Explosive Exercise

Written by Mike Stone, Meg Stone, and Hugh Lamont

Introduction

Before discussing explosive exercise in detail it is necessary to define terms and present a theoretical background for the discussion. Of particular importance for this discussion are the concepts of strength, rate of force development and power.

Strength can be defined as an ability to produce force (Siff 2001, Stone et al 2001). Because force is a vector quantity, strength will have a magnitude and direction. The magnitude of strength output can range from 0 to 100% and the muscles involved determine the direction of force application. It is important to understand that strength can be "applied" using different muscle actions.

Strength is exhibited when muscles act to produce force. Muscle action can take different four different forms:

- Isometric - in which the muscle gains tension but does not appreciably change its length
- Concentric - in which the muscle gains tension and shortens
- Eccentric - in which the muscle gains tension and lengthens
- Plyometric - in which a concentric action is immediately preceded by an eccentric action, thus taking advantage of a stretch-shortening cycle.
- Muscle actions are supported by a number of different physiological and biomechanical mechanisms.

The various mechanisms involved in muscular strength are listed in Figure 1. Two primary factors, which govern muscle activation and the gradation of strength are: 1) the number of motor-units recruited and 2) the frequency of motor unit activation which can be termed "rate coding". These two factors normally work together in increasing force production. The exact degree to which one mechanism is emphasised over the other during muscle activation depends upon the amount of force required and perhaps the size and type of muscle being activated.

Figure 1: Neuromuscular Factors Involved in Strength Production

Neuromuscular Factors Involved in Strength Production	
•	Motor Unit Recruitment
•	MU Activation Frequency (Rate Coding)
•	Synchronisation (Ballistic Movements)
•	Motor Unit Activation Pattern (Intra-Muscular Activation)
•	Muscle Action Pattern (Intra-Muscular Activation)
•	Use of Elastic Energy and Reflexes
•	Neural Inhibition
•	MU Type (Muscle Fibre Type)
•	Biomechanical \ Anthropometric Factors
•	Muscle Cross-Sectional Area

There is doubt that an untrained muscle can be fully activated (Aagaard et al 2000; Semmler and Enoka 2000). Furthermore, strength training can result in a greater activation of muscle, thus influencing strength production.

Another mechanism, which can effect muscle force, is the synchronisation of motor units. Under normal low intensity muscle activation motor-units fire asynchronously. However, as the maximum level of strength is approached some motor units are activated at exactly the same time as other motor units. Synchronisation is also a major factor in ballistic movements and will be discussed later.

There is a great deal of evidence for the concepts of intra and inter muscular task specificity. Intra-muscular task specificity deals with specific patterns of activation for motor units while inter-muscular task specificity deals with the interplay and pattern of activation among muscles during a specific task. The concept of intra-muscular task specificity may help explain the phenomena of regional hypertrophy (Antonio 2000), in which a specific exercise may cause hypertrophy in one region of a muscle but not in others. Bodybuilders have recognised this aspect of training arguing that in order to more completely develop a muscle, many different exercises for that muscle must be performed.

Both intra and inter-muscular activation patterns can change with very slight alterations in movement pattern, eccentric versus concentric actions or with changes in velocity (Semmler and Enoka 2000, Zajac and Gordon 1989). Because of these alterations in activation patterns, selection of exercises for strength/power training should be viewed as movement specific rather than simply training a muscle(s). Improvement in the efficiency of intra and especially inter muscular activation implies an enhanced coordinative ability and is an important mechanism contributing to improved strength expression (Semmler and Enoka 2001).

The use of reflexes and stretch-shortening cycles (SSC) can also alter the production of force (Bobbert et al 1996, Cronin et al 2000). Basically a SSC consists of a plyometric muscle action in which an eccentric action immediately precedes a concentric action. The mechanisms involved in concentric enhancement may include: use of elastic energy, a stretch reflex, optimising muscle length, optimising muscle activation and muscle activation patterns (Bobbert et al. 1996, Bobbert 2001). Some evidence indicates that improving maximum strength can augment the concentric portion of the SSC (Cronin et al 2000). Learning to use a stretch-shortening cycle more efficiently can markedly increase force production.

The degree of neural inhibition can also effect strength capabilities. Inhibition can take two different forms conscious and somatic-reflexive. Conscious inhibition deals with a perception (right or wrong) that a given weight may produce injury. For example, if you have never performed squats before and you are asked to perform a 300-kg full squat, chances are (if you are remotely intelligent) you will refuse. Somatic-reflexive neural inhibition, includes feedback form various muscle and joint receptors, and has been suggested to be part of a protective mechanism. This protective mechanism can reduce muscle tension during maximum and near maximum efforts. Strength training appears to reduce receptor sensitivity, diminish inhibition and is partially responsible for the greater forces achieved (Aagaard et al. 2000).

Motor unit type can also influence strength. Several studies have indicated that a large cross-sectional area of type II muscle fibres may be advantageous in terms of dynamic force production (Powell et al 1984) even when muscle architecture and other mechanical factors are taken into consideration. Strength training, particularly explosive strength training appears to increase the ratio of type II:I muscle fibre cross-section area in a manner favouring strength and power production.

Biomechanical and anthropometric factors such as gross muscle architecture, muscle insertion point, height, limb length and moment arm may alter the mechanical advantage of the intact muscle lever system. For example, weightlifters possess a high body mass to height ratio (Bm/h) compared to untrained subjects and other athletic groups. This Bm/h is advantageous because it can provide an increased force production. This advantage is associated with the strong positive relationship between a muscle's physiological cross sectional area and maximum muscle force generating capabilities (Semmler and Enoka 2000). If two athletes of different heights and different limb lengths have the same muscle mass and volume, the shorter athlete will have the greatest muscle cross-section and therefore a greater muscle generating force.

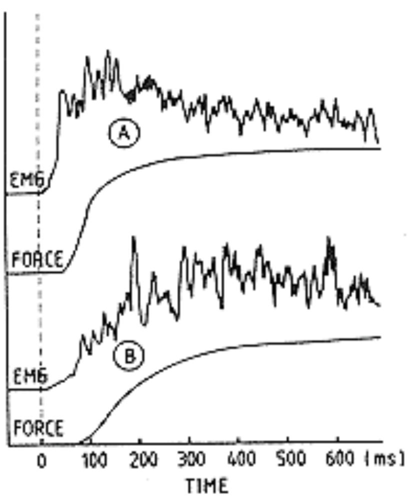
Of the various mechanisms dealing with absolute maximum strength, the most important is the physiological cross-sectional area of a muscle. From a practical standpoint, if cross-sectional area were not the most important factor effecting absolute muscular strength then there would not be body weight classes in sports such as boxing, judo, wrestling or weightlifting. The relationship between strength and the physiological cross-section area stems from the number of sarcomeres in parallel. The more sarcomeres in parallel the greater the maximum strength of a muscle. The process of hypertrophy, resulting from strength training adds sarcomeres in parallel thus raising the muscle's potential force production.

Explosive Exercise

Explosive exercise can be defined as a movement in which maximum or near maximum rates of force development are attained. Explosive exercises can be either isometric or dynamic. Several factors contribute directly to explosive exercise these include muscle activation rate, and synchronisation.

Rate of Activation: An important factor, which effects the rate of force development, is concerned with the rate of muscle activation. - Work by Viitasalo and Komi (1981) clearly pointed out that the rise in motor unit activation as measured by EMG is associated with a rise in muscle force. Evidence of this relationship can be observed in Figure 2 Note in that in tracing A the initial rate of activation and force development is higher than in tracing B. Thus, the rate of force development is largely a function of the nervous system's ability to activate muscle. Typically, high rates of force development are necessary for success in "explosive and high power activities" such as sprinting, throwing and weightlifting.

Figure 2: Rate of Activation.

