Module 4

Endurance

Introduction

Aerobic endurance

Aerobic fitness is primary for most sports. However, it is not the only fitness area and if it is focused on too much it can be detrimental to strength and power, which are equally, if not more, important in many sports. Trainers must think carefully about the fitness level they believe is appropriate for peak performance and then achieve that. For example, in elite football a high aerobic capacity is important, but for volleyball a moderate level will suffice. For most games, aerobic fitness governs how quickly one recovers between high-intensity sections, and how much distance can be covered in a game.

Anaerobic endurance

During anaerobic (meaning without oxygen) work, involving maximum effort, the body is working so hard that the demands for oxygen and fuel exceed the rate of supply and the muscles have to rely on the stored reserves of fuel. In this situation waste products accumulate, the chief one being lactic acid. The muscles, being starved of oxygen, take the body into a state known as oxygen debt. The body's stored fuel soon runs out; activity ceases and will not be resumed until the lactic acid is removed and the oxygen debt repaid. Fortunately the body can resume limited activity after only a small proportion of the oxygen debt has been repaid.

Anaerobic endurance, important for many sports, can be developed by using repetition methods of relatively high-intensity work with limited recovery periods. Both the lactate system and the adenosine triphosphate – phosphate creatine (ATP-PC) system should be trained, but targeted in the correct proportions for each sport. For instance, tennis focuses almost solely on the ATP-PC system, due to short bursts and frequent rest play pattern, whereas squash requires significant lactate system training as play is much more continuous.

Overview of the endurance module

In this module we look at how you can develop your aerobic endurance to meet the demands of your sport.

- Brian Mackenzie explains how you can assess and improve your VO_2max.
- Frank Horwill explains how to develop your aerobic endurance with an example training programme.
- Raphael Brandon explains how swimmers should develop their aerobic endurance – quality is better than quantity.
- Raphael Brandon explains how a heart monitor can help you develop your aerobic endurance.

The articles in this module are applicable to most sports.

VO_2max

Introduction

Aerobic endurance can be measured by the volume of oxygen you can consume while exercising at your maximum capacity. VO_2max is the maximum amount of oxygen in millilitres that you can use in one minute, per kilogram of body weight. Those who are fit have higher VO_2max values and can exercise more intensely than those who are not as well conditioned.

Factors affecting VO_2max

The physical limitations that restrict the rate at which energy can be released aerobically are dependent upon:

- the chemical ability of the muscular cellular tissue system to use oxygen in breaking down fuels
- the combined ability of cardiovascular and pulmonary systems to transport the oxygen to the muscular tissue system.

Improving your VO_2max

Numerous studies show that you can increase your VO_2max by working out at an intensity that raises your heart rate to between 65% and 85% of its maximum for at least 20 minutes, three to five times a week. The following are samples of

Astrand's workouts for improving oxygen uptake:

1. **1.** Run at maximum speed for five minutes. Note the distance covered in that time. Assume that the distance achieved is 1900m. Rest for five minutes, and then run the distance (1900m) 20% slower, in other words in six minutes, with 30 seconds' rest, repeated many times. This is equal to your 10K pace.
2. **2.** Run at maximum speed for four minutes. Note the distance covered in that time. Rest for four minutes. In this case we will assume you run a distance of 1500m. Now run the same distance 15% slower, in other words in four minutes 36 seconds, with 45 seconds' rest, repeated several times.
3. **3.** Run at maximum effort for three minutes. Note the distance covered in that time. The distance covered is, say, 1000m. Successive runs at that distance are taken 10% slower or at 3 minutes 18 seconds, with 60 seconds' rest, repeated several times. This approximates to your 5K pace.
4. **4.** Run at maximum effort for five minutes. Note the distance covered in that time. The distance covered is, say, 1900m. Rest five minutes. Cover the distance 5% slower with one and a half minute's rest.
5. **5.** Run at maximum effort for three minutes. The distance covered is, say, 1100m. When recovered, run the same distance 5% slower, ie three minutes nine seconds, with one minute's rest, repeated several times.

It is suggested that in the winter, sessions 1 and 2 are done weekly, and in the track season, sessions 3, 4 and 5 are done weekly (by runners from 800m to the half marathon). Although it would be convenient to use the original distance marks made by the duration efforts, this does not take into account the athlete's condition before each session, so the maximum effort runs must be done on each occasion when they may be either more or less than the previous distance run.

The maximum duration efforts are in themselves quality sessions. If the pulse rate has not recovered to 120 beats-per-minute in the rest times given, the recovery period should be extended before the repetitions are started. The recovery times between the reps should be strictly adhered to. These workouts make a refreshing change from repetition running. When all five sessions are completed within a month, experience shows substantial improvements in performance.

