Determining Factors of Strength
Part II

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Editor’s Note: This is the second article in a two-part series on determining factors of strength.

Question 1: What is the mechanism behind hypertrophy, and what types of programs induce hypertrophy to the highest degree?

Westcott: Well-designed strength training programs generally produce an increase in muscle mass due to physiological adaptation such as more actin, myosin, myofibrils, capillaries, ATP-PC and connective tissue. These training responses cause individual muscle fibers to increase in size (hypertrophy). It may be possible for stressful strength training to increase the number of muscle fibers (hyperplasia) through the formation of satellite cells, but research evidence is lacking.

Although there is a well-established relationship between muscle strength and muscle size, it is interesting to note that the strongest athletes (weight lifters) do not have the largest muscles and that the largest athletes (bodybuilders) do not have the strongest muscles. It is also interesting to note that weight lifters and bodybuilders follow different training protocols. Weight lifters generally train with fewer sets, fewer repetitions, heavier weight loads and longer rests between sets. Bodybuilders usually train with more sets, more repetitions, lighter weight loads and shorter rests between sets.

Both training programs produce significant gains in muscle strength and muscle size when practiced in a progressive manner. However, shorter-rest training that saturates the muscles with blood and temporarily increases muscle size may be more effective for maximizing muscle growth. It should be emphasized, however, that the potential for muscle hypertrophy is largely determined by genetic factors.

Lambert: Heavy weight training appears to induce a degree of hypertrophy through increasing muscle cell size. I have heard discussions that an increase in muscle cell size is not the predominant effect in hypertrophy experienced as a result of low weight, high repetition weight training, often associated with “bodybuilding” training. In that case, perhaps a “size” effect due to a change in the circulatory system may be involved.

Edgerton: The best evidence by far is that the tension produced by a muscle in training has a major influence on the cross-sectional area of a muscle. Highly repetitive low-force movements do not induce hypertrophy. Extensor muscles atrophy rapidly when weight support is eliminated for a week or more. When weight support demands are increased, the muscle mass increases. Even increasing tension in a muscle by stretching (passive tension) can induce muscle hypertrophy. Results from basic research are consistent with the practice of lifting near-maximal weights with few repetitions to induce muscle hypertrophy and improve strength.

Pedemonte: Even if big muscles are necessary for many sporting events, they are the kingdom of bodybuilders. If you investigate the training programs of many bodybuilding champions, you will notice how different they are. In other words, it seems that there is no one way to determine muscular hypertrophy. Some lifters use very heavy weights for a few sets and repetitions, while others lift for many repetitions with average loads. In the climate of uncertainty, one thing seems sure: the increase of muscular mass is a requisite for greater strength and not a direct method for improving maximal strength. So, we are faced with two different but connected systems for improving strength: the first (building muscular mass) can be called indirect, the second (maximal strength) is direct.

Hypertrophy is based on metabolic processes, while maximal strength is especially the result of the perfect of the nervous (neuromuscular) mechanism.

According to the Soviets, hypertrophy can be explained through the activation of metabolic processes under anaerobic conditions. As a result of training, we obtain a prevalence of catabolic processes of white fibers. This requires a reconstitution, the recovery, of the protein content of the white fibers, thus leading to an increase of the muscular mass. More the content of white fibers lowered through training, the less the supercompensation will be.

For building muscular mass, normal tensions are not necessary. The level of muscular tension will allow for the energy supply for muscular activity, at the expense of anaerobic mechanisms (5).

Once we have ascertainment hypertrophy is a result of the process, it’s time to say that the system is the alactic acid or acid system. My answer is not to be elusive or an oversimplification, but the two systems stably used together. We still don’t exactly if hypertrophy is the repeated muscular tension or if an effective answer of the product.
acid. In addition, even if we would know for sure that hypertrophy is dependent on an lactic acid mecha-
nism, we still should work on lactic acid methods to enable muscles to become bigger (as a result of the
increased number of capillaries, thicker tendons and ligament(s) and more protected against injuries.