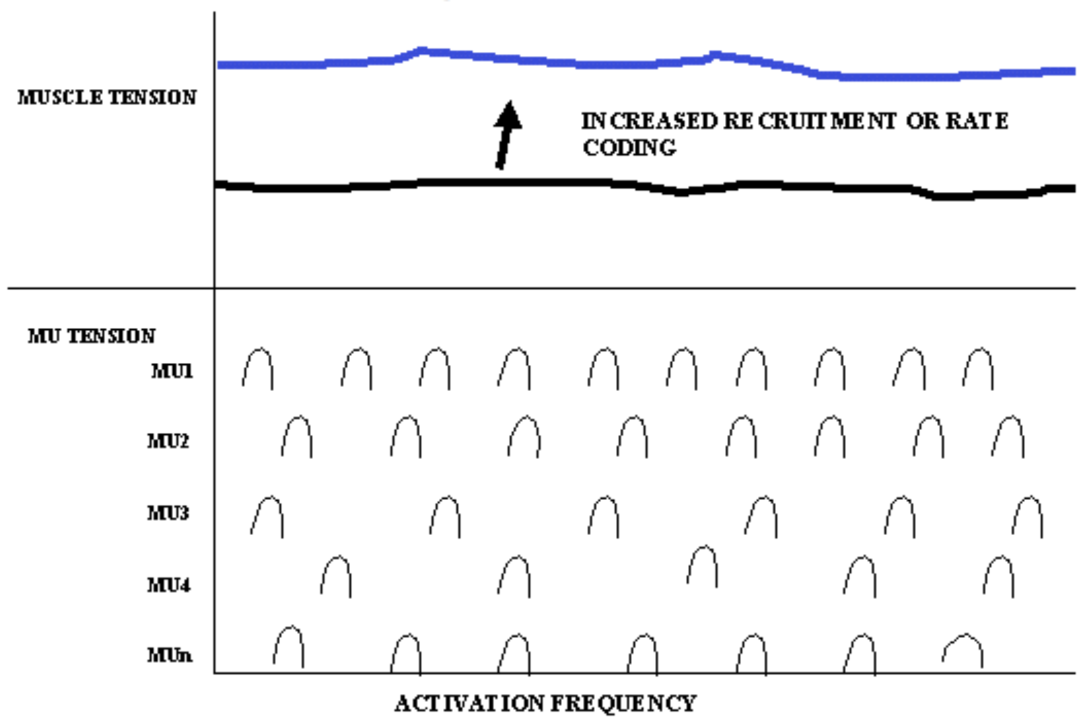


Komi 1986.

Synchronisation: At low muscle tension very little synchronisation is noted. Motor units typically are activated as brief "dynamic" twitches. Figure 3 depicts the asynchronous activation patterns of several motor units. Note that during asynchronous activation when one motor unit deactivates another is being activated; this pattern creates a muscle tension production, which allows a relatively smooth movement to occur. Increased muscle activation through recruitment or rate coding can increase muscle force.

As force output is increased greater levels of synchronisation can occur. The maximum frequency of activation can range from 30-50 htz for low threshold motor units, up to 100 htz for high threshold motor units depending upon the type and the intensity of the muscle action. Furthermore, strength training can enhance the number of motor units synchronising and can result in synchronisation at lower force outputs (Semmler and Nordstrom 1998). However, the degree to which synchronisation effects maximum strength, especially when measured isometrically appears to be minimal (Yao et al 2000). Synchronisation does appear to play an important role in ballistic movements.

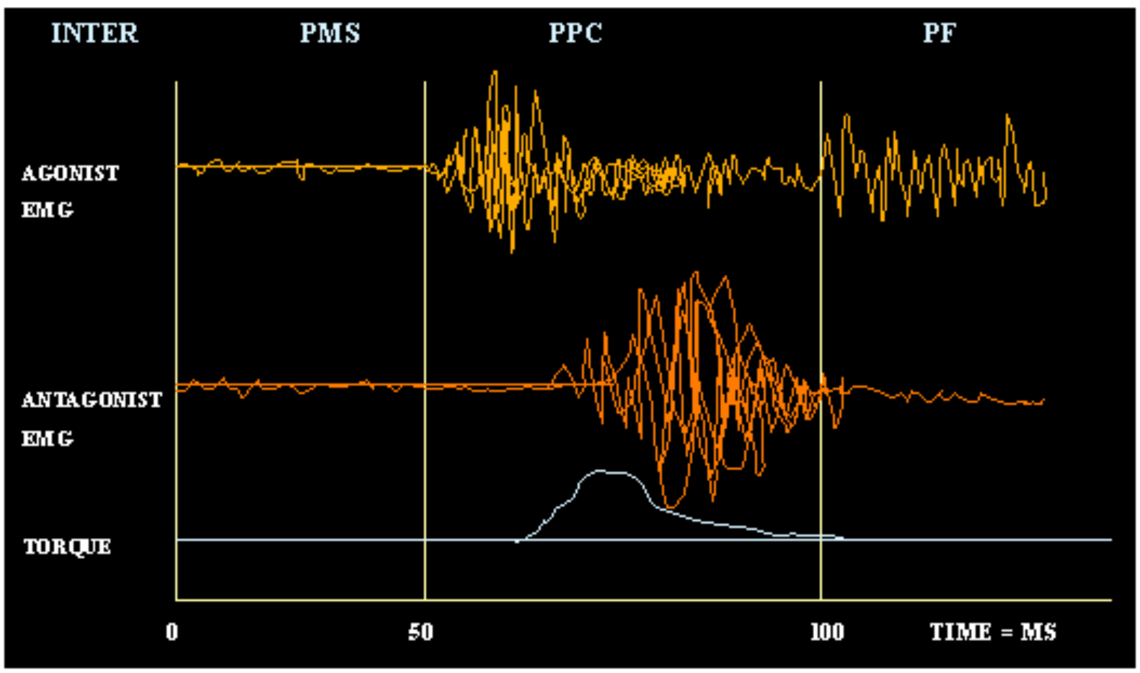
Figure 3: MU Activation



Ballistic movements: Dependence on Synchronisation: In Figure 4 note the characteristic triphasic muscle activation pattern as recorded by EMG. In the first phase there is a silent period in which the motor units have enough time to complete their refractory periods. This "pre-motor silent period" precedes activation of the prime mover or agonist. The pre-motor silent period allows for a large number of motor units to synchronise, which in turn produces a brief, but very large force impulse during the 2nd phase or pre-programmed period. After the burst of activity from the prime mover the agonist is activated and acts as a braking system, which slows movement and reduces injury potential. In the 3rd and final phase of "proprioception" the prime mover again becomes active in order to produce subtle adjustments in the final stages of movement.

This basic triphasic response is activated in all ballistic movements and can be refined by appropriate training procedures.

Figure 4: Triphasic Activation Pattern

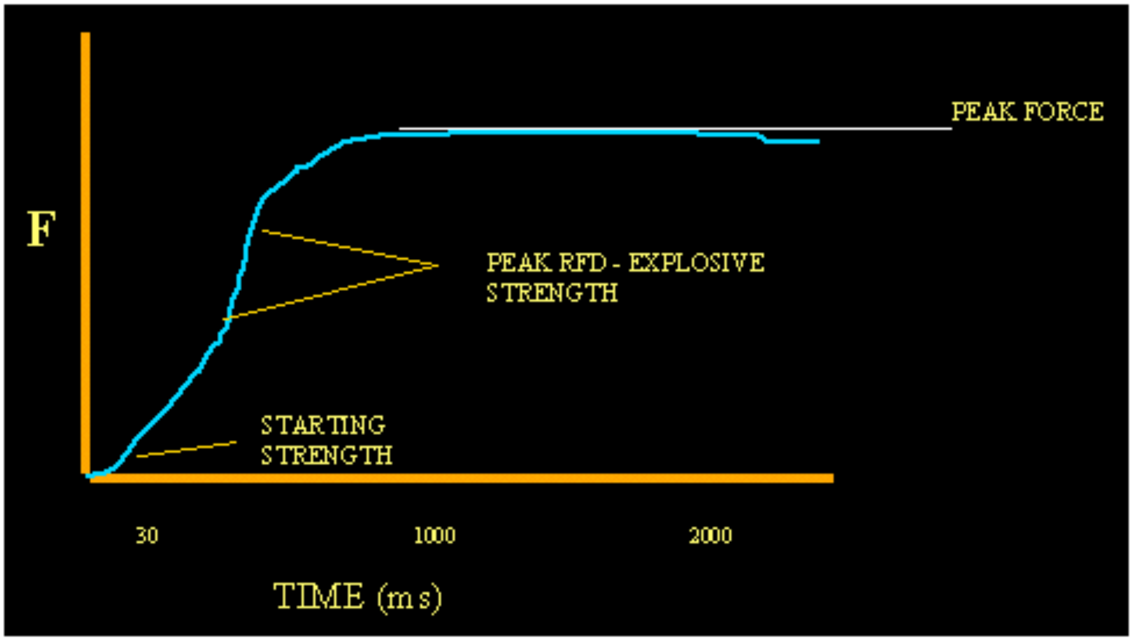


The Measurement of Explosive Strength

To adequately describe "explosive strength" both peak force and a reasonable measure force development is necessary. Typically a force plate is used.

