Roundtable

Determining factors of strength

Part I

Question 1: Discuss the role played by the number and frequency of motor units firing. Describe how this can be improved through training.

Digby Sale, Ph.D.:

The nervous system can vary the force (strength) of muscle contraction by varying the number of motor units recruited and by varying the firing rate of motor units. For example, a muscle composed of 500 motor units would have 500 gradation "steps" available to it. In addition, each motor unit (consisting of a motor nerve cell and the few hundred muscle fibers it innervates) can vary its force output over about a 10-fold range by varying its firing rate (e.g. from 10–50 impulses per second). For any set of conditions (e.g. contraction type, contraction velocity, muscle length), the force of contraction is maximal when all motor units have been recruited and all are firing at the optimal rate for force development. This is referred to as complete motor unit activation. Using electromyographic techniques, in which the extent of motor unit activation is measured by recording the action potentials of muscle fibers of active motor units, it has been demonstrated that strength training increases the degree of motor unit activation achieved by voluntary effort (Hakkinen & Komi, 1983; Komi et al., 1978; Moritani & de Vries, 1979; Sale et al., 1983). This effect of training on the nervous system would account in part for the increases in strength that occur in the initial stages of a training program, despite no increase in muscle size (Hakkinen & Komi, 1983; Moritani & de Vries, 1979).

Per A. Tesch, Ph.D.

Basically, the force output during muscle contraction is regulated by the number of motor units being recruited and the firing frequency of those units. Thus, to increase force, more motor units have to be recruited and/or fired at a higher frequency. Low contraction forces can be attained by a few motor units firing at a submaximal frequency. As force increases, additional motor units are recruited and/or those already recruited increase their firing frequency. Already at forces on the order of 50% of maximum force, some motor units have reached their maximum frequency and thus their maximum tension. Accordingly, further increase in force can only be produced by recruitment of new motor units. It appears that the modulation of strength by these mechanisms (that is, recruitment of motor units and increased firing frequency) differs from muscle to muscle. Consequently, in some muscles, all motor units are brought into action at fairly low contraction levels and a further increase in force is the result of increase in firing frequency. In other muscles, some motor units are not recruited unless the force demand gets close to maximum voluntary force.

Numerous reports have shown that at the start of a strength training program muscle strength is rapidly increased. This is also consistent with practical experiences. This is because more motor units are brought into action. Once the individual is able to recruit all his/his motor units at their maximum firing frequency, the gain in muscle strength will be much less.

Further improvement is then mainly attributed to increased synthesis of contractile material—muscle mass. Although the time course, the loads, intensity and training frequency to attain optimal recruitment of motor units remain to be demonstrated, it is obvious that overloading is necessary to produce this response.

Bill Allerheiligen:

This question will be examined from the standpoint that maximum strength is desired and that strength is not of an endurance-type activity. When a motor unit (the motor nerve and the muscle fibers it innervates) is stimulated, all of the muscle fibers of that unit contract maximally. A muscle fiber contracts maximally (100%) or not at all; this is the "all or none principle." If the motor nerve innervates a large number of muscle fibers, then the contraction will be strong. The large muscle groups of the body generally involve many muscle fibers for each motor nerve. A large number of motor units contracting in the quadriceps muscles will result in a large amount of force.

When the frequency of motor unit firing increases, along with the increase in number of motor units, then the maximum force will be reached more quickly and for a longer duration. When repetitions are performed at submaximal loads, more and more motor units are called upon to complete each repetition. As motor units are fatigued, other motor units are "kicked in" in order to accommodate the loss of strength. If a person with a 1RM of 300 pounds in the bench press performs one set of 10 reps at 135 pounds, not all motor units are activated. Now if this person tries to perform 50 reps with the same weight, motor units will be fatigued, which will result in a loss of maximum force in some motor units. Some motor units will cease to contract because extreme lactic acid build-up will inhibit any contraction.

An interesting question arises concerning intense training and muscle fatigue. During an intense training set, how does a person "lose strength?" An example would be a person performing a set of eight reps with maximum weight. Remember the all or none law. During initial contractions, are all motor units contracting, followed by fatigue setting in which decreases strength? Or, do 90% of the motor units fire and, as some motor units fatigue, the other 10% assist with the task? The answer to these questions is unclear, but it would appear the latter question is somewhat more accurate. It would also seem likely that at some point the muscle predominately fatigues as a whole, as in the first example.

Strength training is usually short in duration, ranging from 1 to 10 seconds. We must remember that fast twitch (FT) muscle fibers contract approximately three times faster than the slow twitch (ST) muscle fibers. They are, therefore, anaerobic in nature, whereas the slow twitch fibers are aerobic in nature. Because of this our strength training program is anaerobic in nature and develops predominately FT fibers.

The ratio of FT and ST fibers cannot be changed, but how they function can be changed metabolically. Enzymes in FT and ST fibers are similar in facilitating reactions of the ATP-PC system, but enzymes of the FT fibers are about three times more active.

Because a maximal motor unit contraction is a maximal contraction, strength must be increased in other ways. A neuromuscular pattern is developed through strength training. As this pattern is developed, a greater number of motor units may be activated and with a greater frequency. Along with hypertrophy of the muscle fiber and the improved neuromuscular pattern, strength will be increased.

Peak force is greater in FT fibers than in ST fibers but FT fibers fatigue sooner. Rate of fatigability is related to initial strength levels and not to fiber type ratios.

Wayne L. Westcott, Ph.D.:

The two basic components in strength are the number of motor units recruited and the frequency of motor unit activation. Strength of muscle contraction can be increased by recruiting more motor units, activating the motor units at a higher firing rate, or both.

A motor unit fires when the net effect of all neuro-stimuli on the motor neuron reaches a predetermined threshold level. Motor neuron stimuli include input from the brain, from higher levels of the spinal cord, from lower levels of the spinal cord, from muscle spindles, from receptors in the joints, ligaments and tendons.

Regular and progressive resistive training may facilitate the transmission of excitatory stimuli to the motor neuron. As a result, trained individuals may be able to recruit a greater percentage of available motor units and thus produce stronger muscle contractions.

Jimmy Pedemonte:

Sometimes I happen to notice skinny guys doing better strength performances compared to heavier and more muscular athletes. How can this fact be explained?

If the level of quantitative development of the muscles (hypertrophy) is lower, there should be a qualitative compensation which justifies this phenomenon.

Bill Allerheiligen is the strength coach for the Houston Oilers professional football team. A charter member of the NSCA, he has published a number of articles in the *NSCA Journal*. Allerheiligen is the NSCA Region 3 Director and a member of the certification committee.

V. Reggie Edgerton, Ph.D. is professor of kinesiology and a member of The Brain Research Institute at UCLA. He has performed research related to adaptation of the neuromuscular system of laboratory animals and humans for 16 years at UCLA. Edgerton obtained his B.S. from East Carolina University, his M.S. from the University of Iowa and his Ph.D. from Michigan State University.

Bill Hayman has been successfully competing in weight lifting and bodybuilding for nearly 10 years. He received his B.S. in biochemistry from the University of Santa Clara, and is currently working on a Masters in sports nutrition at San Jose State University.

John Kuc operates Kuc's Fitness Store in Wilkes-Barre, Pennsylvania. He is a four-time world powerlifting champion. Currently, Kuc is involved in powerlifting seminars and exhibitions and active with the American Drug Free Powerlifting Association.

Mike Lambert is publisher and editor-in-chief of *Powerlifting USA*. He competed up to the national level in powerlifting from 1968 through 1980, and is currently chairing the publicity committee of the United States Powerlifting Federation. His articles and photographs on powerlifting have been widely published.

J. D. MacDougall, Ph.D. is a physiologist at McMaster University in Hamilton, Ontario, Canada, where he is a professor in the School of Physical Education and Athletics and an associate member of the Department of Medicine. His research is directed toward the adaptation of skeletal muscle to physical training. Recently, he and his colleague, Dr. Digby Sale, have focused on those adaptations which occur in response to strength and power training.

