

Part I: Training Fast Twitch Muscle Fibers: Why and How

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Abstract

With the finding that short, intense sprints can improve aerobic capacity (36), there has been a huge increase in the number of experts who advocate this kind of training over traditional endurance training. Several successful swim coaches are among those recommending more high-intensity training while an equal or even greater number are warning of the pitfalls of training in this manner. A theory is presented in this paper that high-intensity training is essential for improving aerobic endurance. An argument is also presented for a balanced approach to training that includes adequate quantities of moderate-, and low-intensity swimming.

Introduction

In 1996 Dr. Izumi Tabata and associates published the results of a study that challenged traditional assumptions about endurance training. These researchers reported that training with a series of short sprints at very fast speeds, was just as effective for improving VO_{2max} as traditional endurance training at moderate speeds. High-intensity training, as it was termed, also produced an additional benefit. The group that trained with sprints improved their anaerobic capacity by 28% while the traditional endurance-training group did not improve on this measure. The training protocols and results of the study are summarized in Table 1.

Table 1 High intensity versus traditional endurance training.

Training groups	Training program	VO_{2max}	Anaerobic capacity
Traditional training group	Cycling at 70% VO_{2max} for 60 mins./daily, 5 days/wk. for 6 weeks	Inc. 10% (53 to 58 ml/kg/min.)	No change
High-intensity training group	8 x 20 sec sprints with 10 sec. rest between at 170% VO_{2max} , 5 days/wk. for 6 weeks.	Inc. 14% (48 to 55 ml/kg/min.)	Increased 28%

Data from "Effect of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO_{2max} .", by I. Tabata, K. Nishimura, M. Kouzaki, Y. Hirai, F. Ogita, M. Miyachi, and K. Yamamoto, (1996), *Medicine & Science in Sports & Exercise*, 28(10): 1327-1330.

Dr. Tabata's results were no "fluke". They have been replicated in several additional studies. In one of these, previously well-trained elite cyclists improved their 40 km time trial performances by 3% after only four weeks by replacing 15% of their aerobic-base work with six high-intensity training sessions (22). On the high-intensity days the cyclists performed several five-minute efforts at 86% of VO_{2max} , with one-minute rest periods between each repeat. In another study, participants increased VO_{2max} by nearly 9% following seven weeks of sprint training. The subjects trained three times per week, doing four to ten, 30-second sprints each session, with 4 minutes rest between each sprint (26).

How is it that training which has traditionally been thought of as anaerobic can produce improvements of aerobic capacity that equal, and in some cases surpass those of traditional methods of endurance training for both untrained and previously well-trained subjects? I believe the answer to this question has to do with the way that fast twitch muscle fibers are recruited during exercise.

Purpose

The major purpose of this paper will be to describe a theory that explains why high-intensity training can improve aerobic capacity. Additional purposes will be to outline some types of repeat sets that are effective for training fast twitch muscle fibers and to describe some questions that need to be answered about their training. The paper will be presented in two parts. In Part I the characteristics of the various muscle fiber types and how they are recruited during training will be discussed. Part II will focus on the how information in Part I can be used to training swimmers. Let's begin with a description of the muscle fibers types and their characteristics.

Characteristics of muscle fiber types in humans

Over the last several decades it has become common knowledge that the muscles of humans (and animals) contain two distinct categories of fibers, slow twitch and fast twitch. Slow twitch muscle fibers are also commonly labeled Type I, or red fibers, while fast twitch fibers have also been identified as Type II, or white fibers. Slow twitch fibers are genetically very well suited for aerobic metabolism and, therefore, endurance work. At the same time, they have a limited capacity for anaerobic metabolism. Fast twitch muscle fibers are very well suited for anaerobic metabolism but much less so for aerobic metabolism. They contract rapidly and powerfully but also fatigue more quickly than their slow twitch counterparts. Consequently, they are genetically best suited for sprint and power work.

Slow twitch muscle fibers got their name because their time to peak contraction is approximately 110 milliseconds. While contraction velocities in this range cannot really be considered slow, they are slower than those of fast twitch muscle fibers which are in the range of 40 to 60 milliseconds (7).

Slow twitch fibers have a generous supply of myoglobin, a substance that enhances the oxygen carrying capability of those fibers. Myoglobin has a reddish pigment that

gives slow twitch fibers their dark red appearance. A function of myoglobin is to transport oxygen to the mitochondria of muscle cells where it can be oxidized, releasing energy for contraction in the process. Figure 1a is a drawing of a single muscle fiber showing the location of the various components that will be discussed in the following paragraphs. An electron micrograph of a muscle fiber enlarged 250,000 times is displayed in Figure 1b. It shows the orderly arrangement of mitochondria, (multiple jagged black lines) within that fiber.

