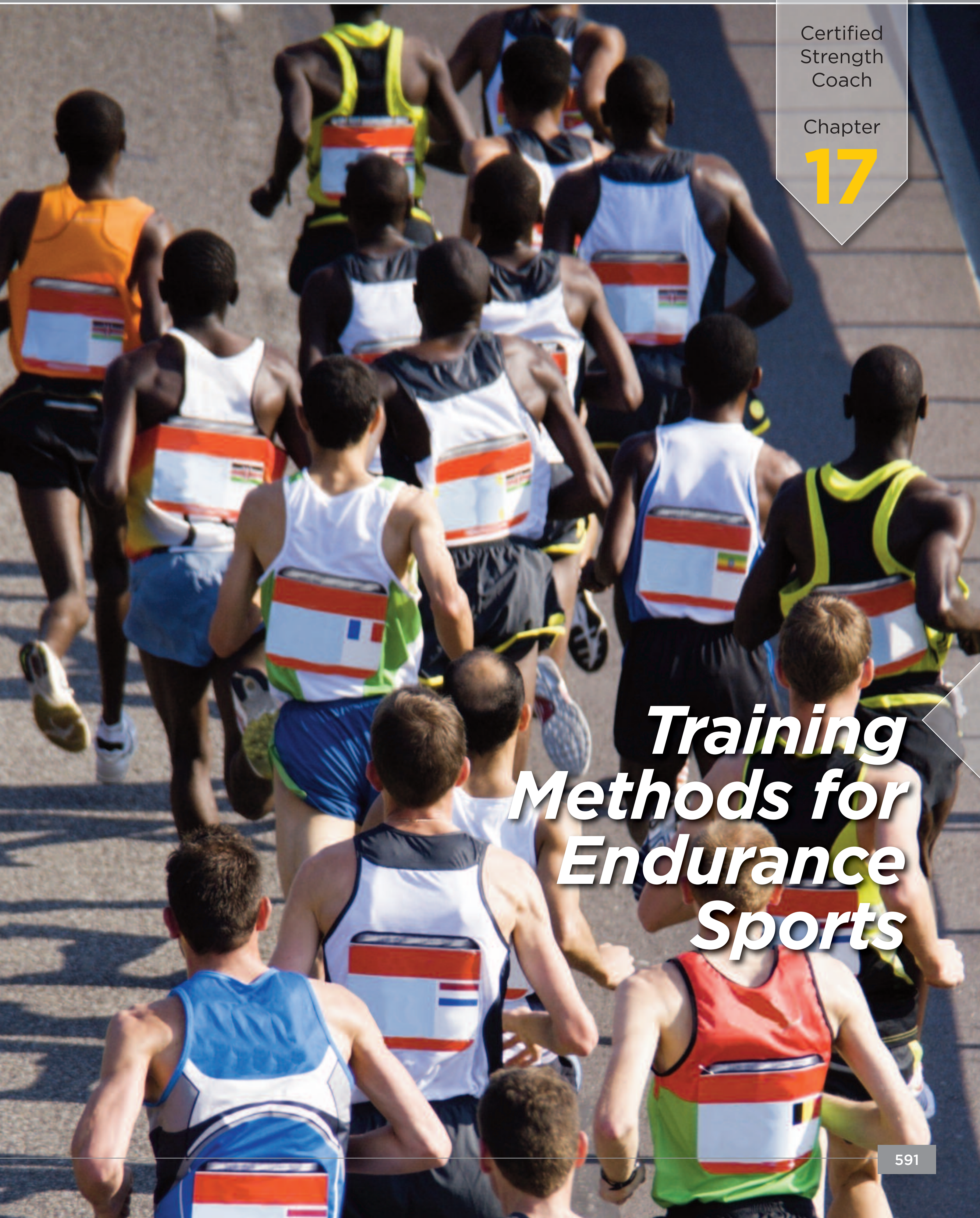
Chapter 17

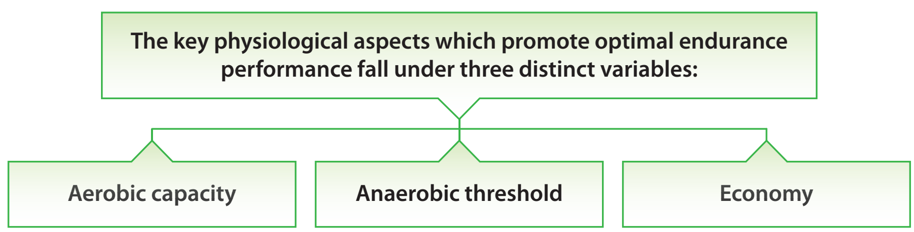


Training Methods for Endurance Sports

Strength and Conditioning for Endurance Athletes

Many methods used to train elite athletes for endurance sports are based on empirical evidence and successful routines shared among athletes; thus, some of the concepts in this chapter have not been published in peer-reviewed literature. Research relies on the stringency of the scientific method, which often creates limitations to real-world applications for coaching and conditioning. Training age, fitness level, training cycle, adherence to research protocol, and the type of sport are all variables that present potential challenges to an experimental design that may confound scientific conclusions. Additionally, the relatively short length of many studies can reduce the strength of the conclusions and the applicability to elite-level sports. The information presented in the following text relies on strategies applied by successful athletes and coaches, with progressively improved race times functioning as the supportive evidence for increases in endurance performance.

