Training Zones Revisited

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Abstract

The purpose of this paper will be to describe a different interpretation of training zones, one that is based on training the three muscle fiber types. The physiological rationale for this theory was presented in an earlier paper (12). This follow-up to that paper goes into greater detail concerning how to administer training according to the theory.

Introduction

The notion of training zones is tied to the practice of blood lactate testing which became very popular in the decades from 1980 to 2000. It is still used today in many swimming programs around the world. That practice was based on the Anaerobic or Lactate Threshold concept of training, which postulated that the most effective intensity for aerobic endurance training occurred at the fastest speed where the rates of lactate appearance and disappearance in the blood were approximately equal, i.e. the Anaerobic Threshold. For most athletes this velocity occurred at a blood lactate concentration between 3 and 5 mmols/liter.

The early physiological rationale behind training at the anaerobic threshold was that the aerobic metabolism of muscles would be overloaded maximally at this speed with very little interference from anaerobic metabolism. Thus, by training at anaerobic threshold speed, athletes could overload the mechanisms of oxygen delivery and utilization in muscle fibers for periods of time ranging from 20 to 40 minutes, which was believed to be optimal for achieving an effective aerobic training stimulus. It was also theorized that faster training speeds would not be as effective for improving aerobic endurance because the metabolites of anaerobic metabolism would interfere with and reduce the aerobic training effect.

A typical lactate/velocity curve that can be used to locate the anaerobic threshold is shown in figure 1. The athlete represented in this figure has completed a descending series of six, 300m swims. The speed of the first swim was, purposely, very slow so that nearly all of the energy would be supplied aerobically. Each swim became progressively faster until the final swim was a maximum effort and, therefore, quite anaerobic. Blood lactate measurements were taken after each 300m swim and plotted against the velocity of that swim. The plots were then joined to form the lactate/velocity curve.

The lactate/velocity curve for this athlete indicates that his anaerobic threshold (AnTh) occurred at a swimming velocity of approximately 1.63 m/sec. while his VO_{2max} velocity is estimated to be approximately 1.7 m/sec. The third measure on the graph in figure 1 is an estimate of the athlete's aerobic threshold velocity (AerTh). This threshold is believed to represent the minimum training velocity where aerobic metabolism can be improved. This swimmer's aerobic threshold occurs at approximately 1.23m/sec.

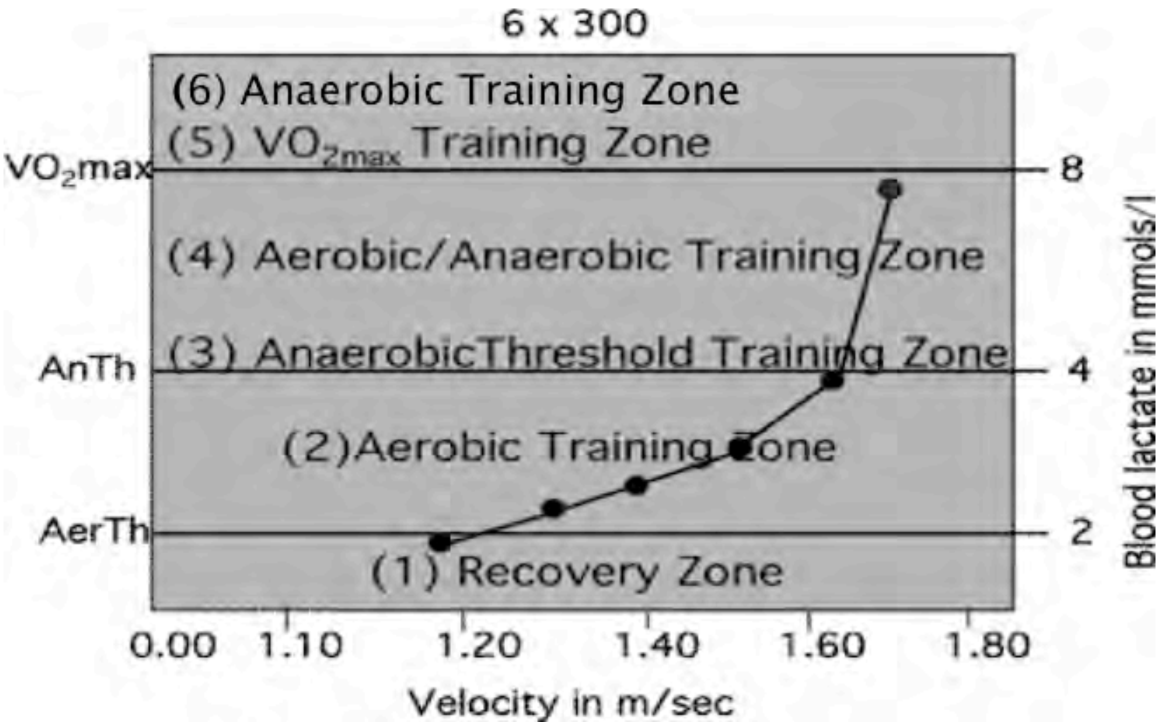

Figure 1. *Training velocities and zones suggested by a typical lactate/velocity curve . This curve indicates the athlete's anaerobic threshold occurs at a swimming velocity of approximately 1.63 m/sec. Other measures calculated were the aerobic threshold (1.23m/sec, and* VO_{2max} *(1.70m/sec) velocities. Six training zones have been designated.*

Aerobic and Anaerobic threshold and VO_{2max} are the three swimming velocities that are usually estimated from lactate/velocity curves. However, it is also possible to estimate several additional swimming velocities. As a result a number of aerobic and anaerobic training zones can also be estimated from these data. In figure 1, six training zones have been designated based on these three velocities; (1) the recovery zone, (2) the aerobic training zone, (3) the training velocity at the anaerobic threshold, (4) the combined aerobic/anaerobic training zone, (5) the training velocity at VO_{2max}, and, (6) the anaerobic training zone. These are the most commonly identified training velocities and zones although, as mentioned, some programs include additional velocities and zones within these 6 categories.