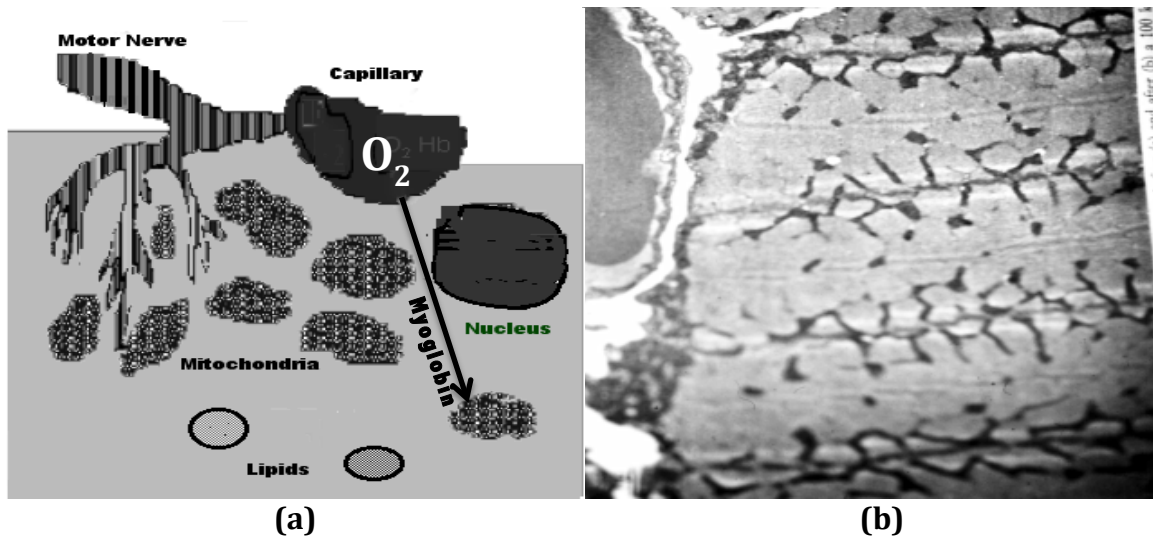


Figure 1 Figure 1a is a drawing of a single muscle fiber. It shows the motor end plate where the contractile impulse arrives and a capillary where oxygen diffuses into the fiber. Also shown are mitochondria. They are the structures where aerobic metabolism takes place. The role of myoglobin in transporting oxygen to the mitochondria is also represented. Figure 1b is an electron micrograph of a muscle fiber showing the orderly arrangement of mitochondria (the black, jagged objects).

As indicated, mitochondria, the so-called “power plants” of muscle cells, are the structures wherein aerobic metabolism takes place. Mitochondria contain large supplies of aerobic enzymes, such as citrate synthase (CS) and succinate dehydrogenase (SDH), that catalyze the aerobic breakdown of pyruvate and hydrogen ions to carbon dioxide and water. Slow twitch muscle fibers naturally contain more mitochondria than fast twitch fibers.

Another factor that enhances the endurance of slow twitch muscle fibers is the large number of capillaries surrounding them. This allows more oxygen to be delivered to them via the circulatory system.

In comparison, fast twitch muscle fibers tend to be naturally larger in cross-sectional area than slow twitch fibers, and this, together with their faster speed of shortening, makes them capable of generating more power with their contractions. They also have greater supplies of myosin ATPase, an enzyme that catalyzes the rapid release of energy from ATP and they contain more creatine phosphate, the substance that replaces ATP more rapidly than any other chemical in the body (5). In addition, they contain larger quantities of anaerobic enzymes, such as

phosphofructokinase (PFK) and the muscle form of lactate dehydrogenase (M-LDH) that enable them to deliver energy faster via anaerobic glycolysis, (the breakdown of muscle glycogen to lactic acid) (31). On the negative side, these fibers have less myoglobin and fewer mitochondria, which reduces their capacity for aerobic metabolism. Untrained fast twitch muscle fibers usually have a smaller number of capillaries surrounding them than do slow twitch fibers which compromises their ability to absorb oxygen. Consequently, they fatigue more quickly.

In humans, fast twitch muscle fibers have been further classified into two sub-categories, FTa, and FTx fibers. The latter were formerly designated FTb fibers. However, that changed with the advent of a new system of fiber typing that relies on identifying the number of myosin heavy chain filaments they contain. Heavy chain myosin can combine with actin more strongly and at a faster cycling rate during contractions because it contains more of the enzyme myosin ATPase. (7). As a result, fibers with heavy chain myosin will contract faster. Fast twitch muscle fibers contain heavy chain myosin while the myosin in slow twitch fibers is of a lighter chain variety.

