Muscle Fiber Types and Training

Jason R. Karp, M.S.

From *Strength and Conditioning Journal*, 23(5):21-26, Oct. 2001.

How skeletal muscles adapt to a repeated stimulus depends, to a large extent, on the neuromuscular recruitment of muscle fibers, as well as on the inherent characteristics of the muscles themselves. The specific types of fibers that make up individual muscles greatly influence the way your clients will adapt to their training programs. There is a reason why some people get bigger muscles more easily than others, and why some people are able to run for much longer periods of time without fatigue. In order to design programs that will work best for each of your clients, it is important for fitness professionals to understand at least some of the complexity of skeletal muscles.

Types of Muscle Fibers

Humans have basically three different types of muscle fibers. Type I (slow-twitch or ST) fibers are identified by a slow contraction time and a high resistance to fatigue. Structurally, they have a small motor neuron, a high mitochondrial and capillary density, and a high myoglobin content. Energetically, they have a low supply of creatine phosphate (CP), a low glycogen content, and a wealthy store of triglycerides. 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, Type I fibers are used for aerobic activities requiring low-level force production, such as walking and maintaining posture. Most activities of daily living use Type I fibers.

Type II (fast-twitch or FT) fibers are identified by a quick contraction time and a low resistance to fatigue. The differences in the contractile properties that gives the fibers their names can be explained, in part, by a specific component of the myosin filament—the myosin heavy chain—which exists in three different varieties, or isoforms: Type I, IIa, and IIb. In addition, the rate of release of calcium by the sarcoplasmic reticulum (the muscle's storage site for calcium) and the activity of the enzyme (myosin-ATPase) that breaks down ATP inside the myosin head influence the speed of contraction among the fiber types. Both of these characteristics are faster and greater in the Type II fibers (13,20).

Type II fibers are further divided into Type IIA (fast-twitch A or FT-A) and Type IIB (fast-twitch B or FT-B) fibers. Type IIA fibers have a moderate resistance to fatigue and represent a transition between the two extremes of the Type I and Type IIB fibers. Structurally, Type IIA fibers have a large motor neuron, a high mitochondrial density, a medium capillary density, and a medium myoglobin content. They are high in CP 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 running a long sprint and carrying heavy objects. Type IIB fibers, on the other hand, are very sensitive to fatigue and are used for short anaerobic, high-force production activities, such as sprinting, jumping, and lifting a very heavy object. Type IIB fibers contract about 10 times faster than Type I fibers (4). These fibers are also capable of producing more power than Type I fibers. Like the Type IIA fibers, Type IIB fibers have a large motor neuron, but a low mitochondrial and capillary density and myoglobin content. They also are high in CP 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.

In addition to the three major divisions of muscle fibers, there are also hybrid forms of these fiber types which contain mixtures of slow and fast myosin isoforms. These hybrid fibers are scarce in young people, with older adults having a greater amount of hybrid fibers.

Table 1: Characteristics of the Three Main Muscle Fiber Types

Property	**Type I (ST)**	**Type IIA (FT-A)**	**Type IIB (FT-B)**
Contraction time	Slow	Fast	Very Fast
Size of motor axon	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

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 (13). 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 a dynamic contraction. 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. However, regardless of fiber fiber-type distribution, as the velocity of movement increases, the force produced decreases (7,11,18,36,37).

There is great variability in the percentage of fiber types among people. 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 (9,29). The greater percentage of FT fibers in the sprinters enables them to produce greater muscle force and power than their ST-fibered counterparts (13). However, FT fiber percentage has a greater influence on the production of explosive maximal strength (i.e., power), than on the production of maximal strength alone (8). It seems that FT fibers are the main contributors to force production during maximal ballistic movements, such as jumping or sprinting, while ST fiber contribution increases as the muscle contraction time increases. Differences in muscle fiber composition among individuals 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 greatly genetically determined (26). However, there is evidence that both the structure and metabolic capacity of individual muscle fibers can adapt specifically to different types of training. For example, heavy resistance training has been reported to cause a decrease in the percentage of Type IIB fibers and an increase in the percentage of Type IIA fibers (2,19,31). This finding seems to be a result of the change in the myosin heavy chain isoform content (2,3), suggesting that training can cause a genetic transformation among the fast-twitch fiber subtypes.