The recovery zone is just what its name implies. Swimming at speeds slower than aerobic threshold velocity will encourage recovery and regeneration of muscles but will produce little if any useful training adaptations in well-trained athletes.

The aerobic training zone lies between the swimmer's aerobic threshold velocity and his anaerobic threshold velocity. It has been designated as the zone where aerobic metabolism can be improved with little interference from anaerobic metabolism. As indicated previously, the anaerobic threshold velocity is thought to be the training speed where aerobic metabolism can be improved optimally. I will discuss my opposition to this belief later in the paper.

The aerobic/anaerobic training zone represents a range of training velocities between the anaerobic threshold and VO_{2maz} where both the aerobic and anaerobic metabolic systems can be trained. Swimming in this zone is believed to simulate the interaction of aerobic and anaerobic energy generation that occurs in races. The belief is that training in this zone will enhance adaptations to both aerobic and anaerobic training such that anaerobic metabolism will not reduce muscle pH so rapidly.

The VO_{2max} training velocity approximates the swimming velocity where oxygen is being consumed maximally by a particular swimmer. Training at this velocity is believed to be optimal for increasing oxygen consumption during races, although I will also offer a rebuttal to this belief later in this paper.

The anaerobic training zone is indicative of swimming repeats that are short and swimming speeds that are so rapid that the major portion of the energy for muscular contraction is supplied by anaerobic metabolism. Hence, it is the recommended training zone for improving anaerobic metabolic function as well as muscle buffering capacity and lactate (pain) tolerance.

In a previous paper (12), I suggested that a more definitive explanation of the physiological adaptations occurring in these zones involves the recruitment and training of the three major types of muscle fibers in humans, slow twitch (ST), fast twitch A (FTa), and fast twitch X (FTx) fibers. (FTx muscle fibers were referred to as FTb fibers in earlier papers, but the former term is now more popular). In this paper, I want to describe my hypothesis in greater detail while also suggesting guidelines for designing repeat sets that might be more accurate for targeting each of the three types of muscle fibers and, therefore, more effective for improving their aerobic and anaerobic capacities.

A Different Interpretation of Training Zones

It should be apparent from the preceding descriptions of the various training velocities and zones that the metabolic adaptations produced in each are very vaguely stated, especially as concerns the aerobic/anaerobic and anaerobic training zones. In fact, one prominent international coach has been quoted as referring to the aerobic/anaerobic training zone as a "mystery zone" because the adaptations that result from training in that zone have never been clearly defined. The descriptions and explanations for each training velocity and zone do not always make it clear to what extent aerobic and anaerobic metabolism are overloaded particularly in those zones above the anaerobic threshold. For example, are both metabolic processes overloaded maximally or does aerobic metabolism dominate in the aerobic/anaerobic zone? Obviously, anaerobic metabolic mechanisms are being taxed in the anaerobic training zone. However, to what extent are aerobic metabolic mechanisms also being improved, if at all?

Another matter that is not clear concerns the extent to which each of the three muscle fiber types are being trained in the various zones and whether the training effects occurring within them are entirely aerobic, anaerobic or some combination of the two. In most training zone schemes the terms aerobic and anaerobic metabolism are used as though they were independent of the types of muscle fibers being used by swimmers, be they ST, FTa, or FTx. But, in fact, as you will see, the type of energy metabolism that is evoked in each fiber type can be very different when training in certain zones

A review of muscle fiber recruitment patterns and training effects. At this point, a brief review of my previous paper, *Training Fast Twitch Muscle Fibers: Why and How* (12) may be in order for those of you who have not read it. Some of the salient points are summarized in figure 2.

1. **ST muscle fibers do most of the work at swimming speeds that are slower than anaerobic threshold velocity.**
2. **FTa fibers are recruited to assist the ST when swimming speeds approach and exceed anaerobic threshold velocity with progressively more joining in as swimming speeds approach VO_{2max} velocity.**
3. **FTx fibers are recruited in greater numbers to assist the ST and FTa fibers as training speeds approach and exceed VO_{2max} velocity.**
4. **In all fiber types, the major training effect when they are recruited for work is an increase in aerobic metabolic capacity.**
5. **Anaerobic metabolic capacity, lactate removal rate and buffering capacity will also be increased when training speeds exceed anaerobic threshold and VO_{2max} velocities**

Figure 2. *Some important points concerning muscle fiber recruitment and training.*

Contrary to what some think, the order of muscle fiber recruitment results from the force or power required to perform a movement, and not the speed needed to perform it. For example, slow twitch, rather than fast twitch, muscle fibers would be primarily recruited for a fast movement that requires little force, like spinning on a bicycle ergometer. On the other hand, lifting a heavy weight very slowly would require the recruitment of all three fibers types nearly simultaneously.

This point is really academic to us because swimmers usually stroke slower and with less force when they are moving slowly through the water, and, therefore, recruit slow twitch muscle fibers to do the work. Conversely, they stroke both faster and with greater force when they are sprinting, in which case, the fast twitch muscle fibers will be recruited to assist, *not replace,* the slow twitch fibers.

It is possible to estimate the swimming intensities where the FTa and FTx muscle fibers will be recruited to assist with the workload from research with both humans and animals. FTa fibers appear to be recruited into the effort as swimming speeds approach anaerobic threshold velocity with progressively more recruited to assist the ST fibers as speeds approach VO_{2max} velocity. It also appears the FTx muscle fibers are not recruited in great numbers until swimming speeds exceed VO_{2max} velocity, or until a significant number of FTa fibers have become fatigued at some slower velocity, in which case, the FTx fibers would be recruited in an effort to maintain the swimmer's pace. To summarize, at slow speeds slow twitch fibers do most of the work while at progressively faster speeds fast twitch A and finally fast twitch X muscle fibers are recruited to assist the slow twitch fibers so that, at near-maximum swimming speeds, all three fiber types are recruited to perform the work. This so-called "ramp effect" of muscle fiber recruitment is illustrated in figure 3. My interpretation of the training effects occurring in the various training zones is also illustrated in this figure and will be described in the following paragraphs.
I believe there should be three zones of endurance training and one category of sprint training that are necessary to train the three muscle fiber types in humans for optimal performance. The endurance levels are listed as En-1, En-2 and En-3. The purpose in the En-1 zone is to train the aerobic metabolic processes of slow twitch muscle fibers without interference from anaerobic metabolism. The En-1 lies between the aerobic threshold and anaerobic threshold training velocities.

