Muscle Fiber Types And Training

The author describes the three types of muscle fiber and discusses their implications for the training of athletes.

REPRINTED FROM TRACK COACH #155

How skeletal muscles adapt to a repeated stimulus depends, to a large extent, on the inherent characteristics of the muscles themselves. Specifically, the types of fibers that make up individual muscles greatly influence the way your athletes will adapt to their training programs. There is a reason why some athletes can sprint faster and get bigger muscles more easily than others, and why some athletes are able to run for much longer periods of time without fatigue. In order to design training programs that will work best for each of your athletes, it is important for the coach to understand at least some of the complexity of skeletal muscles.

TYPES OF MUSCLE FIBERS

Humans have basically three different types of muscle fibers. **Slow-twitch (ST or Type I)** fibers are identified by a slow contraction time and a high resistance to fatigue. Structurally, they have a small motor neuron and fiber diameter, a high mitochondrial and capillary density, and a high myoglobin content, Energetically, they have a low supply of creatine phosphate (a high-energy substrate used for quick, explosive movements), a low glycogen content, and a wealthy store of triglycerides (the stored form of fat). They contain few of the enzymes involved in glycolysis, but contain many of the enzymes involved in the oxidative pathways (Krebs cycle, electron transport chain). Functionally, ST fibers are used for aerobic activities requiring low-level force production, such as walking and maintaining posture. Most activities of daily living use ST fibers.

Fast-twitch (FT or Type II) fibers are identified by a quick contraction time and a low resistance to fatigue. The differences in the speeds of contraction that gives the fibers their names can be explained, in part, by the rates of release of calcium by the sarcoplasmic reticulum (the muscle's storage site for calcium) and by the activity of the enzyme (myosin-ATPase) that breaks down ATP inside the myosin head of the contractile proteins. Both of these characteristics are faster and greater in the FT fibers (Fitts & Widrick, 1996; Harigaya & Schwartz, 1969).

Fast-twitch fibers are further divided into **fast-twitch A (FT-A or Type IIA)** and **fast- twitch B (FT-B or Type IIB) fibers.** FT-A fibers have a moderate resistance to fatigue and represent a transition between the two extremes of the ST and FT-B fibers. Structurally, FT-A fibers have a large motor neuron and fiber diameter, a high mitochondrial density, a medium capillary density, and a medium myoglobin content. They are high in creatine phosphate and glycogen and medium in triglyceride stores. They have both a high glycolytic and oxidative enzyme activity. Functionally, they are used for prolonged anaerobic activities with a relatively high-force output, such as racing 400 meters.

Fast-twitch B fibers, on the other hand, are very sensitive to fatigue and are used for short anaerobic, high-force production activities, such as sprinting, hurdling, jumping, and putting the shot. These fibers are also capable of producing more power than ST fibers. Like the FT-A fibers, FT-B fibers have a large motor neuron and fiber diameter, but a low mitochondrial

By Jason R. Karp, M.S.

Table 1: Characteristics of the Three Muscle Fiber Types.

Fiber Type	Slow-Twitch (ST)	Fast-Twitch A (FT-A)	Fast-Twitch B (FT-B)
Contraction time	Slow	Fast	Very Fast
Size of motor neuron	Small	Large	Very Large
Resistance to fatigue	High	Intermediate	Low
Activity used for	Aerobic	Long-term Anaerobic	Short-term Anaerobic
Force production	Low	High	Very High
Mitochondrial density	High	High	Low
Capillary density	High	Intermediate	Low
Oxidative capacity	High	High	Low
Glycolytic capacity	Low	High	High
Major storage fuel	Triglycerides	CP, Glycogen	CP, Glycogen

and capillary density and myoglobin content. They also are high in creatine phosphate and glycogen, but low in triglycerides. They contain many glycolytic enzymes but few oxidative enzymes. Table 1 summarizes some major characteristics of the three fiber types.

At any given velocity of movement, the amount of force produced depends on the fiber type. During a dynamic contraction, when the fiber is either shortening or lengthening, a fast-twitch (FT) fiber produces more force than a slow-twitch (ST) fiber (Fitts & Widrick, 1996). Under isometric conditions, during which the length of the muscle does not change while it is contracting, ST fibers produce exactly the same amount of force as FT fibers. The difference in force is only observed during dynamic contractions. At any given velocity, the force produced by the muscle increases with the percentage of FT fibers and, conversely, at any given force output, the velocity increases with the percentage of FT fibers.