Vermeil and Hayman: The mechanism behind hypertrophy relates to the adaptation process. A muscle fiber is
loaded over its maximum capability and then allowed recovery time. During recovery, biochemical changes
occur to allow tissues to rebuild to handle the heavier loads.
The best training methods include sets of 10s, 3 to 5 sets, pyramids and eccentric work.

Allerheiligen: Hypertrophy is the increase in the cross sectional size of a muscle fiber. This should not be con-
fused with hyperplasia, which is an increase in muscle size due to an increase in the number of muscle
fibers. Hyperplasia is also known as longitudinal fiber splitting.

Hypertrophy has been demonstrated in humans and animals, but hyperplasia is seen primarily in animals. A
few studies have shown hyperplasia in competitive weight lifters, but the jury is still out.

The increased size of a muscle fiber via hypertrophy is due to:
1. Increased diameter of existing fibers (due to a greater number of myofibrils per fiber).
3. Increased size and number of mitochondria.
4. Increased amount of sarcoplasm.

It is also thought that selective hypertrophy occurs in fast twitch (FT) fibers due to weight training; the area of
the FT fibers would then increase. One study showed the percentage of FT fibers to be greater in weight lifters
than in untrained persons, and particularly greater than in endurance ath-
letes.

Hypertrophy is not as great in females as in males. Even when rela-
tive strength gains are similar, females show a very small increase in size. A
concentrated bicep program only showed an increase of one quarter of
an inch. Muscular hypertrophy is regulated mainly by the hormone testos-
terone, of which females have a small amount.

Some people look at the competitive bodybuilder as the extreme exam-
ple of muscle hypertrophy. Reasons for the bodybuilder’s physique are:
hereditary qualities, steroids, a vast amount of workout time and large
numbers of reps, sets and exercises. While bodybuilders are “strong”, they
may not be powerful. A shot putter, a lineman or competitive weight lifter
requires as much power as possible. Great strength may be useless to the
power lifter if the time of the event or lift increases.

Programs for the power athlete should include a moderate number of
exercises, use 5 to 7 sets of major exercises, use reps in the range of 2 -
8, depending on the training phase, and allow sufficient rest time between
sets (minimum of 3 minutes).

Kue: Hypertrophy results from an increase in the cross sectional area of
the individual muscle fibers. Hypertrophy of individual muscle fibers is caused by an increase in the
number of myofibrils per muscle fiber, increased total amount of protein, increased capillary density per
fiber, increased amounts of connec-
tive, tendinous and ligamentous tis-
ues. The overload principle employ-
ing resistance, time and repetitions
induces hypertrophy to the fullest.

MacDougall: The increase in muscle size which occurs with training is
caused by an increase in the cross sec-
tional area of the Type I and Type II
fibers, and an increase in connective
tissue volume which is proportional to the
increase in fiber area (8). The
increase in fiber area is directly related
to an increase in both the size and
number of the myofibrils within the
fiber. The change in myofibril size is
the result of additional actin and
myosin filaments, and the increase in
number is apparently due to a longitudi-
nal splitting of myofibrils (9).

The mechanism(s), however, by
which heavy resistance training trig-
gers enhanced synthesis of contractile
proteins are not known. Several stud-
ies with animals suggest that it may be
stretch and/or tension on muscle fibers
which provides the stimulus for pro-
tein synthesis (11, 5). Although it
has been demonstrated that increased
synthesis of RNA is an essential
requirement for the hypertrophy pro-
cess, the stimulus for increased muscle
uptake of amino acids apparently
occurs before there is any evidence of
increased RNA synthesis (5).

A second possible mechanism, and
one that can be found in the popular
strength and bodybuilding lore, is
what might be termed the “break down
and build up theory.”

