IAAF @-Letter

for CECS Level II Coaches

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SPECIFIC THEME: Improving Aerobic Capacity

GENERAL THEME: Factors Affecting the Response to Aerobic Training

Specific Theme

IMPROVING AEROBIC CAPACITY

1 Introduction

One important aim of training for events of 400 m and over is to build up aerobic capacity. This involves an increase in the number and volume of mitochondria, an increase in the concentration of enzymes within the mitochondria, an increase in the capillary density and a conversion of some fast-twitch glycolytic (FT_b) fibers into fast-twitch oxidative (FT_a) fibers (see for more details @-*Letter* 4/2003).

Various distances are run in training for the middle- and long-distance athletes. What these distances are doing for the limiting processes is explained below.

2 Short intervals (below 400 m)

At first sight a schedule of short intervals, separated by short recovery times, would appear to benefit the aerobic capacity, but this is the very approach that benefited German middle-distance athletes in the 1930s.

Dr. H. Reindell from Germany, a cardiologist who used exercise to strengthen the hearts of some of his patients, during the 1930s developed the first really scientific approach to physical training. The aim was to improve the performance of the heart, and careful measurements showed that the most effective method was for the patient to run repetitive short distances with short rest periods between each – precisely what we would now call interval training. During the run, the heart reached 170-180 beats/min (bpm) and fell below 120 bpm during the rest period. Reindell showed that this training increased both the size of the heart and the volume of blood expelled by the heart during each beat. He also found a marked increase in the maximum rate at which oxygen could be used by the whole body in such patients. This showed that the beneficial effects of this training program were not restricted to the heart.

The interval training regimes were first systematically applied to top-class athletes by the German Woldemar Gerschler. Gerschler's star pupil was Rudolf Harbig, who in 1939 took nearly 2 sec off the world record for the 800 m. Harbig's record of 1 min 46.6 sec was so good that it lasted for 16 years. Soon afterwards Harbig became the first European to hold the world record for 400 m (46.00 sec). Interval training also played its part in setting new world records in the early post-war years. One of the beneficiaries was the British runner Gordon Pirie, who was advised by Gerschler and held world records for 3000 m, 5000 m and 6 miles. Other coaches adopted interval training, among them the Austrian Franz Stampfl and the Hungarian Mihaly Igloi. Stampfl advised both Roger Bannister – the world's first-ever sub-four-minute miler – and Chris Chataway, who briefly held the world record for 5000 m. During the early 1950s many of the middle- and long-distance track running records were held by Hungarians; in 1955 these included world records for 1500 m (Iharos and Tabori, jointly), 1000 and 2000 m (Rozsavolgyi), 3000 m, 5000 m and 10,000 m (Iharos), and in 1956 Rozsnyoi broke the world record for the 3000 m steeplechase. Igloi had demonstrated beyond doubt the value of systematic and intensive training and of interval training in particular.

The fact is that improvement of the aerobic system occurs most rapidly and most effectively when muscles are used at, or close to, their maximal aerobic capacity. At such levels of aerobic metabolism, a degree of anaerobic metabolism is inevitable, so lactic acid will build up and soon cause fatigue and restrict the training effect. This is where the intervals come in, since the rest periods allow the lactic acid to be flushed out from the muscle for buffering and removal. To encourage this flushing out of lactic acid, the 'rest' periods must be active, involving perhaps as much as 50% of the effort achieved during the interval. Once this flushing out is achieved, fatigue disappears and the next interval is possible, exerting a similar stress on the aerobic system. In this way, the aerobic system is stressed over the entire period of the training session, which may last for 1-2 hours.

There is a case for even shorter intervals in aerobic training, at least at the beginning of a training season. In intervals of about 100-150 m, oxygen released from myoglobin in the fibers will supplement that entering from the capillaries, so that the number of capillaries will be less likely to limit aerobic capacity, allowing oxygen consumption to be very high for this short period of time. This means that great stress will be put on oxidative pathways in the fiber, with the result that the activities of enzymes in them will increase quickly. The result is aerobic training of the muscle, provided that the intervals are run almost as fast as possible. As the activity of the oxidative enzymes increases, longer intervals should then be run to stress the oxygen supply system itself. Intervals of 300-400 m will increase capillary density as well as benefiting the aerobic system within the muscle fibers.