The primary purpose in the En-2 zone is to train the aerobic metabolic processes of fast twitch A muscle fibers. The En-2 zone lies between the anaerobic threshold and VO_{2max} velocities. The purpose in the En-3 zone is to train the aerobic metabolic processes of fast twitch X fibers. That requires speeds in excess of VO_{2max} velocity.

The purposes I have attributed to training in the En-2 and En-3 zones may have surprised you because swimming in excess of the anaerobic threshold velocity is thought to involve, primarily, anaerobic metabolism. In fact, however, an improved ability to supply energy aerobically is the major effect training in these zones has on fast twitch muscle fibers. When fast twitch fibers are used to perform work they improve their capacity for aerobic metabolism by increasing capillarization around these fibers, as well as by increasing their myoglobin, and mitochondrial content.

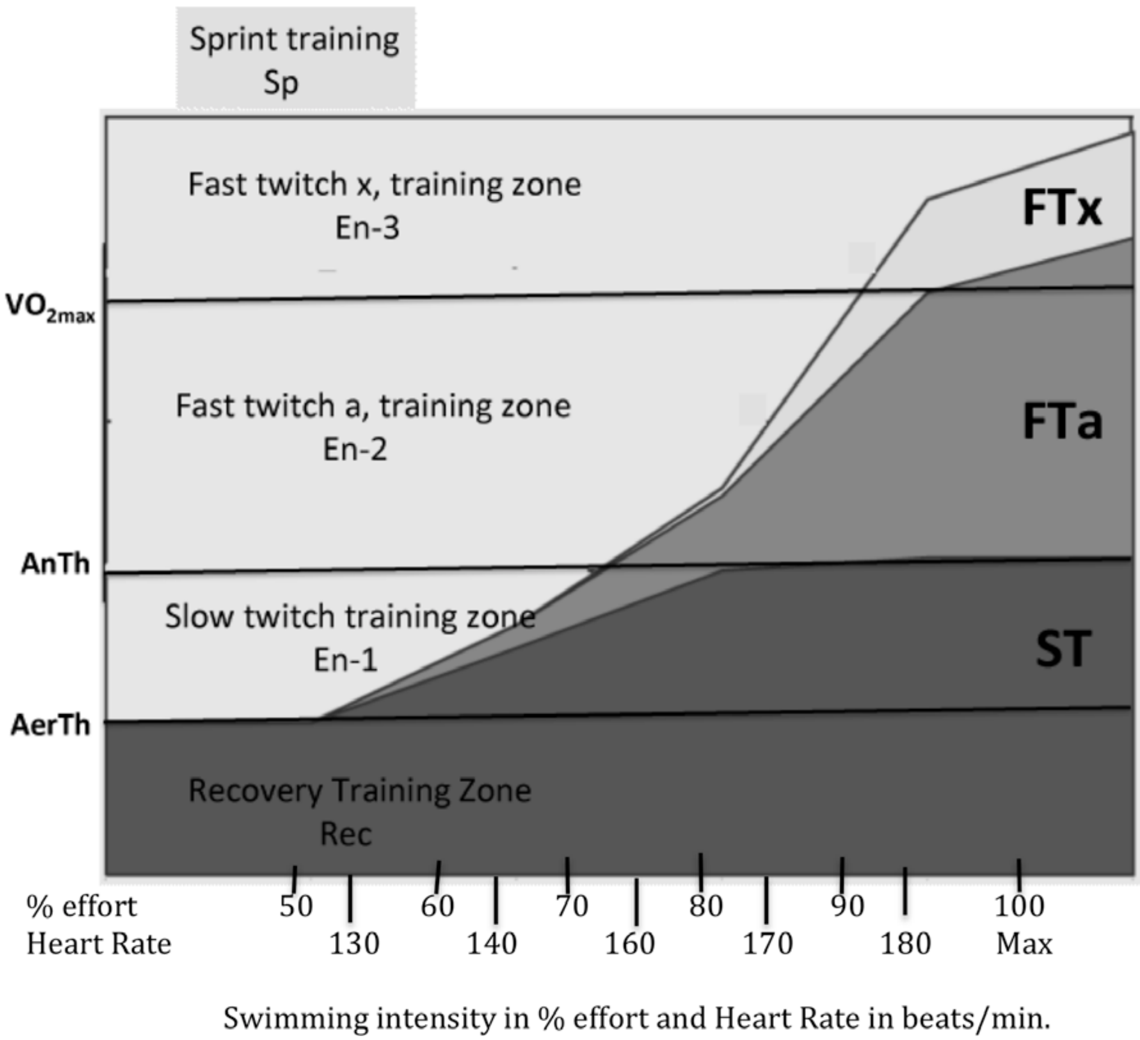

Figure 3. *The ramp effect of muscle fiber recruitment. Adapted from J.H. Wilmore and D.L. Costill (2004*). ***Physiology of Sport and Exercise****, p. 50. Champaign, IL: Human Kinetics. This figure is a graphic representation of the manner in which the three muscle fiber types, slow twitch (ST), fast twitch A (FTa), and fast twitch X (FTx) are recruited during different intensities of work. This figure also displays the location of three zones of endurance training relative to measures of aerobic threshold, anaerobic threshold and VO_{2max} velocities on the left vertical axis. Estimates of percent efforts and heart rates that correspond to training in each zone are listed on the horizontal axis. A fourth category of training, sprint training, is located at the top of the chart.*

This is true regardless whether the FTa or FTx fibers are being used for this work, and, regardless of the fact that the work is intense, rapid, and of short duration. In other words, work that we usually think of as anaerobic is really improving the aerobic capacity of fast twitch muscle fibers in the En-2 and En-3 zones. This makes sense when we realize that all muscle fibers will attempt to adapt so that, first and foremost, a greater percent of the work they do can be fueled by aerobic metabolism instead of anaerobic metabolism. They adapt in this way in order to delay fatigue. The reason that athletes must train in excess of anaerobic threshold velocity to improve the aerobic metabolic processes of fast twitch muscle fibers is because those speeds are required to recruit them.

