improvements in high-speed strength, neurological adaptations that enhance neuromuscular output at and below the training velocity cannot be excluded (11). Both slow- and high-speed strength is determined not only by the quantity and quality of involved muscle mass, but also by the extent to which the muscle mass may be activated neurally by voluntary effort (43). The importance of neural adaptations in increases in slow-speed strength were also noted by Schmidtleicher (46), who pointed out that in addition to hypertrophy and perhaps hyperplasia, adaptations of the nervous system to the training stimulus are also important. According to Schmidtleicher, there is clear evidence that following a high intensity strength training session there is an improvement in the ability to quickly recruit the muscle fibers. It has been assumed that the cause of this adaptation is within the nervous system. In the case of trained athletes, this improvement in high speed strength is due to an improved ability to rapidly recruit motor units and increase the firing rate of motor neurons. In addition, because there is evidence that the brain organizes and initiates fast, ballistic movements differently than slow movements, many believe that neural adaptations are primarily responsible for improvements seen in the development of high-speed strength (44).

Neural improvements occur by increasing both the number of motor units recruited and improving the synchronization of this recruitment (11). Coyle et al. has speculated that the neurological adaptations which occur as a result of high velocity training may not only include the ability to recruit more motor units during the activity, but also the synchronization with which these motor units are recruited. The improvement in synchronization is probably a result of the dendrites of the alpha motor neurons receiving increased input from the sensory fibers and the higher motor centers increasing their descending activity (26). It was suggested by Komi that while both of these mechanisms contribute to the increased ability to generate force, the latter mechanism has received more conclusive support. As Coyle et al. (11) noted, it is technically difficult to determine the extent to which these neural mechanisms contribute to the training-induced improvements in neuromuscular high-speed strength.

**Intramuscular Coordination**

Another mechanism by which high-speed strength is increased is improved intramuscular coordination (46). Intramuscular coordination, as defined by Schmidtleicher, describes the ability of all the muscles involved in a movement to cooperate wholly with respect to the aim of the movement. Poliquin (41) suggested that the amount of adaptation that occurs is directly related to the velocity of training. The closer a given load is moved to maximal velocity the greater the intensity of the exercise and the greater the training effect on a neuromuscular basis. The highest firing rates are seen in maximal ballistic contractions in which the subject attempt to contract muscle as rapidly as possible (13, 43) is in agreement, suggesting repeated attempts of explosive training may increase the ability to fire motor units briefly at high rates. Thus, for increases in neural activation, specificity of speed of motion has to be considered (20).

The speed of movement at which the athlete trains, as a rule, will determine the speed necessary for optimum performance (36). This suggests that increases in muscular strength are explained largely by improved neural control of the motor function. Based
on this, it seems appropriate to include high speed exercises in the training programs of athletes.

**Slow Speed**

As suggested by Sale and MacDougal (44), the question of whether there is justification for slow velocity strength training for athletes who perform high velocity movements remains unanswered. However, the answer is yes, based on the following adaptations to slow velocity training:

1. Slow velocity training may be necessary to stimulate maximal adaptation within the muscle. Muscle growth and increases in contractile strength are related to the amount of tension developed within the muscle (18).

2. Slow-speed training augments both the duration of the stimulus and the levels of tension imposed on the muscle, thus favoring a faster development of strength and muscle mass (41).

Based on these facts, it is clear that slow-speed strength training is essential for athletes. When designing resistance training programs it is important to remember that the potential for strength gains are much greater at slow speeds than at high speeds (10, 34). For example, athletes can expect much greater strength gains performing the back squat (slow speed) than from power cleans (fast lift) (41).

It must be noted, however, that slow- and high-speed strength are not distinct entities, but have a hierarchic relationship (49). Slow-speed strength is the basic quality that influences high-speed strength performances. Because high-speed strength is the result of a combination of speed and strength, increasing only high-speed strength, or only slow speed strength, will limit the potential for improving high-speed strength. As explained by Stamford, because the effect of strength and speed on power is multiplicative, athletes may be better off trying for smaller gains in both slow- and high-speed strength rather than concentrating on improving only one of these components. This concept was supported by Verkhosansky and Lazarev (52). They noted that it is necessary to increase the amount of slow-speed strength available to achieve optimal gains in high-speed strength. Stone (50) was in agreement, noting that stronger subjects are generally able to produce superior high-speed strength than are weaker subjects. For example, subjects with high levels of leg and hip slow-speed strength produce superior maximum high-speed strength outputs, as determined from counter movements and static vertical jumps. Poliquin (41) suggested that while high-speed strength training is specific to movements performed in most sports, this high velocity training must be done only after obtaining a solid base of slow-speed strength. The latter can be obtained through slow movements. Thus, instead of constantly striving for improvements in only speed or strength, including both variables in the training program will result in the best increases in power.