It is likely that these very short intervals will have a particularly beneficial effect on the aerobic threshold, for the greater the capacity of the aerobic system, the better it will cope with the end-products of the first part of the glycogen metabolism, including pyruvate. As a result more pyruvate (an end-product of glycolysis) will enter the (oxidative) Krebs cycle, so less will be converted to lactate.

During this training, the overall aerobic capacity of the muscle should increase dramatically, as evidenced by a decrease in the time taken to run a particular interval. The speed of recovery during the rest period is also an indication of improvement; how quickly does the pulse rate decrease to 120 bpm timed from immediately after the interval has been completed?

3 Long intervals (500 m to 2 km)

Long interval training improves three aspects of aerobic metabolism:

(1) cardiac output,

(2) control of blood distribution,

(3) control of the rate of glycogen mobilization in muscle.

Cardiac muscle is highly aerobic and responds to the stresses of long intervals in much the same way that skeletal muscle responds to short intervals, i.e. by increasing the number of mitochondria, the amounts of enzymes within the mitochondria and the capillary density. Intervals are needed because when the heart is working very hard it relies a little more on aerobic metabolism, and the products of this must be cleared by coronary blood during the gaps between intervals to allow the high workload to be sustained. Again, like skeletal muscle, the heart responds to exercise by enlargement of muscle fibers. This leads to an increased capacity which – together with more complete emptying – results in an increased stroke volume. For the same heart beat frequency, a trained heart can pump from two to three times the amount of blood as that of an untrained heart. Similarly to skeletal muscle, capillary density and mitochondrial volume are increased, ensuring that the aerobic capacity of the heart, which is already high, is even higher.

An increased blood flow to skeletal muscles must be accompanied by a decreased flow to ‘less vital’ parts of the body, including the intestines and liver. To reduce the blood supply to the intestines, training (and racing) should be carried out on an empty stomach and the largest meal of the day should be eaten some time after training has been completed.

Although long interval training may actually increase the amount of glycogen that can be stored in a muscle, its real benefit is to train the control mechanisms that regulate the rate of glycogen breakdown according to the demand of adenosine triphosphate (ATP). If breakdown is too fast, a valuable resource is wasted; if breakdown is too slow, performance is limited. To optimize glycogen utilization, the long intervals should be run almost as rapidly as possible but without causing total exhaustion, so that several repetitions can be completed in one training session. Each interval will use 40 g or more of glycogen, so that at the end of a hard training session little glycogen will be left in the active muscles. Some carbohydrate should be ingested as soon as possible after the exercise has finished and a carbohydrate-rich meal is essential before the next training session.

4 Longer distances (3 to 20 km)

Running 3-10 km at a pace corresponding to the anaerobic threshold will tell the athlete just how fast he or she can run without the dangers of 'anaerobic fatigue' or rapid depletion of glycogen stores. As some acid production will occur, factors affecting its removal from blood will also be trained, so improving the aerobic threshold. Use of the stopwatch will show how well the athlete's body is responding to this training. Longer distances (15-20 km) will have to be run below the anaerobic threshold and should improve the integration of all the aerobic processes.

5 Very long distances (30 km and more)

For marathon or ultra-marathon runners only, one long run of 30 km or more should be undertaken at a good pace, once a week. A run of this distance necessitates the use of some fat and so trains the ability of adipose tissue to mobilize fatty acids for oxidation by the muscles. If too much fatty acid is released, more will be oxidized by the muscle, which will then consume more oxygen, which could limit the power output. In addition, it may increase the plasma fatty acid level too much and so induce 'central fatigue'. If too little fatty acid is released, more glycogen will be used and glycogen stores will be depleted prior to the end of the run. The result is that fatigue will rapidly set in. It is necessary, therefore, to train the biochemical process of mobilization of fatty acid from adipose tissue so that it neither under- nor overresponds to the pace of running.