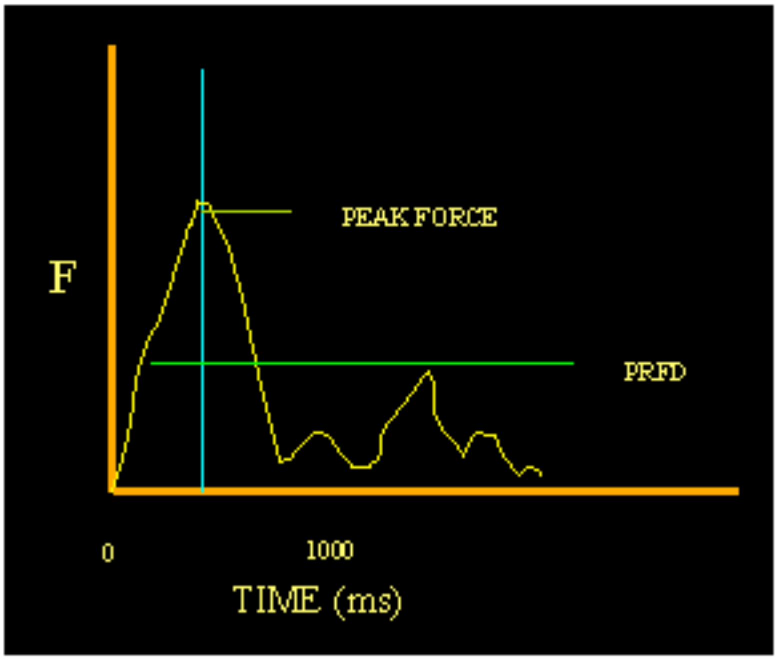
Isometric force-time curve: Figure 5 represents a typical isometric force time curve produced from a mid-thigh clean pull. The force produced in the first 30 milliseconds has been term "Starting Strength". Starting strength is associated with the ability to produce high velocity "quick" movements such as punching or kicking. Peak force is the maximum force attained under the measurement conditions and is associated with the ability to lift heavy objects. The peak rate of force development has been termed "Explosive Strength" and is associated with the ability to accelerate objects.

Figure 5: Explosive Exercise: Measurement - Isometric force-time curve



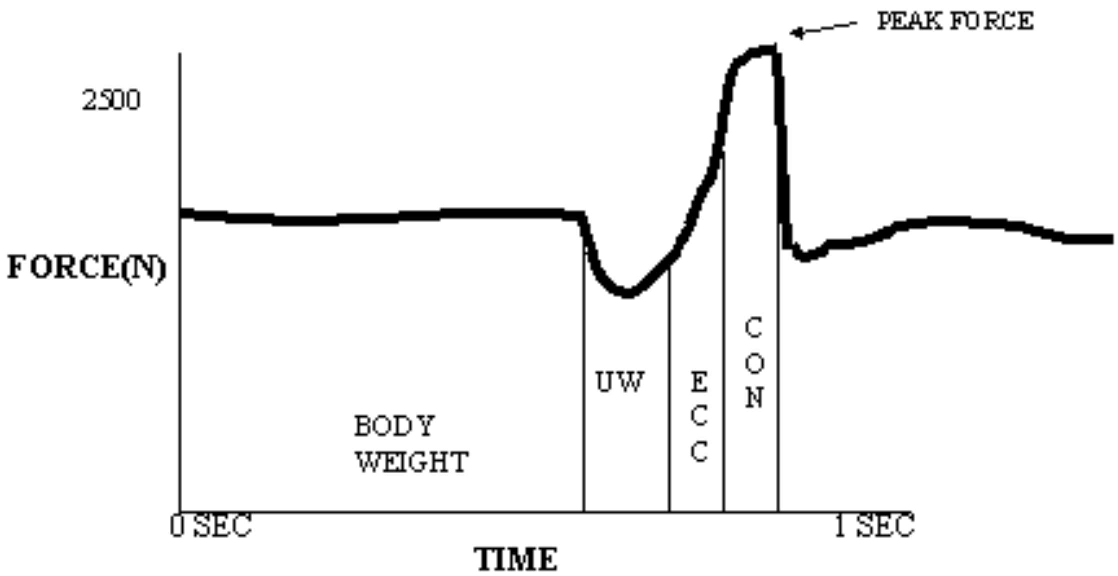
Concentric force-time curve: Figure 6 represents a force-time curve for a concentric mid-thigh pull. Note that at any dynamic effort at weights less than the maximum isometric capability, peak force will be correspondingly less. For example the peak force would be lower at each decreasing percentage of maximum from 90 to 80 to 70 and so on. However, some evidence indicates that the peak rate of force development is correspondingly higher as the load decreases, at least to a point. Thus, in general, peak force and peak rates of force development are inversely related.

Figure 6: Explosive Exercise: Measurement - Concentric force-time curve



Plyometric force time curve: Many exercises involve a plyometric movement in which there is a stretch-shortening cycle. Figure 7 shows a typical force-time curve, which can be generated as a result of a jumping movement. During a typical counter-movement jump there is an un-weighting phase, which initiates the stretch shortening cycle and produces a plyometric movement. The resulting upward force can be augmented by previously stretching the muscle. As previously noted the mechanism(s) by which concentric force can be augmented by a previous stretch is not completely clear but involves several possibilities including: a) muscle elastic properties, b) a myototic reflex, c) returning the muscle to its optimum length or d) optimising the muscle activation pattern (Bobbert 2001).

Figure 7: Vertical Force: Importance of SSC - Plyometric force-time curve



For many sports the ability to produce force rapidly may be more important than maximum force production. Rate of force production is a change in force/ change in time. As previously noted, the rate of force development is primarily a function of the rate of increase in muscle activation by the nervous system (Komi and Viitasalo 1976, Viitasalo and Komi 1981). Although force is directly responsible for the acceleration of an object it may be argued that the faster a given force is attained, the more rapid the corresponding acceleration occurs. Thus rate of force development can be associated with the ability to accelerate objects (Schmidtbelicher 1992). So, attaining a high peak rate of force development or explosive strength would be associated with high acceleration capabilities. The importance of both peak force production and high rates of force development can be ascertained by using Newton's 2nd law and by considering sprinting as an example.

$F = MA + W$

In this equation representing Newton's 2nd law, force (F) minus the weight (W) of an object is equal to mass (M) times acceleration. Rearranging the equation, force (F) is equal to the weight (W) of an object plus mass (M) times acceleration (A).

Studies have indicated that the limiting forces during sprinting are vertical forces, effecting stride length, rather than horizontal (Weyand et al. 2000). During sprinting elite male sprinters use an alternating pattern of vertical ground reaction forces and the center of mass moves upward at a velocity of 0.49 m x s-1 and downward at 0.49 m x s-1. Their average foot contact time is 0.087s and the average body mass is approximately 79.5 kg. Peak force typically occurs at a knee angle of approximately 135-140° (Mann 1996).

Substituting these values, for elite male sprinters, into the force equation (Newton's 2nd Law)

VF = 79.5 (0.98 m x s-1)/0.087s = 895.5 N + 779.1 = 1674.6N

we find that the typical elite male sprinter has to produce 1675 N or 375 lbs. of vertical force, on one leg. Thus sprinters must be quite strong. Furthermore it is important to note that this force production must occur in only 0.087s, thus the rate of force production is quite high. So, these sprinters must be very strong and "explosive" in that this peak force must be produced very rapidly.

