

INTENSITY OF STRENGTH TRAINING FACTS AND THEORY: RUSSIAN AND EASTERN EUROPEAN APPROACH

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Many attempts have been made to determine which training is more effective, lifting maximal or intermediate weights. This is similar to the question of whether 800-meter runners should train at distances shorter or longer than 800 meters. It is advisable to run both. The same holds true for strength training; exercises with different resistances must be employed.

The objective of this paper is to describe and explain the training routine employed by elite Russian and Bulgarian weightlifters. Athletes from these countries have won almost all of the gold medals at the World and Olympic championships over the last 25 years.

Three main problems exist in strength conditioning of elite athletes:

1. Selection of exercises used by an athlete;
2. Training load, in particular training intensity and volume; and
3. Training timing, i.e. the distribution of the exercises and load over the time periods.

The training intensity of elite athletes is the only problem covered in this article.

Exercise Intensity Measurement

Exercise intensity during heavy resistance training can be estimated in four ways:

1. Magnitude of resistance, i.e., weight lifted, expressed as a percentage of the best achievement (F_M) in relevant movement. Expressing the weight lifted in kg, it is difficult to compare the training load of athletes of various skill levels and from different weight classes.

2. Number of repetitions (lifts) per set (a set is a group of repetitions performed consecutively).
3. Number (or percentage) of repetitions with maximal resistance (weight).
4. Workout density, i.e. the number of sets per one-hour workout.

The first three methods are described below:

1. To characterize the magnitude of resistance (load), use the percentage of the weight lifted relative to the best performance. Depending on how the best achievement is determined, two main variants of such a measure are utilized. The athletic performance attained during an official sport competition (competition $F_M = CF_M$) is used as a “best performance” in the first case. In the second, a so called maximum training weight (TF_M) is used for comparison.

By definition, maximum training weight is the heaviest weight (one repetition maximum - 1 RM) which can be lifted by an athlete without substantial emotional stress. In practice, experienced athletes determine TF_M by registering heart rate. An increase in heart rate before the lift is a sign of emotional anxiety. The weight exceeds TF_M in this case. The difference between the TF_M and the CF_M is approximately 12.5 +/- 2.5 percent for superior weight lifters. The difference is greater among athletes in heavy weight classes. In the case of an athlete who lifts 200 kg during competition, 180 kg weight is typically above his TF_M .

The difference between CF_M and TF_M is great. After an important competition, weight lifters are extremely tired, although they perform only six lifts in comparison to nearly 100 during a regular training session. The athletes have a feeling of “emptiness” and they cannot lift large volumes of weight. The athletes need about one week of rest and may compete in the next important competition only after one month of rest and training (compared with other sports in which athletes compete two to three times a week). The reason for this is the great emotional stress while lifting CF_M , rather than the physical load itself. TF_M can be lifted at each training session.

It is more practical to use CF_M rather than TF_M for the calculation of training intensity. In a sport such as weight lifting, the training intensity is characterized by an intensity coefficient.

$$\text{intensity coefficient} = \frac{\text{average weight lifted, kg.}}{\text{athletic performance}} \\ \text{(Snatch plus clean and jerk), kg}$$

On average, the intensity coefficient for superior Russian athletes is 38 +/- 2 percent.

It is recommended to use a CF_M value (the average of the two performances attained during official contests) immediately before and after the studied period of training. For instance, if the performance was 100 kg during a competition in December and it was 110 kg in May, the average CF_M for the January - April period was 105 kg.

There are many misconceptions in sports science literature regarding weight loads used in heavy resistance training. One reason is that the difference between CF_M and TF_M is not always completely described. The reader must be attentive to this difference.

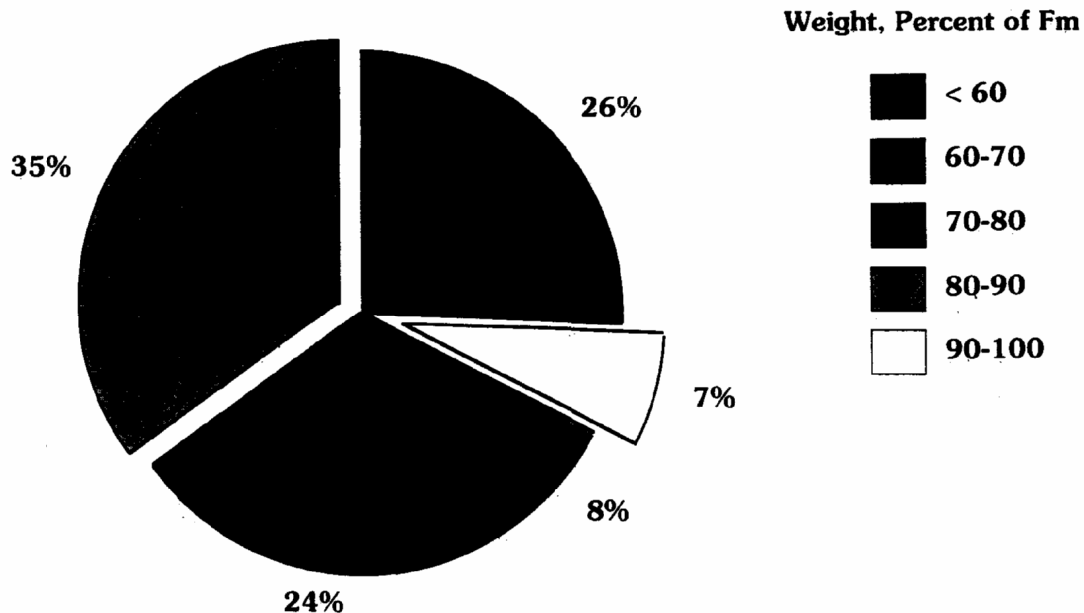


Figure 1: The distribution of weights lifted by members of the National Olympic team of the USSR during preparation for the 1988 Olympic Winter Games; one year of direct observations. (From: 'Preparation of National Olympic team in weight lifting to the 1988 Olympic Games in Seoul.' Technical report #1988-67, All-Union Research Institute of Physical Culture, Moscow, 1989)

2. The number of repetitions per set (repetition maximum - RM) is a popular measure of intensity in exercise where maximal force (F_M) is difficult or even impossible to evaluate, such as sit-ups.