As you would suspect, an additional advantage of training in the En-2 and En-3 zones is that the anaerobic metabolic processes, i.e., the lactate removal mechanisms and buffering capacities, of FTa and FTx fibers can also be improved because a large portion of the energy for contraction must be supplied anaerobically due to the faster swimming speeds required to recruit those fibers.

Since slow twitch muscle fibers are also working when athletes swim at fast speeds, it is possible that training in the En-2 and En-3 zones will also improve anaerobic metabolic processes in slow twitch muscle fibers. However, it is not clear how adaptable slow twitch fibers are where improving anaerobic metabolism is concerned so the extent to which this may occur is unknown at this time.

Sprint training is placed above the graph because it is a category of training rather than a zone. It has nothing to do with swimming above or below certain thresholds or swimming at certain blood lactate concentrations. With regard to muscle fiber recruitment, nearly all of the fibers of each type will be recruited in the working muscles when athletes are swimming at the near-maximal speeds required of sprint training. In such cases, muscles fatigue so quickly that there may not be sufficient time to produce significant anaerobic training effects. Consequently, training in this category probably has little to do with improving aerobic or anaerobic endurance in slow twitch and fast twitch muscle fibers. Nor is it concerned with improving buffering capacity and lactate removal rates. Its primary purpose is to increase their maximum stroking power and the rates of energy release from the ATP-CP and anaerobic metabolic systems of these fibers so athletes can swim at greater maximum speeds.

You will notice that there are no training zones indicated at velocities corresponding to the anaerobic threshold and VO_{2max} in my explanation. This is because I do not believe these two measures are improved most effectively by training at or near those velocities. I suspect that only a small portion of fast twitch muscle fibers are recruited when training at or near the anaerobic threshold velocity, leaving the majority devoid of a training effect. Because of this, their contribution to oxygen consumption and lactate removal should not be enhanced to any great extent by swimming exactly at that velocity. On the other hand, you would expect the aerobic capacity of both slow twitch and fast twitch a muscle fibers would certainly be improved by training at and near VO_{2max} velocity. However, I suspect that only a small number of fast twitch x fibers would be recruited at this speed, that is, until a sizable number of fast twitch A fibers have become fatigued.

I suspect that velocities at the anaerobic threshold and VO_{2max} will be improved most through the summation of improved rates of aerobic metabolism in each of the three major fiber types. Therefore, I am of the opinion that effectively increasing the velocity at both the anaerobic threshold and VO_{2max} requires training in all three endurance zones rather than training exactly at those two velocities.

By doing so, the improved aerobic metabolic capacity of each fiber type, when added together during competition, should create greater maximal oxygen consumption (VO_{2max}), and a lower rate of lactic acid production (a faster Anth). In addition, the rates of lactate removal from the muscle fibers that are working in each training zone and the uptake and subsequent metabolism of lactate, hydrogen ions and other metabolites by non-working fibers should also be enhanced by training at speeds that are both slower and faster than anaerobic threshold and VO_{2max} velocities, This, in turn, improve the swimming velocities at each of those two popular indicators of an athlete's potential for performance in endurance events moreso than they might be improved by training at those velocities.

If this notion is correct, there would be no advantage gained by training exactly at anaerobic threshold and VO_{2max} velocities, which, in turn, would eliminate the need to use blood testing to estimate those velocities. Instead, estimates of perceived effort, and exercise heart rates should be sufficient for approximating the much broader range of training speeds for each of the three endurance zones. This would make it possible for a greater number of athletes and coaches to use the training zones approach effectively, particularly those who do not have the equipment, expertise, or the time for blood testing.

Some suggestions for designing repeat sets in each training zone.

The Slow Twitch Training zone, (En-1). As described previously, the En-1 training zone lies between the aerobic threshold velocity, (the minimum velocity where training effects can be produced), and the anaerobic threshold velocity, (the maximum velocity where the rates of appearance and disappearance of blood lactate are nearly in balance). The purpose of training in this zone is to improve the aerobic capacity of slow twitch muscle fibers with little interference from anaerobic metabolism. With minimal recruitment of FTa muscle fibers and little or no recruitment of FTx fibers, athletes should be able to continue training the slow twitch muscle fibers for longer periods of time with minimal accumulation of the metabolic products that cause fatigue. As you should realize by now, those products are produced in much greater quantity by fast twitch, rather than slow twitch, muscle fibers. This is ideal because slow twitch fibers seem to improve their rates of aerobic metabolism best by increasing training volume, provided, of course, that training speeds are sufficient to recruit the majority of those fibers within the swimming muscles, (that is, training speeds should be between aerobic and anaerobic threshold velocities).

There are two broad categories of repeat sets that I believe should be swum in this zone. I call them *primary* and *secondary* repeats for want of better terminology. The purpose of a primary set of En-1 repeats is to maximally overload all, or most of the slow twitch muscle fibers in working muscles so their rates of aerobic metabolism can be improved as much as it is possible to improve them.

A set of this type should generally be a minimum of 20 minutes in length for sprinters, to 40 minutes for distance swimmers, in order to provide time for the desired training stimulus to take place. (Time rather than distance was used to define the desired training length of sets so the optimal distance could be determined for any age group and ability level). Several shorter sets completed in one training session with very little recovery time between them could also be used for this purpose so long as the sum total training time for all the sets is 20 to 40 minutes or longer within a single training session.