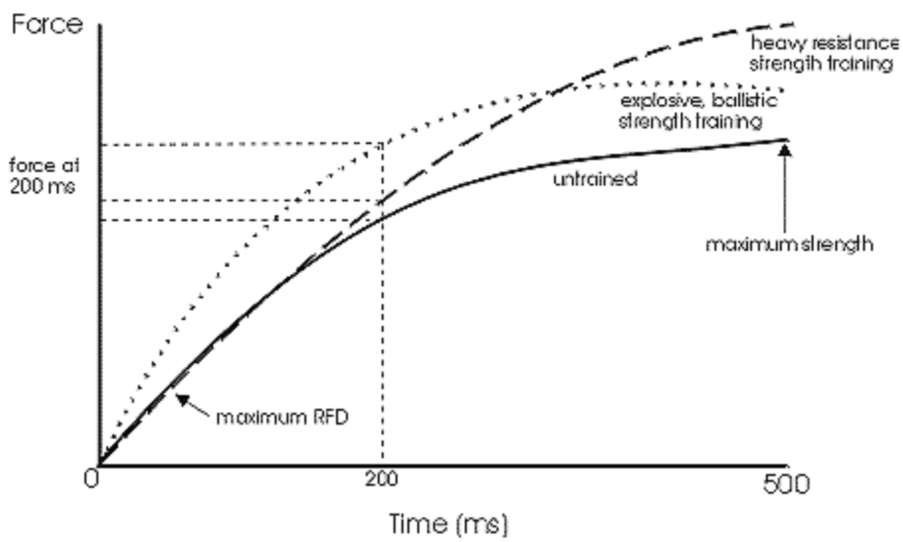
The importance of power production: Work is the product of force and distance. Power is the rate of doing work and can be expressed as the product of force and velocity. Power can be calculated as an average over a range of motion or as an instantaneous value occurring at a particular instant during the displacement of an object. Peak power (PP) is the highest instantaneous power value found over a range of motion. Maximum power (MP) is the highest peak power output one is capable of generating under a given set of conditions such as the state of training or type of exercise. Muscular actions that maximise power include jumping, throwing and kicking; indeed activities in which a movement sequence results in maximum achievable velocities primarily depends upon power production (Young 1993). Furthermore, activities requiring a rapid direction change and acceleration, such as displays of "agility", depend upon bursts of high power output. Thus, power output is likely to be the most important factor in separating sports performances; that is who wins and who loooses. Although average power output may be more associated with performance in endurance events, for explosive activities such as jumping, sprinting and weightlifting movements, PP is typically strongly related to success (Garhammer, 1993; Kauhanen et al 2000; McBride et al 1999; Thomas et al 1994).

Potential Training Adaptations

Training adaptations can depend upon a number of factors including, training variables such as volume and intensity, mechanical specificity and the trained state.

Different methods of training can produce different long-term adaptations (Figure 8). For example typical heavy strength training would be expected to produce increases in the high force end of a force-time curve. Explosive training, particularly dynamic explosive training would likely effect the initial rise in force rather than peak force. It should be noted that in order to effect reasonable long-term adaptations that appropriate volume and intensity characteristics should be considered in training.

Figure 8: Potential Training Adaptations



Threshold value for strength: For, example Hakkinen et al. (1987, 1988) studied elite weightlifters over a 1-year period. It was noted that maximum strength levels depended upon maximum muscle activation. Maximum muscle activation was achieved only when the training intensity was 80% of the 1 RM or greater. When the average training relative intensity dropped below 80%, maximum strength also decreased. These data indicate that among elite weightlifters, the threshold for maintaining or increasing maximum strength is about 80% of 1 RM.

However, Hakkinen et al. (1987, 1988) also notice that if the weightlifters trained at high intensities for too long, then maximum strength and power decreased regardless of the intensity of training. More recently Fry et al (1994) has presented data indicating that constant high-intensity training can diminish maximum strength and explosive strength performance in as little as 2-3 weeks. This type of "overtraining" has been attributed to "neural fatigue" and points out the necessity of variation in training. Similar arguments can be made for volume considerations.

Specificity of Training

"Transfer of training effect" deals with the degree of performance adaptation, which can result from a training exercise and is strongly related to the concept of training specificity. Mechanical specificity refers to the kinetic and kinematic associations between a training exercise and a physical performance. Thus mechanical specificity includes movement patterns, peak force, rate of force development, acceleration and velocity parameters. The more similar a training exercise is to the actual physical performance the greater the probabilities of transfer (Behm 1995, Sale 1992, Schmidt 1991).

There are various strength/power training methods which can be employed. However, the effects of these training methods on neuromuscular physiology and performance variables can be drastically different. Four types of training will be discussed; these training methods are: isometric, heavy weight training, high power or speed strength and intentionally slow training.

Table 1 compares the relative effects on the neuromuscular system resulting from 4 different types of training protocols (Hakkinen 1994, Jones et al 1999, Jones et al 2000, Stone et al 2001): isometric training, typical heavy weight training, dynamic explosive training and intentionally slow training.

Table 1: Specificity of Strength/Power Training: Relative Neuromuscular Adaptations

TYPE OF TRAINING	HYPERTROPHY	II/I CSA	NEURAL
ISOMETRIC	+	+	++
HWT	++++	++	+
SS	+	+++	++++
ISM	+++	+	+

TIME COURSE AND TRAINED STATE ARE PARAMOUNT

Hakkiinen 1994
Stone 1993
Jones et al. 1999
Jones et al. 2000
Stone et al. 2001

Isometric training, which reached peak popularity in the 1960's, has not been shown to produce extensive hypertrophy. Heavy weight training is characterised by loading that is typically 80% of 1 RM or higher and typically uses 5-8 repetitions. The load lifted may move slowly, even if performed explosively, because it is relative close to maximum values. Heavy weight training can produce marked hypertrophy, except during the initial stages of a beginning training programme. Speed-strength weight training with a high power output typically does not produce marked hypertrophy, except in sedentary individuals, but can result in profound alterations in the nervous system. Intentionally slow training has become popular among health clubs recently; basically a relatively light weight is moved in an intentionally slow movement pattern both eccentrically and concentrically. The intentionally slow movement can result in a high motor unit fatigue rate, which is believed to cause more motor units to be recruited. Proponents of intentionally slow movements believe that the time that a muscle is under tension enhances both hypertrophy and strength, Often this type of training is performed for only one set. Although, currently, there is little information concerning intentionally slow movement's effect on hypertrophy a few studies suggests that while some hypertrophy can occur it is not as extensive as that resulting form heavy weight training (Keeler et al 2001).

Differential effects have been noted for fibre type adaptations. Type II fibres typically display a faster rate of hypertrophy than type I fibres, although the reason for faster hypertrophy is not completely clear. Thus weight training can produce fibre hypertrophy such that the II/I cross-sectional area ratio increases; the degree of increase depends upon the type of training. There is evidence that high power training enhances the II/I ratio of cross-sectional area to a greater degree than other types of training. A high II/I ratio is likely advantageous in producing "explosiveness and high power outputs.

Table 2 compares training methods based on potential performance outcomes. Although angle specificity is often observed, isometric training can enhance measures of maximum strength, especially when maximum strength is measured isometrically. In relatively untrained subjects isometric training may enhance speed of movement, provided a conscious effort to move fast is made (Behm 1995). However, the effects on speed are relatively minor compared to speed strength training (Hakkinen 1994). Heavy weight training has its greatest effect on maximum strength as measured by a 1RM. Among beginners and novices, relatively large gains in power, rate of force development and speed can occur. Speed-strength training has its greatest effects on rate of force development and power output, with lesser effects on measures of maximum strength. Intentionally slow training has its greatest effect on measures of maximum strength, with much smaller and perhaps negative effects, on rate of force development, power and speed.