Harold S. O'Bryant, Ph.D. is the director of the Kinesiology/ Biomechanics Lab in the Department of Health Education, Physical Education and Leisure Studies at Appalachian State University in Boone, North Carolina. He is an *NSCA Journal* Associate Editor and a member of the NSCA Scientific Committee.

Jimmy Pedemonte is the throwing coach at the University of Genoa, Italy. He is widely recognized as an expert on eastern European training methods.

Digby Sale, Ph.D. is an exercise physiologist in the Department of Physical Education at McMaster University in Hamilton, Ontario, Canada. For the past 10 years, he and his colleague, Dr. Duncan MacDougall, have conducted research into the effects of heavy resistance exercise upon neuromuscular function. This work, which has resulted in several publications, is still ongoing.

Per A. Tesch, Ph.D. is presently an associate professor in the Department of Environmental Medicine at the Karolinska Institute, Stockholm, Sweden. Tesch received his Ph.D. in 1980 from the Karolinska Institute with main emphasis areas in muscle and exercise physiology. He is a Fellow of the American College of Sports Medicine.

Al Vermeil is currently president of Vermeil's Sports and Fitness, a company which installs, maintains and develops fitness programs for fire, police and business corporations in the state of California. He holds a B.S. and M.S. in physical education from Kansas State University and Utah State University. Vermeil has previously coached high school, college and professional football. The high point of his coaching career was his part in enabling the San Francisco 49ers to bring home the Super Bowl Trophy in 1982.

Wayne L. Westcott, Ph.D. authored the college textbook *Strength Fitness*. He is currently involved with the South Shore YMCA in Quincy, Massachusetts, where his responsibilities include strength testing, strength training, strength research and strength consulting with YMCA fitness directors throughout the United States. Westcott received his Ph.D. from Ohio State University and has been Coordinator of Physical Fitness at Pennsylvania State University, Director of Strength Training at Eastern Connecticut State College, and Associate Professor of Physical Education at Florida State University.

I think that, especially in the field of power, the muscular cross-section represents an important, but indirect contribution to performance, while the percentage of fast twitch fibers, the degree of their innervation and the degree of synchronization of the activity of motor units, is really the heart of the matter.

Keeping in mind that strength is a very wide field, going from resistant strength to explosive power (and many other manifestations), I think that, while the muscular hypertrophy can be more or less important, according to the type of strength required by a certain sporting event, the neuromuscular aspect is always of first importance. It will specialize according to the requirements of each sport, and always represents the most direct contribution to high power feats.

Therefore, I believe that the nervous aspect, chiefly played by the motor units, is of fundamental importance in strength. Every movement starts from the central nervous system; the transmission of nervous impulses through the motor units should be amplified (power) or specifically directed (other strength manifestations).

It is very difficult to determine how this aspect can be improved through training. We still don't know exactly the mechanisms that govern the number of motor units firing and their frequency, and also because the practical applications in sports have been too limited until now. However, as a rule of thumb, the intensity of loads can improve this nervous aspect of strengh training.

V. Reggie Edgerton, Ph.D.:

The number of motor units recruited within a muscle is proportional to the "effort" exerted. If the "effort" level extends beyond the threshold of a given unit, the frequency of firing of that unit will increase beyond the minimal firing frequency. A maximal level will be obtained with a slightly greater effort. For any given motor unit, the relationship of tension to frequency of firing is S-shaped; that is, as the frequency increases, the tension increases slightly up to a point, at which a slight increase in frequency produces a large increment in tension. The total strength of a muscle group is simply the summation of the tension produced by all motor units that are activated.

It is not clear what neuromuscular mechanisms are used to improve strength, but it appears that one can "learn" to optimize activating motor units by perhaps modulating frequency and/or the number of units activated at any one time. There is some evidence that one can increase the probability of two or more units being activated in a synchronous manner. This has been referred to as synchronizing motor unit excitation. It is not clear why, or if this necessarily leads to improved strength.

John Kuc:

An untrained whole muscle (biceps, for example) is composed of many motor units that do not all fire at once. If more motor units fire simultaneously and with greater frequency, then most of the muscle fibers of a whole muscle would be contracting, producing a stronger contraction.

The body adapts to changes only when necessary. If a muscle is exercised to improve strength, then a reaction to the increased work load will slowly cause more and more motor units to fire with increased frequency. This is a gradual process and is only one of many factors affecting increase of strength.

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—Pedemonte

Mike Lambert:

I feel the more motor units firing, in a coordinated fashion, the greater the strength output. Practice of the specific athletic event involved is obviously the best way to develop the appropriate pattern of motor unit firing. In addition, weight training incorporating heavy weights and low reps should develop additional motor unit firing capacity that can be carried over to enhanced performance in the desired athletic event.

Al Vermeil and Bill Hayman:

During an all-out muscle effort which is to last only seconds or less, as many motor units as possible must fire in order to recruit the maximum number of muscle fibers possible.

When the motor unit fires, the faster it fires, the better—to a point. A saturation point is reached eventually. At this point, the muscle fiber is literally contracted all of the time due to the high frequency of motor unit firings. However, strength (maximum strength) is only maintained for a short period of time, due to fatigue setting in on the muscle fiber which is contracted nearly all the time because of the saturation of nerve impulse firings.

In an untrained muscle, the number of recruitable fibers for strength is limited; not all will be recruitable. This rarely occurs even in a trained muscle. However, through proper training, a higher percentage of motor units can be recruited. The better the training, the better the recruitability of the fibers. This results in greater strength and explosive strength.

Two methods of training can help increase and improve the condition of more motor units and a higher frequency of firing: traditional adaptation training such as free weight training, and mental training. Mental training is the area we feel most athletes neglect. The coach should educate the athlete about the muscle group to be trained. This is done through pictures, explanations, etc. so that the athlete has a good knowledge of the muscle to be trained. Next the athlete is taught to visualize the actual nerve impulses firing to the muscle. The athlete is then taught to picture all this happening faster and faster. Then the athlete is taught to employ this type of thinking during the actual activity.

Harold O'Bryant, Ph.D.:

A motor unit consists of a motor neuron and all the muscle fibers it innervates. A motor unit, when innervated by a stimulus of at least threshold level, will contract maximally. The strength of a whole muscle can be near maximum when all of its motor units are stimulated (dependent upon pH, temperature, etc.). The manner of varying the number of motor units brought into play is called "recruitment." Two variables associated with recruitment are: the size of the individual muscle fibers and the number of muscle fibers in a single motor unit.

Generally, a large cross-sectional mass of contractile tissue will exhibit greater contractile force independent of the number of fibers. The number of fibers within a motor unit varies and may have as many as 500 fibers or as few as 25; therefore, theoretically, if each fiber can produce 5 grams of tension, the tension within a single motor unit can vary from .125 kg to 2.5 kg (Fox and Mathews, *The Physiological Basis of Physical Education and Athletics*, 1981). Force generated by a whole muscle is then a function of the quantity of active tissue brought into play at any one time.

Also, the muscle tension increases as the rate of firing (frequency) increases. This becomes increasingly important as recruitment approaches the maximum number of available motor units, as in the performance of high-intensity force work. It is possible that strength training may allow an increased ability to raise motor neuron excitability during voluntary effort (Sale, MacDougall, and Upton, *Medicine and Science in Sport and Exercise*, Vol. 15, 1983). Although the adaptive mechanisms are not at present clearly understood, a response to "high-intensity" weight resistive training appears to more effectively enhance the voluntary recruitment of higher threshold motor units than other less intense modes of conditioning.

Question 2: Describe the manner in which synchronous firing of motor units improves strength and how this can be improved to increase strength.

Tesch:

In addition to the two mechanisms described above, synchronous firing of motor units may increase the force output during contraction. Recent animal and human experiments suggest that increased synchronization occurs after a period of strength training. Because a similar response has been noticed in violinists, overloading does not seem to be the factor causing this adaptation. Nevertheless, it is a challenge for scientists to further study how synchronization can be achieved through strength training.