There is great variability in the percentage of fiber types among athletes. For example, it is well known that endurance athletes have a greater proportion of slow-twitch fibers, while sprinters and jumpers have more fast-twitch fibers (Costill, et al., 1976; Ricoy, et al., 1998). The greater percentage of FT fibers in sprinters enables them to produce greater muscle force and power than their ST-fibered counterparts (Fitts & Widrick, 1996).

Differences in muscle fiber composition among athletes have raised the question of whether muscle structure is an acquired trait or is genetically determined. Studies performed on identical twins have shown that muscle fiber composition is very much genetically determined (Komi & Karlsson, 1979), however there is evidence that both the structure and metabolic capacity of individual muscle fibers can adapt specifically to different types of training.

RECRUITMENT OF MUSCLE FIBERS

Muscles produce force by recruiting motor units (a group of muscle fibers innervated by a motor neuron) along a gradient. During voluntary isometric and concentric contractions, the orderly pattern of recruitment is controlled by the size of the motor unit, a condition known as the size principle (Henneman, et al., 1974). Small motor units, which contain slow-twitch muscle fibers, have the lowest firing threshold and are recruited first. Demands for larger forces are met by the recruitment of increasingly larger motor units. The largest motor units that contain the fast-twitch B fibers have the highest threshold and are recruited last.

No matter what the workout intensity, slow-twitch motor units are recruited first. If the workout intensity is low, these motor units may be the only ones that are recruited. If the workout intensity is high, such as when lifting heavy weights or performing intervals on the track, slow-twitch motor units are recruited first, followed by fast-twitch A and fast-twitch B, if needed.

There is some evidence to suggest that the size principle could be altered or even reversed during certain types of movements—specifically those that contain an eccentric (muscle lengthening) component—such that fast-twitch motor units are recruited before slow-twitch motor units (Denier van der Gon, et al., 1985; Grimby & Hannerz, 1977; Nardone, et al., 1989; Smith, et al., 1980; Ter Haar Romeny, et al., 1982). It is possible that a preferential recruitment of fast-twitch motor units, if it exists, is influenced by the speed of the eccentric contraction, and can only occur using moderate to fast speeds (Karp, 1997; Nardone, et al., 1989).

DETERMINING FIBER TYPE

Since the only way to directly determine the fiber-type composition in an athlete is to perform an invasive muscle biopsy test (in which a needle is stuck into the muscle and a few fibers are plucked out to be examined under a microscope), some studies have tried to indirectly estimate the fiber-type composition within muscle groups of an individual by testing for a relationship between the different properties of fiber type and muscle fiber composition. This type of research has yielded promising results, with significant relationships being found between the proportion of FT fibers and muscular strength or power (Coyle, et al., 1979; Froese & Houston, 1985; Gerdle, et al., 1988; Gregor, et al., 1979; Suter, et al., 1993).

An indirect method that can be used in the weight room to determine the fiber composition of a muscle group is to initially establish the 1RM (the greatest weight that they can lift just once) of your athletes. Then have them perform as many repetitions at 80% of 1RM as they can. If they do fewer than seven repetitions, then the muscle group is likely composed of more than 50% FT fibers. If they can perform 12 or more repetitions, then the muscle group has more than 50% ST fibers. If the athlete can do between 7 and 12 repetitions, then the muscle group probably has an equal proportion of fibers (Pipes, 1994).

Because lifting weights requires the use of many muscles at once, this method does not work for individual muscles, just muscle groups. In order to determine the fiber-type composition of an individual muscle, a needle biopsy of the muscle of interest must be performed.

Another indirect method that the coach can use, especially when the athletes are young or new to the sport, is to have the athletes try a number of different events. Their dominant fiber type will soon become evident based on their success in certain events, and this discovery can lead to more directed future training for each athlete.