Assessing your VO_2max (Cooper test)

Run for 12 minutes on a track, as fast as possible, and record the distance covered. Calculate your VO_2max with the following algorithm:

- (Distance covered in metres - 504.9) / 44.73

Example: In 12 minutes you manage to run 3000m. This gives you an approximate VO_2max score of (3000-504.9)/44.73 = 55.8 ml/kg/min

Analyses of VO_2 max scores

Female (values in ml/kg/min)

Age	Very Poor	Poor	Fair	Good	Excellent	Superior
13-19	<25.0	25.0 - 30.9	31.0 - 34.9	35.0 - 38.9	39.0 - 41.9	>41.9
20-29	<23.6	23.6 - 28.9	29.0 - 32.9	33.0 - 36.9	37.0 - 41.0	>41.0
30-39	<22.8	22.8 - 26.9	27.0 - 31.4	31.5 - 35.6	35.7 - 40.0	>40.0
40-49	<21.0	21.0 - 24.4	24.5 - 28.9	29.0 - 32.8	32.9 - 36.9	>36.9
50-59	<20.2	20.2 - 22.7	22.8 - 26.9	27.0 - 31.4	31.5 - 35.7	>35.7
60+	<17.5	17.5 - 20.1	20.2 - 24.4	24.5 - 30.2	30.3 - 31.4	>31.4

Male (values in ml/kg/min)

Age	Very Poor	Poor	Fair	Good	Excellent	Superior
13-19	<35.0	35.0 - 38.3	38.4 - 45.1	45.2 - 50.9	51.0 - 55.9	>55.9
20-29	<33.0	33.0 - 36.4	36.5 - 42.4	42.5 - 46.4	46.5 - 52.4	>52.4
30-39	<31.5	31.5 - 35.4	35.5 - 40.9	41.0 - 44.9	45.0 - 49.4	>49.4
40-49	<30.2	30.2 - 33.5	33.6 - 38.9	39.0 - 43.7	43.8 - 48.0	>48.0
50-59	<26.1	26.1 - 30.9	31.0 - 35.7	35.8 - 40.9	41.0 - 45.3	>45.3
60+	<20.5	20.5 - 26.0	26.1 - 32.2	32.3 - 36.4	36.5 - 44.2	>44.2

Ideal VO_2 max scores for a selection of sports

VO_2 max	Sport
>75 ml/kg/min	Middle distance Runners (male), Cyclists (male)
65 ml/kg/min	Squash (male)
60-65 ml/kg/min	Rowers (male), Football (male)
55 ml/kg/min	Swimmers (female), Runners (female)
55 ml/kg/min	Weight Lifters (male), Rugby (male)
50 ml/kg/min	Volleyball (female), Baseball (male)
45 ml/kg/min	Fencers (female)

Brian Mackenzie

When winter's coming, use this programme to boost your VO_2max

A 15-minute running test around a 400m track (Balke test) can lead to revolutionary improvements in fitness in just 12 weeks. The object of the 15-minute test is to cover as much distance as possible. A secondary factor is that the distance run can predict VO_2max with 95% accuracy. I tested a male runner this way and estimated his oxygen uptake as 64mls/kg/min. A week later he paid £40 for a sophisticated treadmill VO_2max test at a British Olympic Medical Centre; they gave him 65mls/kg/min.

For the technically minded, here are a few VO_2max predictions:

Distance Run	Predicted VO_2Max (mls.kg.min)
4000m	56.5
4400m	61
4800m	65.5
5200m	70
5600m	75

As the distance run indicates current fitness levels, the same distance run can be used as a basis for further training. Let us imagine that an athlete runs exactly 4000m in 15 minutes. The target in 12 weeks' time is 4400m, which correlates to a 10% improvement in VO_2max. To achieve this, a minimum of four training sessions a week are required, which can be allocated on an every-other-day basis. Should a keen athlete decide on 12 sessions a week (twice-a-day training) there will be a correspondingly greater improvement in fitness, ie a greater distance run on the test.

Here is the procedure:

1. Run the test (in this example, 4000m in 15 minutes).
2. Halve the distance run on the test. In this case, 2000m. Once a week, run 4 x 2000m in 7.5 minutes with 60 seconds' recovery after each rep.
3. Double the distance run on the trial. In this example, 8000m (about five miles). Run this distance once a week in 33 minutes.
4. Calculate the time per lap. In this example, it is 90 seconds per 400m. (If the distance run was 5000m it would be 72 seconds/400m etc.) Halve this time (45 seconds), and subtract 8 seconds = 37 seconds. Once a week run a series of 200m repetitions in 37 seconds starting with 90 seconds' recovery, which decreases by 15 seconds after each 200m run, eg 37/90, 37/75, 37/60 down to 37/15. When you have reached the 15-second rest period, run the timed lap again and re-start from the beginning. Continue this until the time calculated cannot be recorded (either 200m in eight seconds, or 200m in 28 seconds).
5. Multiply the distance run on the original test by four, eg 4 x 4000m = 16K (about 10 miles). Run this distance once a week in 69 minutes.