Table 2: Specificity of Strength/Power Training: Relative Performance Effects

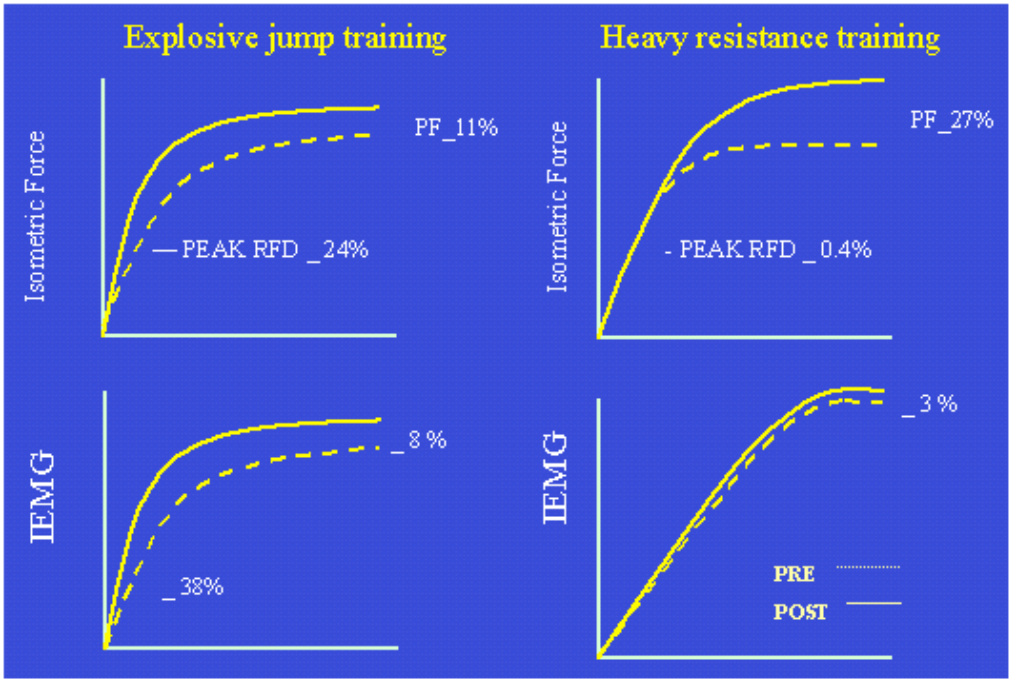
TYPE OF TRAINING	ISOMETRIC PF	1RM	IPRFD	DPRFD	PP	MAX SPEED
ISOMETRIC	++++	+++	++	+	+	+
HWT	+++	++++	++	++	++	++
SS	+	++	+++	++++	++++	+++
ISM	+++	++	?	+	+	+, -

TIME COURSE AND TRAINED STATE ARE PARAMOUNT

Hakkinen 1994
Stone 1993
Jones et al. 1999
Jones et al. 2000
Stone et al. 2001

The specificity effects of training are very apparent in a comparison between heavy weight training and speed strength training (Figure 9) carried out in a series of studies by Hakkinen and Komi (1985a 1985a). One group of physical education students were trained in the half squat using heavy weight training methods, another group used explosive jumping with weights of approximately 30% of their 1RM. Isomeric force-time curves measured pre-posts indicate different adaptations. The heavy weight-training group showed a 27% improvement in peak force but very little alteration in peak rate of force development. Simultaneous EMG tracings show alterations corresponding to changes in the force-time curve with only a 3% increased activation in the peak force region and no change in the peak force region. The gain in peak force shown by the heavy weight-training group was attributed to muscle hypertrophy. On the other hand the speed-strength group showed gains of 11% in the peak force region of the force-time curve and a 24% improvement in the peak rate of force development region. Simultaneous EMG tracings indicated that EMG enhancement generally corresponded to the gains in peak force and force development. Thus, the speed-strength group showed the greatest adaptations in the nervous system while the heavy weight-training group showed greater gains in hypertrophy.

Figure 9: Neural Adaptations to HRT



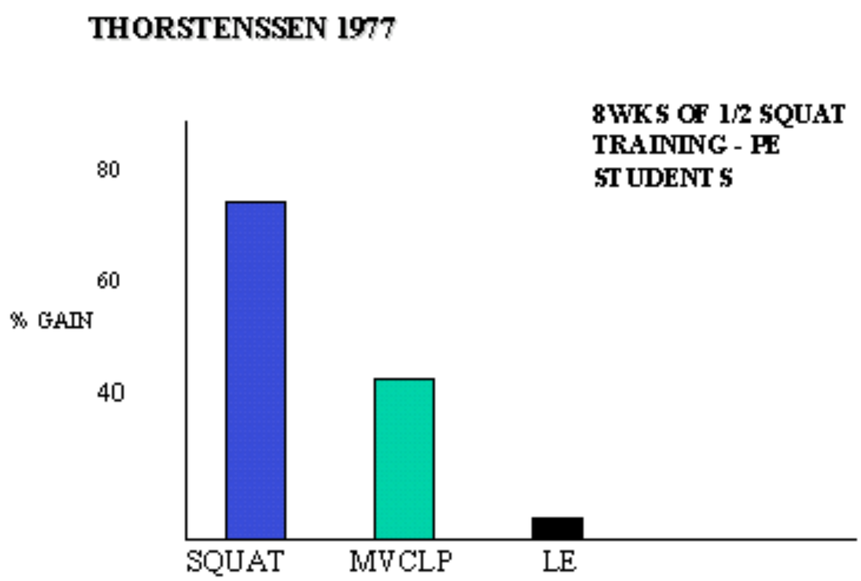
Another factor, which enhances the transfer of training to performance, deals with movement pattern. Movement pattern deals with applying forces in the most efficient manner and in the appropriate directions. Movement pattern specificity includes both intra and inter muscular specific aspects.

Movement pattern specificity (intra-muscular): Several studies have shown that there is a high degree of intra-muscular task specificity. These studies indicate that for a given movement, there are groups of motor neurones, which are activated in a specific manner for a specific task. If the task is changed, through alterations in movement pattern or perhaps velocity, then the neuronal task group will be changed. This type of data lends support for the practice among bodybuilders of using many different exercises to more fully develop a muscle (Antonio 2000).

Movement pattern specificity (inter-muscular): The pattern of activation of whole muscles, as well as the efficient use of reflexes and stretch shortening cycles is also task specific. In this respect the functional role of muscles as agonist, antagonist or stabilisers must be classified with care. These functional roles can change from single joint to multiple joint movements and with changes movement velocity (Zajac and Gordon 1989). Thus in sports or daily living settings in which multiple joint movements occur, especially those requiring high power or high velocity, transfer of training effect is more likely accomplished using complex multi-joint movements which have similar kinetic and kinematic characteristics.

Because of the high degree of task specificity, gains in strength may be effected by a number of factors including the number of joints involved, velocity of movement and position (Rach and Morehouse 1957, Zajac and Gordon 1989, Stone et al 2001). For example, Thorstensson (1977) trained university physical education students in the half squat for 8 weeks. Pre-post measurements indicated approximately a 75% improvement in the 1 RM half squat (Figure 10). However, the improvement in the isometric leg press was only about 40% and essentially no improvement occurred in the seated leg extension. Although the half squat training effected muscles used in all three tests it is clear that movement pattern differences altered the apparent strength gains. These data also indicate that the greater the similarities between training exercises and performance the greater the transfer.

Figure 10: Movement Pattern Specificity



Speed-Strength Exercises

Many sports require the development of speed. In order to enhance speed development a special category of exercise termed "speed strength" can be used. Speed strength exercises are performed with maximal effort and are characterised by having high peak rates of force development and high power outputs. Typically these exercises are performed with sub-maximal weights selected to maximise power. Evidence indicates that for single joint and small muscle mass exercises that power is at its peak at about 30% of peak isometric force. For multiple joint exercises in which the body weight is involved, such as a jump or in weightlifting movements, it appears that peak power may occur some where between 10 and 40% of peak isometric force depending upon the trained state.

If performance is ballistic then evidence indicates that much, if not most, of the training should also be ballistic in nature (Newton et al 1996). Ballistic exercises are not limited by end-point deceleration as are joint range limited exercises such as typical bench presses or typical squats. Ballistic exercises include various types of throws, jumps and weightlifting movements. It should be noted also that ballistic movements can be concentric movements or can have a plyometric nature.

Plyometric versus concentric only exercises: Exercises for the development of power and speed can be divided in different categories based on their speed of movement and on whether they contain a plyometric element. For example (Figure 11) jumping movements can be performed as heavy squats or heavy jump squats or they can be performed as speed-strength exercise - however both would have a preliminary counter-movement. In some sports a movement may be initiated without a counter-movement, for example a sprinter coming out of the blocks. Therefore some of the training exercises should attempt to duplicate this type of start, so for example, heavy squats could be performed by descending, stopping for several seconds before ascending or squats could be performed from a pin at a set height in a power rack.