The send-off times should be short so the athletes cannot swim faster than anaerobic threshold velocity and still complete the set. Let me repeat this last point. It is very important that the send-off times are so short that athletes cannot exceed anaerobic threshold velocity throughout most of the set. As mentioned before, this should ensure that all or nearly all of the slow twitch fibers in swimmers' working muscles are recruited with, at the same time, only minimal involvement of fast twitch fibers.

You might speculate as to why I have recommended training slower than anaerobic threshold velocity for improving the aerobic metabolic function of slow twitch muscle fibers when those fibers are also working very hard at speeds above the anaerobic threshold. It is because, there are indications in the literature that rate of improvement for aerobic metabolic capacity in slow twitch muscle fibers may be compromised by swimming in excess of anaerobic threshold velocity too frequently, if there is not a sufficient balance of sub-threshold training (12).

Make no mistake, a primary set of repeats should not be an easy, or even moderate effort. The set should be designed such that a near-maximum effort is required of athletes to maintain the speed of their repeats between aerobic and anaerobic threshold velocities.

As I indicated earlier, it is not necessary to know a particular athlete's exact aerobic and anaerobic threshold velocities to swim in the En-1 zone. Rough estimates of those velocities should be sufficient for this purpose. For this reason, perceived efforts and heart rates can be used to monitor the proper training intensity for these sets. Regarding perceived effort, the swimmers should feel they are swimming between 75 and 90% of maximum effort throughout the majority of the set. Where heart rates are concerned, they should be 160 to 170 b/min (16 to 17 beats for 6 secs.) for the majority of the set. Heart rates may be slightly lower than 160 to 170 bpm. early in the set, and, because of heart rate "creep", may approach maximum near the end of the set. However, as stated, heart rates of 160 to 170 b/min should be maintained for the majority of the repeat set when swimming primary sets in the En-1 zone.

Two and three thousand swims for time make excellent primary En-1 sets for most teenage swimmers and for adult swimmers in their 20's and 30's. As mentioned earlier, in the cases of younger and older swimmers, the total distance of repeat sets should encompass 20 to 40 minutes swimming continuously or with short rest periods. I believe repeat distances should be 200m and longer (2 mins. and longer). My experience as a coach has led me to conclude that repeat distances of 50 and 100m introduce too much rest into a primary En-1 set and, therefore, may not be as effective as longer repeats for isolating and developing the aerobic capacity of slow twitch muscle fibers.

The purpose of secondary En-1 sets is to improve, or at least maintain, the aerobic capacity of slow twitch muscle fibers. As such, they should be swum at a velocity that is faster than that at the aerobic threshold, and somewhat less than anaerobic threshold velocity. In other words, they should be swum in the middle of the En-1 range.

Secondary En-1 sets should also be done on send-off times that provide only 10 to 30 secs. of rest. In addition, they should be swum on days when athletes are recovering from more intense training or during periods within En-2 and En-3 sets that have been designed to rest the fast twitch fibers. This is because fast twitch fibers will not be recruited to any great extent during En-1 swimming. Thus, those fibers can be resting and recovering while slow twitch fibers are working and receiving a training stimulus. Because of this, it should not be necessary to swim slower than aerobic threshold velocities to rest, recover and replenish glycogen in the fast twitch fibers.

Secondary En-1 repeat sets can be any total distance. Ten to 20 mins of continuous or short rest swimming at a time is probably the minimum time required to produce an adequate training effect and longer sets may be even more effective for this purpose. As indicated, the send- off times should be set for short rest. These sets will not require a maximum effort from the swimmers to be effective. Therefore, athletes can, once again, use perceived efforts and heart rates for monitoring purposes if they do not know their individual aerobic and anaerobic threshold velocities. Perceived efforts should be in the range of 70% to 80% of maximum effort. Working heart rates of 130 to 160 b/min (13 to 16 beats for 6 secs.) indicate the proper intensity for the majority of the set.

These repeats can be combinations of pulling, kicking and swimming, and, strokes can be mixed within them. Secondary En-1 swimming is also an excellent way to do stroke, kicking and pulling drills. Because these sets are swum at sub-maximal efforts, athletes can concentrate on the improving their strokes while still receiving the added benefit of improving the aerobic capacity of their slow twitch muscle fibers.

There are also many adaptations to be gained in other physiological systems while swimming secondary En-1 sets. I am referring, primarily, to adaptations of the respiratory, circulatory and hormonal systems. These are termed *central* training adaptations, as opposed to *peripheral* training adaptations that take place in the working muscle fibers.

Central training effects that are produced when training in the En-1 zone include an increase of stroke volume (the amount of blood ejected from the heart per beat), and an increase of capillaries around the lungs, so that more oxygen will be transported from the lungs to the capillaries where it will be carried to the heart and, from there, out to the muscles.

Swimming also appears to improve the vital capacity to a greater extent than other sports while also increasing other lung volumes. This may be because exhaling against hydrostatic pressure increases respiratory muscle strength (13). In addition, the lactate transporters in slow twitch muscles may also increase, allowing a greater percentage of the metabolites produced in working fast twitch fibers to be absorbed by slow twitch muscle fibers during competition.

The number of red blood cells will also increase as well as the fluid volume of the blood (blood volume). The former training adaptation will allow more oxygen to be carried by the blood while the latter keeps the blood from becoming so thick (viscous) from the increase of red blood cells that its rate of flow is decreased. Training may also decrease the catecholamine response to work or, at the least, increase an athlete's resistance to excessive catecholamine release so that overtraining is less likely to occur.

An important peripheral adaptation that can be expected from training in the En-1 zone is an increase in the number of open capillaries surrounding slow twitch muscle fibers. This will make more oxygen and glucose available to the fibers as the blood passes by them. In addition, increased capillarization will allow greater removal of metabolites by those fibers during competition.

The rates of removal from slow twitch muscle fibers of lactate, hydrogen ion (H^+), and other metabolites may also be improved through an increase of MCT lactate/H^+ transporters. The importance of this effect has yet to be determined. As indicated earlier, the anaerobic metabolic capacity of slow twitch fibers is relatively low when compared to that of fast twitch fibers. Consequently, the quantity of anaerobic metabolites produced while training in the En-1 zone may or may not be sufficient to require an increase in the activity of lactate transporters to remove them.