The magnitude of resistance (weight, load) may be characterized by the ultimate number of repetitions possible in one set (to failure). RM

determination entails utilizing a trial-and-error process to find the greatest amount of weight a trainee can lift a designated number of times. RM is a very convenient measure of training intensity in heavy resistance training. However, there is no fixed relationship between the magnitude of the weight lifted (expressed as a percentage of the F_M in relevant movement) and the number of repetitions to failure (RM). The relationship varies with different athletes and motions.

Thus, 10 RM corresponds to approximately 75 percent of F_M . This is valid for athletes in sports in which strength and explosive strength are predominate qualities (weight lifting, sprinting, jumping, throwing, etc.). However, it should be taken into account that a given percent of 1 RM will not always elicit the same number of repetitions to failure when performing different lifts.

During training, elite athletes use varying numbers of repetitions in different lifts.

3. The number for repetitions with maximal resistance is used as an additional measure of the intensity of strength training. All lifts with a barbell above 90 percent of CF_M are included in this category. These loads are above TF_M for most athletes.

Intensity of training

The practical training experience of elite athletes is a very useful source of information in sports science. This experience, while it does not provide sound scientific proof of the optimum results that can be expected from the employed training routines, reflects the most efficient training techniques known at the time.

The distribution of training weights in the conditioning of elite weight lifters is shown in Figure 1. Elite athletes use a broad spectrum of different loads. The loads below 60 percent of CF_M are used mainly for warming up and restitution (they account for eight percent of all the lifts). The main portion of weights lifted (25 percent) is 70 to 80 percent of the CF_M . The loads above 90 percent of CF_M account for only seven percent of all lifts.

According to numerous observations, the average training intensity for elite Russian athletes is 75 +/- 2 percent of the CF_M . Athletes from other countries often use higher or lower training weights. For instance, Finnish weight lifting champions exercise (1987) at an average intensity of 80 +/- 2.5 percent.

The number of repetitions per, set varies by exercise. In both the snatch and clean and jerk lifts (Figure 2), the major parts of all sets are performed with 1-3 repetitions. In the snatch, only 1.8 percent of the sets are done with three four repetitions; in the clean, the percentage of sets with four through six lifts is not

more than 5.4 percent. The majority of sets, roughly from 55 to 60 percent, comprise two repetitions.

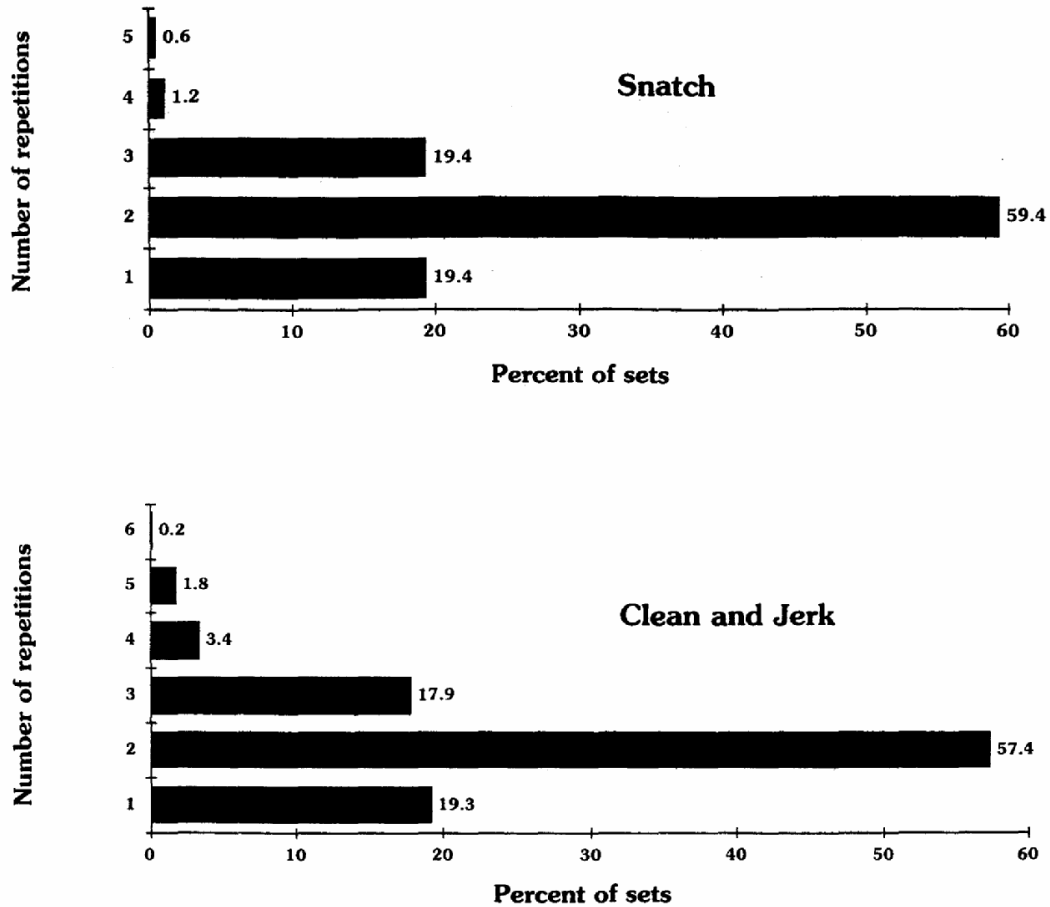


Figure 2. Percentage of sets with various numbers of lifts in the training of elite athletes.

In auxiliary strength exercises, such as squatting with a barbell, in which motor coordination only partially resembles the coordination in the snatch squats, the range is from two to seven lifts per set (more than 93 percent of all sets are performed in this range, Figure 3).