The object of the exercise

The aim of all five of these training sessions is to improve the overall times each month. If the minimum volume is chosen, the sessions can be apportioned each week as follows:
Sunday: long run (4 x test run in 69 minutes or less).
Tuesday: repetition 200m with declining recovery.
Thursday: double-distance run (33 minutes).
Saturday: half the distance run x 4 with 60 seconds' recovery.

If the maximum volume is chosen each week, it is a good idea to do the double-distance run each morning and arrange the remaining sessions as above.

The physiological basis for this regime is as follows:

1) The training is specifically designed to improve the distance run in 15 minutes. If this is achieved, VO_2max (fitness) will correspondingly improve.

2) The world's leading work physiologists are agreed that VO_2max is best improved by running at between 80 and 100% of VO_2max.

To understand this we must remember the key:

Percentage of VO_2 Max	Related Pace
100	3k
95	5k
90	10k
80	Half marathon

We can now apply this key to each individual 3K and 5K pace (100-95% VO_2max). As fitness improves it will approach the latter more. Consider session three. This approaches the athlete's 10K speed (90% VO_2max). As fitness improves, it will also become a lactate response run in the range of 90% to 95% VO_2max. If we analyse session four, this approximates to the 1500m speed which is 110% VO_2max. Finally, session five is analogous to half marathon speed, as the four x the distance run improves from 69 minutes to 63 minutes, which will be 80% VO_2max.

What is a lactate-response-run?

I have mentioned that session three with improved fitness will become a lactate-response-run. Many athletes are mystified by this term. If a person goes for a jog, the amount of lactate circulating around the body will be negligible and the activity can continue for a very long time. If, however, the individual ran 800m full out, the body would be saturated in lactic acid, for no other middle-distance event produces so much saturation. This is why the great Olaf Astrand suggests that all runners should race 800m regularly, because they will be better able to cope with lesser amounts of lactate accumulated in longer and slower races.

In a lactate-response-run we do not want the former (jogging), nor do we desire the latter (800m speed). We require a point in our running speed just below the level where lactic acid begins to accumulate rapidly which we can maintain for four miles (6.5K). Now this cannot be our best 5K speed, nor is it our best 10K speed, for it will be too slow. It is between the two. When we get bogged down for some time with the same VO_2max figure, it is the lactate-response-run that will improve our fitness further with less likelihood of injury doing faster work on the track.
Jack Daniels has evolved a highly accurate table for response-run speeds based on an athlete's 3K time, and when compared to laboratory obtained lactate levels of elite athletes, it is identical with regard to speed per mile to be run.

Here is the table:

Best 3k Time	Suggested Lactate Response run (4 miles)
7 min 30 sec	4 min 16 sec/mile
8 min 30 sec	4 min 53 sec/mile
9 min 30 sec	5 min 40 sec/mile
10 min 30 sec	6 min 23 sec/mile
11 min 30 sec	7 min 05 sec/mile
12 min 30 sec	7 min 45 sec/mile

It is suggested that such runs are done over an exact mile circuit so that times can be monitored more easily. If you are a heart rate monitor enthusiast, a rough guide is that a lactate-response-run is not to be executed at less than 90% of maximum heart rate or more than 95% of maximum.

Start in the winter

After 12 weeks on the outlined programme a second test is carried out, and the further distance covered must inevitably lead to new calculations resulting in progressively faster sessions. This type of training is best started in the winter and continued throughout the year, with modifications made to accommodate specific race requirements. For example, session two, 4 x half the distance run in 7.5 minutes, can be altered to 8 x a quarter of the distance run with three minutes 45 seconds' recovery. Session four, repetition 200m, can be altered to 400m reps at the same speed with the same recoveries as for the 200m. This, of course, will result in fewer reps being done.

So far we have discussed mainly aerobic fitness. The ability to sprint is a major asset in most sports. Basic speed is tested by running 40 yards (36.6m) full out from a standing or crouch start. The general goal is for males to get well below five seconds and for females to get well below six. Whatever figure is recorded, this can predict the potential 400m time with 95% accuracy using this formula: 40 yards time x 10 + 2 seconds = male 400m potential time; 40 yards time x 10 + 3 seconds = female 400m potential time. Thus a male who records exactly five seconds has the potential to run 400m in 52 seconds. A female who records six seconds has a potential 400m time of 63 seconds. When the 400m potential time has not been achieved, it is usually because sprint training repetitions have not exceeded 200m. The burning of sugar (glycolysis) in a 400m race starts after 300m, so work involving 350m full-out sprints is required.