Recruitment of Muscle Fibers

Muscle contractions are initiated by impulses, called action potentials, which are conveyed by a neural cell called a motor neuron. Instead of recruiting individual muscle fibers to perform a specific task, a motor unit—a group of muscle fibers innervated by a single motor neuron—is recruited. This recruitment of motor units is controlled by neuromuscular processes, ultimately leading to the production of muscular forces. Motor neurons originate in the central nervous system and terminate in skeletal muscles. The space where the motor neuron and the muscle meet is aptly named the neuromuscular junction. At rest, sodium ions (Na^+) are most heavily concentrated on the outside of the nerve membrane, causing it to be electrically positive, while the inside of the nerve, which contains potassium ions (K^+), is electrically less positive, or negative with respect to the outside. Under the influence of the neurotransmitter acetylcholine, which is released at the neuromuscular junction, the muscle membrane becomes highly permeable to Na^+, causing Na^+ to rush inside of the membrane. As a result, the outside of the membrane becomes negative and the inside positive, reversing its polarity. This reversal of polarity is called depolarization and results in the formation of an action potential. The action potential propagates along the muscle fiber, eventually leading to muscle contraction.

Motor units are recruited along a gradient. During voluntary isometric and concentric contractions, the orderly pattern of recruitment is controlled by the size of the motor unit (specifically the size of the motor axon supplying the motor unit), a condition known as the size principle (22). Small motor units (those with a small motor axon diameter), which contain Type I (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 (those with the largest axon diameter) contain the Type IIB (fast-twitch B) fibers, which have the highest threshold and are recruited last. Thus, if the exercise intensity is low, ST motor units may be the only ones that are recruited. If the exercise intensity is high, such as when lifting heavy weights or doing interval training, slow-twitch motor units are recruited first, followed by FT-A and FT-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) or ballistic component—such that fast-twitch motor units are recruited *before* slow-twitch motor units (12,19,27,30,34). 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 (23,27).

Determining Fiber Type

Since the only way to directly determine the fiber-type composition in an individual is to perform an invasive muscle biopsy test (in which a hollow needle is inserted into the muscle and a core sample of muscle fiber is extracted for examination 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. Research using isokinetic dynamometers or electrical stimulation has yielded promising results, with significant relationships being found between the proportion of FT fibers and muscular strength or power (10,15-17,33). For the fitness professional or coach who does not have access to laboratory equipment, an alternative method to determine approximate fiber composition using strength training equipment may have some value in directing future training. First, establish the 1RM of your client for different exercises. Then have him or her perform as many repetitions at 80% 1RM as he or she can for each exercise. If he or she can only perform a few repetitions (<7), then the muscle group is likely composed of more than 50% FT fibers. If he or she can perform many repetitions (>12), then the muscle group likely has more than 50% ST fibers. If your client can perform between seven and 12 repetitions, then the muscle group probably has an equal proportion of fibers (28). While this method has not been proven scientifically, it offers a way for the fitness professional to assess the capabilities of his or her clients' muscle groups. Because lifting weights in the fitness center requires the use of many muscles at once, this method only works to assess characteristics of muscle groups, rather than individual muscles. In order to determine the fiber type composition of an individual muscle, a needle biopsy of the muscle of interest must be performed.

Implications for Training

Thinking about the task for which a muscle is used (or for which you want it to be used) will help determine how the muscle should be trained. For example, while a basketball player or sprinter may train the gastrocnemius muscle in the calf for strength and power to improve jumping ability and speed, a distance runner may train it for endurance.

In addition to the variation in fiber type from person to person, muscle fibers will also vary from muscle to muscle within a person. When your clients strength train, their fiber type proportions 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, and the desired outcome (increased muscular strength or endurance). For example, a client 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 a client 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 client. Similarly, an individual with a greater proportion of ST fibers will not be able to lift as heavy a weight as will an individual with a greater proportion of FT fibers and therefore will never be as strong as will the FT-fibered person.