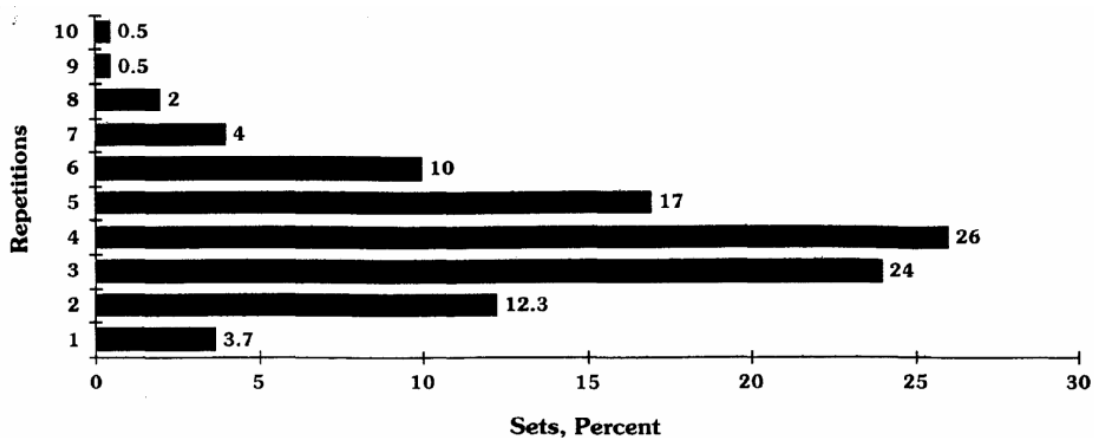


Figure 3. Number of repetitions per set in squatting with a barbell. One year of observations of the training of eight World and Olympic champions in the clean and jerk lift.

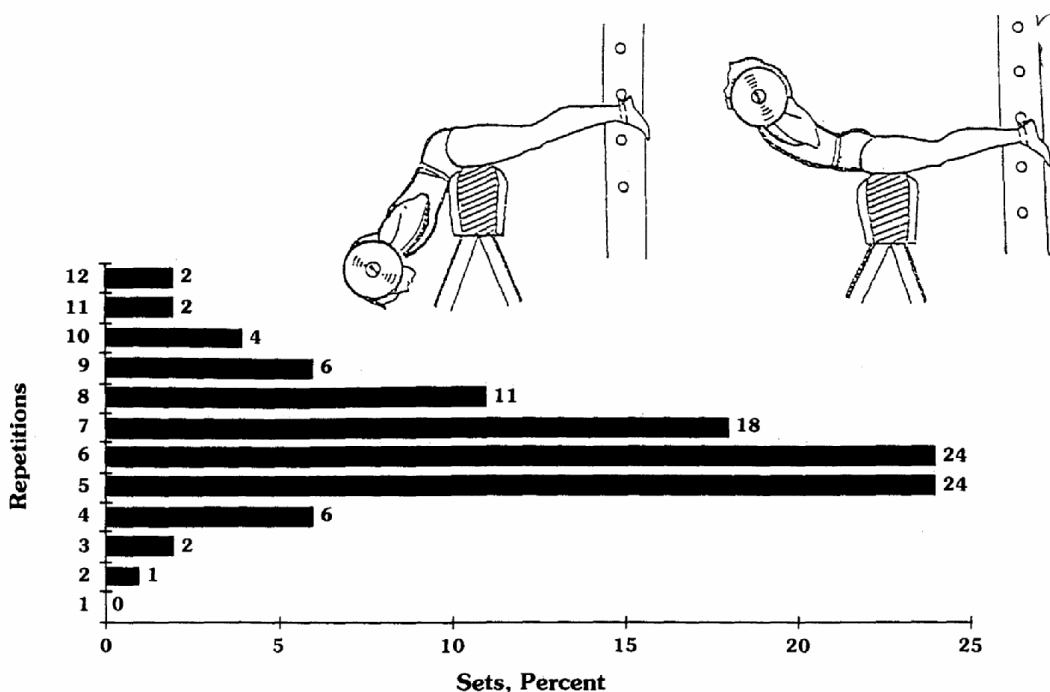


Figure 4. Inverse curl (above) and the percentage of sets with the different number of lifts in this exercise. The results of direct observations of training of V. Alexeev, former World and Olympic champion and World record holder in weight lifting (super heavyweight category), in total 130 sets.

(From 'Preparation of National Olympic team in weight lifting the 1980 Olympic Game in Moscow'. Technical Report #1981-34, All-Union Research Institute of Physical Culture, Moscow, 1981)

Generally, as the intermuscular coordination in an exercise becomes more simple, and as the technique of the exercise deviates from the technique of the main event (in this example, from the technique of both the snatch and clean and jerk), the greater the number of repetitions. In the clean and jerk, it is one to three (54.4 percent of sets were with two lifts only); the typical number of reps in

squatting is three to five, and in the inverse curl the average number of lifts is five to seven per set (Figure 4).

The numbers of repetitions with maximal resistance (CF_M) are relatively low. During the 1984 - 1988 Olympic training cycle, elite Russian athletes lifted a barbell of maximal weight in main exercises (snatch, clean, and jerk) 300 to 600 times a year. This amount comprised 1.5 - 3.0 percent of all their lifts. These weights were distributed as follows:

Weight of Barbell (Percent of CF_M)	Number of lifts (Percent)
90 - 92.5	65
92.6 - 97.5	20
97.6 - 100	15
	Total 100

In a one-month period before important competitions, weights above 90 percent of CF_M are lifted in the snatch and / or clean and jerk 40 to 60 times.

During the 1980s, Russian and Bulgarian weight lifting teams won almost all of the gold medals at World and Olympic competitions. It has been reported many times that Bulgarian athletes lift barbells of maximal weight more than 4,000 times a year. The training intensity of Bulgarian athletes is actually higher than it is for Russian athletes. However, the real source of such a huge discrepancy (600 versus 4,000 lifts a year) is not the training itself, but the method of determining maximal weight. Russian athletes use CF_M in their plans and logs, while Bulgarians stick to TF_M (1 RM in a given training session).

The aforementioned integers should not be mechanically copied. Rather, the underlying concept of such training must be understood and practiced.