Fast twitch A fibers, (also known as FT red, and Type II red fibers) have greater quantities of myoglobin and mitochondria than FTx fibers, but, as mentioned earlier, less of these substances than naturally occurs in ST fibers. This gives the FTa fibers a somewhat more pinkish appearance than FTx fibers and makes them capable of greater aerobic activity and, therefore, greater endurance than FTx fibers.

FTa fibers have greater anaerobic capacity than slow twitch fibers. To avoid confusion in terms, let me explain that I refer to anaerobic capacity as the ability to metabolize muscle glycogen to lactic acid without the use of oxygen. It is common for some experts to also include the processes of lactate removal and muscle buffering under this heading. The first of these training effects allows more of the lactic acid and other metabolites that are produced during exercise to be removed from muscles while they are working (7). The second effect occurs when muscle fibers improve their ability to weaken (buffer) lactic acid. This slows the decline of muscle pH from its normally alkaline level of 7.04, allowing them to release more energy anaerobically before acidosis (low muscle pH) occurs. Both of these training effects are considered anaerobic because they do not require oxygen. However, they are additional mechanisms for delaying muscular fatigue and are not considered in my definition of anaerobic capacity.

When the effect of these two processes, buffering and lactate removal, work together to delay muscular fatigue, it is often referred to as anaerobic endurance or speed-endurance. I prefer the former term. It should be noted that FTa fibers have faster rates of lactate removal and greater buffering capacity and, therefore, greater anaerobic endurance than either FTx or ST fibers (30).

There is still much to learn about FTx muscle fibers.. We do know that they are the largest and the fastest contracting muscle fibers of all. Consequently, they are

capable of producing the greatest amount of power. The power that fibers can generate is determined by a combination of their contractile force and contractile velocity. As mentioned previously, contractile force is largely a consequence of fiber size. Fast twitch fibers are larger and faster than slow twitch with FTx being the largest and fastest of all. Accordingly, FTx fibers, are capable of generating greater power. FTa fibers can generate up to 5 times the power of ST fibers while FTx fibers are nearly twice as powerful as FTa fibers (38). The graph in Figure 2 illustrates differences in contractile power among the three fiber types at various percentages of maximum load.