Figure 11: Specificity: Development of Power and Speed: Exercise Categories

CATEGORY	EXAMPLE
Counter Movement	
a) slow	- heavy squats
b) fast	- weighted VJ
Static Start	
a) slow	- dead stop squats, deadlift
b) fast	- static VJ, snatch, clean

Successful Transfer of Training Effect

As previously noted, there are a number of criteria that an exercise must meet for successful transfer of training effect. These criteria include movement pattern, force production and velocity considerations. There also must be an overload application for successful performance adaptation. If there is no overload then sport performance will not improve beyond adaptation to simple practice of the sport.

Movement pattern characteristics include (Siff and Verkoshansky 1998, Stone et al. 2001):

1. the type of muscle action
2. accentuated regions of force production
3. the complexity, amplitude and direction of movement
4. ballistic versus non-ballistic movements

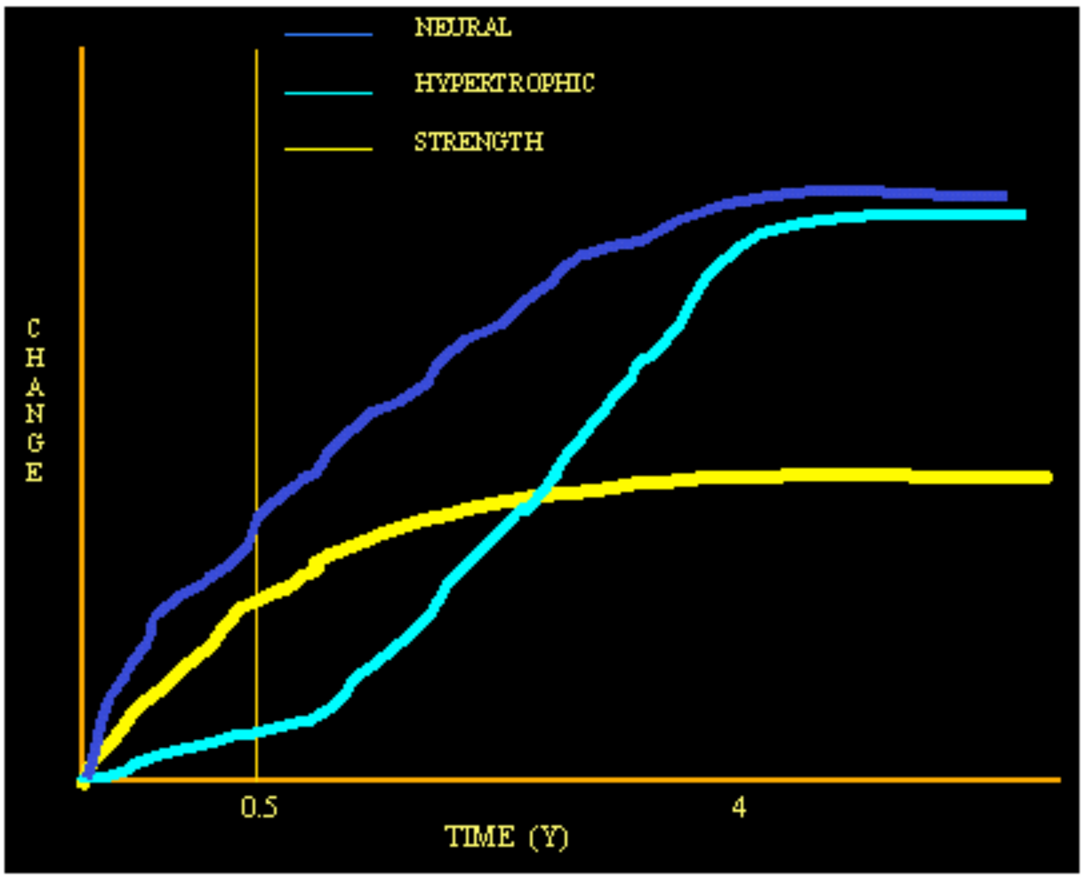
Factors to be overloaded include:

1. force production
2. rate of force production
3. power output

The Trained State

Figure 12 represents a qualitative expression of potential chronological strength adaptations and underlying mechanisms. The underlying mechanisms have been grossly divided into neural and hypertrophic factors. Initial neural adaptation occurs quite rapidly compared to hypertrophic factors and represents the primary mechanism of strength gain during this early phase of training. Later adaptation is typically more dependent upon increased muscle cross-sectional area. However, both of these factors have genetic limitations that make additional strength or power gains among advanced athletes difficult.

Figure 12: Trained State: Time Course of Adaptation



Interestingly, almost any reasonable training programme can enhance maximum strength, power and speed among initially untrained subjects due to rapid neural adaptations. However, the training of advanced and elite athletes requires considerable variation as well as creative approaches in order to elicit gains in performance.

Specificity of Strength/Power Training - Untrained

Table 3 lists the expected primary adaptation of three different methods of training in initially untrained subjects. Based on the current scientific literature, as well as experience, heavy weight training would produce marked and substantial alterations in maximum strength, peak rate of force development and power. Speed-strength training would have its greatest effects on peak rate of force development and power and intentionally slow training would show gains in strength but much smaller effects on rate of force development and power.

Table 3: Summary: Specificity of Strength/Power Training (Performance) - Untrained

TYPE OF TRAINING	PRIMARY ADAPTATION
HIGH FORCE/LOW VELOCITY (HEAVY EXPLOSIVE WT TRAINING)	INC. STRENGTH, RFD, POWER (ESPECIALLY IN WEIGHTED MOVTS.)
LOW FORCE/HIGH VELOCITY (LIGHT WEIGHT EXPLOSIVE MOVTS.)	INCREASED RFD AND POWER SOME GAIN IN MAX STRENGTH
INTENTIONALLY SLOW MOVEMENTS	INCREASED STRENGTH SMALLER GAINS IN RFD AND POWER

SEE SALE, 1993; HAKKINNEN AND KOMI, 1985; STONE, 1979 AND 1993; HAKKINEN 1994

However, the training of advanced and elite athletes requires considerable variation as well as creative approaches in order to elicit gains in performance. Using previously strength trained males Wilson et al. 1993 studied the effects of various types of training on leg and maximum strength and measures of "explosiveness" (Table 4). Fifty five trained subjects were divided into 4 groups. One group continued with heavy weight training, but did not attempt to overload, simply training with already established weights, thus serving as a control group. A second heavy weight training group continued their training routines but did overload by increasing the weights lifted over the experimental period. A third group switched to depth jumps beginning with boxes at 0.2m and progressing to 0.8 m. A forth group switched to explosive jumping movements using a resistance equal to about 30% of there peak isometric force measure at 135° knee angle. Pre-post measurements included counter-movement and static vertical jumps, and isokinetic leg extension at 400°/s and a modified Wingate cycle maximum power test. After 10 weeks of training the control group did not change on any measure. The traditional strength training group improved on the counter-movement and static jumps and the cycle power test. The depth jump group improved only on the counter-movement vertical jump. However, the speed-strength group improved on all measures. Furthermore the percent improvement on these measures was as good or better than any other group. These data indicate that speed-strength exercises can optimise "explosive" performance and it also possible that previous strength training may enhance the optimisation process.

Table 4: Wilson et al. Med Sci Sports Exerc. 1993

EXPERIMENTAL SUMMARY (10 WK)

ALL SUBJECTS (N = 55) WERE PREVIOUSLY WEIGHT TRAINED

VARIABLE	FAST WT (N = 15)	P (N = 13)	TRADITIONAL (N = 13)	CONTROL (N = 14)
CVJ	SI	SI	SI	NC
SVJ	SI		SI	NC
ILE	SI			NC
30 M	SI			NC
CYCLE POWER	SI		SI	NC

FAST WT: OPTIMAL POWER OUTPUT (30% PEAK ISOMETRIC STRENGTH)

PLYOMETRICS: DEPTH JUMPS (0.2 M AT 0 WKS – 0.8 M AT 10 WKS)

TRADITIONAL: 3 SETS OF 6–10 REPETITIONS

Support for the concept of strength training optimising subsequent speed-strength training can be found in the observation of elite weightlifters training in different manners. Medvedev et al. (1981) divided several hundred elite Soviet weightlifters into three different training groups. Group1 trained heavy throughout the entire experimental period lasting several months and emphasised strength increases. Group 2 trained with relatively light weights, between 70-80% of 1RM. However, group 3 trained in a sequenced manner such that the month was devoted to strength training with heavy weights and the remainder of the experimental period was used for speed-strength training. At the end of the experimental period group 3 produced superior improvements in weightlifting total, primarily through an improved snatch. Furthermore group 3 realised superior improvements in other "explosive" measurements such as sprinting ability and medicine ball throws compared to the other two groups. These data indicate that a sequenced training programme in which an emphasis on strength training precedes power-training can produced superior results, particularly in measures of explosiveness.