6 Hill training

Like weight training, hill training improves recruitment but has the advantage that it is more like normal running, so the 'right' muscles are used and therefore trained. Similar results may be achieved by running on sand. The intensity of the exercise can be varied by using hills of different gradients, but duration is also important since some fibers will fatigue early and others will then be recruited and hence trained. Jumping up hills can be beneficial, too, since it increases range of movement and strengthens the body as a whole.

7 Pool running

Running can also be done in the pool – either with a buoyancy aid (deep water running) or on the bottom of the pool.

Formerly used primarily as a method to rehabilitate injured athletes, pool running has taken on many other valuable roles, including:

- regeneration, restoration and recovery from heavy training loads,
- non-weight-bearing loading (reduces stress and trauma in the legs);

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*The topic of pool running or "aquajogging" will be dealt with in more detail in one of the next @-*Letters.*

- injury prevention;
- increases in strength and flexibility while working against a constant resistance;
- pool running adds variety to the program.

Two types of aerobic training are effective in a water workout:

(1) continuous working at 40-60% effort with minmal lactate in the blood (regeneration/recovery work),

(2) extensive efforts at 60-80% effort with minimal lactate buildup or oxygen debt encountered.

Taking up water running does not mean that one has to change his or her basic training plan. It is possibe to adapt whatever running is done on land to the pool.

8 Flexibility training

At each stride much of the energy absorbed as the front leg lands and flexes is not lost as heat but stored (mainly in the Achilles tendon and in the arch of the foot) to assist take-off on the next stride. It should follow from this that athletes with more elastic tendons will run more efficiently and there is some evidence that this is so. When a diverse group of 100 runners were divided into three groups according to measurements of their flexibility, the most flexible group ran significantly more economically at high speeds.

Although tendons have only a few cells it is likely that these can be influenced by exercises which place demands on the tendons so that the elastic component may be increased. Hopping and bounding exercises performed on the track or on a trampoline are considered to be most beneficial. Athletes should start with about 20 and build up to 100 bounds per session. Bounds are best done in the precompetition period. Bounds can cause injury, therefore one should stop if they cause pain.

9 Frequency, duration or intensity – Which is the most important element in training?

When an endurance athlete embarks on a training program, he has to decide one way or another how to structure his training. He or she has the choice between “long”, “intense” or “frequent” sessions. He or she does not know, a priori, whether it is better to train at low intensity over long periods, in very intense (and therefore short) bursts or frequently and with moderate intensity. When the total training volume reaches a certain level, the problem becomes more pressing. In fact, different training regimes with a similar degree of effectiveness can require quite dissimilar recovery times. For a top-class athlete, rest times count. At the same time, in the case of a “forced” reduction in training, it is as well to know what modification will have the most disastrous effects on one’s athletic form. If, for instance, the answer is a reduction in the number of training sessions, the next question is: Can this be compensated for by an increase in the duration of each session?

In this connection, one must realize that it is scarcely possible to demonstrate directly the degree of importance of each of these elements of training taken in isolation. To do so, it would be necessary to subject a large number of volunteers to a series of programs in succession. In each program, only one of the factors under examination would have to be modified. Moreover, it would be absolutely necessary to return to the original condition between the end of one program and the start of the next, i.e. an entirely untrained state. This enforced rest for the purposes of eliminating the effects of one period of training before starting the next would excessively prolong the experiment. However, this is the only possible way of comparing directly the relative effectiveness of different training regimes. To get round this obstacle, a group of American researchers (HICKSON et al. 1981, 1982, and 1985) had recourse to an indirect proof. They did not prove that a given type of training was more effective than another. On the contrary, they measured the amount of de-training, i.e. loss of form, which sets in when something important is changed in an established program. This "something", the importance of which is evaluated in this way, is either the frequency, the intensity or the duration of training. The principle of the experiment may be summed up as follows: First of all, everybody undergoes a period of endurance training:

Phase I: basic training, undergone by everyone:

- frequency: A times a month
- duration: B hours
- intensity: C km/h

At the end of this period, all the volunteers involved in these tests have improved their form.