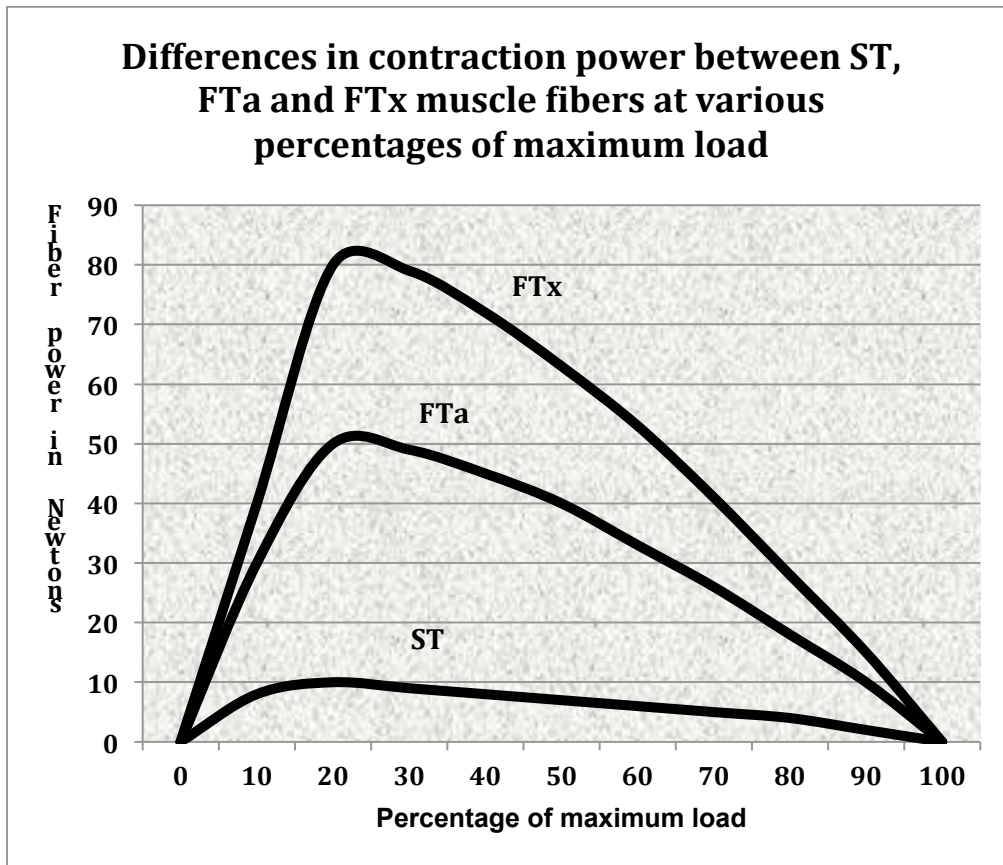


Figure 2 Notice that all fibers achieve their greatest power production when the load is approximately 20% of the maximum capable by the fiber. This is because, the fiber is still able to contract rapidly at this load, whereas, contractile velocity is slowed considerably at higher loads. Modified with permission from, "Muscle mechanics: Adaptations with exercise training," by R.H. Fitts and J.J. Widrick. (1996), in J.O. Holloszy (Ed.), *Exercise and Sports Sciences Reviews* (pp. 427-443). Baltimore MD: Williams and Wilkins,

FTx fibers have the lowest aerobic capacity of the three muscle fiber types. They have less myoglobin and mitochondria and, therefore, a decidedly less pink appearance than FTa fibers. On the other hand, they, like FTa fibers, are rich in anaerobic enzymes and capable of rapid energy release via anaerobic glycolysis. FTx muscle fibers have less buffering and lactate removal capabilities than their FTa

counterparts and this contributes to their rapid fatigability. The different characteristics of ST, FTa and FTx muscle fibers are summarized in Table 2.

Table 2 Characteristics of ST, FTa and FTx muscle fibers.

Characteristics	Muscle Fiber Types		
	Slow Twitch	Fast Twitch a	Fast Twitch x
Aerobic (oxidative) Capacity	High	Moderate	Low
Anaerobic (glycolytic) capacity	Low	High	Highest
Myosin ATPase	Low	High	Highest
Creatine Phosphate Buffering capacity	Low	High	Highest
Lactate removal rate	Low	Highest	High
Capillaries per fiber	High	Moderate	Low
Contractile velocity	Slow	Fast	Fastest
Fibers per motor unit	<300	>300	>300
Contractile force	Low	High	Highest
Power	Low	High	Highest

Most humans are born with approximately equal proportions of fast twitch and slow twitch muscle fibers. The FTa fibers tend to predominate within the fast twitch category, and the percentage of FTx fibers is generally lower.

While the middle 68% of the population have nearly equal percentages of fast twitch and slow twitch fibers, there are persons at either end of the bell-shaped curve who are born with either a much higher percentage of slow twitch fibers or a much higher percentage of fast twitch fibers than the general population. These people tend to excel in endurance or sprint/power events respectively.

How are slow and fast twitch muscle fibers recruited during work?

A common misconception is that slow work is performed by slow twitch muscle fibers and fast efforts are executed by fast twitch fibers. Actually, neither of these statements is entirely true. Sub-maximal work is performed by the more aerobically

efficient slow twitch muscle fibers while progressively more and more fast twitch fibers are recruited to assist them as the effort increases toward maximum.

The orderly arrangement of muscle fibers into contractile units is depicted in Figure 3. Large muscles like the deltoids, are made up of groups of muscle fibers served by a single motor nerve. These groups of fibers are termed motor units. Each motor unit contains fibers of a similar type. Thus, even though a large muscle may contain all three fiber types, the fibers within a particular motor unit will be of the same type, ST, FTa or FTx.

Motor units obey the “all or none” law. That is, if the nervous stimulation is sufficient to cause the fibers within a motor unit to contract, all of the fibers in the unit will contract with maximum force. Thus, the muscular force that can be applied by an athlete is largely due to the maximum number of motor units contracting at any one time and the types of motor units that are contracting. The motor units of slow twitch fibers usually contain fewer than 300 fibers, whereas, the motor units of fast twitch fibers have anywhere from several hundred to thousands of fibers. Since all of the fibers in a motor unit contract at once, and fast twitch motor units contain, not only larger fibers, but also more fibers, it is understandable that fast twitch motor units will generate considerably more force when they contract.

What has become known as the “size principle” of muscle fiber recruitment is also illustrated in Figure 3. The order of recruitment is from ST to FTa to FTx motor units as the intensity of work increases. This is because of the size of the motor nerve innervating the different categories of motor units. Smaller motor nerves require the least amount of nervous stimulation to excite their motor units to contract. Slow twitch muscle fibers have the smallest motor nerves so they will be recruited to perform work that is easy to moderate in nature. Motor units with FTa fibers have larger motor nerves and require a greater neural drive before they will be excited to contract, therefore, they will not be recruited until the work intensity is beyond moderate. The motor nerves of FTx fibers are the largest of all so they will not be recruited until the need for force and power approaches maximum. The illustration in Figure 3 also portrays differences in contractile velocity, contractile force, and fatigability between the three fiber types.