Lambert:

Uncoordinated firing of motor units will lead to no useful athletic result. Practice of an athletic event under near maximal loading will develop the necessary synchronicity of motor unit firing, and the practice of heavy weight training will likewise produce greater strength output.

Kuc:

Synchronous firing of motor units gives a stronger muscular contraction because more motor units fire together, combining their forces in a unit of time, producing more efficient contraction. More efficient training is needed to make motor units fire in greater sync. Efficient training is characterized by getting the most work done in the smallest unit of time. If there are ten 70-lb. dumbbells on the floor and I pick them up one at a time, I've performed 1050 ft. lbs. of work, presuming the rack is 1½ feet high. It takes me a minute to do this work. Now, if I deadlift a 700-lb. barbell, I still did the same amount of work, but it takes only two seconds. All strength building programs should have efficiency as their cornerstone.

Vermeil and Hayman:

Synchronous firing of motor units improves strength by enabling more muscle fibers to be recruited and thus develop a larger force resulting in greater strength.

To improve synchronous firing of motor units, two parameters must be thought about.

1. The athlete must consciously think "speed," "quickness," and explosiveness" during the movements being trained.
2. Movements such as plyometrics must be done because these are the best training methods to improve speed and power, and they provide the athlete with an ideal method to consciously think about getting faster. Plyometrics are the best because you are not getting a self-induced stretch reflex action.

O'Bryant:

The effective force generated by a whole muscle deals with the timing of the stimulus to the various motor units. The "synchronization," or simultaneous firing of large numbers of motor units produces a firing pattern that results in very forceful muscle contractions. Unlike submaximal contractions, the high forces generated during synchronous firing of the motor units may appear jerky. Such movement patterns are likely exhibited by well-trained powerlifters at moments of extreme force generation during maximal attempts and is an observational effect of the synchronization phenomenon. High-intensity weight training is thought to produce both facilitory and inhibitory effects on the nervous system to potentiate strength gain (Hayes, *Biomechanics of Sports and Kinanthropometry*, 1978; Moritani and DeVries, *American Journal of Physical Medicine*, Vol. 58, 1979).

All strength building programs should have efficiency as their cornerstone.

—Kuc

Pedemonte:

As early as 1856, E. Weber found that strength is proportional to the muscle's cross-section. After one century of studies, researchers arrived at the conclusion that for the development of strength, the improvement of the nervous mechanisms is indispensable (A. W. Korobkow, 1954; N. W. Simkin, 1956; A. N. Krestinow, 1957). These experts found that the degree of the muscular tension can be modified through the influence of the central nervous system.

Keeping in mind that strength shouldn't be considered as an isolated contribution to the improvement of sport performances (more strength + more speed + more endurance + more agility, etc. = better performance), but rather, must be associated with the movements that actually represent the complete expression of a given sporting event, one can easily understand the importance of muscular coordination. The more technical the event, the more important muscular coordination.

According to Soviet researchers, we can distinguish two types of muscular coordination: the among-muscles coordination and the intramuscular coordination. While the first is especially trained through technical drills (e.g. gymnastics, diving, ice-skating, etc.), the second is regulated by the synchronous firing of motor units and directly increases strength. According to E. B. Kossowakaja, in the process of developing muscular strength, the fast twitch fibers are the first to be synchronized, and the degree of synchronization is dependent upon the intensity of the loads. With submaximal loads we haven't an effective stimulation on the perfecting of the intermuscular coordination, which means synchronization of the activity of muscles.

A different type of synchronization of motor units can also be distinguished according to different types of strength. While speaking of power, we must have a synchronization of the muscular activity connected with a maximal shortening of the highest possible number of fibers at their highest level of contraction. According to V. W. Kusnezow, slow resistant strength is related with the synchronization of the activity of a maximal number of muscular fibers, at their highest level of contraction, in connection with an optimal frequency and number of nervous impulses.

Therefore, the synchronization of motor units can be improved by means of high intensity-fast movements and, speaking of power, we are now studying a method of fast weightlifting associated with a contemporaneous electro-stimulation.

Sale:

Although increased synchronization of motor unit firing has been observed following strength training (Milner-Brown, Stein and Lee, 1975), it is not clear how this adaptation could increase the force of voluntary contractions. On the contrary, studies with animal muscles have demonstrated that in submaximal contractions

in which the frequency of stimulation is low (e.g. 10–20 Hz), the force of contraction is considerably greater with asynchronous than with synchronous stimulation. At high frequencies of stimulation, the force produced by synchronous and asynchronous stimulation is similar (Lind & Petrofsky, 1978; Rack & Westbury, 1969). If synchronization cannot increase the peak force of contraction, perhaps it can increase the rate of force development. However, a study with human muscle indicated that synchronous stimulation of muscle at frequencies as high as 200 Hz failed to match the rate of force development attained with voluntary contraction, in which the activation of the muscle was relatively asynchronous (Miller, Mirka & Maxfield, 1981). Thus, the contribution of increased motor unit synchronization to strength performance remains unknown.

Allerheiligen:

All of the muscle fibers of a motor unit are fired synchronously. The motor nerve may innervate any number of muscle fibers. Large muscles of the body will involve a large number of muscle fibers per motor unit while small muscles of the body will involve a small number of muscle fibers per motor unit. Over 1000 motor units may be within a whole muscle. Just a small percentage of motor units firing in the quadriceps will yield a contraction of noticeable magnitude.

When a large percentage of the motor units are stimulated synchronously, the resulting contraction is strong. A contraction of this magnitude is very evident in anaerobic activities such as weight lifting, and throwing a shot, discus, javelin, hammer or heavy weight. Synchronous firing of a large number of motor units will enable a person to lift heavier weights and the overload principle will be in effect.

Associated with this is the frequency of stimulation of motor units. The number of impulses may vary from five to eighty or ninety. If a maximum effort is required then motor units should be synchronous with a maximum number of motor units and the highest number of impulses.

Specificity of training must be kept in mind. If power is desired, then train for power. Development of a neuromuscular pattern is refined when training for power or almost any other skill or activity.

It should be pointed out that while motor units are synchronous in firing, the muscle as a whole is asynchronous in its firing pattern. If this were not true then the entire muscle (pectorals, deltoids, etc.) would contract at one time. There would be no refined movements. This is the reason behind the graduation of force.

Question 3: What is meant by the motor unit recruitment pattern, what role does this play in strength and how can it be improved?

Westcott:

Motor unit recruitment is the key to smooth, forceful, and maintained muscle contraction. Each motor unit consists of a motor neuron and a number of muscle fibers (as many as 2000) that contract maximally every time the motor neuron is activated. Because the muscle fibers in a given motor unit are distributed throughout the muscle, only a few motor units need to be activated for coordinated muscle contraction. This arrangement allows individual motor units to alternately fire and rest when work is performed at submaximal strength levels.

In order to develop maximum strength, the highest possible number of FT fibers should be activated, the highest number of motor units must be activated and the greatest frequency of motor units firing must be incorporated. The exercises which should be at the top of the list to meet these requirements are the Olympic style lifts and their supplemental assist exercises.

—Allerheiligen

For more muscle force, motor units are required to fire simultaneously. High frequency activation of individual motor units produces even greater force by means of tetanic contractions.

High intensity strength training with relatively heavy resistance stimulates maximum motor unit recruitment which produces maximum muscle strength.

Tesch:

Motor units can be distinguished into two main categories; slow twitch (ST) and fast twitch (FT) motor units (MU). These two MU-types differ with regard to their activation threshold. The ST-MU is recruited at low forces whereas the FT-MU is recruited at greater tension levels. Some studies suggest that some FT-MU are activated at approximately one fourth to one third of the individual maximal voluntary isometric force and the reliance upon FT-MU is increased the greater the force demand. The FT-MU can also be selectively recruited during rapid, ballistic movements irrespective of force level. Motor unit recruitment pattern refers to the involvement of different MU during contraction. The ability to recruit the high-threshold MU is improved through strength training. It is likely that both explosive-resistance training and heavy-resistance training will produce this effect.