Bodybuilders tend to visualize
their intensive training as “breaking
down” muscle protein, which is
“rebuilt” between training sessions,
leading to a supercompensation of
muscle size. As simplistic as this
sounds, there may be some evidence
to support it. Forceful muscular con-
tractions, especially those involving an
eccentric component, are known to
result in delayed muscle damage (12).
Moreover, such damage appears to be
greatest in the Type II units and per-
sists for two to three days before nor-
mal strength returns (3).

It is thus possible that the training-
induced hypertrophy process in skele-
tal muscle is simply a repair process.
Lifting (and lowering) of heavy
weights during a training session may
result in damage to contractile ele-
ments and connective tissue which is
repaired over the several days which
normally elapse between training ses-
sions. This repeated process of dam-
age and repair may result in an over-
shoot of protein synthesis, somewhat
similar to the overcompensation of
muscle glycogen which occurs in
response to endurance training.
Whatever the mechanism for stimu-
lation of protein synthesis, it is known
that it is the intensity of the loading on
the muscle which is the main determinant of whether or not increments in strength and size will occur. Training at low resistance (less than 60 percent of maximal voluntary strength) is ineffective for increasing strength, even though the athlete may perform hundreds of such contractions in a training session. On the other hand, five to six contractions at 90 percent of maximal strength (5 to 6 RM) will prove effective in increasing both the size and the strength of a muscle group.

However, this direct relationship between the intensity of the load and the training effect does not appear to exist to the same extent at very high percentages of maximal strength. In our laboratory, Digby Sale has recently demonstrated that subjects who trained one arm with sets of 10 to 12 RM showed greater gains in strength and size than in the arm which trained with sets of 2 to 3 RM.

O'Bryant: Increase in muscle mass (hypertrophy) is primarily a result of myofibril proliferation, causing the individual muscle fibers to become larger. Strong correlations can be demonstrated between muscle cross-sectional area and force output. The amount of lean body mass is likely the most important factor (given equal training) in determining absolute maximum strength (20), and may be the most dominant factor affecting strength gain in prolonged periods of training. Most important, hypertrophy may lead to an increased potential for overall strength and power gains.

Based on objective and theoretical considerations, purposefully slow movements may not be as effective in producing gains in muscle size as moderate speed or fast movements. Hypertrophy is likely more closely related to the intensity, volume and total load used during training. Higher volume training (8 to 12 reps/set) has been shown to produce greater gains in lean body mass and greater decreases in percent fat than lower volume training (Alexeev and Roman. Yessis Reviews, Vol. 13, 1976; Stone and others. NSCA Journal, Vol. 4, 1982).

Question 2: What role do you feel hyperplasia plays in strength development? If any, and what appears to be the best way to induce hyperplasia if so desired?

Edgerton: No exercise training of any kind induces a significant level of muscle fiber hyperplasia. There is no sound scientific evidence that muscle fiber hyperplasia is a mechanism for increasing muscle strength in laboratory animals or in humans.

Lambert: If hyperplasia exists, the limited information that I have seen on the subject indicates that high load muscular activity over a period of years, particularly in older athletes, may be the circumstances under which it occurs.

Pedemonte: Hyperplasia is a typical example of the present sports situation, in which many factors which recently were considered unquestionable truths are now rejected, or considered myths.

Physiology books always started their chapter on the muscular system with the phrase: "Muscular fibers grow in their diameter and cannot split." The absolute nature of this sentence, which has been a fundamental principle of physiology, is now "sinking down" because some physiologists affirm that under some circumstances, muscle cells can reply via hyperplasia and not only grow bigger via hypertrophy.

Certainly, if hyperplasia is proven, it can have a tremendous impact on strength training. But at the same time, I think that it is very difficult to say, O.K., now I use this or that system for inducing hyperplasia. Because how can the effect of hyperplasia be visualized and quantified? There is still many problems for effectively judging hypertrophy (meant as increase of lean body mass), since body fat has to be considered in the meantime, and muscular biopsies repeated many times and on muscular groups with newly-implanted innervation must still be perfect.