In order to further investigate the concept of sequenced training, Harris et al. 1999 used a group of 42 American football players. The study concentrated on leg and hip maximum strength and explosiveness. For 4 weeks all of the players trained using a high volume strength endurance programme. Following the initial 4 weeks the players were divided into three groups equalised on the 1 RM squat and body mass. Group 1 trained for an additional 9 weeks using explosive heavy weight training. Group 2 using speed-strength-training methods used weights equivalent to 30-40% of their 1 RM squat. Group 3 used a sequenced combination training programme; for the first 5 weeks group 3 trained in the same manner as group 1 except heavy and light days were used. Light days consisted of the same lifts except at using 20% less weight. During the last 4 weeks group 3 used a combination of heavy weight training and speed strength exercises. For example, in the squat, after warm-up sets, one heavy set of 85-90% of 1 RM was performed and then followed by 3 sets of jumps at 30% of the 1 RM. All lifts were performed as explosively as possible.

Pre-post measures included various measurements of maximum strength, a counter-movement vertical jump, vertical jump power, a Margaria stair limb power test, a 30 m sprint, 9.1 m agility test and a standing long jump. The results indicate that the heavy weight training group (Gp1) and the combination group (Gp3) produced the best gains in maximum strength measures. However, in measures of power and explosiveness the speed strength group (Gp2) and the combination group (Gp3) produced the best gains. Furthermore the percent gains for combination group (Gp3) in all tests were as good or better than the other two groups. These data indicate that 1) combination training can produce superior gains across a wide spectrum of performance variables and 2) that sequenced training consisting of strength-endurance, strength and speed-strength phases can optimise these training responses (Table 5).

Table 5: Harris et al. JSCR 2000: American Football Players

VARIABLE	SS (n = 16)	COMBO (n = 13)	HWT (n = 13)
1 RM SQUAT		*	*
1 RM 1\4 SQUAT	*	*	*
1 RM MTP	*	*	*
VJ	*	*	*
VJPI		*	
M-K POWER INDEX	*	*	*
30 M		#	
10 Y SHUTTLE	*		
SLJ	*		

*p < 0.05
p = 0.08 ALL SUBJECTS WERE PREVIOUSLY TRAINED (1 RM SQUAT)

SS – SPEED STRENGTH (HIGH POWER)

HWT – HEAVY WEIGHT TRAIINING

COMBINATION – 5 WKS HEAVY AND LIGHT DAY PROTOCOL
4 WKS COMBINATION

Specificity of Strength/Power Training - Previously Trained

Of concern to the coach is creating continued gains in trained athletes. Table 6 lists the potential strength/power adaptations in athletes already strength trained. For example we would expected that continued heavy weight-training would result in diminished or little gain in maximum strength, rate of force development or power; intentionally slow movements would also result in diminished adaptations. Some evidence actually indicates that by switching to intentionally slow movements, maximum strength and especially rate of force development and power may be reduced. On the other hand switching to a speed strength type of training can elicit beneficial and quite marked alterations in rate of force development and power (Wilson et al. 1993, Harris et al. 1999).

Table 6: Summary: Specificity of Strength/Power Training (Performance) - Trained

TYPE OF TRAINING	PRIMARY ADAPTATION
HIGH FORCE/LOW VELOCITY (HEAVY WT TRAINING)	DIMINISHED OR LITTLE GAIN IN MAX STRENGTH, RFD, POWER
HIGH FORCE/HIGH VELOCITY	INCREASED RFD AND POWER
INTENTIONALLY SLOW MOVEMENTS	DIMINISHED OR LITTLE GAIN IN MAX. STRENGTH, DIMINISHED RFD AND POWER

SALE 1993; HAKKINNEN AND KOMI 1985; STONE 1979 AND 1993; WILSON ET AL. 1993; HAKKINEN 1994

Factors Effecting Explosiveness

In addition to specific training protocols, several different factors can have a marked impact upon the development of explosive qualities in an athlete. These factors include maximum strength, fatigue levels and cross-training.

The interaction of strength and power is of paramount importance. Evidence indicates that

1. measures of maximum strength and power have moderate to very strong correlations
2. the strength of the relationship in part depends upon the mechanical similarity of the measures
3. although maximum strength influences power output at light resistances its effect on power appears to increase with load.
4. sequenced periodised training and its variations can offer advantages

Thus, the development of power and explosiveness can be augmented through development of strength.

While factors such as maximum strength can have a positive effect on explosiveness, other factors such as fatigue and cross-training can have a negative impact. Two factors, which must be considered in training programmes, are the degree of fatigue, which occurs within a training session, and the degree of residual fatigue, which can accumulate between training sessions.

Fatigue results in reductions in maximum strength, peak rate of force development and power output. Because of the fatigue-induced reduction in performance capability high fatigue levels can interfere with technique and interfere with learning or stabilising technique. Thus learning to be explosive" can be compromised.

Evidence indicates that the combination of typically aerobic training, such as distance running, and resistance training can result in decreased maximum strength and power. Thus, if maximum levels of strength and especially power and speed are desired, then typical aerobic training should be minimised or eliminated.

Injury Potential of Resistance Training

It is well known that the injury potential of weight training is low compared to other recreational (Powell et al 1998) and sports activities (Hamill 1994). Although it is commonly believed that free weights produce a higher injury rate then machines there is no evidence for this belief (Requa et al. 1993). This last statement is particularly important to understand because free weights can produce a superior transfer of training effect, especially for explosive strength compared to machines (Stone et al 2001).

It is also commonly believed that weightlifting and other ballistic explosive exercises produce high rates of injury. Again there is little data to support this idea. Hamill (1994) studied the injury rates of several different sports in the United Kingdom and in the United States. Based on injury rates per 100 participation hours both general weight training and weightlifting training produced injury rates that were among the lowest of the sports studied. Thus, there is little evidence that weight training, including explosive weight training, produces excessive injuries (Table 7).

Table 7: .Injury Rates Among Sports: Hamill 1994

SPORT	INJURIES PER 100 PARTICIPATION HOURS
SCHOOLCHILD SOCCER	6.20
UK RUGBY	1.92
USA BASKETBALL	0.03
UK CROSS-COUNTRY	0.37
SQUASH	0.10
USA FOOTBALL	0.10
BADMINTON	0.05
USA GYMNASTICS	0.044
USA POWERLIFTING	0.0027
USA TENNIS	0.001
USA VOLLEYBALL	0.0013
WEIGHT TRAINING	0.0035 (85,733 H)
WEIGHTLIFTING	0.0017 (168,551 H)

Summary

In summarising various aspects of explosive exercise it should be noted that:

1. different training programmes can elicit very specific long-term adaptations
2. different trained states alter training adaptations
3. in order to elicit maximum responses all strength training should incorporate maximum efforts regardless of the weight used
4. training for maximum explosiveness requires emphases on both maximum strength and explosive training
5. straining advanced athletes requires creative planning. This planning should incorporate a periodised sequenced structure.

Thus we can conclude that "explosive exercise", when properly integrated into a training programme, can be a valuable part of training.

References

Aagaard, P. Simonsen, E.B., Andersen, J.L., Magnusson, S.P., Halkjaer-Kristensen, J. and Dyhre-Poulsen, P. Neural inhibition during maximal eccentric and concentric quadriceps contraction: effects of resistance training. Journal of Applied Physiology 89:2249-2257, 2000.

Antonio, J. Nonuniform response of skeletal muscle to heavy resistance training: can bodybuilders induce regional muscle hypertrophy? Journal of Strength and Conditioning Research 14:102-113, 2000.

