Roundtable:

Determining factors of strength
Part II

Editor's Note: Part I of "Determining factors of strength" appeared in the February/March NSCA Journal Roundtable. Current topics discussed by our expert panel include hypertrophic mechanisms and programs, hyperplasia's role in strength development, anthropometric and biomechanical factors, and the training of muscle fiber elasticity.

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

Wayne L. Westcott, Ph.D.:

Well-designed strength training programs generally produce an increase in muscle mass due to physiological adaptation such as more actin, more myosin, more myofilaments, more capillaries, more ATP-PC and more 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. Weightlifters generally train with fewer sets, fewer repetitions, heavier weightloads and longer rests between sets. Bodybuilders usually train with more sets, more repetitions, lighter weightloads and shorter rests between sets.

Both training programs produce significant gains in muscle strength and muscle size when practiced in a progressive manner. However, short-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 one's potential for muscle hypertrophy is largely determined by genetic factors.

Mike Lambert:

Heavy weight training appears to induce a degree of hypertrophy through increasing muscle cell size. I have heard discussions that muscle cell size increase 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 change in the circulatory system may be involved.

V. Reggie Edgerton, Ph.D.:

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.

Jimmy 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 easily notice how different they are, one to another. In other words, it seems that there is no one way to determine muscular hypertrophy. Some guys use very heavy weights for a few sets and repetitions, while others lift for many repetitions with average loads. In this climate of uncertainty, one thing seems to be 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 perfection of 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, during the recovery, of the proteic content of the white fibers, thus leading to an increase of the muscular mass. The more the content of white fibers is lowered through training, the harder the supercompensation will be (N. N. Tschagowez, 1959).

For building muscular mass, maximal tensions are not necessary. The level of the muscular tension should allow for the energy supply for the muscular activity, at the expense of anaerobic mechanisms (W. M. Zacorski, 1966).

Once we have ascertained that hypertrophy is a result of the anaerobic process, it's time to say if the best system is the alactacid or the lactic acid system. My answer isn't intended to be elusive or an oversimplification, but I think that the two systems should be used together. We still don't know exactly if hypertrophy is the result of a repeated muscular tension or the reactive answer of the production of lactic acid. In addition, even if we would know for sure that hypertrophy is dependent on an alactacid mechanism, we still should also work on lactic acid methods, since this way muscles will become bigger (as a result of the increased number of capillaries, thicker tendons and ligaments) and more protected against injuries.

Al Vermeil and Bill 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, 5 to 5 sets, pyramids, and eccentric work.

Bill Allerheiligen:

Hypertrophy is the increase in the cross sectional size of a muscle fiber. This should not be confused 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 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 athletes.

Hypertrophy is not as great in females as in males. Even when relative strength gains are similar, the 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 testosterone, of which females have a small amount.

Some people look at the competitive bodybuilder as the extreme example of muscle hypertrophy. Reasons for the bodybuilder's physique are: inherited qualities, steroids, vast amount of workout time, and large number of reps, sets and exercises. While bodybuilders are "strong," they may not be powerful. A shot putter, linesman 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, 5-7 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).

John Kuc:

The process of a muscle increasing in size is called hypertrophy. It 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 connective, tendinous and ligamentous tissues. The overload principle employing resistance, time and repetitions induces hypertrophy to the fullest.

J. D. MacDougall, Ph.D:

The increase in muscle size which occurs with training is caused by an increase in the cross sectional area of the Type I and

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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.

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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.
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Type II fibers, and an increase in connective tissue volume which is proportional to the increase in fiber area (MacDougall et al., 1984). 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 longitudinal splitting of myofibrils (MacDougall et al., 1976).

The mechanism(s), however, by which heavy resistance training triggers enhanced synthesis of contractile proteins are not known. Several studies with animals suggest that it may be stretch and/or tension on muscle fibers which provides the stimulus for protein synthesis. (Sola et al., 1973; Goldberg, 1979). Although it has been demonstrated that increased synthesis of RNA is an essential requirement for the hypertrophy process, the stimulus for increased muscle uptake of amino acids apparently occurs before there is any evidence of increased RNA synthesis (Goldberg and Goodman, 1969).