But hyperplasia in adults who weight train, in my opinion, represents only one (and perhaps the least important) aspect of this point. I expressly refer to hyperplasia in growing children as a topic that, in the present situation of earlier and earlier initiation of youth in sports, should be attentively considered.

East German researcher Siegfried Israel says, "Muscles in adults men adapt to external loads mainly through hypertrophy, while this adaptation in children is also via hyperplasia." In East European countries, the early specialization of children in sports influences the growing phenomena, according to a precise multi-year program, because the level of some capacities when adult is also determined by when a direct training toward these physical properties was begun.

This practice negates the principle that strength can be improved only after puberty, as a consequence of hormones that become present in the blood.

Tesch: Overall, muscle hypertrophy is mainly the result of increased size of individual muscle fibers. It appears that strength training may also increase the number of muscle fibers. Numerous studies have, in fact, demonstrated hyperplasia in animal muscles subjected to overload. Whether these observations reflect "splitting" of already existing muscle fibers or the formation of new muscle fibers from satellite cells has not been conclusively proven. In patients with various neuromuscular disorders, muscle fiber hyperplasia seems a common observation. This response has been attributed to splitting of some due to functional overload as a result of dysfunction of other muscles. In some reports, high calorie dieters and bodybuilders were found to exhibit surprisingly small muscle diameters. Thus, despite their small size, and vastus muscles, the muscle fiber size was very similar to that of physical education students. These findings lead us to applaud...
established clinical method to assess muscle fiber density in biceps brachii and quadriceps of highly trained bodybuilders. The single fiber electromyography technique allows us to detect whether or not hyperplasia is present. The outcome from the experiments (Larsson and Tesch, unpublished observations) are exciting. Those bodybuilders who had been training for 10 to 15 years showed an abnormal fiber density, whereas the younger bodybuilders, who had performed strength training for five to six years, exhibited a normal fiber density pattern. From the study it was evident that hyperplasia may occur with long-term, intense, heavy resistance training.

Allerheiligen: As mentioned before, there is not a great amount of evidence of hyperplasia in humans. The animal studies used intense weight lifting type activities and showed hyperplasia. Therefore, if hyperplasia is to be evident in humans, the training program should include intense weight training.

Westcott: Some researchers believe that muscle hypertrophy accounts for moderate increases in muscle size and that muscle hyperplasia is partly responsible for the unusual increases in muscle size evident in competitive bodybuilders. Although the recent identification of satellite cells lined up adjacent to the muscle fibers lends some support to the theory that muscle fibers proliferate to form additional fibers, there is not yet sufficient research evidence to conclude that hyperplasia occurs in human muscles.

Kuc: Hyperplasia would increase strength and size because it would be adding more cross sectional area and more contractile tissue to the muscle. If hyperplasia does take place, intense weight training would be the best way to induce it.

O'Bryant: Some have proposed that in extreme hypertrophy, exercise induced formation of new muscle fibers (hyperplasia) may occur (8, 16, 21).

The stimuli for this fiber splitting is not completely understood but has been suggested as a result of very intense resistive training (demonstrated in animal models). The recent evidence, though mounting, is not yet conclusive. Therefore, until further research has been completed, I do not consider hyperplasia an important factor in strength development.

MacDougall: I am familiar with the studies which have demonstrated increases in muscle fiber numbers in biceps brachii in a group of elite bodybuilders, a group of novice bodybuilders and a group of untrained controls of the same age (8). This was done by correlating muscle cross sectional areas, from CT scans with fiber areas obtained from needle biopsies. Although we found wide ranges in fiber numbers between different individuals, the average number of fibers was the same for each group. As both groups of bodybuilders had been training their biceps for six to eight years, we interpret our results as indicating that such training does not result in an increase in muscle fiber numbers.

It should also be pointed out, however, that within each group, we found a tendency for the individual with the largest muscle to also have a higher than average number of fibers. Thus, although it is the size of the individual fibers that is the main determinant of muscle size, the bodybuilder who also inherits a larger than average number of fibers will have a greater potential for increasing his muscle size than would the bodybuilder with an average number of fibers.