Edgerton:

Motor unit recruitment simply means the activation of a motor unit: the term "pattern" has been used to mean a variety of things. "Pattern" most often refers to the frequency of electrical impulses that occur within a motor unit when it is excited. The frequency of firing of a motor unit increases with "effort" or level of excitation. The maximum frequency is probably determined by the inherent properties of the motor neuron that innervates the muscle fibers. This maximum level is not likely to be trainable. However, strength could be improved by learning to activate more motor units closer to their maximum level in a more synchronized manner; that is, learn to provide a greater excitation level to a group of the appropriate motor neurons.

O'Bryant:

The timing of the contraction of specific patterns of motor units (and whole muscles) is critical to performing strength-power related activities. Research strongly suggests that motor units are recruited in order of size (smallest to largest), and this recruitment is largely a function of the force of muscle contraction (Edgerton, *Canadian Journal of Exercise Physiology*, Vol. 1, 1976; McDonach and Davies, *European Journal of Applied Physiology*, Vol. 52, 1984). Fast motor units are generally the larger motor units, which may be recruited when greater muscular force is needed (Hopper, *Swimming Techniques*, August 1980; Komi, *Scandinavian Journal of Sports Sciences*, Vol. 1, 1979).

Both high force and high speed weight training exercise will recruit fast twitch fibers, moving one closer toward the force-velocity capacity curve, increasing the power output, and subsequent strength-power training effect (Atha, *Exercise and Sports Sciences Review*, Vol. 9, 1981; Edington and Edgerton, *The Biology of Physical Activity*, 1976; Stone and Garhammer, *NSCA Journal*, Vol. 3, 1981). The most efficient manner of producing increases in strength-power and speed of movement is through a logical progression and combination of training speeds. Simplistically, this method

entails developing a strength base (high force work) before moving to high speed, high power work (Stone and O'Bryant, *Weight Training: A Scientific Approach*, 1985).

Sale:

There are at least two aspects of the motor unit recruitment "pattern" that may be relevant to strength performance and training. One aspect is the relative importance of recruitment and firing rate variation in grading the force of muscle contraction. In two small human muscles which have been investigated, most motor units are recruited at thresholds less than 50% of maximum strength (MVC); thereafter, force is increased further almost solely by increasing the firing rate of motor units. In contrast, in two larger more proximal muscles (biceps and deltoid), recruitment of additional motor units occurs throughout the force range up to 100% MVC (DeLuca et al., 1982; Kukulka & Clamann, 1981; Milner-Brown, Stein & Yemm, 1973). This latter pattern may present a greater challenge to achieving full motor unit activation during voluntary effort, and could provide the scope for the increased motor unit activation that has been observed in strength training experiments.

A second aspect of the recruitment pattern is the order of recruitment of motor units in voluntary contractions. The recruitment order of motor units is rather fixed for a muscle involved in a specific movement, even if the rate of force development or speed of contraction varies over a wide range (Desmedt & Godaux, 1977). Motor units are generally recruited in order of size of the neuronal cell bodies; thus, the smaller slow twitch motor units are recruited before the larger fast twitch motor units. Further, the results of electromyographic studies do not support the notion of "selective" or "preferential" recruitment of fast twitch motor units in contractions performed at high velocity. If this is the case, to what can be attributed the specificity of velocity that has been observed in strength training experiments (e.g. Kanehisa & Miyashita, 1983)? While the pattern of motor unit recruitment may not change in high speed contractions, the pattern of motor unit firing changes markedly in slow vs. fast contractions, with the firing rates being much higher in fast contractions (Desmedt & Godaux, 1977). Further, there is evidence that the brain organizes the initiation of fast contractions differently than slow contractions (Desmedt & Godaux, 1979). Finally, there is recent evidence that there are velocity specific effects of training on the contractile properties of the muscle itself (Duchateau & Hainaut, 1984).

While the recruitment order of motor units is fixed for a muscle involved in a specific movement, in the case of a change in position (Person, 1974) or in the case of a multifunctional muscle performing different movements (Desmedt & Godaux, 1981; Haar Romeny, Dernier Van Der Gon & Gielen, 1982; Schmidt & Thomas, 1981), recruitment order of some motor units can be altered. Thus, some motor units within a muscle might have a low threshold for one movement and a higher threshold for another movement. The variation in recruitment order according to movements may be partially responsible for the specificity of training that has been observed (Sale & MacDougall, 1981), and may provide a basis for the notion long held by strength trainers that full development of a muscle is only possible when it is exercised in all its possible movements.

Kuc:

Motor unit recruitment pattern is bringing into simultaneous function more motor units during a contraction of a whole muscle. The more motor units firing simultaneously, the stronger a muscle contraction will be. More motor units will gradually be brought into play if there is greater demand continuously applied to a muscle than previously encountered.

Progressive resistance exercises, especially with the overload principle, will improve strength. This increased strength is due to increased motor unit recruitment.

Simply, plyometrics may be considered the link between strength and speed. The theoretical basis for plyometric training lies in the rebound movement patterns so prevalent in sport activities.

—O'Bryant

Allerheiligen:

Motor recruitment can be thought of in four ways: 1) fiber type recruitment (FT or ST), 2) number of motor units recruited, 3) order of recruitment with regard to type I, IIA, IIB, and 4) frequency of motor unit contraction. A motor unit innervates either all FT fibers or all ST fibers. If the task is endurance (aerobic) in nature the ST motor units are of major importance. If the task is power (anaerobic in nature), the FT motor units are of major importance.

Item 2 is related more to the strength of the contraction. The smaller class I motor units may be recruited first even though a power activity may be involved. The IIA and then the IIB are next in line for recruitment. In other words, recruitment is from the small to large muscle fibers.

The frequency of motor unit firing ranges from 5 to 90 per second. If a slight or "refined" movement is required, then a small number of impulses are required. When a powerful movement is required the number of impulses per second are large. The number of impulses is regulated mainly by the muscle spindles which monitor tension (static length, change in length and pressure) on the muscle. Another regulator of the number of impulses is a person's kinesthetic sense. Many a person has experienced a situation where they are ready to lift a heavy weight only to find someone has changed it to a lighter weight. A person getting ready to lift 400 pounds on a leg press gets a big shock when there is only 200 pounds loaded.

In order to develop maximum strength, the highest possible number of FT fibers should be activated, the highest number of motor units must be activated and the greatest frequency of motor units firing must be incorporated. The exercises which should be at the top of the list to meet these requirements are the Olympic style lifts and their supplemental assist exercises. The list of exercises would include:

1. Clean and jerk
2. Snatch
3. Power clean
4. Power snatch
5. Hang clean or snatch
6. High pull
7. Jerk

Several other lifts are also a foundation of many programs which include the bench press, squat, incline, military press and deadlift. Although large amounts of weight may be handled during these exercises they are not thought of as "explosive." As mentioned earlier, an explosive type move will recruit primarily FT fibers, maximum number of motor units with a high frequency of stimulation. But it must also be noted that a max set of two reps is a very intense activity. In other words, a bench press may recruit FT fibers with a maximum number of motor units and the highest possible frequency of stimulation.

Some of the major concepts of strength training speed of movement are 1) slow concentric and eccentric contractions; 2) fast concentric and eccentric contractions; 3) smooth (neither fast or slow) concentric and eccentric contractions, and 4) isokinetic contractions. While smaller amounts of weight can be used explosively they will not allow for recruitment of a sufficient number of FT fibers (if maximum strength is desired). Isokinetic training will allow for constant speed and accommodating resistance. While performing a movement, maximum effort may be exerted through the full range of motion. When there is a

mechanical advantage or disadvantage, isokinetics will accommodate for this with constant speed. It is because of this fact that some coaches feel isokinetic strength training is superior to other training methods.