The concept was formulated in 1970 and has since been used as a theoretical background for strength conditioning of elite athletes. Though the concept is not scientifically validated in detail (it should be considered as a hypothesis rather than a scientific theory), it is useful from a practical standpoint. When training elite athletes, it is impossible to wait until scientific research provides all of the necessary knowledge.

The training concept is based on the idea that strength manifestation is determined by two latent factors:

1. Peripheral muscles and
2. Central coordination.

These factors should be trained in different ways. It is assumed that there is no optimal exercise intensity to develop maximal strength, however, it is possible to choose an exercise intensity which is optimal for the improvement of either peripheral or central factors.

Causes and Effects in Strength Manifestation

The following briefly explains biological mechanisms which form the basis of training:

Peripheral Factors-Muscles

The capacity of a muscle to produce force depends on its physiological cross-sectional area, and in particular on the number of muscle fibers. Muscle size increases primarily as a result of increases in individual fiber size and not by fiber gain (through fiber splitting).

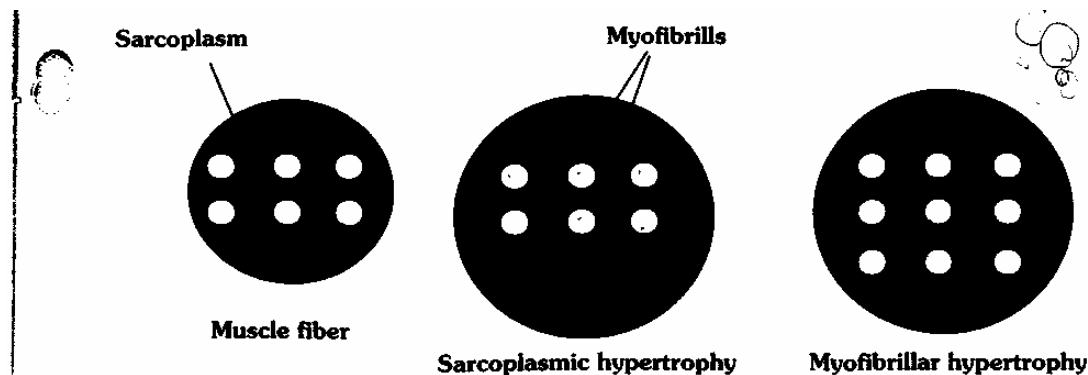


Figure 5. Sarcoplasmic and myofibrillar hypertrophy (a scheme).

Two types of muscle fiber hypertrophy can be schematically discerned, sarcoplasmic and myofibril (Figure 5).

1. *Sarcoplasmic Hypertrophy* of muscle fibers is characterized by the growth of sarcoplasmic (semi-fluid interfibrillar substance) and non-contractile protein which do not contribute directly to the production of muscle force. Specifically, filament area density in the muscle fibers decreases, while the cross-sectional area of the muscle fibers increases without an accompanying increase in muscle strength.
2. *Myofibrillar Hypertrophy* is defined as an enlargement of the muscle fiber size by gaining more myofibrils and, at the same time, more actin and myosin filaments. Furthermore, contractile proteins are synthesized and filament density increases. This type of fiber hypertrophy leads to increased muscle force production.

Except for very special cases, when the aim of heavy resistance training is to achieve body weight gains, athletes are interested myofibrillar hypertrophy. Training must be organized in a manner to stimulate synthesis of contractile protein and to increase filament muscle density.

It is assumed that exercise activates protein catabolism (break down of muscle proteins) creatine conditions for the enhanced synthesis of contractile proteins during the rest period (break down and build up theory). During the strength exercise, muscle proteins are forcefully converted into more simple substances (breaking down); during restitution (anabolic phase) the synthesis of muscle proteins is vitalized. Fiber hypertrophy is considered to be a supercompensation of muscle proteins.

The mechanisms involved in muscle protein synthesis, including the initial stimuli triggering the increased synthesis of contractile proteins, have not been well established.

A few hypotheses, popular among coaches 20 to 30 years ago but completely disregarded today, include:

1. The blood over-circulation hypothesis suggests that increased blood circulation in working muscles is the triggering stimulus for muscle growth. One of the most popular methods of body building training, called flushing, is based on this assumption. It has been shown, however, that active muscle hyperemization (i.e. increase in the quantity of blood flowing through a muscle) caused by physical therapeutic means does not, in itself, lead to the activation of protein synthesis.
2. The muscle hypoxia hypothesis, contrary to the theory described above, stipulates that deficiency, not abundance, of blood and oxygen in muscle tissue during strength exercises triggers protein synthesis. Muscle arterioles and capillaries are compressed during resistive exercise and blood supply to an active muscle is restricted. Blood is not conveyed to muscle tissue if the tension exceeds approximately 60 percent of maximal muscle force.

However, by inducing a hypoxic state in muscles it has been shown that oxygen shortage does not stimulate an increase in muscle size. Professional pearl divers, synchronized swimmers and others who regularly perform low intensity movements in oxygen-deficient conditions do not have hypertrophied muscles.

3. The ATP-debt theory is based on the assumption that ATP concentration is decreased after heavy resistive exercise (about 15 repetitions in 20 seconds per set were recommended for training). However, recent findings indicate that even in a completely exhausted muscle, the ATP level does not change.

Energetical Theory

Finally, the energetical theory of muscle hypertrophy appears more realistic and appropriate for practical training, despite the fact that it is not validated in detail.

According to this theory, the crucial factor for increasing protein catabolism is a shortage of energy in the muscle cell that is available for protein synthesis during heavy strength exercise. Synthesis of muscle proteins requires a substantial amount of energy. The synthesis of one peptide bond, for instance, requires energy liberated during hydrolysis of ATP molecules. For each instant in time, only a given amount of energy is available in a muscle cell. This energy is spent for anabolism of muscle proteins and muscular work. Normally, the amount of energy available in a muscle cell satisfies these two requirements. During heavy resistive exercise, however, almost all of the available energy is conveyed to the contractile elements of muscle and spent for muscular work (Figure 6).