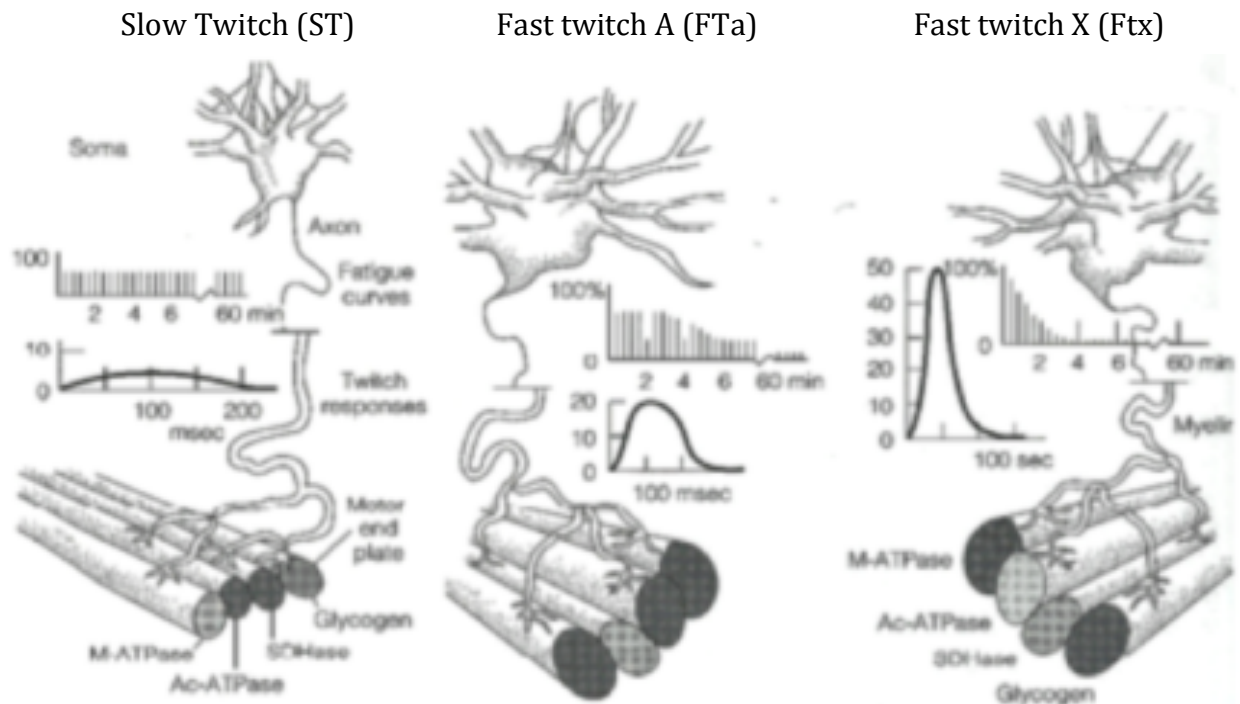


Figure 3 This figure illustrates several characteristics of ST, FTa and FTx motor units. Notice that the motor nerve that serves the ST fibers is smaller than the other two. It has a lower threshold for excitation so that slow twitch fibers can be recruited at low levels of effort. The motor nerve serving FTa fibers is larger and requires a greater amount of excitation before the electrical messages it sends to its fibers causes them to contract. Thus, FTa fibers will not be recruited until the level of effort is moderate to high. The motor nerve that innervates FTx motor units is the largest of all so it will require the most stimulation for its fibers to contract. The set of graphs just below each motor nerve indicate the fatigability of the fibers in that motor unit. You will notice that the FT motor units fatigue more rapidly than the ST, and that, within the fast twitch group, FTx motor units fatigue more quickly than FTa motor units. The next set of graphs displays contractile speed and force. ST motor units contract slowest and with the least force. FTa contract considerably faster and with greater force. FTx motor units are the largest and fastest contracting, so they generate the greatest amount of force.

Modified from *Biology of Physical Activity* (p. 53), by D.W. Edington, and V.R. Edgerton. (1976), Boston, MA: Houghton-Mifflin, with permission.

To be precise, the order of muscle fiber recruitment results from the force required (since power is a function of velocity, I recommend leaving it out here, your last sentence in this para then explains the loose use of the terms) to perform a movement, and not the speed needed to perform it. For example, slow twitch muscle fibers will be recruited to perform a fast movement that requires little force, like spinning on a bicycle ergometer, while lifting a heavy weight very slowly would require the recruitment ST, FTa and FTx fibers nearly simultaneously. It happens, however, that in most athletic activities, an increase in effort is also accompanied by an increase in speed, so, in a sport like swimming,, increases in effort are usually accompanied by increases of speed. Hence, the terms force, power, intensity and

speed are often used interchangeably when discussing the order of muscle fiber recruitment.