Vermeul and Hayman: Hyperplasia can play a role in strength development if the proper training is done at the proper time. Young athletes, ages 12 to 17 years, have a natural hyperplasia occurring simply due to the maturation process. If strength training is done at this time, additional hyperplasia may occur. However, it is doubtful that any hyperplasia can occur in the older athlete.

Question 3: What anthropometric and/or biomechanical factors affect strength and how can they be enhanced to improve strength?

MacDougall: Maximal voluntary strength is affected by the total amount of contractile tissue available and the ability of the athlete’s central nervous system to activate this tissue. The amount of contractile tissue is a function of the cross sectional area of each sarcomere and the total number of sarcomeres. Strength is thus affected by the total volume of contractile tissue. Because of this, individuals with long limbs will have a greater volume of contractile tissue for a given cross-sectional muscle size than shorter subjects. This accounts for the common finding that short subjects with large muscle cross-sectional areas or girths are often not as strong as taller individuals who may have smaller muscle girths.

The athlete’s body size also influences the potential for achieving a high absolute strength versus high strength relative to body mass (strength/mass ratio). There is a high correlation between body size and maximal strength expressed in absolute units and a negative correlation between body size and strength/mass ratio. Thus, large athletes tend to have higher strength/mass ratios (10). This is why sports which require high absolute strength, such as shotputting, are dominated by large athletes, while sports which require a high strength/mass ratio, such as gymnastics, are dominated by small athletes.

Pedemont: Among the anthropometric factors, I would mention the width of the bones, the length of muscles and the solidity of tendons. For achieving top strength performances (this is also true for speed, endurance, etc.) we have to train the organism until the physiological limit is reached. Under this critical threshold, we maintain a
through training. However, the same factors that are a disadvantage for movement/strength are advantageous for movement/speed.

Lambert: Muscle size, limb length and tendon attachment points are all "leverage" factors, which have an effect on strength from a mechanical point of view. Hypertrophy of the arms has been suggested as a means to improve performance on the bench press, through a "rebound" effect of the compressed musculature, and this would seem to be the only practical means of enhancing a biomechanical characteristic of an athlete to produce more strength.

Edgerton: Muscle strength is determined principally by the functional cross-sectional area of muscle. This is not equivalent to the circumstances of a muscle because muscle fibers do not project the length of a muscle. Basically, a muscle's functional cross-sectional area is determined primarily by the muscle mass divided by the average fiber length. For example, two muscles having the same mass but different fiber lengths will have a different strength potential; the muscle with the shorter fiber will have the larger cross-sectional area and greater strength potential.

Other factors that determine strength potential (torque) are the force and resistance arms. These same factors are important in determining the velocity potential about a joint. The importance of these variables in explaining individual differences in strength is unknown. These mechanical factors are not affected by training.

Allerheiligen: There are several factors which affect strength development by means of biomechanical and/or anthropometric features. These factors include the following:

1. The angle of pull of the muscle.
2. At any given time, the length of the muscle.
3. Velocity of contraction or muscle shortening.
4. Amount of muscle mass.
5. Length of resistance arm.

The human body is composed primarily of third class levers. In a third class lever the resistance arm is always longer than the force arm. This arrangement favors range of motion and speed. Maximum force is created when the muscle (its lengthwise axis) is pulling at a right angle to the bone. For example, the greatest amount of force is created at 90 degrees during the arm curl.

Muscle length determines the amount of muscle tension development. Because of the elastic properties of muscles, a muscle which is stretched will have a greater potential for the production of force.

As the speed of muscle contraction increases, and, therefore, limb movement, the amount of force decreases. The rate of decreased force to increased speed is disproportional. This could mean that certain activities may require a certain speed to achieve the desired amount of force.

Muscle mass will affect the range of motion of a joint. The loss of range of motion will decrease flexibility. If maximum strength is desired, then a large muscle mass will usually be helpful because of increased strength with muscle hypertrophy. If endurance or speed is desired then a large muscle mass will be detrimental to performance.

