The principles of muscle fiber recruitment applied to strength training

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Among today's power athletes and coaches it is readily accepted that a team's physical strength is a significant factor in determining its success. Granted, ability and strategy are a must in today's athletics, but when these are combined with stronger athletes, the end result is a team that's tough to beat.

There are many different theories in the area of strength development. Some are factually based on research, while others are fallacies passed down over the years. Two thoughts upon which nearly everyone agrees are: 1) that in training, one wants to recruit as many muscle fibers as possible, and 2) then overload those fibers to cause hypertrophy.

This article will discuss the anatomy of the neuromuscular system and the facts on muscle fiber recruitment, followed by the application of that knowledge in discussing the most effective manner for developing strength and power through weight resistance exercise.

The nerve

The basic functional and anatomical unit of the nerve is the neuron, or nerve cell. It consists of a) cell body, or soma; b) several short nerve fibers called dendrites; and c) a longer nerve fiber called an axon. The dendrites transmit nerve impulses toward the cell body, whereas the axon transmits them away from that same structure.

In large nerve fibers, like most of those innervating skeletal muscle, the axon is surrounded by a myelin sheath. The myelin sheath is not continuous along the entire length of the fiber, but rather is laid down in segments. The spaces between the segments are called nodes of Ranvier, whose contribution to impulse transmission will be discussed at a later time in this article. (6)

Very simply, nerves can be thought of as highways which carry information from one point in the body to another. A single nerve can only relay the impulse in one direction, therefore, there are basically two different types of nerves.

The afferent, or sensory nerve, carries messages from receptors toward the central nervous system (CNS), while the efferent, or motor nerve, relays impulses from the CNS to the muscles.

Muscle sense organs

There are different types of receptors within the body, but the two important muscle sense organs are the muscle spindles and the Golgi tendon organs. Both of these organs are concerned with kinesthetic sense, the awareness of body position, as well as the control of voluntary and reflex movements. (6, 10)

The muscle spindles, located within special muscle fibers called intrafusal fibers, have a sensory nerve wrapped around the center portion of its body. When the spindle is stretched, nerve impulses are generated in the sensory nerve, and information relative to both the rate and the magnitude of the stretch is sent to the CNS. (6, 10)

The Golgi tendon organs, which are also sensitive to stretch, are located within the tendons. However, since they lie in the tendons rather than in the muscle itself, they are stretched when the muscle in whose tendon they lie contracts. Therefore, the information sent to the CNS is relative to the strength of the contraction.

The nerve impulse

The nerve impulse is transmitted along the nerve in a self-propelled continuous motion. When a nerve fiber is at rest, sodium ions (Na+) are most heavily concentrated on the outside of the nerve membrane, resulting in an electrically positive charge, while the inside of the nerve is less positive with potassium ions (K+) or negative with regard to the outside. When a stimulus is applied to the nerve, its membrane becomes highly permeable to sodium ions, allowing them to pass inside of the nerve. The outside of the nerve becomes less positive, while the inside is more positive, resulting in a reversal of polarity called an action potential. The current is self-regenerating in that it flows to adjacent areas of the nerve, causing each area to undergo a reversal of polarity. This action is repeated until the impulse has traveled the entire length of the nerve. (6)

Nerve impulses cannot penetrate the part of the nerve fiber covered by the myelin sheath. This sheath is found on most nerves that innervate skeletal muscles. Instead, it jumps along the nodes of Ranvier. This action, called the saltatory conduction, greatly increases the conduction velocity of the nerve impulse. For example, the conduction velocity of large medullated fibers, those having a myelin sheath, is 60-100 meters per second, while that of nonmedullated fibers of the same diameter is only 6-10 meters per second. (6)

When the nerve impulse reaches the end of the axon, it causes the release of a chemical transmitter substance. The transmitter substance serves to relay information either from nerve to nerve at the synapse, or from nerve to muscle at the neuromuscular junction. It does this by evoking a new nerve impulse in the nerve or muscle on which it is secreted. For example, a nerve impulse propagated along a motor nerve causes acetylcholine to be released at the neuromuscular junction. In turn, the acetylcholine initiates an action potential in the muscle, which spreads throughout so that the muscle contracts. (6)

The motor unit

Much has been said of the neural aspects of the neuromuscular system. It is necessary to include the muscle fibers. The motor unit consists of a motor neuron and those skeletal muscle fibers innervated by it. Most single motor nerves have many branches and thus, in entering a muscle, innervates numerous muscle fibers that are dispersed throughout
the muscle. When a motor neuron of a motor unit is stimulated, all of the muscle fibers within that unit contract synchronously. This action is in accordance with the "all-or-none" principle. If there are many fibers within the unit, a strong contraction is the result; while if only a few fibers are present, the contraction is weak. The response of the muscle can thus be graded depending upon the size and number of motor units stimulated. Such an arrangement allows for fine, delicate movements as well as for gross, large-scale actions. (6, 9)