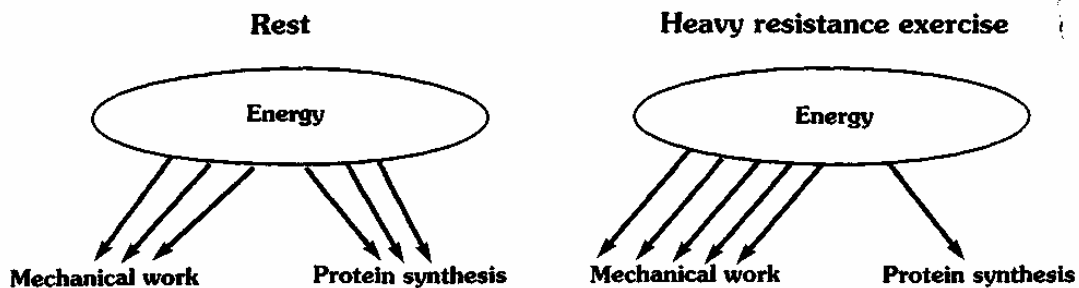


Figure 6. Energy supply at rest and during heavy resistance exercise (a scheme).

Since the energy supply for the synthesis of proteins decreases, protein degradation increases. The uptake of amino acids from the blood into muscles is depressed during exercise, while the mass of proteins catabolized during heavy resistive exercise exceeds the mass of protein that is newly synthesized. As a result, the amount of muscle protein decreases somewhat after a strength workout and the amount of protein catabolized (estimated, for instance, by the concentration of non-protein nitrogen in the blood) rises above its resting value. Between training sessions, protein synthesis is then increased. The uptake of amino acids from the blood into muscles is above resting values. This repeated process of enhanced degradation and synthesis of contractile proteins may result in super-compensation of protein (Figure 7). This principle is similar to the overcompensation of muscle glycogen that occurs in response to endurance training.

Whatever the mechanism for stimulating muscle hypertrophy, the vital parameters of a training routine that induce such results are exercise intensity - the exerted muscular force - and exercise volume - the total number of repetitions, performed mechanical work, etc.

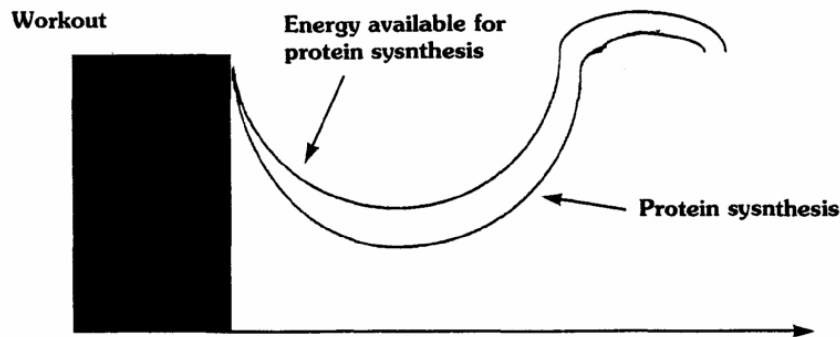


Figure 7. “Energetic potential” of muscle cell and the rate of protein anabolism (a scheme).
 [Adapted from A.A. Viru, Influence of exercise on protein metabolism. In A.A. Viru (Ed.) Lectures in exercise physiology. Tartu, 1990]

Intra-muscular Coordination

The nervous system uses three options for varying muscle force production:

1. Recruitment — gradation of total muscle force by addition and subtraction of active motor units;
2. Rate coding — changing the firing rate of motor units; and
3. Synchronization — activation of motor units in a more or less synchronized way. Motor units (MU) can be classified as fast or slow on the basis of contractile properties.

Slow MU, or slow twitch (ST) motor units, are specialized for prolonged usage at relatively slow velocities. They consist of small, low threshold motoneurons with low discharge frequencies, axons with relatively low conduction velocities and motor fibers highly adapted to lengthy aerobic activities.

Fast MU, or fast twitch (FT) motor units, are specialized for relatively brief periods of activity characterized by large power outputs, high velocities and high rates of force development. They consist of large high threshold motoneurons with high discharge frequencies, axons with high conduction velocities and motor fibers adapted to explosive or anaerobic activities.

MU's are activated in accordance with the all-or-none law: at any point in time, the MU is either active, or it is inactive. There is no gradation in the level of motoneuron excitation. The gradation of force of one MU occurs through changes in its firing rate (rate coding).

In humans, contraction times vary from 90 to 110 milliseconds for ST motor units and from 40 to 84 milliseconds for FT motor units. The maximal shortening velocity (V_M) of FT fibers is almost four times greater than the V_M of ST motor

fibers. The force per unit area of fast and slow motor fibers is similar; however the FT motor units typically possess larger cross-sectional areas and produce greater force per motor unit.

Almost all human muscles contain both ST and FT motor units, but the proportion of fast and slow MU's in mixed muscles varies among athletes. Endurance athletes have a high percentage of ST motor units, while FT motor units are predominant among strength and power athletes.

Recruitment. It is accepted in strength training, that during voluntary contraction, the orderly pattern of recruitment is controlled by the size of motoneurons (so-called size principle). Small motoneurons with the lowest threshold are recruited first and demands for larger forces are met by the recruitment of an increasingly forceful MU. The MU's with the largest motoneurons, those which possess the largest and fastest twitch contractions, have the highest threshold and are recruited last. This implies, in mixed muscles containing both ST and FT motor units, that the involvement of motor units is forced, regardless of the magnitude of muscle tension and velocity being developed. On the contrary, full FT motor unit activation is difficult to achieve. Untrained people cannot recruit all of their FT motor units. Increased motor unit activation is observed in athletes engaged in strength and power training.

The recruitment order of MU's is relatively fixed for a muscle involved in a specific motion, even if the movement velocity or rate of force development is altered. However, the recruitment order can be changed if the multifunction muscles operate in different motions. Different sets of MU's within one muscle might have a low threshold for one motion and a higher threshold for another.

The variation in recruitment order is partially responsible for the specificity of training effect in heavy resistance exercise. If the object of interest in training is full development of a muscle (not high athletic performance), one must exercise this muscle in all its possible ranges of motion. This situation is typical for bodybuilders and novice athletes, but not elite athletes.