Training for endurance, strength, or power causes changes in the genetic expression of myosin ATPase and myosin heavy chains (2,3), resulting in an altered contractile function of myosin that favors the specific demand of training. For example, depending on the specific 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. Heavy strength training (6 to 8 RM) has also been shown to decrease the percentage of Type IIB fibers while increasing the percentage of Type IIA fibers (31). It seems that any interconversion of fibers that exists is limited to the FT fiber subtypes. There is no evidence that a ST fiber can be converted to a FT fiber as a result of training. Therefore, no matter how much sprint training an elite marathon runner performs, he will never become an elite sprinter. There is some interesting evidence from studies performed on rabbits that a ST fiber can be made to behave like a FT fiber if the nerve which supplies the ST fiber is surgically interchanged (cross-reinnervated) with one which supplies a FT fiber (5,6), suggesting that the behavior of muscles is greatly influenced by the activity of their nerves. However, no similar studies have been performed on humans, and there is no evidence that training has a similar effect on muscle fibers. Until surgically cross-reinnervating nerves in humans is considered ethical practice, we're left with old-fashioned training.

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, someone may have a 50/50 mix of FT/ST fibers in a muscle, but since FT fibers have a larger cross-sectional area than ST fibers, much more than 50% of that muscle's area may be FT and much less than 50% may be ST (28). Following a resistance 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 (28). Depending on the specific training intensity used, the muscle may change to a 75% FT area and a 25% ST area. The change in area will lead to greater strength. In addition, since the mass of FT fibers is greater than that of ST fibers, the individual will gain mass, as measured by the circumference of the muscle.

If a relatively untrained individual trains for muscular endurance (and therefore has minimal recruitment of FT fibers), the ST fibers will hypertrophy, causing a greater relative cross-sectional area of ST fibers and a smaller relative area of FT fibers. The area of the muscle, which may have begun at 65% FT and 35% ST before training, may change to 50% FT and 50% ST following training. The endurance capability of the muscle will increase while its strength will decrease, and the individual will lose some muscle mass, again because ST fibers are lower in mass than FT fibers. In addition, long-term aerobic training is associated with a decreased cross-sectional area of all fibers to optimize oxygen uptake kinetics (25,35). The decrease in muscle mass may be observed by a smaller circumference of the muscle.

In order to improve muscular strength, many muscle fibers need to be recruited simultaneously. Lifting heavy weights recruits the FT-B fibers, which are capable of producing a greater dynamic force than the ST or FT-A fibers. Positive changes in strength (or endurance) will only occur in those muscle fibers that are overloaded, so the FT-B fibers must be recruited in order to be trained (38). Training with a low or moderate intensity will not necessitate the need to recruit the FT-B 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 using loads less than a 10 to 12RM (the maximum amount of weight that can be lifted 10-12 times) (38). When the aim of training is to increase maximum strength via emphasis on neuromuscular processes, at least 95% of the individual’s 1RM and 1 to 3 repetitions should be used. This intense type of training increases muscle force production by enhancing the neuromuscular processes responsible for the simultaneous recruitment of motor units and the frequency of their stimulation. When the aim of training is to increase maximum strength by stimulating muscle hypertrophy, multiple sets of 5 to 8 repetitions at 80% or higher of 1RM should be used (38) and should include systematic variation in volume and intensity (32), such as with periodized training programs (24). Hypertrophy can result either from a growth of the sarcoplasm and nonconractile proteins, or from an increase in the number of actin and myosin filaments (38). This latter type of hypertrophy leads to a greater strength potential, since the amount of muscle force production is proportional to the number of actin and myosin cross-bridges. This difference in hypertrophy may be observed in the difference between Olympic weightlifters and bodybuilders—both types of individuals have muscle hypertrophy, however the Olympic weightlifter can produce a greater force. Typically, fewer sets are used when training for muscular strength. Remember, in order to improve muscular strength, FT-B fibers must be recruited. If the aim of training is to increase muscle size (hypertrophy) and definition with moderate gains in strength, then multiple sets of 6 to 12 repetitions should be used (14). Bodybuilders typically use this repetition range.