Behm, D.G. Neuromuscular implications and applications of resistance training. Journal of Strength and Conditioning Research 9(4): 264-274, 1995.

Bobbert, M.F., Gerritsen, K.G., Litjens, M.C. and Van Soest A.J. Why is countermovment jump height greater than squat jump height? Medicine and Science in Sports and Exercise 28:1402-1412, 1996.

Bobbert, M.F. Dependence of human squat jump perfromance on the series elastic compliance of the triceps surae: a simulation study. Journal of Experimental Biology 204(pt 3): 533-542, 2001.

Cronin, J. B., P.J. McNair and R.N. Marshall. The role of maximal strength and load on initial power production. Medicine and Science in Sport and Exercise, 3:1763-1769, 2000.

Fry, A.C. W.J. Kraemer, F. van Borselen, J.M. Lynch, J.L. Marsit, E.P. Roy, N.T. Triplett and H.G. Knuttgen. Performance decrements with high intensity resistance exercise overtraining. Medicine and Science in Sports and Exercise 26:1165-1173, 1994.

Garhammer, J.J. A review of the power output studies of Olympic and powerlifting: Methodology, performance prediction and evaluation tests. Journal of Strength and Conditioning Research, 7:76- 89, 1993.

Hakkinen, K. Neuromuscular adaptation during strength training, aging, detraining and immobilization. Critical Reviews in Physical and Rehabilitation Medicine 6(3): 161-198, 1994.

Hakkinen, K. and P.V. Komi. Changes in electrical and mechanical behaviour of leg extensor muscle during heavy resistance strength training. Scandinavian Journal of Sports Science 7:55-64, 1985a

Hakkinen, K. and P.V. Komi. The effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch shortening cycle exercises. Scandinavian Journal of Sports Science 7:65-76, 1985b.

Hakkinen, K., P.V. Komi, M. Alen and H. Kauhanen. EMG, muscle fibre and force production characterisitcs during a 1 year training period in elite weightlifters. European Journal of Applied Physiology 56:419-427, 1987.

Hakkinen, K. A. Pakarinen, M. alen, H. Kauhanen and P.V. Komi. Neuromuscular and hormonal adaptations in athletes to strength training in two years. Journal of Applied Physiology 65:2406-2412, 1988.

Hamill, B.P. Relative safety of weightlifting and weight training. Journal of Strength and Conditioning Research. 8(1): 53-57, 1994.

Harris, G.R., Stone, M.H., O'Bryant, H., Proulx, C.M. & Johnson, R. Short term performance effects of high speed, high force and combined weight training. Journal of Strength and Conditioning Research 13: 14-20, 1999.

Jones, K. G. Hunter, G. Fleisig, R. Escamilla, and L. Lemak. The effects of compensatory acceleration on the development of strength and power. Journal of Strength and Conditioning Research 13: 99-105, 1999.

Jones, K., P. Bishop, G. Hunter and G. Flesig. The effects of varying resistance-training loads on intermediate- and high- velocity- specific adaptations. Journal of Strength and Conditioning Research 15: 349 -356, 2001.

Kauhanen, H., J. Garhammer and K. Hakkinen. Relationships between power output, body size and snatch performance in elite weightlifters. Proceedings of the 5th annual Congress of the European College of Sports Science, Jyvaskala, Finland (J. Avela, P.V. Komi and J. Komulainen, eds) pp. 383, 2000.

Keeler, L.K., L.H. Finkelstein, W Miller and B. Fernhall. Early-phase adaptations of traditional- speed vs. superslow resistance training on strength and aerobic capacity in sedentary individuals. Journal of Strength and Conditioning Research 15: 309-314, 2001.

Komi, P.V. and J. H. Vitasalo. signal characteristics of EMG at different levels of muscle tension. Acta Physiologica Scandinavica 96:267-276, 1976.

Mann, R. Fundementals of sprinting and hurdling. Presentation at Level 3 track and field clinic, Orlando, Fl, 1996.

McBride, J.M., T.T. Triplett-McBride, A. Davis, and R.U. Newton. A comparison of strength and power characteristics between power lifters, Olympic lifters and sprinters. Journal of Strength and Conditioning Research 13:58-66, 1999.

Medvedev, A.S., Rodionov, VF. Rogozkin, V. Gulyants, A.E. Training content of weightlifters in preparation period. (translation: M. Yessis) Teoriya I praktika Fizcheskoi Kultury 12: 5-7, 1981.

Powell, KE., G.W. heath, M.J. Kresnow,JJ. Sacks and C.M. Branche. Injury raes from walking, gardening, weightlifting, outdoor bicycling and aerobics. Medicine and Science in sports and Exercise. 30: 1246-1449, 1998.

Powell, P.L., Roy, R.R., Kanim, P. Bello, M.A and Edgerton, V.R. Predictability of skeletal muscle tension from architectural determinations in guinea pig muscle. Journal of Applied Physiology 57: 1715-1721, 1984.

Rasch, P.J. & Morehouse, L.E. (1957) Effect of static and dynamic exercises on muscular strength and hypertrophy. Journal of Applied Physiology 11: 29-34.

Requa, R.K., DeAvilla L.N. & Garrick, J.G. Injuries in recreational adult fitness activities. The American Journal of Sports Medicine 21(3): 461 -467, 1993.

Sale, D.G. Neural adaptation to strength training. In P.V. Komi (ed), Strength and Power in Sport. pp. 249 - 265, 1992.

Semmler, J.G. and Enoka, RM. Neural contribution to changes in muscle strength. In V.M. Zatsiorsky (ed) Biomechanics in Sport, Blackwell Science Ltd, London, pp. 3-20, 2000.

Semmler, J.G. and Nordstrom, Motor unit discharge and force tremor in skill- and strength- trained individuals. Experimental Brain Research 119: 27-38, 1998.

Schmidt, R.A. Motor Learning and Performance Champaign, Il: Human Kinetics, 1991.

Schmidtbleicher, D. Strength training: part 2: Structural analysis of motor strength qualities and its application to training. Science Periodical on Research and Technology in Sport 5:1-10, 1985.

Schmidtbleicher, D. Training for power events. In Strength and Power in Sports (P.V. Komi Ed) London, Blackwell Scientific Publications pp. 381-395, 1992.

Siff, M. Biomechanical foundations of Strength and power training- In: V. Zatsiorsky ed. Biomechanics in Sport London, Blackwell Scientific Ltd., pp. 103-139, 2001.

Siff, M.C. & Verkhoshanski. Supertraining: Strength Training for Sporting Excellence (3rd edition). Johannesburg: University of the Witwatersrand, 1998.

Stone, M.H., Plisk, S. and Collins, D. Training Principle: evaluation of modes and methods of resistance training - a coaching perspective. Sport Biomechanics 1(1): (In Press), 2001.

Thomas, M., A. Fiataron and R.A. Fielding. Leg power in young women: relationship to body composition, strength and function. Medicine and Science in Sports and Exercise, 28:1321-1326, 1996.

Thorstensson, a. Muscle strength, fibre types and enzyme activities in man. Acta Physiologica Scandinavica Suppl: 443::1977.

Vitasalo J.T. and P.V. Komi. Interelationships between electromyographic, mechanical, muscle structure and reflex time measurements in man. Acta Physiologica Scandinavica 111: 97-103, 1981.

Weyand, P.G., D.B. Sternlight, M.J., Bellizi and S. Wright. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. Journal of Applied Physiology, 89:1991-1999, 2000.

Wilson, G.J., Newton, R.U., Murphy, A.J. & Humphries, B.J. (1993) The optimal training load for the development of dynamic athletic performance. Medicine and Science in Sport and Exercise 25(11): 1279-1286, 1993.

Yao, W.X., Fuglevand, A.J., and Enoka, R.M. Motor unit synchronization increases EMG amplitude and decreases force steadiness of simulated contractions. Journal of Neurophysiology 83: 441-452, 2000.

Young, W. Training for speed/strength: Heavy versus light loads. National Strength and Conditioning Association Journal 15(5): 34-42, 1993.

Zajac, F.E. & Gordon, M.E. Determining muscle's force and action in multi-atrticular movement. In K. Pandolph, (ed), Exercise and Sport Sciences Reviews Williams and Wilkins, Baltimore.