A problem arises when using a small amount of weight for a very fast contraction as in the bench press. A ballistic force is created. If the lifter would relax their grip, the bar would fly out of the hands. During such a lift very little work is performed because the hands and arms just "follow the bar."

One small note here: the term "isotonic contraction" is used when speaking of exercise with free weight. When examining the word isotonic we find iso = "same" and tonic = "tension." As a body part goes through its normal range of motion there are gains and losses in mechanical advantage. The tension is not always the same. An arm curl of 100 pounds will never change in weight but it will change mechanically. To clarify this situation the term "dynamic contraction" should be used, meaning a "change in tension."

Vermeil and Hayman:

The motor unit recruitment pattern depends upon the type of physical stimulus being placed on that motor unit. The pattern will be one of mainly slow twitch fibers with a few fast twitch fibers when aerobic, endurance type activity is done, requiring low force output. The situation will be reversed for an activity requiring a high force output. In other words, the nervous system selectively recruits the fibers needed for a particular activity.

By selectively training fast twitch fibers, the motor unit pattern will develop a higher ratio of fast twitch to slow twitch nerve impulse firings which will result in a greater force output and greater strength. The recruitment pattern will differ from individual to individual depending on the genetic makeup of fast and slow twitch fibers in that particular individual.

Question 4: What role does neuromuscular inhibition play in strength, and how can it be altered in such a way as to improve strength?

Lambert:

Neuromuscular inhibition is a self-protective reaction of the human body. The threshold of stress at which the body responds with inhibition appears to be alterable, through various training methods, with PNF being the most direct of which I am aware. Partial rep squats, benches, or deadlifts with overload poundages in a power rack seems to also be a means to push back the level at which the body shuts itself down and inhibits muscular contraction. Fred Hatfield often leaps high into the air before attempting a heavy deadlift on the assumption that this will temporarily push back the threshold of neuromuscular inhibition and allow him to exert more force on a maximum strength effort.

Kuc:

There are proprioceptors in our muscle tendons and joints which inhibit the strength of a muscular contraction if it senses tearing or collapse of a joint. Examples of blocking neuromuscular inhibitors are sometimes seen in life or death situations in the form of extraordinary feats of muscular strength and endurance. Psyching up before an athletic event, especially one involving great strength, is one way to partially override neuromuscular inhibition. A reduction in central nervous system inhibition also comes from devoted participation in proper weight training programs. It is believed that changes take place in the central nervous system as a result of heavy weight training.

While shouting, hypnosis and fear may also reduce neuromuscular inhibiton, the most effective way to accomplish this objective is through regular resistive training with careful attention to proper technique.

—Westcott

Vermeil and Hayman:

Neuromuscular inhibition plays the role of slowing an individual's strength gains. An individual usually will have the ability to create enough force needed for the movement, but the lack of neuromuscular coordination and specific movement inexperience will be the limiting factor.

This can be improved through the practicing of the motion to learn proper techniques and overcome the conscious thoughts of not having the specific motion skill. Duplication of the learned motion (after a solid strength foundation has been built) explosively with heavy weights (70–95% of max) lessens the body's conscious holding back from an all-out effort.

Westcott:

A recent research study revealed that previously untrained women increased their 10-repetition performance on a leg extension exercise approximately 60 percent during a four-week training period. However, pre- and post-training assessments on computerized strength testing equipment showed only 10 percent improvement in maximum quadriceps strength. These findings indicated that a large part of the performance improvement was due to factors other than increased muscle strength.

One of these factors may have been a reduction in neuromuscular inhibition as a result of neurological adaptations to the training process. For example, the Golgi tendon mechanism appears to limit muscle force production under conditions of high resistance. Although the exact process is uncertain, regular strength training seems to reduce Golgi tendon mechanism sensitivity to muscle stress. This reduces inhibitory stimuli to the motor units, which makes more of the muscle fibers available for force production.

While shouting, hypnosis and fear may also reduce neuromuscular inhibition, the most effective way to accomplish this objective is through regular resistive training with careful attention to proper technique.

O'Bryant:

Research has shown that voluntary attempts at maximum concentric force production result in inhibitory responses (Perrine and Edgerton, *Medicine and Science in Sports and Exercise*, Vol. 10, 1978) from "golgi tendon organs," etc., as well as conscious aversion to maximal or near maximal exertion, which can limit force output (Caiozzo, Perrine, and Edgerton, *Journal of Applied Physiology*, Vol. 51, 1983). The degree of inhibition is likely related to skill acquisition. High force training can reduce this inhibition better than purposeful slow, lower force movements (Stone and Garhammer, *NSCA Journal*, Vol. 5, 1981).

Edgerton:

There is some indirect evidence that some type of inhibitory phenomenon operates during very slow velocity movements. This phenomenon seems to be present in elite athletes as well as in untrained individuals. However, it appears that one can improve their force output at a range of velocities with muscle hypertrophy occurring and further, this improvement is influenced by the speed at which the training is executed. Whether

this improvement is due to more excitation by the nervous system or less inhibition, is unknown.

Sale:

Inhibition of reflex or behavioral (e.g. fear of injury) origin may limit full activation of muscles. Special sensory stimuli and hypnosis have been shown to partly overcome this inhibition (Ikai & Steinhaus, 1961). Repeated maximal efforts in strength training may, by increasing the ability to excite motoneurons, help to overcome inhibition. Two related observations should be of interest to strength trainers. First, conventional strength and power training often involves exercises in which the same muscle groups of both limbs contract simultaneously. It has been observed in these bilateral contractions that the force produced is less than the sum of forces produced by the right and left limbs contracting singly (Ohtsuki, 1981; Secher, Rorsgaard & Secher, 1978), and that this bilateral "deficit" is associated with reduced motor unit activation (Ohtsuki, 1983; Vandervoort et al., 1984). Training with bilateral contractions reduces the bilateral deficit (Secher, 1975) and this could be considered a form of neural adaptation to training. Some strength training equipment manufacturers have wittingly or unwittingly avoided the bilateral deficit problem by producing machines which permit unilateral performances. Depending on the sport, this may or may not be an advantage.

Secondly, the force and motor unit activation of a muscle group in a MVC are increased if the contraction is immediately preceded by a MVC of the antagonists. In the case of isokinetic concentric contractions, this enhancement is most pronounced in the low velocity-high force region of the force-velocity relationship (Caiozzo et al., 1981a). It has been proposed that a tension-dependent, neurally mediated force limiting mechanism provides inhibitory input to agonist motoneurons during MVCs against high resistance (Perrine & Edgerton, 1978). The precontraction of antagonists in some way counters the inhibitory influence and allows greater activation of the agonists in their subsequent contraction. A strength training program which employs the precontraction technique is more effective for increasing low velocity strength than a program which consists only of prime mover contractions (Caiozzo et al., 1981b). Some types of training equipment allow the precontraction technique to be used.

Question 5: What is the importance of the different fiber types in strength, and to what degree can this be a limiting factor in strength development?

Pedemonte:

As time goes by, we learn more and more about different types of muscular fibers and also learn how important they are in sport.

According to Hungarian biologist M. Nemessuri, fast and slow twitch fibers represent the outermost limits of a quite wide range of muscular fibers. Some sporting events require fast movements, while others need endurance. If, on one hand, the athlete who has a great number of fast or slow twitch fibers in his muscles can be favored by this genetic advantage, and, on the other hand, training can help in changing the intermediate types of fibers (not the pure fast and pure slow fibers), training to such an extent may allow great improvements in all sporting events.

Recent studies tend to delineate a sort of "fiber topography" which can be of enormous help for us as coaches. These studies try to give general indications about a "normal" percentage of slow-fast twitch fibers in each single muscle. In other words, they found that each muscle has a different percentage of slow-fast fibers. For instance, the latissimus dorsi has 51% of slow fibers while the rectus femoris has 38% and the soleus has 88%. Can this aspect be of some

benefit for us? I think so, but further practical studies are still necessary for telling us the practical applications of this knowledge.