Small amounts of sprint work done every other day in winter will get the reflexes toned up. All distance runners should have a sprint coach as well as their own distance running coach. To ignore this often leads to the athlete becoming a one-pace runner.

Frank Horwill

Why high-intensity training is a better model than high-volume training for swimmers, especially sprinters

It is probably fair to say that most swimmers and swim coaches see the number of hours spent in the pool as the main ingredient of swimming success and distances of 6K to 10K per day are not uncommon in elite swimming circles. Is this really the key to success, or is there an alternative approach that can produce even better results? This section aims to stir up the debate by suggesting that the traditional high-volume model of training will not optimise performance, especially for 100m and 200m swimmers.

This is written not from a swimming coach's perspective, but in the light of research on swim training. Scientific analysis of the demands of competitive swimming and running training methods has been shown to optimise performance. Swimmers should read on with open minds and may then choose to apply some of the principles to their own training programmes.

Research into the effects of high-volume swim training on performance suggests there is no advantage to piling on the kilometres. The legendary US physiologist Dave Costill has undertaken a great deal of research on swim training over the last three decades. In one study his team of scientists followed two groups of swimmers over a 25-week training period. Both groups began with once-daily training, but one group moved to twice-daily training in weeks 10 to 15, reverting to once-daily for the rest of the study period. At no stage of the 25-week training period did this group show enhanced performance or increased aerobic capacity as a result of their extra training. Basically, it was a waste of time.

In another study, Costill tracked the performance of competitive swimmers over a four-year period, comparing a group averaging 10K per day with a group averaging 5K per day, in relation to changes in competitive-performance-time over 100, 200, 500 and 1600m. Improvements in swim times were identical for both groups at around 0.8% per year for all events. Again, even though one group did twice as much training, both groups benefited to the same extent in the long term.

To quote Costill directly: 'Most competitive swimming events last less than two minutes. How can training for three to four hours per day at speeds that are markedly slower than competitive pace prepare the swimmer for the maximal efforts of competition?'

Research from France supports Costill's conclusions. A team of scientists analysed the training and performance of competitive 100m and 200m swimmers over a 44-week period. Their findings were as follows:

- Most swimmers completed two training sessions per day.
- Swimmers trained at five specific intensities. These were swim speeds equivalent to two, four, six and a high 10mmol/L blood-lactate concentration pace and, finally, maximal sprint swimming.

- Over the whole season, the swimmers who made the biggest improvements were those who performed more of their training at higher paces. The volume of training had no influence on swim performance.

Feeling comfortable is not the point

The only conclusion to be drawn from this research is that faster and not longer training is the key to swimming success. Nevertheless, the high-volume, low-intensity training model probably remains the most common practice among elite swimmers, with even sprint swimmers focusing on clocking up the kilometres rather than more race-pace-specific training.

One of reasons for this high-volume bias is that swimmers and coaches believe that swimming technique, efficiency through the water and the 'feel' of the stroke are optimised by spending many hours in the pool. I have heard swimmers say they do not feel as comfortable in the water and confident about their technique unless they complete high doses of training. As a non-swimmer I am happy to admit my ignorance and to concede that the technical aspect of swim training is very important. However, the idea that high-volume training equates to superior race technique has no logical basis. If you told a 100m runner that the best way to optimise his sprint technique at maximum speed would be to complete many miles a week at 10K pace, you would be laughed off the track. Track sprinters focus on workouts and technical drills carried out at high intensity and positively avoid low-intensity/high-volume training in the belief that it inhibits power development.

The same must be true of swimming to a large extent. If a swimmer wants to increase stroke efficiency and technique during a competition, surely the best way to do this is to train at target race-pace. The more training time is spent at target race-pace, the more comfortable it will feel in competition. Dave Costill says: 'Large training volume prepares the athlete to tolerate a high volume of training but likely does little to benefit actual performance'. When swimmers talk of 'feeling comfortable' in the water, they may be referring to the sub-maximal speeds they perform in training, not the maximal efforts required in competition. Not only does high-volume training offer no benefit for swim performance, it may have negative effects. Two known consequences of high-volume training are depletion of glycogen muscle stores and fatigue of the fast-twitch muscle fibres, both of which will reduce the effectiveness of high-intensity race-pace training sessions and severely compromise any competitive performance.

Research has also shown that periods of high-volume training reduce the force production in the fast-twitch muscle fibres, which are essential for producing the fastest swim speeds. It has been shown that sprint swimmers have quite high proportions of fast-twitch muscles, over 60% in the deltoid and quadriceps. High-volume training does nothing for these fibres: indeed, it will dampen their force production by reducing the shortening velocity of the muscle contraction.