For maximum results, try to train your clients according to their genetic predisposition. For example, someone with a greater proportion of slow-twitch fibers would adapt better to a muscular endurance program, using more repetitions of a lighter weight. Likewise, someone with a greater proportion of FT fibers would benefit more from a muscular strength program, using fewer repetitions of a heavier weight. Of course, the client's goals and needs should be considered as well. You wouldn't want to train a 40-year-old female client to develop larger muscles if she doesn't want to develop larger muscles, even if she does have a greater proportion of FT fibers.

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

1. Abernethy, P.J., J. Jurimae, and P.A. Logan. Acute and chronic response of skeletal muscle to resistance exercise. *Sports Med*. 17(1):22-38. 1994.

2. Adams, G.R., B.M. Hather, K.M. Baldwin, and G.A. Dudley. Skeletal muscle heavy chain composition and resistance training. *J. Appl. Physiol*. 74(2):911-915. 1993.

3. Andersen, J.L. and P. Aagaard. Myosin heavy chain IIX overshoot in human skeletal muscle. *Muscle Nerve*. 23:1095-1104. 2000.

4. Andersen, J.L., P. Schjerling, and B. Saltin. Muscle, genes, and athletic performance. *Sci. Am*. 283(3):48-55. 2000.

5. Bacou, F., P. Rouanet, C. Barjot, C. Janmot, P. Vigneron, and A. d'Albis. Expression of myosin isoforms in denervated, cross-reinnervated, and electrically stimulated rabbit muscles. *Eur. J. Biochem*. 236(2):539-547. 1996.

6. Barjot, C., V. Laplace-Marieze, L. Gannoun-Zaki, G. Mckoy, M. Briand, P. Vigneron, and F. Bacou. Expression of lactate dehydrogenase, myosin heavy chain and myogenic regulatory factor genes in rabbit embryonic muscle cell cultures. *J. Muscle Res. Cell Motil*. 19(4):343-351. 1998.

7. Bosco, C. and P.V. Komi. Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. *Acta Physiol. Scand*. 106(4):467-472. 1979a.

8. Bosco, C. and P.V. Komi. Mechanical characteristics and fiber composition of human leg extensor muscles. *Eur. J. Appl. Physiol. Occup. Physiol*. 41(4):275-284. 1979b.

9. Costill, D.L., J. Daniels, W. Evans, W. Fink, G. Krahenbuhl, and B. Saltin. Skeletal muscle enzymes and fiber composition in male and female track athletes. *J. Appl. Physiol*. 40(2):149-154. 1976.

10. Coyle, E.F., D.L. Costill, and G.R. Lesmes. Leg extension power and muscle fiber composition. *Med. Sci. Sports Exerc*. 11(1):12-15. 1979.

11. Cress, N.M., K.S. Peters, and J.M. Chandler. Eccentric and concentric force-velocity relationships of the quadriceps femoris muscle. *J. Ortho. Sports Phys. Ther*. 16(2):82-86. 1992.

12. Denier van der Gon, J.J., B.M. ter Haar Romeny, and E.J. van Zuylen. Behavior of motor units of human arm muscles: differences between slow isometric contraction and relaxation. *J. Physiol*. 359:107-118. 1985.

13. Fitts, R.H., and J.J. Widrick. Muscle mechanics: adaptations with exercise training. *Exer. Sport Sci. Rev*. 24:427-473. 1996.

14. Fleck, S.J., and W.J. Kraemer. *Periodization Breakthrough*. Ronkonkoma, NY: Advanced Research Press, 1996. p. 33.

15. Froese, E.A., and M.E. Houston. Torque-velocity characteristics and muscle fiber type in human vastus lateralis. *J. Appl. Physiol*. 59:309-314. 1985.

16. Gerdle, B., M.L. Wretling, and K. Henriksson-Larsen. Do the fiber-type proportion and the angular velocity influence the mean power frequency of the electromyogram? *Acta Physiol. Scand*. 134(3):341-346. 1988.