Motor unit types

There are two general types of motor units present within humans, slow or type I, and fast or type II. It is an attractive idea that fibers in a single motor unit are similar in composition, but there is considerable diversity in composition among different motor units of the same major fiber group. Thus it must be interpreted carefully. The fast motor units are broken down even further to fast oxidative glycolytic (FOG) or type IIA and fast glycolytic (FG) or type IIB. A motor unit is made up of identical fibers, so that a slow motor unit will include all type I fibers, and a fast motor unit will include all or one of the type II fibers.

The type I fiber has a greater aerobic capacity than the type IIB and thus has more heart Lactate Dehydrogenase, Succinate Dehydrogenase, Malate Dehydrogenase, greater number and size of the mitochondria, and a higher myoglobin content. The motor neuron is small, lightly myelinated, and has less membrane surface area. The type I motor units are recruited for the less powerful, endurance types of activity. (4)

The type IIB fiber, on the other hand, has a much greater anaerobic capacity with a higher content of Phosphorylase, Phosphofructokinase, Muscle Lactate Dehydrogenase, and Myosin ATPase. The fibers are innervated by a very large, heavily myelinated nerve that has more membrane surface area than that of the type I nerve. These motor units are only called upon for the quick, powerful movements. (4)

The type IIA fiber is an intermediate fiber, whose outcome depends on the manner it is trained. The fiber type cannot be changed, but the enzyme system is altered. What remains consistent is that the IIA fiber is more fatigueresistant than the IIB, has a high tension output, although not as high as the IIB, and has a motor neuron that is in between the size of the other two types. While these fibers can generate power, they can also continue for long periods of time. These motor units are needed for those activities which require power over a period of more than ten seconds. (4)

Motor unit recruitment

The motor units are recruited by direction of the CNS. The CNS has a choice of modifying the output of a muscle by: 1) varying the number of motor units recruited per unit of time, 2) the kind of motor units recruited, or 3) the frequency at which a motor unit will be activated. These decisions are made depending upon the feedback from the muscle sense organs, primarily the muscle spindles. The greater the tension on the muscle, the more the spindle is stretched, and thus, more motor units are recruited in addition to an increase in the firing of those already activated. (2, 9)

Psychological input also contributes to the recruitment pattern. As one prepares to lift an object, the item's weight is perceived through visual observation. This feedback gives the CNS the necessary information to modify the tension exerted by the active muscles. Sometimes this perception can be deceiving. Surely, one has experienced the lifting of a light object mistakenly thought to be quite heavy. The CNS has been misinformed.

Recruitment order

As the muscular effort is increased in force and speed, the relative importance of the fast-twitch units becomes increasingly greater. However, there is an orderly recruitment of the motor units. Based on the size principle, the smaller type I motor unit is always recruited first followed by the type IIA and then the type IIB. It has been found that the slow twitch units have been recruited even during very powerful activities. (3) However, the fast twitch fibers will not be activated unless the activity is intense and powerful.

Speed of movement does not affect the normal recruitment pattern. There is no evidence for any preferential recruitment of the larger, faster motor units in brisk or ballistic movements in man. However, it has been determined that the faster the contraction, the less the force that is necessary for firing of the type IIB unit. (12) Therefore, the type IIB unit can be recruited with a light impetus if it is moved very quickly.

Recruitment and fatigue

During maximal contraction, as fatigue sets in, there is a drop in the number of activated units and the contraction is weakened. (12) It is uncertain what the effects of fatigue are during high levels of submaximal contractions. As one motor unit becomes incapable of responding, does another one become activated? One would expect this response during submaximal activity, but Burke and Edgerton write, "Whether or not fatigue during prolonged work causes additional recruitment of previously inactive groups of motor units remains to be clarified." (3)

Muscular development

Gains in muscle strength during training result from two factors: 1) a gradual increase in the ability of the contractile elements in each fiber to contract more strongly, and 2) a gradual recruitment of a higher proportion of the total available fibers in each contraction. (19) These constituents can be developed with application of the Overload Principle, which states that "Strength, endurance, and muscle size increase, within limits, in response to repetitive exercise, against progressively increased resistance." (5, 7, 8, 10)

Tension and recruitment patterns

Tension is the key to strength development. The amount of stress put on the muscle spindles allows for the recruitment pattern of the proper units. A fast powerful contraction is the result of a short burst of impulses from a large number of motor neurons. A slower and less powerful contraction results from a more prolonged discharge at a lower frequency and from fewer motor neurons. (9) Remember that it is the IIB motor units that are responsible for great productions of strength and power. The athlete concerned with strength and power wants to hypertrophy these fibers with the intent of increasing their ability to contract more strongly. Hypertrophy only occurs in those fibers that are overloaded, so the IIB fibers must be recruited during training in order to be hypertrophied. (9) Training with low or moderate intensity loads will not necessitate the need of the IIB motor unit. The load intensity must be high.