IMPLICATIONS FOR TRAINING

Your athletes' fiber type proportion will play a major role in the amount of weight that they can lift, the number of repetitions that they can complete in a set or interval workout, and the desired outcome (increased muscular strength/power or endurance). For example, an athlete with a greater proportion of fast-twitch fibers will not be able to complete as many repetitions at a given relative amount of weight as will an athlete with a greater proportion of slow-twitch fibers and therefore will never attain as high a level of muscular endurance as will the ST-fibered athlete.

Similarly, an athlete with a greater proportion of ST fibers will not be able to lift as heavy a weight or run intervals as fast as will an athlete with a greater proportion of FT fibers and therefore will never be as strong or powerful as will the FT-fibered athlete.

It is important to remember that, even within the group of sprinters or distance runners on your team, there will still be a disparity in the fiber types. Not all the sprinters will have the same percentage of FT fibers, nor will all the distance runners have the same percentage of ST fibers. Therefore, some sprinters may be able to complete 10x200 meters in a workout while others are fatigued after 8 repetitions. Likewise, some distance runners may be able to complete 8x800 meters, while others may fatigue after 5 repetitions.

Depending on each particular athlete, the coach should decide whether those who fatigue sooner (because of more FT fibers) should be given longer rest periods between intervals in order to complete the workout, or should run fewer repetitions at a faster speed.

Training a FT-fibered muscle for endurance will not increase the number of ST fibers, nor will training a ST-fibered muscle for strength and power increase the number of FT fibers. With the proper training, FT-B fibers can take on some of the endurance characteristics of FT-A fibers and FT-A fibers can take on some of the strength and power qualities of FT-B fibers. However, there is no interconversion of fibers. FT fibers cannot become ST fibers, or vice versa. What an athlete is born with is what he or she must live with.

Although the type of fiber cannot be changed from one to another, training can change the amount of area taken up by the fiber type in the muscle. In other words, there can be a selective hypertrophy of fibers based on the type of training.

For example, an athlete may have a 50/50 mix of FT/ST fibers in a muscle, but since FT fibers normally have a larger cross-sectional area than ST fibers, 65% of that muscle's area may be FT and 35% may be ST. Following a strength training program for improvement in muscular strength, the number of FT and ST fibers will remain the same (still 50/50), however the cross-sectional area will change. This happens because the ST fibers will atrophy (get smaller) while the FT fibers will hypertrophy (get larger).

Depending on the specific intensity used in training, the muscle may change to a 75% FT area and a 25% ST area. The change in area will lead to greater strength but decreased endurance capabilities. In addition, since the mass of FT fibers are greater than that of ST fibers, the athlete will gain mass, as measured by the circumference of the muscle.

Conversely, if the athlete trains for muscular endurance, the FT fibers will atrophy while the ST fibers hypertrophy, causing a greater area of ST fibers. The area of the muscle, which began at 65% FT and 35% ST before training, may change to 50% FT and 50% ST following training, The endurance capabilities of the muscle will increase while its strength will decrease, and the athlete will lose some muscle mass, again because ST fibers are lower in mass than FT fibers. The decrease in mass may be observed by a smaller circumference of the muscle.

Many coaches know that, for gains in muscular strength, one should train with heavy weights and few repetitions. This training regimen works because using heavy weights recruits the FT-B fibers, which are capable of producing a greater force than the ST or FT-A fibers. Hypertrophy will only occur in those muscle fibers that are overloaded, so the FT-B fibers must be recruited during training in order to be hypertrophied (Morehouse & Miller, 1976).

Training with a low or moderate intensity will not necessitate the cruitment of the FT-B muscle fibers. Therefore, the training intensity must be high. But how heavy a weight and how many repetitions should you use?

Muscular strength is primarily developed when an 8-repetition maximum (8RM, the maximum amount of weight that can be lifted eight times) or less is used in a set. When the aim of training is to increase the neuromuscular component of maximum strength, at least 95% of the athlete's 1RM and 1 to 3 repetitions should be used. When the aim is to increase maximum strength by stimulating muscle hypertrophy, at least 80% of 1RM should be lifted 5 to 8 times or until failure (Zatsiorsky, 1995).

This latter recommendation assumes that the focus of training is hypertrophy for strength, rather than hypertrophy simply for muscle size. If the aim of training is to increase muscle size (hypertrophy) with moderate gains in strength, then 6 to 12 repetitions should be used (Fleck & Kraemer, 1996). Remember, in order to improve muscular strength, FT-B fibers must be recruited.