In this way, high-volume training can change fast-twitch fibres into those of the slow-twitch variety.

This probably explains why 'tapering' is so effective at improving performance for swimmers, as the fast-twitch fibres are able to recover during the period of low-volume training. It is known that maximal power increases after a tapering period, probably due to the fast-twitch fibres reproducing their high-velocity contraction properties. The French researchers mentioned above analysed the effects of tapering on swim performance and found that swimmers who used the most severe tapers, reductions of about half normal training volume, produced the biggest improvements in performance.

This begs the following questions:

- If such dramatic tapers in training are required to optimise performance, why are training volumes so high in the first place?
- Would it not be better for swimmers to develop power in a positive fashion during the training period?

Examination of the demands of sprint swimming events will help to answer these questions.

The metabolic demands of swimming

The shorter the swimming event, the greater the demand on the anaerobic energy systems. This is particularly true of the 50m, 100m and 200m events, lasting from around 20 to 120 seconds. The longer events, from 800m upwards, demand a larger contribution from the aerobic energy system. Evidence for this comes from blood-lactate concentrations following 100m and 200m competition swims, which are a very high 16 to 20mmol/L, suggesting that a great deal of energy is derived from the anaerobic breakdown of glycogen, resulting in lactic acid as a by-product. The highly anaerobic nature of sprint swim events would support the argument for higher-intensity and lower-volume training.

Some athletes and coaches go wrong by assuming it is best to do training that will reduce blood-lactate concentrations. This philosophy is based on the idea that high lactate is bad and will have a negative impact on performance. This leads to training programmes that focus on 'lactate threshold' training to improve the turnover of lactate and enhance the ability of the aerobic systems to produce more of the energy required for the event.

There are two problems with this model of training:

1) You need to be careful about assuming that a high lactate level is a bad thing. Remember that lactic acid is the by-product of anaerobic breakdown of glycogen. Lactic acid splits into the H+ ion and the lactate ion. It is the acidic H+ ion that is the bad guy, interfering with force production in the muscles and reducing the rate of glycolysis, thus slowing the athlete down. The lactate ion simply diffuses through the muscle and into the bloodstream, with no evidence to suggest it has any negative impact on muscle function or energy production. In fact, the lactate ion can be recycled in the energy production cycle and used positively to help produce energy. So a high level of lactate in the blood is not bad in itself: it is simply an indicator that a lot of anaerobic energy production is occurring. The training adaptation you are seeking is not a reduction in lactate production, but rather an increase in the buffering of the H+ ion. Training at high intensities and so generating high levels of lactic acid helps the body get used to the increase in H+ in the muscles and improve its ability to buffer the acid.

2) Anaerobic glycolysis involves the fast breakdown of glycogen into energy-giving phosphates, while aerobic glycolysis involves a much slower breakdown. Without the anaerobic energy systems, maximal power and high speeds would be impossible, as the muscles would not get a fast enough supply of energy. If you want high power you have to have high levels of anaerobic energy supply.

For sprint swimming, anaerobic capacity is the good guy and it needs to be developed. If an event places great demands on the anaerobic system, the athlete needs to become more anaerobic. This may seem odd to those with traditional beliefs about training, but it is true. By focusing on high-volume aerobic training to reduce lactate levels you are in fact compromising your anaerobic fitness, which is the most important attribute for competitive success in sprint swimming.

For sprint swimmers, lactate threshold training geared to keeping lactate levels low is irrelevant. For swim distances up to and including 200m, the accumulation of high levels of lactate does not matter: indeed, it is probably a good thing as it reflects a good anaerobic capacity. For longer events, such as 800m and 1500m, where the aerobic system is much more important, lactate threshold training would be relevant, as swimmers need to maintain an intensity level for much longer, relying on the aerobic energy system.

The race-pace model of training

The implication of all the research mentioned above is that spending more training time at high-intensity levels, at and above race-pace, will offer greater benefits than swimming lots of kilometres per day at much slower than race speeds.

In the world of running, thanks to the influence of pioneering physiologists and coaches such as Frank Horwill, Veronique Billat, Jack Daniels and Owen Anderson, the focus of training is now on ‘pace’ rather than lactate levels or heart rates. By using pace to monitor the intensity of training, the athlete is switching into a performance mentality, ensuring the training is specific to the competitive event.

Middle-distance running coach Frank Horwill created a five-pace system of training, which involves performing regular, quality training sessions at two paces higher than race-pace, race-pace itself and two paces slower than race-pace. If you are a 1500m runner, you will complete interval workouts at 400m, 800m, 1500m, 5000m and 10,000m race-paces. This model of training breeds a philosophy that values high-intensity ahead of high-volume.