Rate Coding. This is considered the primary mechanism for the gradation of muscle force. The discharge frequency of motoneurons can vary over a considerable range. However, generally the firing rate increases with increased force and power production.

The relative contribution of recruitment versus rate coding in grading the force of voluntary contractions is different in small and large muscles. In small muscles, most MU's are recruited at the level of force less than 50 percent of F_M ; thereafter, rate coding plays the major role in further development of force up to F_M . In large proximal muscles, such as the deltoid and biceps, the recruitment of additional MU's appears to be the main mechanism for increasing force development up to 80 percent of F_M and even higher. In the force range between

90 and 100 percent of F_M , force is increased almost exclusively by intensifying the firing rate of MU.

Synchronization. Normally MU's work asynchronously to produce smooth, accurate movement. However, there is some evidence that in elite power and strength athletes MU's are activated synchronously during maximal voluntary efforts.

In conclusion, maximal muscular force is achieved when the maximal number of both ST and FT MU's are recruited, rate coding is optimal to produce a fused tetanus in each of the motor fibers and MU's work synchronously over the short period of maximum voluntary effort.

The psychological factors are also of primary importance. Under extreme circumstances, i.e. in a "life-or-death" situation, people may develop extraordinary strength. When untrained subjects (not superior athletes!) are given hypnotic suggestions of increased strength, strength increases are found, whereas strength decrements are shown both by athletes and untrained people after hypnotic suggestion of decreased strength. Such a strength enhancement is interpreted to mean that the central nervous system, in extraordinary situations (extreme fear, hypnosis, etc.), either increases the flow of excitatory stimuli or decreases the inhibitory influence to the motoneurons.

It may be speculated that the activity of motor neurons of the spinal cord is normally inhibited by the central nervous system and it is not possible to activate all of the motor units within a muscle group. Under the influence of strength training and under exceptional circumstances, important sport competitions included, a reduction in neural inhibition occurs with the accompanied expansion of the recruitable motoneuron pool and increase in strength.

Exercising With Different Resistance

When exercising with varying levels of resistance (weights), differences exist in both metabolic reactions and neural coordination.

Metabolic Reactions. According to the "energetic hypothesis" of muscle cell hypertrophy described above, the crucial factor determining the balance between protein catabolism and anabolism is the amount of energy available for protein synthesis during exercise. If the resistance is relatively small, the energy available in the muscle cell is conveyed for muscle action and at the same time for anabolism of muscle proteins. Thus, the energy supply satisfies both requirements. During heavy weight lifting, a greater amount of energy is provided to the contractile muscle elements and spent on muscular work. Energy transfer for the synthesis of proteins decreases, while the rate of protein breakdown (the amount of degraded protein per one lift) increases. The rate of protein

degradation is a function of the weight lifted; the heavier the weight, the higher the rate of protein degradation.

The total amount of degraded protein is, however, the function of both the rate of protein catabolism and the mechanical work performed or the total weight lifted. The mechanical work is greater if resistance is moderate and if several consecutive lifts are performed in one set. For instance, if an athlete presses a 100 kg barbell one time (it is his 1 RM), the total weight lifted is also 100 kg. However, if he lifts a 75 kg barbell to failure, and he can lift it about 10 times, the total weight lifted equals, in this case, 750 kg.

The mass of protein catabolized during heavy resistive exercise can be presented as a product of the rate of protein breakdown and the number of lifts. If the resistance is very large, such as 1 RM, the rate of the protein breakdown is high but the number of repetitions is small. At the other extreme, if the resistance is small (50 RM), the number of lifts and mechanical work are great, but the rate of protein degradation is very small. So the total amount of the degraded protein is small in both cases but for different reasons. The optimal (for inducing maximal changes in protein metabolism) solution is somewhere in the range of five and six through 10-12 RM (Table 1).

Table 1. The amount of degraded protein during heavy resistance training

Resistance, Rm	Rate of protein degradation	Mechanical work (number of repetitions)	Total amount of degraded protein
1	High	Small	Small
5-10	Average	Average	Large
>25	Low	Large	Small

An additional feature of such training, which is important from a practical standpoint, is that a very high training volume (or the total amount of weight lifted during a workout), is five to six times greater than during a conventional training routine. Athletes who train over a certain period of time in this manner (to gain body weight and induce muscle cell hypertrophy in order to compete in a heavier weight class) amass a training volume in one workout over 20-30 tons and in some cases above 50 tons per day. Such a training volume hinders the athlete's capacity to perform other exercises during this period of training.

Coordination. When lifting maximal weight, the maximum number of MU's are activated, the fastest MU's are recruited, the discharge frequency of motoneurons is at its highest and MU activity is synchronous.

However, MU's exist that many athletes cannot recruit or raise to the optimal firing rate intensity to develop maximal force.

The “hidden potential” of a human muscle to develop higher force can also be demonstrated by electro-stimulation. In experiments during maximum voluntary contraction, the muscle is stimulated with electrical current that induces an increase in the force production. This indicates that human muscles typically have hidden reserves for maximal force production that have not been used during voluntary efforts.

One objective of heavy resistance training is to teach an athlete to recruit all the necessary MU's at a firing rate that is optimal for producing a fused tetanus in each motor fuser.

When lifting sub-maximal weight, an intermediate number of MU's are activated, the fastest MU's are not recruited, the discharge frequency of the motoneurons is submaximal; and MU activity is asynchronous. The difference in intramuscular coordination between exercises with maximal versus sub-maximal weight lifting, are evident. Accordingly, exercises with moderate resistance are not an effective training means for strength development, particularly when improvement of intramuscular coordination is desired.

In the preparation of elite weight lifters, the optimal intramuscular coordination is realized when weights equal to or above TF_M are used in workouts. It is not mandatory from this standpoint to lift CF_M during training sessions. Differences in the best performance attained during training sessions (i.e. TF_M) and during important competition (i.e. CF_M) are explained by psychological factors, such as the level of arousal and by increased rest before a contest. Differences in coordination (intra and intermuscular), however, do not affect performance. Weights above TF_M are only used sporadically in training (four to seven percent of all the lifts).