There follows a period of reduced training. The reduction may be carried out in three ways: by reducing the frequency, the duration or the intensity of the exercises.

Phase IIa: de-training 1:

- reduced frequencies: ⅓ A, ⅔ A
- duration: B (unchanged)
- intensity: C (unchanged)

Phase IIb: de-training 2:

- frequency: A (unchanged)
- reduced durations: ⅓ B, ⅔ B
- intensity: C (unchanged)

Phase IIc: de-training 3:

- frequency: A (unchanged)
- duration: B (unchanged)
- reduced intensities: ⅓ C, ⅔ C

The researchers observed clearly differing effects depending on the reduced training regime selected. When the duration or the frequency was cut down in the program, the performance capacity was affected only very slightly. Reducing one or the other (but not at the same time!) caused the same slight drop in performance. The relative importance of the duration factor therefore seems to be the same as that of the frequency factor. However, in the case of reduced intensity, the de-training effect was much greater.

The conclusion to be drawn is that it is a reduction in intensity which diminishes most promptly the performance capacity acquired through endurance training. It is therefore by keeping up that element in particular that the initial form can be mostly maintained. Duration and frequency on the other hand may vary considerably, since a 30% reduction in the initial value has no major effect on the condition of the trained athlete.

In very concrete terms, this means that during a competition period, when travel makes it impossible to maintain the regularity and duration of training sessions, the coach should ensure, above all, that their intensity is maintained. This applies to all sports disciplines in which endurance plays a role of any significance (cf. MÖSCH 1985/1986).

Model Weekly Training Schedule to Accomplish 8:10/14:15 min Over 3000 m/5000 m (According to Bruce Tulloh)

Conditioning Phase

Session 1 (daily)

		10 min steady running
		5-10 min loosening and stretching exercises
		10 min steady running

Session 2 (at least 4 h after session 1)

Daily warm-up:		800 m jog
		5 min stretching exercises
		5 min trunk-strengthening exercises
		5 min steady running
MONDAY:	(a)	10 km fartlek on hilly course, with hard bursts
	or (b)	8-12 x 150-200 m hill run (10% slope) with jog down recovery
TUESDAY:		10 km steady run, starting at 3:45 min/km and increasing speed in the second half
WEDNESDAY:		8 x 300 m; 60-90 sec recovery
		10 min jog
		8 x 300 m; 60-90 sec recovery
THURSDAY:		3 km fast run (3:05 min/km)
		10 min easy run
		3 km fast run (3:05 min/km)
		10 min easy run
FRIDAY:		Rest or 30 min easy run
SATURDAY:		Cross-country race
	or	3 x 1600 m fast run; 5 min rest after each 3000 m warm-down
SUNDAY:		16 km steady run (60 min)

Pre-Competition Phase

Session 1 (daily except Sunday)

		10 min slow running
		5-10 min loosening and stretching exercises
		10 min steady running

Session 2 (at least 4 h after session 1)

Daily warm-up:		800 m jog
		5 min stretching exercises
		5 min trunk-strengthening exercises
		5 min steady running
MONDAY:	(a)	2 x 8 x 200 m (30-31 sec); 40 sec recovery between runs and 5 min jog between sets
	or (b)	5-20 x 100 m fast hill run (10% slope) with jog down recovery
TUESDAY:		10 km steady run (3:35 min/km)
		5 x 50 m high-knee stepping
		5 x 50 m bounding
WEDNESDAY:	(a)	6 x 1000 m (2:50 min); jog recovery
	or (b)	2 x 800 m (65-66 sec/400 m); 2:30 min jog recovery
		2 x 600 m (65-66 sec/400 m); 2:00 min jog recovery
		2 x 400 m (65-66 sec/400 m); 1:30 min jog recovery
		2 x 200 m (100% effort); 1:00 min jog recovery
THURSDAY:		8 km steady run
FRIDAY:		Rest or 30 min easy running
SATURDAY:		2-3 km time trial; 10 min rest
		2 x 400 m (100% effort); 3 min rest between
		2-3 km warm-down
SUNDAY:		13-16 km run (3:45 min/km) with 6 x 80 m acceleration runs at the end