The coaches referred to above also recognise that different events call for different kinds of training. The 5K running event, which takes about 12 to 15 minutes, requires a high proportion of aerobic training and 5K-pace-specific workouts, while the 800m event, lasting about two minutes, requires a high proportion of anaerobic training and 800m-pace workouts. I would argue that this kind of training model would serve competitive swimmers much better than the traditional high-volume approach.

There is evidence that the difference between swimmers who reach the Olympics and those who do not is due more to the distance achieved per stroke than to stroke frequency. The way to increase your distance per stroke is to increase the force generated by the active muscles and achieve an optimum position in the water. This is best achieved by high-intensity training, with the aim of developing power in the water at race-pace.

How can swimmers change their training to enhance power at pace speeds?

Again, there may be lessons to learn from running. The 100m swim takes about 50 seconds, and so is similar to the 400m track event; the 200m swim takes about 110 seconds and so is analogous to the 800m running race. It may therefore be possible for swimmers to improve their performances by modelling their training on that of middle-distance and long sprint track athletes.

For example, an international 800m runner will carry out a preparation period of aerobic capacity training with continuous running at 10K pace and slower, plus interval training at 5K pace. The 200m swimmer's equivalent could be the usual high-volume training programme.

This base training phase will be followed by more specific training, with more 5K and 10K pace runs and some more interval workouts for the anaerobic system, at 800m and 1500m pace, probably about three times a week. The 200m swimmer's equivalent could be to maintain a fairly high volume but include more above-lactate-threshold-pace workouts and race-pace or close to race-pace interval workouts three times a week: for example, 10 x 100m at 400m race-pace, with 60 seconds' rest.

This phase is followed by a very intense pre-competition phase of training, the goal of which is to maximise the athlete's anaerobic capacity. Aerobic training is cut to a minimum maintenance level, and high-intensity anaerobic sessions at 400m, 800m, and 1500m paces performed about five to six times a week. For the swimmer, this could involve a morning swim at an easy lactate-threshold pace or below, with very high-quality race-pace and faster-than-race-pace interval workouts in the evening. For example, eight x 50m at 200m race-pace, with 60-seconds rest.

The competition phase for runners will simply maintain aerobic and anaerobic fitness with maintenance training and plenty of recovery between races. For the swimmer this could involve some 'aerobic' slow-speed workouts and some race-pace and sprint workouts, probably limiting training to five to six times per week. The best middle-distance runners probably perform a maximal sprint workout once a week throughout the year to keep speed up to scratch. Swimmers could also incorporate this into their programmes with, for example, 10 x turn into 20m max sprint with three minutes rest, once a week.

I have argued, based on research, analysis of the energy demands of swimming races and the training methods of comparable athletes, that it is best for swimmers to focus on high-intensity rather than high-volume training. More specifically, swimmers would benefit from plenty of race-pace training to develop power and efficiency in the water at the speeds they use in competition.

Raphael Brandon

How to use heart rate to quantify your fitness training intensity

Articles in *Peak Performance* often detail elite and complex aerobic training methods to boost endurance performance, VO_2max and lactate threshold. These articles typically refer to target training intensities and heart rates to achieve, say, a new 10K or marathon best. They recommend high-intensity training, with very high target heart rates, to complement the longer 'steady state' sessions at more moderate intensities.

However, using target training intensities and heart rates is also useful for those of us whose aerobic training is aimed at improving general health and fitness, or as general conditioning for a recreational sport. In this more modest form, aerobic training involves an endurance activity, such as cycling, running or rowing, performed continuously for a certain amount of time, usually 20 to 30 minutes. It is recommended that if this kind of activity is performed three to five times a week, it will bring about optimum benefits. Obviously if you do more you will get fitter, but as a general rule, three to five x 20 to 30 minutes a week yields a good fitness reward for the amount of time invested, and so is optimal for general fitness needs.

It is also advisable that, with this kind of aerobic training, the exercise intensity should be moderately hard. The American College of Sports Medicine (ACSM) officially recommends that the optimal intensity is between 60% and 80% of VO_2max. VO_2max is the maximum amount of oxygen, in millilitres, one can use in one minute per kilogram of bodyweight. It is the standard measure of aerobic fitness. However, it is impossible to maintain maximal oxygen use for longer than about eight to 10 minutes. Thus, for general fitness training, one should aim to be at 60% to 80% of maximum capacity and maintain this level for 20 to 30 minutes. This intensity is comparable to the training levels elite athletes would use on their 'steady state' sessions. When performing some of the more advanced interval sessions, elite athletes will be at intensities greater than 85% VO_2max. At the other extreme, activity at an intensity of 40% VO_2max is likely to improve health but will not significantly improve aerobic fitness.