Length of the force arm in the human body cannot be changed and is not usually great in length. The resistance arm is always longer than the force arm. Normally when lifting free weights, the resistance arm is the same for the same person and the same exercise. When performing an arm curl, the resistance arm is basically the same at all times. If the weight being lifted could be moved up the arm and shorten the resistance arm, a greater force would be created. Speed of movement would decrease.

There are certain instances when the resistance arm is shortened. Many athletes perform lateral shoulder raises with the upper and lower arm at a 90 degree angle. A major reason for this is to allow the athlete to handle a heavier dumbbell. If the athlete would straighten the arms almost full, the mechanical advantage would decrease, which means lighter weight must be used. Of course, this is totally wrong and the athlete should use 60 pounds, instead of 30 pounds.

Equipment companies continue to develop strength training equipment to compensate for the problems of mechanical disadvantage. We now have canes, hydraulics, pneumatics, water and isokinetics as well as the free weights. Some of these machines work (in regard to true correction of mechanical disadvantage) and some do not. Some research indicates isokinetics develop power at all speeds (degrees per second), while other equipment does not.

While it is true that isokinetics will increase strength at various speeds, it does not, however, have the capability of eccentric (negative) work. It is well known that free weights develop strength because of both concentric and eccentric work. More research would be useful in this area.

The cam was designed to increase or decrease the mechanical advantage according to the lever system of the body. When the body segment cannot produce enough force because of a poor leverage position, the cam will decrease the resistance. This will allow the movement to continue. When the leverage position is good, the cam increases the resistance.

After all of this, which will increase strength and power to its maximum? The jury is still out. This will all increase strength and power, but in their own way. We are talking about specificity. It would seem the advantages of free weights could be incorporated with isokinetics. The evidence of strength and power increases via both programs reveal good results. Here again, this would be a good research project.

Question 4: How can the elastic component of muscle fibers aid
given level of performance and do not improve it. This fact involves another thought: top level strength athletes always train close to an injury threshold: the unstable balance becomes steady if he or she has followed a gradual approach that starts very young, when tendons can be effectively lengthened. It can appear a cynical statement, but if we look for a talent in the strength area, we have to discard those who, in spite of a favorable physical frame, are often injured, i.e. their skeletal-tendinous system cannot support the necessary heavy training loads.

Speaking of biomechanical factors, I point out the learning of a proper technique of executing strength drills. There are other more complicated biomechanical factors to be considered, but I believe that too many athletes don’t take enough care on the execution of strength drills. I even believe that technical execution is the most sound way for determining a proper training load. Many athletes are capable of lifting heavier weights, but would do so with poor technique, thus increasing their risk of injury. They cannot understand the importance of proper form until they are injured, but we coaches, knowing how thin the difference is between training with all-out effort and being injured, must emphasize this fact to all our athletes.

Vermeil and Hayman: In terms of anthropometrics, it appears that bone size and muscle length (distances from origin to insertion) may play a role in strength. In theory, larger bones should be able to support heavier loads and thus make way for better absolute strength. Theoretically, the longer the muscle, the more work the muscle should be able to perform since work = force x distance. Hypertrophy of the muscles can increase strength.

Biochemically, larger, and perhaps more mitochondria per muscle cell, may help with energy production. Also, the rate at which some enzymes are produced may affect energy levels. By making available more energy for the muscle cells, the muscle cells should theoretically be able to recruit energy faster and more efficiently. This may help the acquisition of maximum strength more quickly.

The practical application of all this can be achieved through proper periodization and applying exercises such as Olympic lifts, plyometrics, etc.

O’Bryant: Some internal anthropometric and biomechanical factors which affect strength are: the length of the muscle, the type of joint traversed, the fiber configuration (fusiform or pennate), nature of bone-muscle leverage and nature of the origin and insertion of the muscle attachments.