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 contractions, especially those involving an eccentric component, are well known to result in delayed muscle soreness and actual muscle damage (Tiidus and Iannuzzo). Moreover, such damage appears to be greatest in the Type II units and persists for 2-3 days before normal strength returns (Friden et al., 1983).

It is thus possible that the training-induced hypertrophy process in skeletal muscle is simply a repair process. Lifting (and lowering) of heavy weights during a training session may result in damage to contractile elements and connective tissue which is repaired over the several days which normally elapse between training sessions. This repeated process of damage and repair may result in an overshoot of protein synthesis similar to that seen in the overcompensation of muscle glycogen which occurs in response to endurance training.

Whatever the mechanism is for stimulating 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% 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, 5-6 contractions at 90% of maximal strength (5-6RM) 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 percentage of maximal strength. In our laboratory, Digby Sale has recently demonstrated that subjects who trained one arm with sets of 10-12 RM showed greater gains in strength and size in that arm than in the arm which they trained with sets of 2-3 RM.

Harold S. O'Bryant, Ph.D.
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 (Stone and O'Bryant, Weight Training: A Scientific Approach, 1985) 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 strength and power gains overall.

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 (8-12 reps/set) has been shown to produce greater gains in lean body mass and greater decreases in % fat than lower volume training (Alexeev and Roman, Yestis Reviues, 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 number 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 called "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- ness 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 really proved, 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 are 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 closely woven innervation must still be perfect.

But hyperplasia in adult weight training, in my opinion, represents only one (and perhaps the least important) aspect of this point. I expressly refer to hyperplasia in growing children 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 adult 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 tots 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 has been started.

This way we also emphasize that the principle that strength can be improved only after puberty, as a consequence of hormones that are now in the blood is wrong, but this is another story.

**Per A. Tesch, Ph.D.**

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 is a common observation. This response has been attributed to splitting of some fibers due to functional overload of some fibers as a consequence of dysfunction of others. In some reports, high-caliber swimmers and bodybuilders were found to exhibit surprisingly small muscle fiber diameters. Thus, despite their bulky deltoid and vastus muscles, the mean muscle fiber size was very similar to that of physical education students. These findings lead us to apply a well-established clinical method to assess muscle fiber density in biceps brachii and quadriceps of highly trained bodybuilders. The single fiber electromyography (SFE MG) technique used 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 10–15 years showed an abnormal fiber density whereas the younger bodybuilders, who had performed strength training for 5–6 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 show 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:**


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 (MacDougall et al., 1984). 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 6–8 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.

**Vermeil 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 hyperplasia can occur at all 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 his or her potential for achieving a high absolute strength vs. 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 (Sale and Norman, 1982). 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.

**Pedemonte:**

Among the anthropometric factors I would mention the width of the bones, the length of the 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. Under this critical threshold, we maintain a given level of performance and do not
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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 from the youthful age, 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 guys 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 refer to those complexes of biomechanical factors to be considered here, but I believe that still too many athletes don’t take enough care on the execution of strength drills. Even if we don’t consider the fact technical execution is the most sound way for determining a proper training load. Many athletes are certainly able to lift heavier weights, but with poor technique and so they are prone to injuries. They cannot understand the meaning of proper form until they are injured, but we coaches, since we know how thin the difference is between training with all-out efforts and being injured, must emphasize this fact to all our athletes.

Vermeil and Hayman:

Anthropometric-wise, 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.

Biomechanically, 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 use 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’Bryan:

Some internal anthropometric-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 levers, 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 a 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.

It can appear a cynical statement, but if we look for a talent in the strength area, we have to discard those guys who, in spite of a favorable physical frame, are often injured, i.e., their skeletal-tendinous system cannot support the necessary heavy training loads.

Pedemonte

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 seem 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).

Consequently, strength gained from isometric training at single joint angles does not transfer well to performance of an athletic task that requires strength in a wide range of movement. Strength training for sport should be as biomechanically specific to the characteristic movement patterns as possible without sacrificing on safety and intensity of exercise.