The proposed pattern of recruitment for fast and slow twitch muscle fibers can be represented by a graph like the one in Figure 4. This graph illustrates the so-called “ramp effect of muscular contraction” (40).

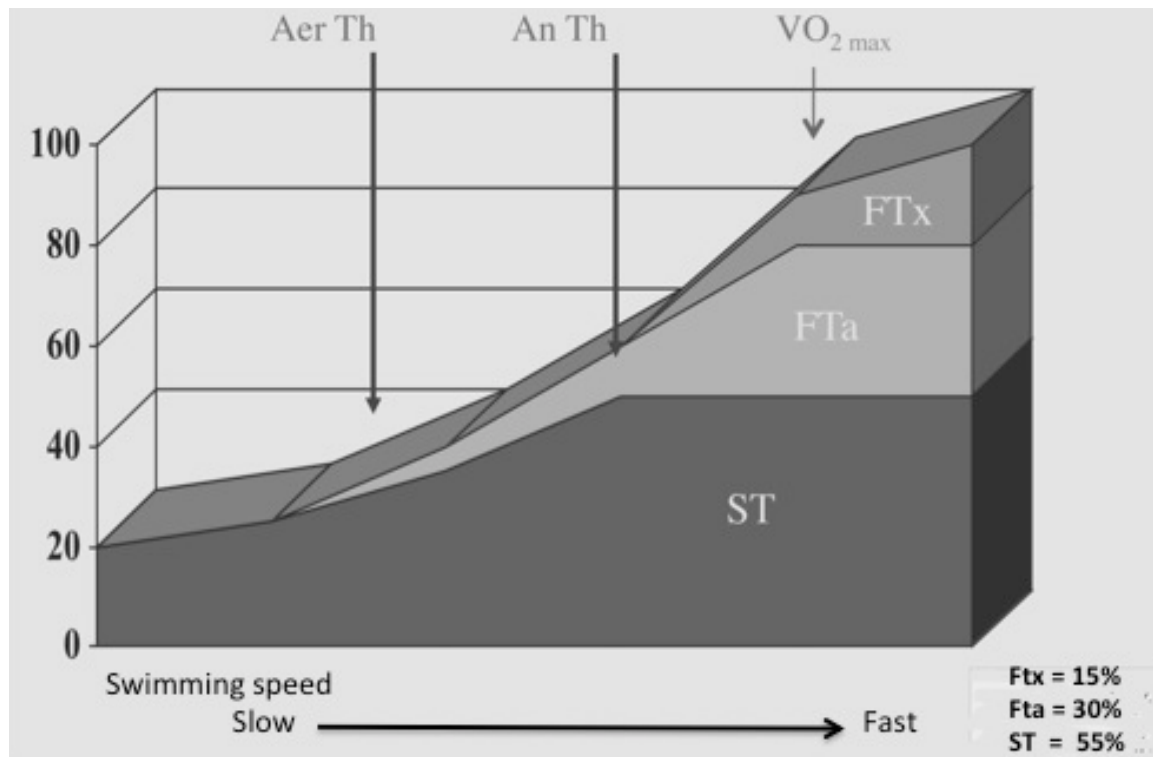


Figure 4. The ramp effect of muscle contraction. The graph shows that progressively greater and greater numbers of muscle fibers are recruited as athletes swim faster. Slow twitch are the first fibers to be recruited. FTa fibers are added to the effort as speed increases. FTx are the last fibers to be recruited and this occurs when speeds are near maximum. Chart modified with permission from *Physiology of Sport and Exercise*, (p. 50) by J.H. Wilmore, and D.L. Costill, (1999), Champaign, IL: Human Kinetics.

To summarize what was said before, at low levels of effort it is primarily the slow twitch muscle fibers that do the work. When the effort increases, fast twitch muscle fibers will be recruited to assist (not replace) their ST counterparts. FTa fibers are the first of the fast twitch group to be recruited as the effort increases, with FTx fibers recruited to assist both the ST and FTa fibers as the effort approaches maximum.

The threshold for significant FTa fiber recruitment is believed to approximate a workload that corresponds to the lactate threshold (7). Since fast twitch fibers produce more lactate than slow twitch fibers during work, the exponential rise in blood lactate at workloads exceeding the lactate threshold probably occurs because significant numbers of FTa fibers are now contracting. Although no threshold for

recruitment of FTx fibers has been posited, it is reasonable to assume, based on research with rats that will be presented later, that they will not contribute substantially to a particular effort until the intensity approaches or exceeds 100% of VO_{2max} .