Take the case of Joe

It is possible to estimate your exercise intensity as a percentage of VO_2max from your training heart rate. This is very useful, for elite and recreational athlete alike, because by monitoring your heart rate you can quantify your training effort and target the correct intensity for maximum benefits. These calculations are possible because of the linear relationship between heart rate (HR) and oxygen use (VO_2) with increasing rates of work. For example, if Joe is sitting down doing nothing, his resting HR might be 70bpm. At this HR, VO_2 would be at its baseline level, which is approximately 3.5 ml/kg/min. If Joe starts to walk, his HR may increase to around 100bpm as the VO_2 goes up to cope with the extra energy demand. If Joe now breaks into a jog, his HR will go higher again, up to 140bpm, say, as VO_2 increases further. Then, if Joe runs as fast as he can for three minutes, his HR might go up to its maximum of 190bpm. At this point Joe will have reached his VO_2max. Therefore, at VO_2max, HR is also at maximum and at a percentage of VO_2max, there is a corresponding percentage of HRmax. This relationship has been shown to hold true across sex, age and exercise type. The ACSM suggests a correlation that looks like this:

VO_2max	HRmax
40%	55%
60%	70%
80%	85%
85%	90%

These values are derived from various studies which have compared VO_2 with HR and determined regression equations for percentage HRmax versus percentage VO_2max.

Revising the ACSM formula

These target values of percentage HRmax provide a means of quantifying exercise intensity to optimise training results. If the optimal training intensity is 60% to 80% of VO_2max, then according to the ACSM the corresponding optimal training HR is 70% to 85% of HRmax. However, the ACSM made these official recommendations in 1991. Since then, a study by David Swain and his US-based research team has criticised the mathematical methods used to derive the regression equations in previous research. Using more correct statistical procedures, they re-examined the relationship between percentage VO_2max and percentage HRmax and found that the ACSM formula underestimates HR at the target values of percentage VO_2max. Their results led to a regression equation of *percentage of HRmax* = 0.64 x % VO_2max + 37. This produces the following figures:

VO_2max	HRmax
40%	63%
60%	75%
80%	88%
85%	92%

Therefore, using these results, the optimal training HR range for general aerobic fitness is 75% to 88% HRmax, significantly higher than the 70% to 85% HRmax from the ACSM. For Joe, with his HRmax at 190bpm, using Swain et al's method, his target HR range is 143 to 168bpm, as opposed to the ACSM's recommended range of 133 to 161bpm. The improved research from Swain et al thus suggests that the training HR should be pushed up a little to 75% to 88% HRmax to bring about optimum results.

For elite athletes, Swain et al showed that percentage HRmax for the same percentage VO_2max were slightly higher compared to average. Therefore, for steady state training, an HR range of 77% to 89% VO_2max would be appropriate for an elite athlete. For advanced interval training, the intensity must be above 85% VO_2max or above 92% HRmax. For example, during a session comprising 6 x 800m runs at 5K pace, the training intensity will be at 90% to 95% VO_2max. This would correspond to a training HR of 95% to 97% HRmax.

We can see clearly from these examples that knowing accurately what percentage HRmax corresponds to a target percentage VO_2max is very useful for both the average and the elite athlete. By using the formula derived by Swain et al, we can calculate a target training heart rate for the particular goal of the individual. So, how precisely is HRmax calculated?

The easiest and best-known method is to use the formula *220 – age*. This is the method recommended in the ACSM guidelines. However, the actual derivation for this regression equation has never been published. It is used since it is a simple way to get a good estimate of HRmax. In an attempt to be more accurate, numerous cross-sectional studies have been done to investigate the relationship between HRmax, age and other factors. A paper by Londeree and Moeschberger from the University of Missouri, Columbia, collates the data from all these studies in order to bring together the findings.

What they show is that HRmax varies mostly with age, but the relationship is not a linear one. Thus the 220 – age formula is slightly inaccurate. For adults under 30, it will overestimate HRmax and for adults over 45 it will underestimate HRmax. This is especially true for well trained over-45s whose max HR does not reduce as much as with sedentary individuals of the same age. Londeree and Moeschberger suggest an alternative formula of *206.3 – (0.711 x age)*. Similarly, Miller et al from Indiana University propose the formula *217 – (0.85 x age)* as a suitable HRmax calculation. In my experience, it is the Miller formula which gives appropriate estimates when calculating HRmax from age alone.

Swimming heart rates are lower

Londeree and Moeschberger also looked at other variables to see if these had an effect on HRmax. They found that neither sex nor race make any difference. However, HRmax does vary with activity and fitness level. Studies have shown that HRmax on a treadmill is consistently five to six beats higher than on a bicycle ergometer and two to three beats higher than on a rowing ergometer. Heart rates while swimming are significantly lower still, around 14bpm, than for treadmill running. Running and Versaclimber show similar HRmax.