Competition Phase

Session 1 (daily except Sunday when replaced by 8 km run)

10 min slow running

10 min loosening and stretching exercises

10 min steady running

Session 2 (at least 4 h after session 1)

Daily warm-up:	800 m jog
	10 min loosening and stretching exercises
	800 m steady run
	800 m with 4 x 80 m acceleration runs
MONDAY:	5 x 600 m (90-94 sec); 5 min recovery
	2-3 km warm-down
TUESDAY:	6 x 50 m high-knee stepping
	15 min steady run
	4 x 400 m tactical practice, striding (68 sec) and sprinting in response to coach's signal
	15 min steady run
WEDNESDAY:	6 x 400 m (65 sec); 60 sec jog recovery
	4 x 300 m (44 sec); 2 min jog recovery
	2-3 km warm-down
THURSDAY:	8 km run on grass (3:35 min/km)
	4 x 100 m acceleration runs
FRIDAY:	30 min steady run
SATURDAY:	Race
SUNDAY:	8-10 km fartlek

General Theme

FACTORS AFFECTING THE RESPONSE TO AEROBIC TRAINING

When discussing general trends in adaptations that occur in response to endurance training one must always remember these adaptations occur in individuals and that everyone does not respond in the same manner. The following factors can affect individual response to aerobic training:

1 Level of conditioning and VO_2max

The higher the initial state of conditioning, the smaller is the relative improvement for the same program of training. In other words, if two people, one sedentary and the other partially trained, undergo the same endurance training program, the sedentary person will show the greatest relative improvement – those who are less trained have the most room for improvement.

It appears that in fully mature athletes, the highest attainable VO_2max is reached within 8-18 months of heavy endurance training, indicating that each athlete has a finite attainable level of oxygen consumption. The conjecture that this finite range seems to be influenced by training in early childhood needs to be substantiated by experimental research.

2 Heredity

Maximal oxygen levels depend on genetic limits. This, however, should not be taken to mean that each individual has an exact VO_2max that cannot be exceeded. Rather, a range of VO_2max values seems to be predetermined by an individual's genetic makeup and the individual's highest attainable VO_2max falls in that range.

BOUCHARD et al. (1992) have concluded that heredity accounts for between 25% and 50% of the variance in VO_2max values. This means that of all factors influencing VO_2max, heredity alone is responsible for one quarter to one half of the total influence. World-class athletes who have stopped endurance training continue for many years to have high VO_2max values in their sedentary, deconditioned state. Their VO_2max values may decrease from 85 ml/kg/min to 65 ml/kg/min, but this deconditioned value is still very high.

> Heredity is a major determinant of aerobic capacity, accounting for as much as half of the variation in VO_2max values.

Thus, both genetic and environmental factors influence VO_2max values. The genetic factors probably establish the boundaries for the athlete, but endurance training can push VO_2max to the upper limit of these boundaries.

3 Age

Age can also influence VO_2max. However, VO_2max values that have been reported in the research literature could lead to an improper interpretation of true age differences if compared across ages. If two groups of endurance athletes, those who maintained their training intensity and those who reduced it, are considered, it turns out that for those who continued to train at the same intensity the rate of decline in VO_2max was attenuated. This indicates that age-related decreases might result partly from an age-related decrease in activity levels. This decrease is not an absolute trend: Endurance training of untrained elderly subjects results in substantial VO_2max increases (KOHRT et al. 1991).

4 Sex

Healthy untrained girls and women have much lower VO_2max values (20-25% lower) than healthy untrained boys and men. However, highly conditioned female endurance athletes have values much closer to those of highly trained male endurance athletes (about 10% lower).