Before leaving this section, I should mention that muscle fatigue causes a similar effect on muscle fiber recruitment to that of work intensity. As indicated earlier, ST fibers, and, perhaps, some low threshold FTa muscle fibers will be recruited first during long training sessions when most of the swimming is done slower than lactate threshold speed. However, after 1 to 2 hours many of these fibers will lose a large portion of their fuel supply and become fatigued. When this happens, the nervous system will recruit additional FTa fibers to maintain the desired swimming speed. Even later, when most of the ST and FTa fibers are nearly exhausted, FTx fibers will be recruited to preserve that speed (41). Unfortunately, the FTx fibers will fatigue quickly after recruitment and the swimmer will have to reduce his or her pace considerably soon after they join the effort.

Training the fast twitch fibers after first exhausting the slow twitch fibers could be likened to survival swimming and is not recommended. For one thing, muscle glycogen depletion will be severe after each session and trying to train from day to day with an inadequate supply of fuel may cause failing adaptation. For another, there is no need to train fast twitch fibers in this manner when there are potentially less harmful ways to do so.

The Effects of Training on Muscle Fibers:

It is well documented that training improves the aerobic capacity of FTa fibers so that they fatigue less rapidly. The mitochondria become larger and more numerous and the number of capillaries surrounding them increases. The aerobic capacity of trained FTa fibers often approaches that of untrained ST fibers (28). Training will also elevate their buffering capacity and lactate removal rates, which will increase the time they can assist ST fibers in maintaining a particular pace.

There are strong indications in the literature that the aerobic capacity, buffering capacity and lactate removal rates of FTx muscle fibers can also be increased with training until they function much like FTa fibers. One such indication is that fibers previously typed as FTx become less numerous while those typed as FTa fibers become more numerous after training. The data in Table 3 shows the results of a study where a group of college students were subjected to eight weeks of resistance training (2). Muscle biopsies and subsequent fiber typing showed a decrease in the number of FTx fibers and a concomitant increase in FTa fibers after training. The training program in this study consisted of 4 to 5 sets of leg presses, hack squats, knee extensions and leg curls, performed three days weekly, for three months. Subjects began training with 10-12 repetitions of each exercise, increasing weight and decreasing repetitions through the course of training until they were performing 6 to 8 repetitions of each.

Table 3 The effects of training on muscle fibers.

Fiber type percentages			
Fiber types	Before training	After training	Difference
Slow twitch	60	60	0
Fast twitch a	34	39	+5
Fast twitch x	6	1	-5

Data from "Changes in the human muscle force-velocity relationship in response to resistance training and subsequent detraining," L.L Andersen, *et al.* (2005), *Journal of Applied Physiology*, 99: 87-94.

These results seem counterintuitive in that one would expect training with a high power output would encourage a switch from FTa toward FTx fibers types instead of the other way around. This is not the case, however. A consistent finding is that FTx fibers respond by gaining aerobic and anaerobic endurance whether the training program is made up of endurance or sprint/power activities.

An unwelcome consequence is that the contraction speed and, therefore, the power generating capacity of FTx and FTa fibers decreases as they become trained even when that training consists of sprints and weight training (3,37).

Slow twitch muscle fibers are also amenable to training despite their already generous supplies of capillaries, mitochondria, and aerobic enzymes. The quantities, and activities of each will be enhanced considerably by training, in addition to improving the ability of ST fibers to metabolize fat for energy (32).

Information in the literature is scarce concerning the effects of training on the mechanisms of anaerobic metabolism, buffer capacity and lactate removal in ST fibers. I would assume each of these would also be improved with high intensity training. However, considering the affinity of these fibers for aerobic metabolism, I suspect the degree of improvement would be slight. One significant finding has been that any type of exercise, whether it is endurance or sprint in nature, will increase the contractile velocity of slow twitch muscle fibers and thus, their ability to generate power (38). Resistance training will also increase their size, further increasing their ability to generate force and, thus, power (25; 34).