Additionally, each joint action displays a characteristic “strength curve” specific not only to the joint, but to the individual. Such variable potential to exert force exists as a result of muscle length-tension dynamics associated with the actin-myosin interaction and the constantly changing muscle angle of pull on the bone-lever system (the greatest potential for force production occurs as muscle insertion angle of 90 degrees to the bone lever). The body is a system of levers with “moments of force” (MF) and “moments of resistance” (MR). The larger the ratio of MF/ MR, the more effective the force which can be exerted by the bone-muscle lever. Some suggest the MF/MR ratio can be potentiated through hypertrophy where exercise induced increases in total muscle girth and/or connective tissue causes lever-specific biomechanical adaptations leading to improved capacity for strength production.

There are a variety of external anthropometric and/or biomechanical factors which can vary from person to person. Nevertheless, the range of emphasis on training angles seems to play a dominant role on force production in specific patterns of movement. Likewise, strength gain is dependent upon the angle of training (full squats produce more efficient strength gains for force production at acute hip and knee angles than do half or quarter squats).

Kuc: The bones and joints form a system of levers in the human body with the muscular system providing force and movement to the levers. The force that a joint can exert by flexion or extension is determined by the point of muscle insertion into the bone. Heredity has complete control over this. This accounts for two people of equal musculature and body weight having different strength levels. Increasing muscular body weight, strength and lowering body fat levels through weight training is the only way a person can change anthropometric factors.

Westcott: The human body moves as a function of a muscle pulling a bone in a rotary movement about a joint. There are three biomechanical factors principally responsible for functional force production. These are the length of the movement bone, the length of the muscle, and the point of tendon insertion on the movement bone.

A shorter movement bone provides a leverage advantage for lifting a weightload. This is a simple application of the formula: muscle force x force arm = resistance x resistance arm. The shorter the resistance arm, the less muscle force required to lift a particular resistance.

A longer muscle has greater potential for force production than a shorter muscle. The person who inherits long muscles with short tendon attachments has a strength advantage over the person who has shorter muscles with long tendon attachments. This is because a long muscle has the potential to develop greater muscle mass (volume) than a short muscle.

A more distant point of tendon insertion on the movement bone provides a leverage advantage for lifting a weight load. This is also an application of the formula: muscle force x force arm = resistance x resistance arm. The longer the force arm (perpendicular distance), the less muscle force required to lift a particular resistance.

These biomechanical factors are genetically determined and unchanged.
force production by a muscle? In what way can this be trained to improve strength?

Westcott: The elastic component of muscle tissue provides a significant advantage when properly utilized in force production. A critically timed muscle stretch followed immediately by muscle contraction produces greater force due to a combination of elastic recoil and the stress (myostatic) reflex.

The recoil component is similar to the effect of stretching thick rubber tubing. The reflex component is a central nervous system response that stimulates forceful contraction of the stretched muscle fibers.

One example of using muscle elasticity to advantage is the sequential stretching of each muscle group involved in throwing a discus. The rotation of the hips stretches the midsection muscles, the rotation of the midsection stretches the torso muscles, the rotation of the torso stretches the shoulder muscles. The athlete who successfully interperses muscle stretch between peak muscle contractions maximizes force production. Timing and technique are the best means of improving this component of force production.

Lambert: Taking advantage of the stretch reflex is one way that powerlifters increase their ability to move heavier and heavier maximum poundages. One example is a controlled "quick dip" or descent below parallel in the squat to stimulate more muscular involvement in the recovery ascent of the lift.