**Greater Forces**

In addition to being less effective in bringing about positive increases in slow-speed strength, explosive strength training results in potentially greater forces applied to muscles, ligaments and tendons (5). For these reasons and others, some believe high velocity training should be avoided. Other researchers (33, 37), while not suggesting that high velocity training should be avoided, suggest that, because the strength and mass of connective tissue is positively affected by strength training, it makes sense that connective tissue should first be strengthened with slow-speed training. This training should occur before any high-speed training is performed, reducing injury potential.

With high-resistance, low-velocity strength training, high-speed strength may be increased only at lower velocities, according to Mayhew et al. (32). These authors suggested that high-speed strength at higher velocities may actually decrease as 1RM strength increases. As Mayhew et al. suggested, “slow-speed nonspecific, heavy-resistance training may have very little effect on sports performance high-speed strength output. However, when high velocity overload training is performed in the specific range of motion of the activity, performance may be enhanced.”

**Velocity**

As suggested by Stone (50), the resistance training program for sports that require high-speed strength should be established so that following a period of high-resistance, low-velocity training, a transition to higher-velocity training be made. This is supported by recent studies (14, 41, 53) that demonstrated that periodized training in which individuals move from low to high velocity may be necessary if increases in force are required at both speeds. Research conducted by Doherty et al. (14) supports velocity-specific resistance training: low-velocity training produces greater increments in force production at low-speed than high velocity training. Doherty et al. also suggested that resistance training in the general phase should be completed at slow to moderate speeds, with gradual increases of movement speed as the competitive season approaches.

Gambetta (16) and Garhammer (17) suggested that another benefit of incorporating periodization into a strength training program is that heavy resistance low-repetition training, carried out for an extended period of time, may result in maladaptation symptoms seen in overtraining. This overtraining interferes with the learning of skills and perfecting technique. To avoid this situation Gambetta and Garhammer advised coaches and athletes to vary the intensity of training so that lighter resistance, higher velocity training follows periods of higher resistance, slower velocity training. This higher velocity training would occur (16) when the emphasis is on learning and perfecting technique within the sport. Considerable variation may be required in the training programs of advanced strength/power athletes to maximize increases in both slow- and fast-speed strength (50).
Speed of Movement

Training with lower resistances and higher speeds results in little change at the high force end of the force/velocity curve. However, such training does produce greater increases at the high velocity end of the force/velocity curve (50). Similarly, while high-resistance, low-velocity training results in little change in time to peak isometric force, low-resistance, high-velocity training results in a faster rate of isometric force development. Thus, training for high velocity or high force performance should be done with high velocity/high force exercises similar in movement patterns to the performance (50). This is in agreement with many strength coaches who believe that the degree of carry-over is improved as the exercise movement pattern and velocity more closely duplicates the movement patterns of the sport (Stone, 1993).

To accomplish this high velocity training, Poprawski (42) suggests ignoring the traditional theory which states that more weight is automatically better. Instead, the chosen resistance should be smaller than normal so that the athlete can concentrate on speed of movement. Behm (3) suggested when the training goal is to increase high speed strength, the resistance should be limited to 50 percent of maximum slow-speed strength (1RM) because higher tensions inhibit the ability to generate speed. In contrast, Poprawski (42), Spassov (48) and Verkhoshansky and Lazarev (52) believed the ideal range is between 50 and 70 percent 1RM.

One exception to the use of lower percentages may be when utilizing the Olympic lifts or associated training exercises. According to Garhammer (17), power output decreases very little in these lifts as the weight approaches 1RM. This is due to the necessity of completing these movements in a very limited period of time if the lift is to be successful. In contrast with other types of resistance training exercises (i.e. squat, bench press), power outputs decrease markedly and high speed is not necessary for success of the lifts (17) (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Power Outputs of Different Exercises</th>
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<tr>
<td>Exercise</td>
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<td>Bench Press</td>
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<td>Squat</td>
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<td>Deadlift</td>
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<tr>
<td>Snatch*</td>
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<td>2nd pull**</td>
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<tr>
<td>Clean</td>
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<td>2nd pull</td>
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<td>Jerk</td>
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Adapted from Stone (50).

Regardless of the percentage of 1RM, the emphasis when training for high-speed strength should be on training speed (42). This is important because training has a favorable influence on velocity only when the goal during training is to achieve the highest velocity possible (48). This can be readily demonstrated on a force-time curve. Training at slow speeds raises the force time curve (increasing the time to peak power), while training at high speeds shifts it to the left (reducing time to peak power) (Figure 2).

High Velocity Training

While isometric strength is primarily determined by cross-sectional muscle area, contraction speed is influenced by such factors as chemical energy reaction, neural input and muscle fiber composition (25). Thus, training programs for improving high speed strength should be more complex than training for slow-speed strength.