Tesch:

From a number of studies we know that high-caliber sprinters, throwers, jumpers and weight-lifters possess a high percentage of fast twitch (FT) muscle fibers and/or selective hypertrophy of FT fibers. Hence, in these athletes, the cross-sectional area of the muscle occupied by FT contractile proteins is typically greater than in other individuals. Endurance athletes, on the other hand, have a high percentage of slow twitch (ST) fibers. Today, it is generally agreed that the muscle fiber type composition of successful endurance athletes is the result of both inheritance and training adaptation. In power activities such as throwing, jumping, sprinting and Olympic weightlifting the importance of having a high percentage of FT is related to the superiority of the FT fibers with regard to rate of force development. Thus individuals with a high percentage of FT are able to produce force at a greater rate. In powerlifting, contrary to Olympic weightlifting, where the rate of force development is of little importance in competition, it is less likely that fiber type composition per se is a limiting factor. Yet, high-caliber powerlifters exhibit either a high percentage of FT and/or hypertrophied FT fibers. In elite bodybuilders, fiber type composition seems to vary, which suggests that fiber type composition does not limit the capacity to produce muscle hypertrophy. This is surprising, as it is obvious that the FT fiber is more sensitive to hypertrophy than the ST fiber. In other studies of previously non-strength trained individuals it has been shown that the rate of strength improvement is greatest in individuals having a high FT percentage. Whether this also applies to athletes competing at a high level is not known. Nevertheless, the fact that strength and power, especially at higher contraction speed, is positively correlated with percentage of FT suggests that fiber type composition is an important feature in strength development.

Edgerton:

There is contradictory evidence regarding the strength potential of slow and fast muscle fibers at zero velocity (isometric). However, fast muscle definitely has the greater force potential at the higher velocities. The percentage of slow and fast fibers in a muscle is determined almost entirely by genetics. Although there have been claims of converting fibers from fast to slow, and even slow to fast, these changes seem to be of such a small magnitude as to be of questionable physiological significance. At best, one can expect a change by only a few percent. Certainly, few of the improvements realized in training can be accounted for by a change in fiber types.

O'Bryant:

Fiber type varies from one person to another with considerable differences existing between endurance and strength-power athletes (**Table 1**). Generally, endurance athletes have higher (SO) percentages while strength-power athletes have higher (FG) percentages. It is known that both the distribution and functional characteristics of fiber types are, to a very large degree, determined genetically. Strength research generally agrees that the quantity of muscle correlates with maximal isometric strength and likewise, a significant positive relationship exists between this value and the proportion of fast twitch muscle fibers (Komi, *Scandinavian Journal of Sports Science*, Vol. 1, 1979). More recent evidence suggests that there is both a qualitative as well as a quantitative adaptation of muscle tissue in response to training. Even though fiber distribution, based on myosin-ATPase, is still thought to be governed largely by genetic factors, high fast twitch to slow twitch ratios are found in sprinters and jumpers appear to be a result of strength training with similar results reported in weightlifters (Edstrom and Ekblom, *Scandinavian Journal of Clinical Laboratory Investigation*, Vol. 30, 1972).

The "type" of strength program may also be an important factor. Changes in enzyme activity following sprint strength training have been shown to cause increased creatine phosphokinase (CPK), and myokinase (MK) activity within the muscle (Thorstensson and others, *Acta Physiologica Scandinavica*, Vol. 99, 1977). Higher demands may also be placed on faster ATP synthesis when rapid maximal contractions are repeated 5–8 times with brief rest intervals. Consequently, a high rate of tension development will yield a higher force output. Likewise, a faster intrinsic speed of shortening in FG fibers leads to higher force output for FG fibers.

Group (men)	Approximate average (FG) %
Marathoners	17.0
Swimmers	26.0
Distance runners	31.0
Speed skaters	31.5
Orienteers	32.0
Cross-country skiers	36.0
Nordic skiers	36.0
Alpine skiers	36.0
Ice hockey	39.0
Race walkers	41.0
Canoeists	41.0
Cyclists	41.0
Bodybuilders	44.0
Javelin throwers	50.0
Runners, 800m	52.0
Downhill skiers	52.0
Untrained	54.0
Weightlifters	60.0
Shot-putters	62.0
Discus throwers	62.0
Sprinters/Jumpers	63.0
Group (women)	**Approximate average (FG) %**
Runners, 800m	39.0
Cross-country skiers	40.5
Cyclists	49.0
Shot-putters	49.0
Discus throwers	49.0
Untrained	49.0
Long & high jumpers	51.5
Javelin throwers	57.5
Sprinters	72.5

Table 1: Distribution of fast twitch fibers among different athletic groups. (Stone and O'Bryant, *Weight Training: A Scientific Approach*, 1985).

at high contraction velocities. As one might expect, the percentage of fast twitch muscle fibers correlates positively with force and speed of contraction.

In addition, muscle fiber composition may be one factor determining the individual shape of the torque-velocity curve. The fast twitch (FG)/slow twitch (SO) cross-sectional ratio may be more important in determining strength and power than simple percentages. Weight training regimens characterized by more repetitions with smaller intensities affect both fast and slow fiber types and can be used effectively to enhance local muscle endurance and to stimulate muscle growth, although not necessarily maximizing strength and power. Training programs sometimes used by strength-power athletes utilize fewer repetitions with near maximal loads. This higher intensity, lower volume approach stimulates the fast twitch fibers (Schmidtbleicher and Haralambie, *European Journal of Applied Physiology*, Vol. 46, 1981) and typically results in faster contraction speeds, hence development of higher power outputs at relative workloads. This ability to produce higher power outputs may be the one most important physiological determinant affecting performance, and therefore, success in most major sports.

Likewise, a few can argue against the importance of quickness and speed (in general) for most athletic endeavors. Some may confuse "competitive fitness" with general "physical fitness." This issue often leads to much emphasis on endurance. Consequently, many coaches and athletes integrate distance running into their strength conditioning programs as they attempt to enhance "cardiovascular" (CV) endurance. There is substantial evidence to suggest that simultaneous endurance training, utilizing low intensity, long duration work, is counterproductive to strength-power development. This is consistent with other findings which state aerobic training results in adaptations toward oxidative metabolism at the expense of fast contracting tissues.

Recent study, based largely upon immunohistological data, suggests that there exists a continuum of fiber types, ranging from the slowest to the fastest contracting motor units and that the contractile profiles and morphological characteristics can be changed by aerobic training to more slow twitch and conversely, by anaerobic training to more fast twitch fibers (Billeter and others, *Histochemistry*, Vol. 65, 1980). Qualitative examination of skeletal muscle of endurance trained individuals reveals an ultrastructure representative of aerobic metabolism with a well-developed mitochondrial network and greater cristae surface area for oxidative enzyme storage. On the other hand, weight lifters' muscle show an adaptation of the tissues' ultrastructure involving an extensive sarcoplasmic reticulum, which is a benefit toward faster and more efficient Ca^{++} transport during the production of power. **Table 2** lists three major muscle fiber types and a summary of their respective characteristics.