For maximum results, train your athletes according to their genetic predisposition. For example, an athlete with a greater proportion of slow-twitch fibers would adapt better to running more weekly mileage and a muscular endurance program, using more repetitions of a lighter weight. Likewise, an athlete with a greater proportion of fast-twitch fibers would benefit more from sprint training and a muscular strength program, using fewer repetitions of a heavier weight.

Jason R. Karp has a master's degree in exercise physiology and biomechanics. A former university lecturer, personal trainer, and coach of the Impala Racing Team, he has coached cross country and track & field at the high school, college, and club levels. A freelance writer and competitive distance runner who trains all of his muscle fibers to varying degrees, he is currently pursuing his Ph.D. in exercise physiology at the University of New Mexico.

REFERENCES

Costill, D.L., et al. (1976). Skeletal muscle enzymes and fiber composition in male and female track athletes. *Journal of Applied Physiology,* 40: 149-154.

Coyle, E.F., et al. (1979). Leg extension power and muscle fiber composition. *Medicine and Science in Sports and Exercise,* 11:12-15.

Denier van der Gon, J. J., et al. (1985). Behavior of motor units of human arm muscles: Differences between slow isometric contraction and relaxation. *Journal of Physiology,* 359:107-118.

Fitts, R.H., & Widrick, J.J. (1996). Muscle mechanics: adaptations with exercise training. *Exercise and Sport Science Reviews,* 24:427-473.

Fleck, S.J., & Kraemer, W.J. (1996). *Periodization Breakthrough*. Ronkonkoma, NY: Advanced Research Press, Inc.

Froese, E.A., & Houston, M.E. (1985). Torque-velocity characteristics and muscle fiber type in human vastus lateralis. *Journal of Applied Physiology,* 59:309-314.

Gerdle, B., et al. (1988). Do the fiber-type proportion and the angular velocity influence the mean power frequency of the electromyogram? *Acta Physiologica Scandinavica,* 134:341-346.

Gregor, R. J., et al. (1979). Torque-velocity relationships and muscle fiber composition in elite female athletes. *Journal of Applied Physiology,* 47:388-3 92.

Grimby, L., & Hannerz, J. (1977) Firing rate and recruitment order of toe extensor motor units in different modes of voluntary contraction. *Journal of Physiology,* 264:865-879.

Harigaya, S., & Schwartz, A. (1969). Rate of calcium binding and uptake in normal animal and failing human cardiac muscle. Membrane vesicles (relaxing system) and mitochondria. *Circulatory Research, 25,* 781-794.

Henneman, E., et al. (1974). Rank order of motoneurons within a pool: Law of combination. *Journal of Neurophysiology,* 37:1338-1349.

Karp, J.R. (1997). Motor unit recruitment strategy in muscle during eccentric contractions. *Unpublished master's thesis.* The University of Calgary.

Komi, P.V., & Karlsson, J. (1979). Physical performance, skeletal muscle enzyme activities and fibre types in monozygous and dizygous twins of both sexes. *Acta Physiologica Scandinavica,* 462(Suppl.): 128.

Morehouse, L.E., & Miller, A. T. (1976). *Physiology of Exercise*. St. Louis: CV Mosby Co.

Nardone, A., et al. (1989). Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *Journal of Physiology,* 409:451-471.

Pipes, T.V. (1994). Strength training and fiber types. *Scholastic Coach*.

Ricoy, JR., et al. (1998). Histochemical study of the vastus lateralis muscle fibre types of athletes. *Journal of Physiological Biochemistry,* 54(l): 41-47.

Smith, J.L., et al. (1980). Rapid ankle extension during paw shakes: Selective recruitment of fast ankle extensors. *Journal of Neurophysiology,* 43:612-620.

Suter, E., et al. (1993). Muscle fiber type distribution as estimated by cybex testing and by muscle biopsy. *Medicine and Science in Sports and Exercise,* 25(3):363-370.

Ter Haar Romeny, B. M., et al. (1982). Changes in recruitment order of motor units in the human biceps muscle. *Experimental Neurology,* 78: 360-368.

Zatsiorsky, V.M. (1995). *Science and Practice of Strength Training*. Champaign, IL: Human Kinetics.