Developing explosive strength

Research has shown that explosive strength has best been developed by using high weight with repetitions of six or less. (6, 9) High intensity provides the necessary stress to incorporate the use of the IIB motor units. There is a terrific rate of impulse discharge that cannot be maintained for more than a brief period, because the fuel is furnished by the ATP-PC energy system. (9) For one to exceed six repetitions, the initial tension...
on the muscle had to be reduced. With a reduction in weight, less of the IIB motor units are needed to generate the effective force to move the load. A recent study (14) has shown a lack of Fast Twitch fiber hypertrophy in bodybuilders whose workout sets consist of 8–20 Repetition Maximum. On the contrary, power lifters, whose workout sets are high in weight and low in repetitions, had significantly larger Fast Twitch fibers. In addition, Morehouse and Miller (9) have reported only a moderate correlation between muscle hypertrophy and the demonstration of strength. This evidence suggests that as repetitions exceed six, less of the IIB motor units are recruited.

Multiple sets vs. one set

Because the Overload Principle states that “...repetitive exercise against progressively increased resistance" is needed for strength gains, multiple sets of low repetitions are used. A rest period of approximately three minutes between sets allows for the replenishment of the ATP-PC stores. In this fashion, high intensity exercise can be repeated without the production of the fatigue substance, lactic acid. (9)

Some authorities feel that if a muscle fiber is overloaded in one set, then additional sets are useless. Such individuals fail to recognize that the human body is content in the state of homeostasis and does not wish to change. Repeatedly overloading human tissue forces it to make the necessary adaptations. Just as the sprinter cannot run one vigorous sprint to exhaustion and expect to improve his anaerobic capacity, neither can the athlete perform one set of resistance exercise and expect to get the best development of strength. Berger has shown that one set of ten repetitions will significantly increase strength, but three sets of six repetitions will be more effective. (1) It is this writer’s speculation that because there is a decrease in intensity with ten repetitions, the IIB motor units are not recruited. However, those units are recruited and repeatedly stimulated with the three sets of six repetitions.

The weight training cycle

Some individuals believe that training at such high intensity can lead to physical and mental overtraining, as well as ligament, cartilage and tendon damage. More recently than Berger’s research the concept of periodization has been examined. Its goal is to gradually bring the body to the intense training levels of power over a period of weeks. Such a protocol avoids the constant pushing of one’s body which leads to chronic fatigue.

The training cycle can be for any length of time, but usually ranges from seven to twelve weeks. This period is divided into three segments of training: 1) hypertrophy, 2) basic strength, and 3) strength and power. It is believed that a hypertrophied muscle can be expected to have a higher potential to gain strength and power than a nonhypertrophied muscle. (9) In addition, enlargement of the connective tissue will also occur to increase joint stability. (9)

Hypertrophy is best developed by three sets of 8 to 20 RM. Basic strength training follows hypertrophy with 3–5 sets of 2–6 RM. The cycle concludes with very intense training for power using 3–5 sets of 1–3 repetitions. (13)

This training protocol was found by Stone, et al., (12) to be more effective in producing strength and power than the more conventional 3 sets of 6 repetitions. Subjects using the cycle program increased significantly more in the 1 RM squat and the vertical jump. Stone, et al., contribute the early development of hypertrophy as a key factor for the program’s success. (13)

The ultimate goal of the cycle is the same as has been discussed, to produce strength and power by recruiting the type IIB units with high intensity, low repetition exercise. However periodization brings the muscle to great power outputs over a period of time which helps prevent the athlete from chronic fatigue.

Concluding remarks

The type IIB motor units are most important in the production of powerful movements. Athletes in quest of strength and power must train the IIB motor units through the use of high weight, low repetition exercise. Such intensity stimulates the recruitment of the necessary fibers, therefore making it possible that they can be overloaded. These fibers respond to the overload by increasing their ability to contract more strongly. As a result, the athlete is able to produce stronger and more powerful movements.