Regardless, whether the ability of slow twitch muscle fibers to remove lactate, H+ and other metabolites and be improved significantly, it seems reasonable that ability of resting slow twitch fibers to take-up some of the metabolites that were produced in working fast twitch fibers during races should be augmented. This is accomplished through an increase of another type of MCT lactate/H+ transporter. This transporter, termed MCT1, is found in great quantities in ST muscle fibers. Its function is to transport lactate and H^+ into slow twitch fibers where they can be reconverted to glucose.

Another important peripheral training adaptation will be an increase of myoglobin, in slow twitch fibers. This substance transports oxygen across the cytoplasm to the mitochondria where it can be used to replace ATP and energy for muscular contraction.

Perhaps, the most important peripheral training adaptation will be an increase in the size and number of mitochondria in slow twitch muscle fibers. Mitochondria are the organelles within muscle fibers where aerobic metabolism takes place. Therefore, an increase in these structures should increase the rate of energy release via aerobic metabolism within slow twitch muscle fibers so that they can supply a greater percentage of the total energy needed during races. These peripheral adaptation should, in turn, reduce an athlete's dependence on anaerobic metabolism from the fast twitch muscles during competition, and, in doing so, delay fatigue.

The Fast Twitch A training zone, (En-2). As is obvious from the name, training in this zone is primarily for the purpose of improving the rate of aerobic metabolism in FTa muscle fibers. Slow twitch muscle fibers will also be recruited and, therefore, should improve their rate of aerobic metabolism, although, as mentioned previously, training too frequently in this zone may reduce the magnitude of aerobic metabolic adaptations in slow twitch muscle fibers.

Training velocities should be between those at the anaerobic threshold and $VO_{2max.}$ Consequently, the rate of metabolite accumulation will increase markedly when training in this zone. This cannot be avoided because faster swimming speeds are required to recruit fast twitch fibers. At the same time, however, their rate of aerobic metabolism will also increase, because of training adaptations that improve aerobic metabolic capacity.

The peripheral aerobic training adaptations that fast twitch muscle fibers receive when recruited are identical to those produced in slow twitch muscle fibers. The mitochondria become larger and more numerous, myoglobin increases, and the number of capillaries surrounding them increases (10). These adaptations will increase their oxygen supply, thereby, reducing their dependence on anaerobic metabolism so they operate more like ST muscle fibers. As a result, the aerobic capacity of trained FTa fibers often approaches that of untrained ST fibers (11).

Unlike slow twitch muscle fibers, fast twitch A fibers rely much more heavily on anaerobic metabolism for their energy supply. Therefore, when trained, they will improve their anaerobic capacity as well as their aerobic capacity.

Training in the En-2 zone will produce a large increase of MCT-4 lactate/H^+ transporters in fast twitch muscle fibers. This will significantly increase the rate of metabolite transport from these fibers, and, therefore, slow the rate at which they fatigue. Another important effect of training in the En-2 zone will be an increase in metabolite absorption by organs and non-working muscle fibers (3,14). This is because, increasing the removal rate of metabolites from working fast twitch A muscle fibers should also increase their rate of transport to, and absorption by the heart, liver, kidneys and non-working muscle fibers. Training will also elevate their buffering capacity, and this will, increase the time they can assist ST fibers in maintaining a particular pace.

Central training effects include improvements in pulmonary diffusing capacity and cardiac output (stroke volume) because a significant number of both slow twitch and fast twitch a muscle fibers will require an increased rate of oxygen consumption as well as greater rates of carbon dioxide and metabolite removal (8, 16).

Sets designed to be swum in the En-2 zone will necessarily have to be shorter than those designed for the En-1 zone because the rapid rate of metabolite accumulation in fast twitch muscle fibers will cause them to fatigue more quickly than slow twitch fibers. They usually become exhausted within 10 to 20 minutes of intense swimming. Therefore, where skilled senior swimmers are concerned, repeat sets should probably 2000 meters. The distance of repeat sets for younger, older, and less skilled swimmers will need to be scaled down accordingly to stay within the 10 to 20 minutes time frame.

Rest periods between repeats should not exceed work time and, should usually be shorter than the work time. For repeats in excess of 100m, the rest period should probably be less than one-half the work time. Rest periods should never be so short that athletes cannot swim in the En-2 zone, however.

Monitoring training in this zone is fairly easy. Perceived efforts should be between 80 and 90% of maximum. Heart rates should start at 150 to 160 b/min and reach maximum in the last half of the set. The goal should be to complete the set with the fastest possible average time without a noticeable fall-off of repeat times from the beginning to the end of the set. Quite often athletes who are swimming repeats that are one-half their race distance or less will be repeating at race speed when swimming En-2 sets, except when the repeat distances are 600 m and longer.

The Fast Twitch X training zone, (En-3). Training in this zone is designed to recruit and train FTx muscle fibers. The training effects they receive will be identical to those discussed for FTa fibers in the previous section. The most important training effect will be an improvement in their aerobic metabolic capacity although other adaptations that are generally considered anaerobic should also improve.

There are strong indications in the literature that the aerobic capacity, buffering capacity and lactate removal rates of FTx muscle fibers can be increased with training until they function much like FTa fibers. One such indicator is that fibers previously typed as FTx become less numerous while those typed as FTa fibers become more numerous after training (1).

Of course, FTx fibers will also be recruited when training in the En-2 zone. As FTa fibers become fatigued, it is to be expected that FTx fibers will be recruited to replace them, so athletes can maintain a desired swimming velocity. At this point, a logical question, might be, "Why swim in the En-3 zone if FTx muscle fibers can be recruited and trained in the En-2 zone?" I can think of at least three reasons for doing so. First, there is the possibility that the rapid accumulation of metabolites that takes place when training in the En-2 zone may cause fatigue before a sufficient number of FTx fibers can be recruited and trained adequately. This may happen because metabolite buildup causes repeat speeds to drop-off before the FTx fibers are sufficiently recruited. Secondly, there is also a possibility that FTx fibers may be able to, more rapidly, regain, any force and contraction velocity that might have been lost when their aerobic capacity was increased (6), if they are not continually subjected to the long repeat sets and distances that are recommended for the En-2 zone. This would be particularly important for athletes in 100 and 200 events who, should err on the side of maintaining speed and power while attempting to increase the aerobic capacity of their fast twitch X muscle fibers.