The differences in underlying physiological mechanisms, while exercising with various loads, explain why muscular strength only increases when exercises requiring high forces are used in training. In principle, workloads must be above those normally encountered. The resistance must continually be increased as gains in strength are made (the principle of progressive-resistance exercises).

In untrained people, the strength levels fall when resistance is below 20 percent of their F_M . In athletes who are used to great muscular efforts, reduced strength may result even if they use relatively heavy loads, although lower than their usual level. For instance, if qualified weight lifters train with weights of 60 to 85 percent TF_M and not lift these loads in one set to failure (to fatigue), the strength level is kept constant over the first month of such training and drops five to seven percent during the second month. Athletes in seasonal or winter sports, such as rowing, lose the strength level previously attained in the preparation period if they do not use high resistance training during a competition period, regardless of intense specific workouts.

Only muscle size, not muscular strength, may be retrained with moderate (non-maximal) resistances and moderate (non-maximal) repetition in qualified athletes over a period of several months.

Methods of Strength Training

Strength training is classified according to methods of attaining maximal muscular tension which can be attained in one of three ways:

1. Method of maximum efforts. Lifting a maximum load (exercising against maximal resistance).
2. Method of repeated efforts. Lifting a non-maximal load to failure; during the latest repetitions the muscles develop the maximum force possible in the fatiguing state.
3. Method of dynamic efforts. Lifting, throwing, etc. a non-maximal load with the highest attainable speed.

In addition, the lifting of non-maximal loads an intermediate number of times (not to failure) is used as a supplementary training method (method of sub-maximal efforts).

Methods of maximum efforts.

Considered superior for improving both intramuscular and intermuscular coordination. The method of maximum effort should be used to bring forth the greatest strength increments. Central nervous system inhibition, if it exists, is reduced with this method; thus, the maximal numbers of MU's are activated with optimal discharge frequency and the biomechanical parameters of movement and intermuscular coordination are similar to analogous values in a main sport exercise. A trainee then "learns" to enhance and to "memorize" these changes in motor coordination (evidently on an unconscious level).

It was previously mentioned that the magnitude of resistance should be close to TF_M while employing this training method. To avoid high emotional stress, CF_M must be included into the training routine only intermittently. If the aim of a training drill is to train movement (i.e. both intramuscular and intermuscular coordination are the object of training), the recommended number of repetitions per set is one to three. Exercises such as the snatch or the clean and jerk may serve as an example (Figure 2). When training muscles, rather than movement training, is the drill objective (i.e., the biomechanical parameters of the exercise and intermuscular coordination are not of primary importance since the drill is not specific and its technique is different from the sport technique of the main exercise) the number of repetitions increases. One example is the inverse curl (Figure 5), in which the typical number of repetitions is four to eight.

The method of maximum efforts, while a popular method among elite athletes, has several limitations.

The main limitation is the high risk of injury. Because of this, it cannot be recommended for beginners. Only after proper technique of an exercise (i.e. barbell squat) is acquired and the relevant muscles (spinal erectors and abdomen) are adequately developed, can maximal weights be lifted. In some exercises, such as sit-ups, this method is rarely used.

The method of maximum efforts, when employed with a small number of repetitions (one or two), has the limited ability to induce muscle hypertrophy. This is because only a minor amount of mechanical work is performed and in turn, the amount of contractile proteins degraded is limited.

Due to the high motivational level needed to lift maximal weights, athletes can easily become burned out. The staleness syndrome is characterized by decreased vigor, elevated anxiety and depression, sensation of fatigue in the morning hours and increased perception of effort while lifting a fixed weight, etc. High blood pressure at rest is also a further symptom. This response is typical if CF_M , rather than TF_M , are used too often in workouts. Staleness depends not only on the weight lifted but also on the type of exercise used. It is easier to lift maximal weights in the bench press, in which the barbell can simply be fixed and the leg and trunk muscles are not activated, than in the jerk, where demands for the activation of leg and trunk muscles, balance and arousal are much higher.

Sub-maximal efforts and repeated efforts

These methods differ only in the number of repetitions per set — intermediate for sub-maximal efforts and maximal (to failure) for repeated efforts.

The stimulation of muscle hypertrophy is similar between the two methods. According to the energetic hypothesis described above, two factors are of primary importance to induce a discrepancy in the amount of degraded and newly synthesized proteins. Those factors are the rate of protein degradation and the total value of performed mechanical work. If the number of lifts is not maximal, mechanical work somewhat diminishes. However, if the amount of work is relatively close to maximal values (i.e., if 10 lifts are performed instead of the maximum 12 possible) then the difference is not crucial. It may be compensated, for example, by shortening the time intervals between sequential sets. It is a common belief that the maximal number of repetitions in a set is desirable, but not required, for inducing muscle hypertrophy.

The situation is different if the main objective of a heavy resistance drill is to learn a proper pattern of muscle coordination.

This issue is analyzed in the following example (Figure 8):