Characteristic:	(FG)	Source (FOG)	(SO)
Structural:			
Mitochondria number	fewer	more	most
Mitochondria size	small	larger	largest
Cristae development	less	—	most
Myofibril size	small	small	large
Myofibril packing density	small	small	large
Myofibril X-sectional area	largest	small	smaller
Hypertrophy response (strength training)	high	lower	lowest
Sarcoplasmic reticulum	extensive	—	sparse
Anaerobic:			
Velocity of contraction	highest	high	low
Force of contraction	highest	high	low
Velocity of relaxation	high	high	low
Myosin-ATPase activity	highest	high	low
Glycolytic activity	highest	high	low
Glycogen stores	high	—	high
Creatine phosphokinase (CPK)	2x more	—	—
Myokinase (MK)	2x more	—	—
Ability to resegregate Ca^{++}	high	high	low
Cholinesterase	highest	high	low
Sulphur concentration	high	high	low
Phosphocreatine stores (PC)	high	high	low
Aerobic:			
Fatigability	highest	high	low
Endurance	low	high	highest
Oxidative activity	low	high	mod-high
Capillization	low	mod-high	high
Myoglobin	low	mod-high	high
Triglyceride stores	low	—	high
Succinate dehydrogenase	low	high	highest
Neurological:			
Type motor neuron (alpha)	1	1	2
Action potential	larger	—	smaller
Neuromuscular junction	large complex	large simple	small simple
Terminal axon vesicles	high conc.	—	lower conc.
(Ach) to revoke response	more	—	less
Subneural folds	more & complex	—	less & simple
Motor end-plate area	larger	—	smaller
Receptors	20% more	—	—
Terminal axon length	longer	—	shorter
Mitochondria in bouton	fewer & smaller	—	more & larger
Excitatory postsynaptic potential (EPSP)	low	high	highest

Table 2: Muscle fiber types and summary of respective characteristics. (Stone and O'Bryant, *Weight Training: A Scientific Approach.* 1985.)

J. D. MacDougall, Ph.D.:

Nomenclature for the different fiber types varies, but in our lab we consider there to be three principal types in humans: Type I or slow twitch oxidative fibers, Type IIA or fast twitch oxidative fibers and Type IIB or fast twitch glycolytic fibers. The Type II fibers have larger cross sectional areas than Type I fibers, possess slightly more contractile protein per cross sectional area (Alway et al.,1981) and undergo greater hypertrophy with strength training (MacDougall et al., 1979). Thus, although all fiber types are recruited during a maximal voluntary contraction, it would be advantageous for the individual seeking maximal strength (or size) development to possess a high percentage of Type II Fibers, and especially Type IIB fibers.

(Continued, page 22)

Roundtable

(Continued from page 19)

Although recent evidence indicates that it may be possible to increase the proportion of Type I fibers by endurance training (Green et al., 1984), conventional strength training does not appear to have the opposite effect, that is, to increase the proportion of Type II fibers. This conclusion is based on our findings that biceps and triceps muscles of elite bodybuilders have the same percentage of Type I and Type II fibers as untrained subjects, despite the fact that such individuals may have trained intensively for 8–10 years (MacDougall et al. 1982; MacDougall et al. 1984). It thus appears that one's potential for developing maximal size or strength, in a given muscle, is to a certain extent genetically limited by the fiber type composition of that muscle.

Moreover, because the Type II fibers also develop force more rapidly than the Type I fibers, it is not surprising that there is a high correlation between the % Type II fibers and strength measured at high velocities (Coyle et al., 1979). Thus, in "power" sports such as sprinting, jumping and throwing, the athlete with a high proportion of Type II fibers will also have an advantage.

Lambert:

The muscle fiber type distribution an athlete possesses may be a very strong determinant of success in the athletic activities the athlete attempts. Roger Estep, a world record-breaking powerlifter who handles 800 pounds in competition style squats, was one of the first athletes to participate in a muscle biopsy program at Ohio State. The study found that Roger had fast twitch fibers, which are supposed to produce explosive power, that were four times the size of both the control group and the marathon runners that were tested. Just as Roger's muscle fiber type distribution may have predetermined his excellence in the domain of powerlifting, another athlete's distribution may lead him to great success as a cross country runner.

Westcott:

Slow twitch muscle fibers bear the major burden in activities that require submaximal muscle contraction. These fibers are better suited for aerobic energy utilization because they contain more mitochondria, more endurance enzymes, more blood capillaries and more intracellular fat. The slow twitch fibers are able to produce low force contractions for a relatively long period of time. Elite distance runners may have up to 75 percent slow twitch fibers in their leg muscles.

Fast twitch muscle fibers bear the major burden in activities that require maximal muscle contraction. These fibers are better suited for anaerobic energy utilization because they have more myosin ATPase activity and more enzymes for anaerobic breakdown of glycogen and glucose. The fast twitch fibers are able to produce high force contractions for a relatively short period of time. Olympic sprinters and jumpers may have up to 75 percent fast twitch fibers in their leg muscles.

Research indicates that both muscle fiber types are actively recruited during maximal muscular contraction regardless of the movement speed. Research also shows that endurance training facilitates aerobic energy utilization in both slow twitch fibers and fast twitch fibers. However, there is no evidence that slow twitch fibers can be turned into fast twitch fibers or vice-versa, since this would require changing the entire nerve innervation network.

Because strength events depend on anaerobic energy production, the person who is genetically endowed with a high percentage of fast twitch muscles fibers is likely to be more successful than the person who has a low percentage of fast twitch muscle fibers.

Vermeil and Hayman:

A higher fast twitch to slow twitch muscle fiber ratio means a potential greater force output and thus greater strength. If an athlete has a high slow twitch to fast twitch ratio, this will limit his/her ability to develop a great amount of force.

Kuc:

There are two muscle fiber types. Red, or slow twitch fibers, are used for aerobic activity, endurance, long distance running. White, or fast twitch fibers, are used in anaerobic activity, such as weight lifting, sprinting and explosive movements. Strength training causes an increase in size and capacities of each fiber type, but cannot change a red fiber to a white one. Individual differences in percentage composition of red and white fibers in any given muscle are largely a matter of genetics. Everyone can increase their strength through weight training, but in the end, the person endowed with more white fibers will be the strongest.

Allerheiligen:

Ratios of FT fibers to ST fibers are inherited and cannot be changed. It can be reasoned from this that a person with a high number of FT fibers will tend to be more powerful. I like to use the word tend. One study showed that a marathon runner and a sprinter had the same ratio of FT to ST fibers. Evidently, some other factors were involved here such as metabolic changes, motivation, superior training techniques and mechanical differences. Most marathoners and sprinters have a certain "range" of fiber composition. Marathoners may have a range of 50–95% ST fibers but an average of 80% ST fibers. Sprinters may have a range of 50–80% FT fibers but an average of 65% FT fibers.

We may get into trouble by trying to predict what position or sport a person should be in by such tests as muscle biopsy and/or vertical jump. I would like to share one individual case, which may be far from reliable and valid, but it does follow the results of some research. I once had a linebacker who wanted to get into great shape and ran long-slow-distance all summer. When he was tested in the 1.5 mile run he had a great time, but his vertical jump dropped 5 inches. In other words, as a result of his training he lost explosiveness.

An athlete has a "range" on certain physical tests. For example, let's look at the vertical jump. If an athlete is given the world's worst program for power development, a 24-inch jump might be achieved. If this same athlete is given the world's greatest program for power development, a 34-inch jump might result. For this example we will say he has a 50–50 ratio of FT-ST fibers. Now, when the coach first tests this athlete, and the athlete has been on the bad program, the coach will think this guy is terrible. But, if the athlete were tested with a good program the coach would think he is great. So, does the athlete have potential or not?

Anaerobic training will develop the anaerobic capabilities of both ST and FT fibers. Aerobic training will develop the aerobic capabilities of both ST and FT fibers. Remember that specificity of training will help design your program. Some training (sports) is 50% anaerobic and 50% aerobic. A person in this sport would be very transitional but would probably not excel in endurance or sprint/power activities. This is the predictable outcome, but it's nothing you can bet the farm on.○

Part 2 of "Determining factors of strength" will be featured in the April/May *NSCA Journal* Roundtable. Topics discussed by our expert panel will include hypertrophic mechanisms and programs, hyperplasia's role in strength development, anthropometric and biomechanical factors, and the training of muscle fiber elasticity.

References for J. D. MacDougall, Ph.D.

Alway, S. E.; MacDougall, J. D.; Sale, D. G.; Elder, G.; and Sutton, J. R. 1981. Ultrastructure of Type I and Type II fibers in human skeletal muscle. *Med. Sci. Sports and Exercise.* 13: 95–96.