A third reason why it might be more advantageous to recruit FTx fibers with short repeat distances is because research cited in my previous paper (12) suggests that training speeds must be in excess of VO_{2max} velocity to recruit these fibers early in a set. Therefore, it seems that an athlete might be able to provide a greater training stimulus for FTx fibers by keeping the repeat distances and set distances shorter and the training speeds faster so these fibers can be recruited earlier and to a greater extent before fatigue occurs.

For these reasons, I recommend repeat distances of 25 and 50m for training in this zone. There is no doubt, however, that fast repeats of 75m and 100m would also cause FTx fibers to be recruited. It would probably be a good idea to try various repeat distances and evaluate the effects on performance for yourself.

I indicated in my previous paper, that repeats as short as 30 secs. in length with rest periods of 3 to 4 minutes improved VO_{2max} (2), and endurance performance (4, 7, 10). Nevertheless, I suspect that shorter rest periods in the neighborhood of 10 to 15 secs. for 25m repeats, and 30 secs. for 50m repeats would produce even better results where improving the rates of aerobic and anaerobic metabolism in Fast twitch X fibers is concerned.

As a rule of thumb, the repeat distance should be short enough to be performed at speeds where FTx fibers would be recruited, that is, beyond VO_{2max} velocity and the rest periods should be sufficient to permit a reasonable number of repeats to be performed at those speeds. Repeat speeds in the En-3 zone should be swum at or near race speeds for 50 and 100 swimmers and faster than race pace for swimmers in longer events.

Careful monitoring is probably not required when training in this zone. Since training speeds must be very fast in order to recruit FTx muscle fibers, it goes without saying that athletes will be swimming close to maximum effort and that their heart rates will reach maximum over the duration of the set

While the main concern for training in the En-3 zone should be to increase the aerobic metabolic capacity of FTx muscle fibers, it is also reasonable to assume that metabolite removal rates from FTx fibers would be enhanced by increases in their MCT transporters and the number of open capillaries them. It is difficult to determine whether some higher quality central adaptations might also be produced by training in this zone. This is because most research on stroke volume, cardiac output and pulmonary diffusion rates, has been conducted with training velocities that approached but did not exceed VO_{2max} velocity.

Before leaving this section I would like to mention another potentially important training adaptation that might be achieved by training in both the En-2 and En-3 zones. It concerns improvements of swimming skill that can transfer to race performances. We have all coached swimmers who swam flawlessly during warm-up, only to see their strokes deteriorate in competition. Perhaps this was because they practiced stroke corrections only at slow speeds where slow twitch motor units were the major type of fiber recruited?

There is quite a bit of attention given recently to the importance of increasing the density of myelin sheaths around nerve fibers and the beneficial effect that can have on learning skills (5). Could it be that some swimmers are not increasing myelin around the motor nerves that serve their fast twitch muscle fibers when they swim their stroke drills only at slow speeds? Although most muscles contain all three types of muscle fibers, the many motor units* within those muscles are made up of only one type of fiber.

Perhaps we only increase myelin around those motor nerves serving slow twitch muscle fibers when stroke drills are performed at slow speeds, in which case, the fast twitch motor units within those same muscles would sustain little or no learning effect. This might cause fast twitch motor units to act like the "weak links" in skill performance and "break down" during competition. That is, they might not function in the correct sequence with appropriate contraction force and speed. For this reason, it is possible that swimming stroke drills in the En-2 and En-3 zones

*_Muscles are made up of muscle fibers that are grouped into motor units within the muscle. A motor unit consists of a sensory nerve, its branches and the muscle fibers it serves. When the electrical impulses are sufficient to "excite" it, a sensory nerve will sends out impulses to all of the muscle fibers within a particular motor unit causing them to contract maximally._

might also increase myelin density around the nerves serving fast twitch motor units, and allow athletes to control their stroking movements to a greater extent during competition. Provided, of course, that, when swimming in these zones, athletes are attentive to correcting mistakes immediately as they occur.

You might reason that this same training effect could be accomplished through sprint training. However, the improved aerobic and anaerobic endurance training effects in fast twitch motor units that results from swimming in the En-2 and En-3 zones might also be accompanied by an improved ability to maintain proper stroke mechanics when fatigued late in races, while swimming only rested sprints would not achieve this same effect.

Sprint Training, (SP). The purpose for training in this category is to increase maximum sprint speed. Although there will be some overlap with the central and peripheral physiological adaptations that take place when training in the En-2 and En-3 zones, the most desired adaptations from sprint training include increases in fiber force and contraction velocity in all three fiber types so the muscles can produce more stroking power. In addition, muscle stores of ATP and CP should increase in all three types of muscle fibers as well as the activity of enzymes that permit the rapid release of energy for muscular contraction from these two sources. Activity of the glycolytic enzymes that are involved in anaerobic metabolism should also be increased particularly with longer sprint repeats (25's and 50's).

The common types of repeat sets that are in use for improving speed should be swum when training in this zone. These include sprints of 10 to 50m. Long rest periods should be taken between repeats to allow sufficient recovery toward the rested state so that metabolite accumulation does not slow the speed of subsequent repeats. Recommend rest periods are 15 to 30 secs for 10m repeats, 30 secs. to 2 minutes for 25m repeats and 2 to 5 minutes for 50m repeats. Remember that you are trying to improve rested speed, not fatigued speed. Improvements of fatigued speed can and should be accomplished by training in the En-2 and En-3 zones.

The ideal number of repeats is not known but should probably be kept small; 10 to 15, 10m sprints, 6 to 10, 25m sprints, and 3 to 6, 50m sprints. The best rule of thumb is to stop when athletes are no longer able to repeat at speeds that are faster than those in the En-3 zone. Both sprint-resisted and sprint-assisted training should be included within this framework.