An example of this complexity was provided by Verkhoshansky and Lazarev (52). They suggested that for sports that require speed and endurance, a training program of six to eight exercises, six sets per exercise, in the following progression:

Set 1 = 50 percent of 1RM for 10 repetitions
Set 2 = 60 percent of 1RM for 10 repetitions
Set 3 = 70 percent of 1RM for 8 repetitions
Set 4 = 60 percent of 1RM for 8 repetitions
Set 5 = 50 percent of 1RM for 8 repetitions
Set 6 = 50 percent of 1RM for 6 repetitions

Verkhoshansky and Lazarev (52) noted that during each set strong emphasis needs to be on speed of execution. The ability to execute the training at higher speed of execution is enhanced by the lower percentages of 1RM recommended by these authors. While training at percentages below 70 percent of 1RM is generally considered too low for optimal slow-speed strength gains, speed of movement will be greatly enhanced.

In contrast to the protocol suggested by Verkhoshansky and Lazarev, the 1987 Soviet Lecture Series #2, in the NSCA Journal (35), suggested the following protocol when the emphasis is on increases in explosive strength:

Sets 1 and 2 = 90 percent of 1RM for 2 to 3 repetitions. Rest 2 to 3 minutes between sets.

Sets 3 and 4 = 30 percent of 1RM for 6 to 8 repetitions done explosively. Rest 6 to 8 minutes between sets.

Figure 2. Effect of training: force-time curve

![Figure 2](image-url)
Sets 4 and 5 = depth jumps for 10 repetitions

At this point the athlete rests for 10 to 15 minutes and completes the sequence again. Based on the information provided, the principle of heavy resistance followed by explosive movement must be maintained.

Pedemonte (39) provided information on percentages to be used during explosive training based on the results of a study conducted by Soviet researchers. This investigation evaluated the effect of various percentages on speed of movement of lifters performing a hang snatch. Subjects used loads of 30, 40, 50, 60 and 70 percent of 1RM. The athletes were told to perform continuous repetitions until maximal speed decreased. With a load of 30 percent 1RM, the athletes were able to maintain speed of movement for 21 seconds. At 40 percent 1RM, the athletes were able to maintain speed of movement for 12 seconds before speed of movement decreased. Time at top speed was reduced to six seconds at 50 percent 1RM. At the heavier loads of 60 and 70 percent, speed remained constant for 18 and 12 seconds, respectively. However, this speed was slower than was achieved with loads between 30 and 50 percent 1RM.

Based on this information, the authors suggested using loads between 30 and 40 percent 1RM, and occasionally 50 percent of 1RM, when seeking to develop high speed strength. Loads of 60-70 percent of 1RM and heavier are effective at increasing slow-speed strength but not high speed strength. As explained by Pedemonte (39), “the athlete needs to seek a light load that allows him to display top speed. In other words, it seems more suitable to pursue greater speed rather than increase the load percentage.”

Stone (50) suggested that in all high-speed strength exercises the speed of movement should be as great as possible for the weight used. This highvelocity training should be completed with exercises similar in movement patterns with the performance.

It is important to note that the specific percentages utilized in the training program depend on the sport the athlete is training for and the specific slow-and high-speed strength requirements of that sport. Stone (50) noted that the degree of emphasis on increases in slow-or high-speed strength depends on the activity for which the athlete is preparing for. For example, in activities that utilize implements or equipment (i.e., shot put, discus) increases in slow-speed strength may be of greater importance than only emphasizing increases in high-speed strength.

There is disagreement as to how long high velocity training should be performed. According to Adams et al. (1) from both physiological and psychological standpoints, four to six weeks of high intensity high-speed strength training is the optimal length of time that the central nervous system can be stressed without excessive strain or fatigue. Some sports physiologists believe that neuromuscular adaptations contributing to high-speed strength may occur during the first two to four weeks in a high-speed strength cycle (1).

In contrast, Schmidtleicher (46) suggested that experience, as well as investigations from Hakkinnen et al. (21) and Hakkinen and Keskinnen (22) indicate that after approximately 9 to 12 weeks of training, depending on the type of training and gender of the subjects, the rate of increase drops off dramatically. Based on this, Schmidtleicher suggested that after 9 to 12 weeks training goals should be altered.

Thus, individuals involved in training athletes use a variety of training protocols to increase high-speed strength in athletes. These variations include program design, the recommended percentages of 1RM and the length of time explosive training can be performed effectively. There has not been enough research completed to be able to state with confidence that any particular program will result in greater or faster increases in high-speed strength.

Conclusions

Despite a lack of substantial scientific evidence, it appears that the ability to generate high-speed strength is positively influenced during strength training when the emphasis shifts from high resistance slow-speed training to training with lower resistances and higher velocities. The ideal loads used during this high speed training would appear to range from 30 to 70 percent of 1RM, depending on the specific demands that face the athlete during competition. However, a variety of techniques have been used with these lower resistances when organizing the training program. Some advocate mixing higher resistance strength training and plyometrics with low resistance high-speed strength training, while others believe all training loads should be at or below 50 percent when training for high-speed strength. As of yet, the best training program to increase high-speed strength is open to speculation. It is up to the individual strength and conditioning coach to establish the protocol believed to result in the desired performance goals, based on demands of the sport, and then carefully modify the program, if necessary, based on the results achieved.

References


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