Coyle, E. F.; Costill, D. L.; and Lesmes, G. R. 1979. Leg extension power and muscle fiber composition. *Med. Sci. Sports.* 11: 12–15.

Fridén, J.; Sjöström, M.; and Ekblom, B. 1983. Myofibrillar damage following intense eccentric exercise in man. *Internat. J. Sports Med.* 3: 170–176.

Green, H. J.; Klug, G. A.; Reichmann, H.; Seedorf, U.; Wiehrer, W.; and Pette, D. 1984. Exercise-induced fibre type transitions with regard to myosin, parvalbumin and sarcoplasmic reticulum in muscles of the rat. *Pflügers Arch* 400: 432–38.

Goldber, A. L. 1979. Influence of insulin and contractile activity on muscle size and protein balance. *Diabetes.* Supplement 1, 18–24.

MacDougall, J. D.; Sale, D. G.; Moroz, J. R.; Elder, G. C. B.; Sutton, J. R.; and Howald, H. 1979. Mitochondrial volume density in human skeletal muscle follwing heavy resistance training. *Med. Sci. Sports* 11: 164–66.

MacDougall, J. D.; Sale, D. G.; Elder, G. C. B.; and Sutton, J. R. 1982. Muscle ultrastructural characteristics of elite powerlifters and bodybuilders. *Eur. J. Appl. Physiol.* 48: 117–126.

MacDougall, J. D.; Sale, D.G.; Alway, S. E.; and Sutton, J. R. 1984. Muscle fiber number in biceps brachii in bodybuilders and controls. *J. Appl. Physiol: Respirat. Environ. Exercise Physiol.* 57: 1399–1403.

MacDougall, J. D.; Sale, D. G.; Elder, C.; and Sutton, J. R. 1976. Ultrastructural properties of human skeletal muscle following heavy resistance training and immobilization. *Med.Sci.Sports* 8: 72.

Sale, D. G. and Norman, R. W. 1983. Testing strength and power. In *Physiological Testing of the Elite Athlete.* J. D. MacDougall, H. A. Wenger and H. J. Green, eds. Ithaca: Movement.

Sola, O. M.; Christensen, D. L.; and Martin, A. W. 1973. Hypertrophy and hyperplasia of adult chicken latissimus dorsi muscles following stretch with and without denervation. *Experimental Neurology.* 41: 76–100.

Tiidus, P. M. and Ianuzzo, C. D. 1983. Effects of intensity and duration of muscular exercise on delayed soreness and serum enzyme activities. *Med. Sci. Sports and Exercise.* 15: 461–65.

References for Digby Sale, Ph.D.

Caiozzo, V. J.; Barnes, W. S.; Prietto, C. A.; McMaster, W. C. 1981a. The effect of isometric precontractions on the slow velocity-high force region of the in-vivo force-velocity relationship. *Med. Sci. Sports Exerc.* 13: 128.

Caiozzo, V. J.; Laird, T.; Chow, K.; Prietto, C. A. and McMaster, W. C. 1981b. The use of precontrations to enhance the in-vivo force-velocity relationship. *Med. Sci. Sports Exerc.* 14: 162.

Deluca, C. J.; LeFever, R.S.; McCue, M. P. and Xenakis, A. J. 1982. Behaviour of human motor units in different muscles during linearly varying contractions. *J. Physiol.* 329: 118–128.

Desmedt, J. E. and Godaux, E. 1977. Ballistic contractions in man: characteristic recruitment pattern of single motor units of the tibialis muscle. *J. Physiol.* 264: 673–694.

Desmedt, J. E. and Godaux, E. 1979. Voluntary motor commands in human ballistic movements. *Ann. Neurol.* 5: 415–421.

Desmedt, J. E. and Godaux, E. 1981. Spinal motoneuron recruitment in man: rank deordering with direction but not with speed of voluntary movement. *Science.* 214: 933–36.

Duchateau, J. and Hainaut, K. 1984. Isometric or dynamic training: differential effects on mechanical properties of a human muscle. *J. Appl. Physiol.: Respirat. Environ. Ex. Physiol.* 56: 296–301.

Hakkinen, K. and Komi, P.V. 1983. Electromyographic changes during strength training and detraining. *Med. Sci. Sports Exerc.* 15: 455–460.

Harr Romeny, B. M.; Denier Van Der Gon, J. J.; Gielen, C. C. A. M. 1982. Changes in recruitment order of motor units in the human biceps muscle. *Exp. Neurol.* 78: 360–68.

Ikai, M. and Steinhaus, A. H. 1961. Some factors modifying the expression of human strength. *J. Appl. Physiol.* 16: 157–163.

Kanehisa, H. and Miyashita, M. 1983. Specificity of velocity in strength training. *Eur. J. Appl. Physiol.* 52: 104–106.

Komi, P. V.; Viitasalo, J.; Rauramaa, R.; and Vihko, V. 1978. Effect of isometric strength training on mechanical electrical and metabolic aspects of muscle function. *Eur. J. Appl. Physiol.* 40: 45–55.

Kulkulka, C. G. and Clamann, H. P. 1981. Comparison of the recruitment and discharge properties of motor units in human brachial biceps and adductor pollicis during isometric contractions. *Brain Res.* 219: 45–55.

Lind, A. R. and Petrofsky, J. S. 1978. Isometric tension from rotary stimulation of fast and slow cat muscle. *Muscle & Nerve* 1: 213–18.

Miller,R. G.; Mirka, A.; and Maxfield, M. 1981. Rate of tension development in isometric contractions of a human hand muscle. *Exp. Neurol.* 73: 267–285.

Milner-Brown, H. S.; Stein, R. B.; and Lee, R. G. 1975. Synchronization of human motor units; possible roles of exercise and supraspinal reflexes. *Electroencephalogr. Clin. Neurophysiol.* 33: 245–254.

Milner-Brown, H. J.; Stein, R. B.; and Yem, R. 1973. The orderly recruitment of human motor units during voluntary isometric contractions. *J. Physiol.* 270: 350–370.

Moritani, T. and de Vries, H. A. 1979. Neural factors vs. hypertrophy in the time course of muscle stength gain. *Amer. J. Phys. Med. Rehabil.* 58: 115–130.

Ohtsuki, T.1981. Decrease in grip strength induced by simultaneously bilateral exertion with reference to finger strength. *Ergonomics* 24: 37–48.

Ohtsuki, T. 1983. Decrease in human voluntary isometric arm strength induced by simultaneous bilateral exertion. *Behav. Brain Res.* 7: 165–178.

Perrine, J. J. and Edgerton, V. R. 1978. Muscle force-velocity and power-velocity relationships under isokinetic loading. *Med. Sci. Sports.* 10: 159–166.

Rack, D. M. H. and Westbury, D. R. 1969. The effects of length and stimulus rate on tension in the isometric cat soleus muscle. *J. Physiol.* 204: 443–460.

Sale, D. and MacDougall, D. 1981. Specificity in strength training: a review for the coach and athlete. *Can. J. Appl. Sports Sci.* 6: 87–92.

Sale, D. G.; MacDougall, J. D.; Upton, A. R. M.; and McComas, A. J. 1983. Effect of strength training upon motoneuron excitability in man. *Med Sci Sports Exerc.* 15: 57–62.

Secher, N. H. 1975. Isometric rowing strength of experienced and inexperienced oarsmen. *Med. Sci. Sports.* 7: 280–83.

Secher,N. H.; Rorsgaard, S.; and Secher, O. 1978. Contralateral influence on recruitment of curarized muscle fibers during maximal voluntary extension of the legs. *Acta Physiol. Scand.* 103: 455–62.

Vandervoot, A. A.; Sale, D. G.; and Moroz, J. 1984. Comparison of motor unit activation during unilateral and bilateral leg extension. *J. Appl. Physiol: Respirat. Environ. Ex. Physiol.* 56: 46–51.