5 Responders and nonresponders

For years, researchers have found wide variations in improvement in VO_2max with aerobic training (from 0-43%) in spite of exactly the same training program. In the past, scientists assumed that these variations result from differing degrees of compliance with the training program. Good compliers should show little or no improvement. The idea of comparing compliers with noncompliers has now been replaced with the concept of comparing responders with nonresponders. Given the same training stimulus, implying full compliance with the program, substantial variations occur in the percentage improvements in VO_2max values of different people. BOUCHARD (1990, 150) has now clearly established that the response to a training program is also genetically determined. Ten pairs of monozygotic twins completed a 20-week endurance training program. While there was a high degree of similarity in response (as expressed in the improvement of VO_2max) for each twin pair, improvement varied from 0% to nearly 41% across twin pairs. These results indicate that there will be responders (large improvement) and nonresponders (little or no improvement) among groups of people who experience identical training programs. This is a genetic phenomenon, not a result of compliance or noncompliance.

> When examining training effects, one must always remember that individual differences cause variation in subjects' responses to the training program. Even with identical programs, everyone will not respond the same. Genetics accounts for much of this variation in response.

6 Specifity of training

Physiological adaptations in response to physical training are highly specific to the nature of the training activity. Furthermore, the more specific the training program is to a given sport or activity, the greater the improvement in performance in that sport or activity. The concept of specificity of training is very important for cardiorespiratory adaptations. This concept is also important when testing athletes.

To accurately measure endurance improvements, athletes should be tested while they are engaged in an activity similar to the sport or activity in which they usually participate. STRØMME et al. (1977) studied highly trained rowers, cyclists, and cross-country skiers. Their VO_2max values were tested while they performed two types of work: uphill running on a treadmill and maximal performance of their specific sport activity. The important finding was that VO_2max values attained by all the athletes during the sport-specific activity were as high or higher than the values obtained on the treadmill. For many of these athletes, VO_2max values were substantially higher during their sport-specific activity.

The concept of training specificity was further illustrated in a study by MAGEL et al. (1975). They studied VO_2max improvements with swim training (1 h/day, 3 days/wk, for 10 wks). Subjects performed maximal treadmill running and tethered swimming tests both before and after training. The swimming VO_2max increased by 11.2% following the 10-week swim training period. However, the running VO_2max increased by only 1.5%, not a statistically significant change from the pretraining value. If the treadmill alone had been used for testing, the researchers would have concluded that swim training had no influence on cardiorespiratory endurance capacity!

One of the most elegant designs to study the concept of specificity of training involves one-legged exercise training, in which the untrained opposite leg is used as the control. In one study (SALTIN et al. 1976), subjects were placed in three groups: one group sprint-trained one leg and endurance-trained the other leg; one group sprint-trained one leg, while the other leg remained untrained; and the last group endurance-trained one leg, while the other leg remained untrained. Improvement in VO_2max and lowered heart rate and blood lactate response at submaximal work rates were found only when exercise was performed with the endurance-trained leg.

Much of the training response occurs in the specific muscles that have been trained, possibly even in individual motor units in a specific muscle. From the studies conducted in this area, it appears that this observation applies to both metabolic and cardiorespiratory responses to training.

Close attention must be given to selecting the appropriate training program. It must be carefully matched with the athlete's individual needs to maximize the physiological adaptations to training, thereby optimizing the athlete's performance.

7 Cross-training*

Cross-training refers to training for more than one sport at the same time or training for several different fitness components (such as endurance, strength, and flexibility) at one time. The athlete who trains by swimming, running, and cycling in preparation for competing in a triathlon is an example of the former, and the athlete involved in heavy resistance training and high-intensity cardiorespiratory training at the same time is an example of the latter.

Not much research data are available concerning multisport training. In any cross-training program of this nature, it is important to determine how best to partition the available training time to optimize performance in each of the sports. Although certain aspects of of training are the same for all endurance activities, most training is highly specific to a particular sport.

For the athlete training for cardiorespiratory endurance and strength at the same time, the few studies conducted to date indicate that gains in strength, power, and endurance can result. However, the gains in muscular strength and power are less when strength training is combined with endurance training than when strength training alone is done. The opposite does not appear to be true: Improvement of aerobic capacity with endurance training does not appear to be attenuated by the inclusion of a resistance training program (see for more information on this topic @-*Letter* 3/2003). In fact, short-term endurance can be increased by strength-training supplementation (cf. HICKSON et al. 1988).

*The topic of cross-training will be dealt with in more detail in one of the next @-*Letters.*

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