Exercise of lesser load intensity does not necessitate the recruitment of the IIB fibers. Movement of the load can be executed without incorporating the most powerful fibers. Such fibers are not overloaded, so their ability to contract is not enhanced.

Cycling seems to have evolved as the most popular and effective protocol of strength and power training. The three phases adequately prepare the body for high intensity exercise while preventing chronic fatigue. Stone, et al., have reported results that this method has been shown to increase performance on two strength and power tasks significantly more than the conventional 3 sets of 6 repetitions.

It is recommended that athletes of power investigate the various cyclic programs. One should be selected that will bring them to peak levels of strength and power during the most competitive phase of their season.  

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References


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Coaches Roundtable

Lower body strength and endurance: Parallel Squat 225 lbs. or 275 lbs. or 315 lbs. x max reps.
1. To determine lower body ability to exert maximum force repeatedly
   Assigned reps — determined by 1 RM at end of the winter program (Table 3).
2. Point System:

<table>
<thead>
<tr>
<th>7 pts.</th>
<th>8 pts.</th>
<th>9 pts.</th>
<th>10 pts.</th>
<th>11 pts.</th>
<th>12 pts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5 reps</td>
<td>-4 reps</td>
<td>-2 reps</td>
<td>assigned</td>
<td>+2 reps</td>
<td>+4 reps</td>
</tr>
</tbody>
</table>

Aerobic Run Conditioning: 1.5 Mile Run
1. To determine ability to work continuously without undue fatigue
2. Assigned times:
   a. Defensive Backs/Wide Receivers — 9:00
   b. Running Backs/Quarterbacks/Tight Ends/Linebackers — 10:00
   c. Interior Linemen — 11:00
3. Point System:

<table>
<thead>
<tr>
<th>7 pts.</th>
<th>8 pts.</th>
<th>9 pts.</th>
<th>10 pts.</th>
<th>11 pts.</th>
<th>12 pts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1:30</td>
<td>+1:00</td>
<td>+:30 assigned</td>
<td>-:30</td>
<td>-1:00</td>
<td></td>
</tr>
</tbody>
</table>

Anaerobic Run Conditioning: Repeated 40 yard dashes (Figure 2)
1. To determine your ability to sprint 100% repeatedly without complete recovery between each bout to simulate the running demands of a football game.
2. The sprint test:

<table>
<thead>
<tr>
<th>Distance</th>
<th>Reps</th>
<th>Intensity</th>
<th>Rest Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 yards</td>
<td>10</td>
<td>100%</td>
<td>25 seconds</td>
</tr>
</tbody>
</table>

3. Scores will be determined as follows:
   a. Multiply your offseason 40 yard dash time (determined during winter program) by 10. If you were in perfect condition you would be able to run this time 10 times consecutively with a 25 second rest interval.
   b. Record the actual times for the sprint test above and total them.
   c. Divide (a) above by (b) and multiply by 100. This will give you a percentage score.
   d. Point System:

<table>
<thead>
<tr>
<th>7 pts.</th>
<th>8 pts.</th>
<th>9 pts.</th>
<th>10 pts.</th>
<th>11 pts.</th>
<th>12 pts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%</td>
<td>85%</td>
<td>87.5%</td>
<td>90%</td>
<td>92.5%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Agility: The Edgren Side Step (10 second lateral touch between two lines 12 feet apart) (Figure 5)
1. To determine ability to move laterally and change direction quickly (agility)
2. Point System:

<table>
<thead>
<tr>
<th>7 pts.</th>
<th>8 pts.</th>
<th>9 pts.</th>
<th>10 pts.</th>
<th>11 pts.</th>
<th>12 pts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB/WR</td>
<td>32</td>
<td>34</td>
<td>36</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>QB/RB/TE/LB</td>
<td>30</td>
<td>32</td>
<td>34</td>
<td>36</td>
<td>38</td>
</tr>
<tr>
<td>Interior Line</td>
<td>29</td>
<td>31</td>
<td>33</td>
<td>35</td>
<td>37</td>
</tr>
</tbody>
</table>

Test Scoring
A. Upper Body Strength and Endurance: Bench Press
   10 pts. (+2)
B. Lower Body Strength and Endurance: Parallel Squat
   10 pts. (+2)
C. Aerobic Run Conditioning: 1.5 mile run
   10 pts. (+2)
D. Anaerobic Run Conditionings: Repeated 40 yard dashes
   10 pts. (+2)
E. Agility: Edgren Side Step
   10 pts. (+2)
F. Football Conditioning Evaluation:
   Excellent — 55 + pts.
   Good — 50-54 pts.
   Passing — 48 pts.

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Phys. Basis


Ex. Phys.

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