Londeree and Moeschberger also found fitness levels lead to a variation in HRmax. Elite endurance athletes and moderately trained individuals will have an HRmax three or four beats lower than a sedentary individual. However, as already stated, this is only true for young athletes; well trained over-50s are likely to have a higher HRmax than that which is average for their age.

This is of utmost relevance to those using the rower or bicycle or those who are very fit, since training HRs will have to be calculated differently. To do this, Londeree and Moeschberger offer us another formula, a slightly more complicated interactive equation to calculate HRmax for different ages, activities and fitness levels. However, it is very difficult to use without a calculator and a degree in mathematics! (The details are at the end of this article.)

My own suggestion

Having outlined various methods for calculating HRmax, I would recommend the following, which combines the Miller formula with the research from Londeree and Moeschberger. Use the Miller formula of HRmax = 217 - 0.85 x age for running and Versaclimber training with average trainees.

- Subtract three beats for rowing training.
- Subtract five beats for bicycle training.
- Subtract three beats from these estimates for elite athletes under 30.
- Add two beats for 50-year-old elite athletes and add four beats for 55+ years.

Here is a chart to help you.

age	run/ climb		row		bike	
	average	elite	average	elite	average	elite
20	200	197	197	194	195	192
25	196	193	193	190	191	188
30	192	189	189	186	187	184
35	187	187	184	184	182	182
40	183	183	180	180	178	178
45	179	179	176	176	174	174
50	175	177	172	174	170	172
55	170	174	167	171	165	169
60	166	170	163	167	161	165

One question that you may be justified in asking is, who cares? Will all these complicated percentages and formulae actually make a difference, when the old ACSM recommendations are so straightforward? The point is that, if you want to use heart rate monitors, it serves little purpose unless you know *accurately* what training intensity the measurement represents. For example, a 45-year-old jogging to get fit should maintain 60% VO_2max for 20 to 30 minutes' continuous run. Using the old ACSM recommendations, they would be aiming for 70% HRmax. HRmax would be estimated at 175bpm, using the 220 – age formula. This gives a target training HR of 123bpm. However, the jogger's HRmax is more likely to be 179bpm and, following Swain et al, target training HR should be 75% HRmax. These two changes give a revised training HR of 134bpm, a massive 11bpm difference in target HR. If our 45-year-old had followed the old recommendations, their training would have been below optimal intensity, at 50% VO_2max, and they would not have got the most from the invested training time.

These inaccuracies can also disadvantage the elite athlete. For example, a 25-year-old elite cyclist using the 220 – age formula may think his HRmax is 195bpm. However, it is more likely to be only 188bpm. This could mean he is overestimating target training HR for certain sessions, which can be undesirable if mileage rather than intensity is the aim of the session.

The take-home message of this article is a word of warning if you use traditional calculations to quantify training intensities. If 60% VO_2max is the minimum intensity for aerobic fitness improvements, then 75% and not 70% HRmax is the minimum training target HR. However, using a range of 75% to 88% HRmax for training targets is probably best. To calculate HRmax, the simple 220 – age formula is not always accurate. The alternative formulas provided will give you more accurate estimates.

For beginners and individuals training for a healthy fitness level, or for a recreational sport, I recommend that you calculate your HRmax for your chosen training activity and then the 75% HRmax training target. During your workouts, use an HR monitor or take your pulse and make sure that you put in enough effort to get your HR to the required level for a fitness benefit.

For elite athletes, use the new formulae to accurately calculate your maximum and target heart rates. Remember, tough interval sessions need to be really tough, so make sure your HR reaches around 95% HRmax. However, sometimes you need to keep training moderate, so aim for 77% to 89% HRmax for steady-state training.

Summary data

Target intensity for health benefits = 40% VO_2max = 63% HRmax
Target intensity for aerobic fitness = 60-80% VO_2max = 75-88% HRmax
Target intensity for elite training = >85% VO_2max = >92% HRmax

Swain et al equation: % HRmax = 0.64 x % VO_2max + 37
Miller et al formula: HRmax = 217 - (0.85 x age)
Londeree & Moeschberger interactive formula: training HRmax =
199.1 + 0.119 x AEF4 + 0.112 x AE + 6.28 x EF3 + 3.485 x F2 + 2.468 - 0.0006 x A4 - 0.591 x A

A = age; A4 = (age 4)/1000; E = exercise type,
If run = 1, if bike = 0;
If sedentary F2 = 1, otherwise F2 = 0;
If active F3 = 1, otherwise F3 = 0;
If endurance trained F4 = 1, otherwise F4 = 0

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