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 his or her 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. Other factors being equal, 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.

Other things being equal, 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 short muscles with long tendon attachments. This is because a long muscle has the potential to develop greater muscle mass (volume) than a short muscle.

Other factors being equal, a more distant point of tendon insertion on the movement bone provides a leverage advantage for lifting a weightload. 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 through training. However, the same factors that are disadvantageous for movement strength are advantageous for movement speed.

Lambert:

Muscle size, limb lengths, tendon attachment points are all "leverage" factors, which certainly have an effect on strength, purely 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.

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Edgerton:

Muscle strength is determined principally by the functional cross-sectional area of muscle. This is not equivalent to the circumferences of a muscle because muscle fibers do not project the length of a muscle. Basically, a muscle’s functional cross-sectional area is determined, for the most part, 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 one with the shorter fiber will have the larger cross-sectional area and greater strength potential.

Other factors that determine strength potential (torque) are the moment arms (force and resistance). This same factor is 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, and

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 120° during the arm curl.

Muscle length will determine the amount of muscle tension development. Because of the elastic properties of muscles, a muscle which is put on stretch 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° angle. A major reason for this is to allow the athlete to handle a heavier dumbbell. If the athlete would straighten the arms almost fully, the mechanical advantage would decrease which means lighter weight must be used. Of course this is totally wrong for the athlete because he/she knows he/she should use 60 pounds instead of 30 pounds.

Equipment companies are trying to and have developed strength training equipment to compensate for the problems of

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After all of this, which will increase
strength and power to its maximum? The
jury is still out. They 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 reveals good results.
Here again, this would be a good research
project.

Question 4: How can the elastic component
of muscle fibers aid in 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 pro-
duces greater force due to a combination
of elastic recoil and the stretch (myotatic)
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
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 suc-
cessfully intersperses muscle stretch be-
tween 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 maxi-
mum poundages. One example is a con-
trolled "quick dip" or descent below
parallel in the squat to stimulate more
muscular involvement in the recovery
ascent of the lift.

O'Bryan:
Elastic storage of energy does occur as
a normal muscular function during the
preparation phase of many ballistic move-
ments. Such is the case in jumping and
other propulsive activities in which the
hip and knee extensors are placed on

The person who inherits long
muscles with short tendon attach-
ments has a strength advantage
over the person who has short
muscles with long tendon attach-
ments. This is because a long
muscle has the potential to
develop greater muscle mass
(volume) than a short muscle.

—Westcott

stretch prior to contraction. This stretching
action causes about a three percent
lengthening of the series elastic com-
ponents 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 phe-
nomenon can be conditioned through
"plyometric training," thus improving the
reactive ability of the muscle and subse-
quent power production. The combination
of both eccentric and concentric training
is thought to enhance muscular strength
and power to a greater degree than con-
centric 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 (includes
the electromechanical delay-EMD between
eccentric and concentric contraction) in
which the muscle must rapidly 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 jump-
ing, as in other strength-power activities,
are the quadriceps, hamstrings, erector
spinae, gluteals, deltoids, trapezius and
gastrocnemius. Traditionally, much em-
phasis 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. How-
ever, 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 move-
ment. During rebound movements me-
chanical 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 force of shortening and propel the
jumper higher than could be obtained
without the downward rebound movement.
A progression of weight training, jump
drills, and plyometrics are recommended
to further develop strength, quicker reac-
tions, and agility. A strength base is
considered an important prerequisite and
therefore should be a precedent to bound-
ning as well as plyometric training phases.

Allerheiligen:
Energy may be stored in the muscles in
the form of elastic energy. When a con-
tracting 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 resulted 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. This type of program would seem quite unsafe while performing a bench press. Imagine trying to bounce the bar off the chest as quickly and as 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 that 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. A recent and excellent review of this topic is that of Komi (1984, Ex. Sport Sci. Rev. 12: 81–122).

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

References for Digby Sale, Ph.D.