O'Bryant: Elastic storage of energy does occur as a normal muscular function during the preparation phase of many ballistic movements. Such is the case in jumping and other propulsive activities in which the hip and knee extensors are placed on stretch prior to contraction. This stretching action causes about a three percent shortening of the series elastic components located at the "Z" disc in skeletal muscle tissue. This storage of energy is released during the propulsive phases of the movement and along with the stretch reflex, potentiates the quality of force production by the muscle. The factors governing this physio-mechanical phenomenon can be conditioned through plyometric training, thus improving the reactive ability of the muscle and subsequent power production. The combination of both eccentric and concentric training is thought to enhance muscular strength and power to a greater degree than concentric training alone. Plyometrics relate to specific exercises that involve a rapid stretching of the muscle undergoing eccentric stress, followed by a concentric contraction of that muscle. A major purpose for such exercise is to heighten the excitability of the nervous system for improved reactive ability of the neuromuscular mechanism. 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. There is an "amortization" phase (which includes the electromechanical delay-EMD between eccentric and concentric contraction) in which one must slowly switch from overcoming work to impart the necessary amount of acceleration in the required direction. Explosive power from the knee and hip extensor muscles in jumping provides the type of ballistic movement characteristics exhibited in most anaerobic sports. Likewise, biomechanical analyses reveal a strong similarity in the mechanics of the bone-muscle levers while jumping and the sport specific movement patterns for lower limb propulsion required in weightlifting and many other strength-power activities. Consequently, it is not surprising that strong relationships have been reported in the literature between jumping ability and athletic performance.

Some major muscles involved in jumping, as in other strength-power activities, are the quadriceps, hamstrings, erector spinae, gluteals, deltoids, trapezius and gastrocnemius. Traditionally, much emphasis has been placed on the quads by strength programs, with neglect of some other muscles, particularly the hamstrings. Recent data suggests that the hamstring muscle group may contribute a great deal to the overall movements requiring leg propulsion and should be emphasized in anaerobic conditioning programs. However, simple weight training alone may not fulfill maximum power potential as they may not maximize one's speed in switching from eccentric to concentric contractions within a counter-type movement. During rebound movements mechanical energy is absorbed by the muscle during eccentric contractions and released during the subsequent propulsive phase (concentric contraction). The prestretch of the knee and hip extensors will activate the myotatic (stretch) reflex to potentiate the form of shortening and propel the jumper higher than could be obtained with the downward rebound movement, progression of weight training, jump drills and plyometrics are recommended to further develop strength, quickness, reactions and agility. A strength level is considered an important prerequisite and, therefore, should be a precedent to bounding as well as plyometric training phases.

Allerheiligen: Energy may be stored in the muscles in the form of elastic energy. When a contracting muscle is forced to stretch, some of the work done in stretching the muscles is available in the following contraction.

Even in 1956, the concept of plyometrics was evident because it was determined that maximum force results if the contraction followed the stretch as soon as possible. It has been demonstrated that this type of contraction yields more power, more speed and more efficiency.

Plyometric programs usually incorporate lower body exercises. The type of program would seem quite unsafe while performing the press. Imagine trying to bounce...
bar off the chest as quickly and forcefully as possible. I have seen many athletes lift like that. There would be a great risk of injury in the ribs, sternum, wrists, shoulders and elbows.

An elastic component can be achieved by putting a muscle on the stretch prior to the contraction. A jerking motion should not be used (if strength training). To simplify this, it could be said that the full range of motion should be adhered to. Full range of motion will also help maintain flexibility in the joint.

Sale: The force of a concentric contraction of a muscle can be enhanced if it is immediately preceded by an eccentric contraction of the same muscle. The mechanism is considered to be that elastic energy is stored in the contractile elements of the muscle during the eccentric contraction and is subsequently released during the concentric contraction. There may also be a reflex component to this effect.

There is evidence that certain athletes can handle high stretch loads (as in dropping down from a high box and jumping upward) more effectively than non-athletes, which could be the result of adaptation within the nervous system and within the muscles. The plyometric techniques used by some athletes are an example of exaggerating the eccentric-concentric contraction cycle (also called stretch-shortening cycle). The effects of this form of training on the elastic properties of skeletal muscle are unknown, however, the large contraction forces associated with the technique could intensify the stimulus for protein synthesis within the muscle. Komi recently published an excellent review of this topic (13).

MacDougall References

Sale References
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