One recently discovered response to training the slow twitch muscle fibers is an increase in the lactate transporter MCT1 (6). MCT1 is one of several types of monocarboxylate transporter proteins. Its purpose is to transport lactate from the blood and adjacent fast twitch muscle fibers into slow twitch fibers where it can be carried to their mitochondria and metabolized. MCT1 is found in greatest quantity in ST muscle fibers and in smaller quantities in FTa fibers. Very little, if any of this particular lactate transporter is found in FTx fibers. An increase should delay fatigue by increasing the ability of slow twitch muscle fibers to absorb lactate. The chain reaction effect would be that acidosis, and thus, fatigue, would be delayed in FT fibers if, during training and competition, more of their lactate was transported

into slow twitch fibers where it could be stored and oxidized. (Lactate is transported out of fast twitch muscle fibers by another lactate transporter, designated MCT4. This transporter is also increased with training)

The results of some studies have shown that fast twitch fibers can gain enough myoglobin and mitochondria to be typed as slow twitch muscle fibers after training and vice versa. In one of these, the percentage of ST fibers decreased from 52% to 41% after three months of strength and interval training (3). At the same time, the percentage of FTa fibers increased from 35% to 52% and the percentage of FTx fibers decreased from 13% to 5%. This leaves open the possibility that training could cause a conversion of slow to fast twitch muscle fibers or the other way around. In fact, some experts have postulated the existence of an FTc fiber that may, through training, be converted to either a FTa or ST fiber (41). Brooks and his associates (2005) have also indicated the presence of hybrid muscle fibers that contains elements of both ST and FTa fibers. It is conceivable, but not proven, that hybrids of this type could be converted in either direction with proper training.

Despite these findings, the prevailing opinion is that FT fibers cannot be converted to ST and vice versa. At the present time, most experts believe that conversions of the two fiber types can only be produced by surgically changing the motor nerve innervating them. In other words, the motor nerve that serves a slow twitch motor unit would have to be surgically connected to a fast twitch motor unit before a conversion of FT to ST fibers could take place. The reason for reports of training-induced changes of slow to fast twitch fibers and vice versa in the literature may be due to difficulties in fiber typing. It is a complex and painstaking procedure fraught with possibilities for error. Nevertheless, the controversy concerning whether slow and fast twitch muscle fibers can be converted from one to the other with training is far from resolved.

Implications for training swimmers.

The previous information was presented for the purpose of drawing the reader's attention to an important, but frequently overlooked, feature of training. It is, that an athlete must improve the aerobic capacity of both their slow and fast twitch muscle fibers in order to maximize VO_{2max} . It is not sufficient to work only at lactate threshold and sub-threshold speeds to accomplish this. Those training intensities will improve the aerobic capacity of slow twitch muscle fibers and perhaps some low-threshold FTa fibers. At the same time, however, most of the FTa and very few FTx fibers will be recruited and trained.

The major effect of training on fast twitch muscle fibers appears to be very similar regardless of their type. They undergo changes that make them more capable of sustained activity. When they are used to perform work they improve their capacity for aerobic metabolism by increasing capillarization and mitochondria regardless of whether they are FTa or FTx fibers, and regardless if the work is of a steady, long lasting endurance nature or intense, rapid, and of short duration. Since training that

approaches and surpasses VO_{2max} speeds is probably necessary to recruit high threshold FTa and all FTx fibers into the effort, it is no wonder that improvements of VO_{2max} have been reported where athletes trained with very short, intense efforts.

This, I believe, is the reason why high-intensity training has produced increases in maximal oxygen consumption in so many pieces of research. A greater number of fast twitch muscle fibers are recruited with high-intensity training. As a result, these fibers increase their ability to absorb oxygen from the bloodstream, and transport it to a larger number of mitochondria where it can be made available for aerobic metabolism. Thus, when the pool of muscle fibers capable of taking up additional oxygen has been increased, the result should be an improvement of VO_{2max} .

As I mentioned earlier, it appears that high intensity training also produces endurance benefits that are not achieved during low- and moderate-intensity training. In most studies, subjects who performed high-intensity training also improved buffering capacity and lactate removal rates, while those engaging in moderate intensity training did not (11, 33). These two processes contribute to endurance in FTa and FTx fibers by allowing them to continue contracting with greater power for a longer period of time. Buffering capacity may have also improved in ST muscle fibers, although to a lesser extent.

On the negative side, there is a distinct possibility that high-intensity training reduces contractile velocity in fast twitch muscle fibers. This could be potentially damaging in events that require power. That does not mean that high-intensity training cannot improve speed and power in other ways, however. It may, for example, improve the efficiency and rapidity with which fast twitch (and slow twitch) fibers can be recruited to apply force. Consequently, the nervous system will recruit only those fibers that are needed to perform the work and they will be recruited more rapidly, in a sequence that enhances the proper application of that force. The result should be that athletes can generate more power, which can be used to swim faster despite a reduction in the contractile velocity of some of their fast twitch muscle fibers. In the next section I want to discuss some methods of high-intensity training that have been proven effective for recruiting FTa and FTx fibers.

In part II of this paper I will discuss research on the use of high intensity training for improving aerobic and anaerobic endurance.

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