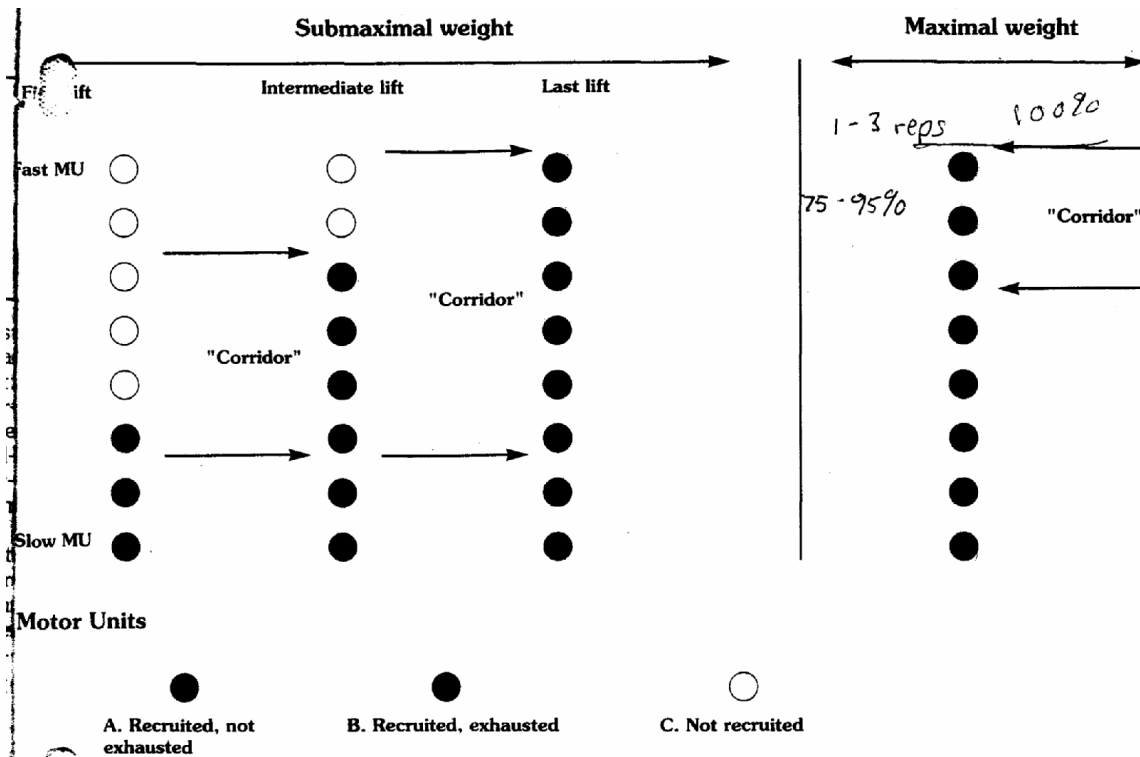


Figure 8. Subpopulations of motor units during strength exercises.

Suppose an athlete is lifting a 12 RM barbell with a given rate of one lift per second. The muscle subjected to training consists of MU's having different endurance times from one to, for example, 100 seconds (in reality, some slow MU's have much longer endurance times; they may be active dozens of minutes without any sign of fatigue). The maximal number of lifts until fatigue among MU's varies from one to 100. If the athlete lifts the barbell only one time, one division of the MU's is recruited and the second is not (Figure 8). According to the size principle, the slow, fatigue-resistant MU's are recruited first (the slow MU's are shown at the bottom of MU columns, Figure 8). After several lifts, some of the shortest endurance times become exhausted. After six repetitions, for instance, only the MU's with endurance times less than six seconds are exhausted. Since the exhausted MU's now cannot develop the same tension as at the beginning, new MU's are recruited. These newly recruited MU's are fast and non-resistant to fatigue. Thus, they may become exhausted very quickly. If only 10 lifts of 12 maximum possible are performed, the entire population of MU's is divided into three divisions (Intermediate lift column, Figure 8). The three divisions of MU's are:

1. MU's that are recruited but not fatigued are not trained. All MU endurance times above 10 seconds are in this category. Evidently, this subpopulation consists of slow MU's. Therefore, it can be concluded that it is very difficult to increase the maximal force of the slow MU's which are fatigue resistant.

2. Only MU's which are recruited and exhausted. Only these MU's are subjected to training stimulus in this set. These MU's possess intermediate features; there are no slowest, although recruited, and fastest MU's, which are not recruited all, in this sub-population. The "corridor" of MU's that are subjected to a training stimulus may be more narrow or more broad. This depends on the weight lifted and on the number of repetitions in a set. One objective of a strength program can be to increase the sub-population of MU's influenced by training, or to increase the corridor.
3. MU's that are not recruited or trained.

If the exercise is performed to failure (method of repeated efforts), the picture is changed in the final lifts. A maximal number of available MU's is now recruited. All MU's are divided into two subpopulations: exhausted (fatigued) and non-exhausted (non-fatigued) with a substantial training effect on the first group only. If the total number of repetitions is below 12, all the MU's with endurance times above 12 seconds fall into the second group. In spite of their early recruitment (due to the higher endurance), these MU's are not exhausted.

When maximal weights are lifted (method of maximal efforts), the MU's "corridor" includes a smaller number of MU's (Figure 8) than if a sub-maximal weight is lifted a maximum possible number of repetitions. This is certainly a disadvantage for the method of maximal efforts. Only fast MU's are subject to the training effect in this case. However, the advantage of this method (see above) outweighs any drawbacks.

If the method of repeated efforts is used, the weight must be lifted with sincere exertions to failure (maximum number of times). This requirement is very important. The popular jokes among coaches are: "Lift the barbell as many times as you can and after that three more times," and "no pain, no gain" I reflect the demand very well. With this method, only final lifts in which a maximal number of MU's are recruited are actually useful. If an athlete can lift a barbell 12 times but lifts only 10, the exercise set is worthless.

In comparison with the method of maximal efforts, the method of repeated efforts has certain pros and cons. Three advantages are most important:

1. A greater influence on muscle metabolism and consequently on the inducement of muscle hypertrophy;
2. The greater sub-population of the trained MU's (the "corridor", compare the two right columns in Figure 8); and
3. A relatively low injury risk.

This method has two limitations:

1. The final lifts in a set are performed when the muscles are tired. Thus, this training alone is less effective than the lifting of maximal weights; and
2. Very high training volume (the total amount of weight lifted) restricts the application of this method in the training of elite athletes.

All of the methods discussed should be used in the strength training of elite athletes.

Method of Dynamic efforts

It is impossible to attain F_M in fast movement against intermediate resistance. Therefore, the method of dynamic efforts is not used for increasing maximal strength. It is employed only to improve the rate of force development and explosive strength.

Practical Recommendations

In conclusion, the following methods are used to increase maximum strength F_M :

To improve neuro-muscular coordination (MU recruitment, rate coding, MU synchronization, entire coordination pattern), use the method of maximal efforts as the first choice and the method of repeated efforts, as the second.

To stimulate muscle hypertrophy, use the methods of repeated efforts and / or method of sub-maximal efforts.

To increase the “corridor” of recruited and trained MU’s, use the method of repeated efforts.

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