17. Gregor, R.J., V.R. Edgerton, J.J. Perrine, D.S. Campion, and C. DeBus. Torque-velocity relationships and muscle fiber composition in elite female athletes. *J. Appl. Physiol*. 47(2):388-392. 1979.

18. Griffin, J.W., R.E. Tooms, R. VanderZwaag, T.E. Bertorini, and M.L. O'Toole. Eccentric muscle performance of elbow and knee muscle groups in untrained men and women. *Med. Sci. Sports Exerc*. 25(8):936-944. 1993.

19. Grimby, L., and J. Hannerz. Firing rate and recruitment order of toe extensor motor units in different modes of voluntary contraction. *J. Appl. Physiol*. 264:865-879. 1977.

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

21. Hather, B.M., P.A. Tesch, P. Buchanan, and G.A. Dudley. Influence of eccentric actions on skeletal muscle adaptations to resistance training. *Acta Physio. Scand*. 143(2):177-185. 1991.

22. Henneman, E., H.P. Clamann, J.D. Gillies, and R.D. Skinner. Rank order of motoneurons within a pool: law of combination. *J. Neurophysiol*. 37(6):1338-1349. 1974.

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

24. Karp, J.R. Periodization of training. *Track Coach*. 154:4905-4908. 2001.

25. Klausen, K., L.B. Anderson, and I. Pelle. Adaptive changes in work capacity, skeletal muscle capillarization, and enzyme levels during training and detraining. *Acta Physiol. Scand*. 113:9-16. 1981.

26. Komi, P.V., and J. Karlsson. Physical performance, skeletal muscle enzyme activities and fibre types in monozygous and dizygous twins of both sexes. *Acta Physiol. Scand*. 462(Suppl.):1-28. 1979.

27. Nardone, A., C. Romano, and M. Schieppati. Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *J. Physiol*. 409:451-471. 1989.

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

29. Ricoy, J.R., A.R. Encinas, A. Cabello, S. Madero, and J. Arenas. Histochemical study of the vastus lateralis muscle fibre types of athletes. *J. Physiol. Biochem*. 54(1):41-47. 1998.

30. Smith, J.L., B. Betts, V.R. Edgerton, and R.F. Zernicke. Rapid ankle extension during paw shakes: selective recruitment of fast ankle extensors. *J. Neurophysiol*. 43(3):612-620. 1980.

31. Staron, R.S., E.S. Malicky, M.J. Leonardi, J.E. Falkel, F.C. Hagerman, and G.A. Dudley. Muscle hypertrophy and fast fiber type conversions in heavy resistance-trained women. *Eur. J. Appl. Physiol. Occup. Physiol*. 60(1):71-79. 1990.

32. Stone, M.H., T.J. Chandler, M.S. Conley, J.B. Kramer, and M.E. Stone. Training to muscular failure: Is it necessary? *Strength Cond. J*. 18(3):44-48. 1996.

33. Suter, E., W. Herzog, J. Sokolosky, J.P. Wiley, and B.R. Macintosh. Muscle fiber type distribution as estimated by Cybex testing and by muscle biopsy. *Med. Sci. Sports Exerc*. 25(3):363-370. 1993.

34. ter Haar Romeny, B.M., J.J. Denier van der Gon, and C.C. Gielen. Changes in recruitment order of motor units in the human biceps muscle. *Experiment. Neurol*. 78(2):360-368. 1982.

35. Terados, N.J.M., C. Sylven, and E. Jansson. Decrease in skeletal muscle myoglobin with intensive training in man. *Acta Physiol. Scand*. 128:651-652. 1986.

36. Thorstensson, A., G. Grimby, and J. Karlsson. Force-velocity relations and fiber composition in human knee extensor muscles. *J. Appl. Physiol*. 40:12-16. 1976.

37. Wilke, K.E., R.D. Johnson, and B. Levine. A comparison of peak torque values of the knee extensor and flexor muscle group using Biodex, Cybex, and Kin-Com isokinetic dynamometers. *Phys. Ther*. 67:789-790. 1987.

38. Zatsiorsky, V.M. *Science and Practice of Strength Training*. Champaign, IL: Human Kinetics, 1995. pp. 63, 88, 103-105.