Mixed zone repeats. Swimming in 2 or more training zones within one set can also be an effective and motivating way to train. This can take at least two forms, descending sets and fartlek-like sets.

Descending sets should begin in the En-1 zone and can finish in the En-2 or En-3 zone. For example, a set of 8 x 200m swims could be completed in the following manner. Swim 4 X 200 in the En-1 zone on a short send-off time, 3 x 200m in the En-2 zone on a slightly longer send-off, and after a short rest period, 1 x 200m In the

En-3 zone. Another example, of a descending set is the traditional down the ladder design where swimmers decrease the repeat distance and increase their swimming speed throughout the set. For example, 3 x 300 on short send-off times in the En-1 zone, followed by, 5 x 100, also on a short-send off, in the En-2 zone. Athletes could finish the with 4 x 50 on 1 minute in the En-3 zone.

The fartlek-like repeat sets are done in a slightly different manner. For example, an athlete might swim 3 x 300 on short rest in the En-1 zone, followed by 6 x 25 on 1 minute in the En-3 zone. This set could be repeated 3 to 4 times with no break between rounds. Another example, would be to swim 800m in the En-1 zone, followed by 8 x 100m on short rest in the En-2 zone, presumably at race speed or faster, followed by 12 x 25 m on 1 minute in the En-3 zone. So long as you are aware of the types of muscle fibers being targeted as well as how and why they are targeted, the possibilities for designing mixed zone sets are only limited by the creativity and knowledge of the coach designing them.

General Suggestions for Structuring a Training Week.

Not having coached swimmers for several years, I do not feel qualified to provide anything but general guidelines concerning how training should be distributed through the four zones, over a week or a season. As a general rule, I would suggest scheduling two major sets in each of the three, endurance training zones each week. Where, the En-1 zone is concerned, the two sets should be of the primary type. Two En-2 sets and two En-3 sets should also be scheduled during the week, usually on days when primary En-1 sets are not being done. The remainder of the week's mileage should be made up of secondary En-1 training and sprint training, with occasional, short, forays into the En-2 and En-3 zones for variety and motivation. The En-2 and En-3 swimming can be structured as short, novel sets that are not exhausting. They can also be done at the tail end of secondary En-1 sets.

With experience coaches should become competent at making adjustments in their weekly and season planning for different events and strokes and for the different physiological and psychological make-up of individual athletes.

References:

1. Andersen, L.L., J.L. Andersen, S.P. Magnussen, C. Suetta, J.L. Madsen, L.R. Christensen, and P. Asgaard. (2005). Changes in human muscle force-velocity relationship in response to resistance training and subsequent detraining. *Journal of Applied Physiology,* 99: 87-94.

2. Barnett, C., M. Carey, J. Proietto, E. Cerin, M.A. Febbraio, and D. Jenkins. (2004). Muscle metabolism during sprint exercise in man: influence of sprint training. *Journal of Science and Medicine in Sport,* 7: 314-322.

3. Bonen, A., K.J. McCullagh, C.T. Putman, E. Hultman, N.L. Jones and G.J. Heigenhauser. (1998). Short-term training increases muscle MCT1 and femoral venous lactate in relation to muscle lactate. *American Journal of Physiology.* 274: E102-E107.

4. Burgonmeister, K.A., S.C. Hughes, G.J. Heigenhauser, S.N. Bradwell, and M.J. Gibala. (2005). Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *Journal of Applied Physiology.* 98: 1985-1990.

5. Coyle, D. 2009. *The Talent Code.* New York, N.Y.: Bantam Books.

6. Fitts, R.H., D.L. Costill, and P.R. Gardetto. (1989). Effect of swim exercise training on human muscle fiber training. *Journal of Applied Physiology.* 66(1): 465-475.

7. Gibala, M.J., J.P. Little, M. van Essen, G.P. Wilkin, K.A. Burgonmaster, A. Safdar, S. Raha, and M.A. Tarnopolsky. (2006). Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *Journal of Applied Physiology,* 575(3): 901-911.

8. Gledhill, N. D. Cox, and R. Jamnik. (1994). Endurance athletes' stroke volume does not plateau: major advantage is diastolic function. *Medicine and Science in Sports and Exercise.* 26: 1116-1121.

9. Holloszy, J. (1967). Effects of exercise on mitochondrial oxygen uptake and respiratory enzyme activity in skeletal muscle. *The Journal of Biological Chemistry.* 242(9): 2278-2282.

10. Jensen, L., J. Bangsbo, and Y. Hellsten. (2004). Effect of high intensity training on capillarization and presence of angiogenic factors in human skeletal muscle. *Journal of Physiology,* 557: 571-582.

11. McArdle, W.D., F.I. Katch, and V.L. Katch. (1996). *Exercise Physiology: Energy, Nutrition, and Human Performance.* Baltimore, MD: Williams and Wilkins.

12. Maglischo, E.W. (2011 & 2012). Training fast twitch muscle fibers: Why and How, Parts I and II. *Journal of Swimming Research.* 18(1), pp. 1-16 and 19(1), pp. 1-18.

13. Ogita, F. (2011). Training energy systems. In, *World Book of Swimming,* New York, N.Y.: Nova Science Publishers, Inc. pp. 241-254.

14. Pilegaard, H., C. Jeul, and F. Wibrand. (1993). Lactate transport studies in sarcolemmal giant vesicles from rats: Effects of training. *American Journal of Physiology, Endocrinolgy and Metabolism,* 264: E156-E160.

15. Wilmore, J.H. and D.L. Costill. (2004). *Physiology of Sport and Exercise.* Champaign, IL: Human Kinetics.

16. Zhou, B., R.K. Conlee, R. Jensen, G.W. Fellingham, J.D. George, and A.G. Fisher. (2001). Stroke volume does not plateau during graded exercise in elite male distance runners. *Medicine and Science in Sports and Exercise.* 33: 1849-1854.