Figure 17.1 Key Components to Endurance Performance



The combination of the above three elements primarily explains the variance in performance among long-distance runners. The aim of this chapter is to describe the underlying physiology of these three components and explain the science behind the various training methods used to optimize performance in endurance competitions. However, as the influences of various types of training on these components are equivocal in research, and in some cases contradictory, it becomes very difficult to rely on research alone. For this reason, only the training methodologies associated with both supportive research and the physiological adaptations empirically linked with improvements in competitive racing are presented.

Aerobic Capacity

An individual's cardiovascular endurance capacity (aerobic capacity) is dictated by his or her ability to produce energy from oxygen. In the 1970's, Dr. Kenneth Cooper termed this "aerobic" energy, which is produced in the mitochondria of cells [1]. Most individuals probably recall 7th grade biology where mitochondria were referred to as the "powerhouse" of the cell. They were given this nickname due to the fact that they function similar to microscopic engines. They use oxygen to strip hydrogen ions (H^+) from carbon fuels (derived from food) to produce energy along with a metabolic "exhaust" consisting of heat, water, and carbon dioxide. Aerobic energy is much more sustainable than the anaerobic processes of energy production because it can be formed from many different substrates, and during homeostatic conditions the by-product is neutral. Anaerobic energy on the other hand is limited by storage, produces less total energy, and due to the lack of oxygen yields H^+ as a byproduct that can lead to acidity. As clarified in previous text, this increase in the pH balance challenges the body's internal environment. Oftentimes an athlete is considered "out of shape" if his or her aerobic efficiency is limited. This is due to a lower availability of oxygen to working tissues and muscular inefficiency. When an aerobic athlete does not have an efficient aerobic system they must increasingly rely on the short-lived anaerobic pathways; which is associated with premature fatigue.

The limit to aerobic capacity is referred to as VO_2max, which is primarily determined by an individual's ability to deliver oxygen-rich blood to working muscles [2]. The size, concentration and density of the aerobic machinery within muscle cells (e.g., capillaries, mitochondria, and respective enzymes) are important; however, not nearly as important as an individual's ability to deliver oxygenated blood [3]. For example, when an athlete begins training he or she must increase the delivery of oxygen-rich blood to working tissues. The progressive increase in training intensity elicits a greater demand for oxygen from working muscles; in response, the heart pumps faster as blood vessels expand to facilitate a heightened delivery system. This demand continues linearly with increasing intensity such that an individual's heart rate (HR) rises proportionally to his or her work rate. In efforts to satisfy the metabolic demands of the working tissues, the body looks for all sources of available oxygen; therefore, blood flow is shunted away from the digestive organs, kidneys, and areas of lower need in order to supply oxygen where it is needed most urgently. This continues until the blood supply to the brain becomes compromised, triggering a "defensive control" of blood flow to the working muscles. Once the brain begins regulating ongoing blood supply to the working tissues, aerobic metabolism will not be able to match steady-state energy demands; forcing skeletal muscle to use anaerobic sources of energy [4]. Consequently, the use of a less-sustainable metabolic system leads to acute fatigue.

Although VO_2max is reflective of aerobic capacity, once a certain level is reached it is actually less of a factor in elite competition. This is due to the fact that among elite-level competitors VO_2max does not independently predict race outcomes [5]. Therefore, while relevant for novice endurance athletes, VO_2max among elite athletes is not a defining variable for success, and tends to remain surprisingly constant (even over an athlete's entire racing career) since VO_2max is largely attributed to heart morphology and cardiovascular physiology. Additionally, endurance sports are not performed at VO_2max; making it a poor predictor of performance among individuals of similar abilities. However, when compared across a group of individuals with wide-ranging abilities, it is a much stronger predictor of success. For example, a classic study revealed a significant inverse correlation with race time ($r = -0.91$) when examining the relationship between aerobic capacity and performance in a 10-mile race [6]. Subjects in the study demonstrated a wide range of VO_2max scores (54.8-81.6 ml/kg/min). Conversely, if one examined a team of cross-country runners with a more narrow range of VO_2max scores (e.g., 65-70 ml/kg/min), the significant correlation between performance and aerobic capacity would be unlikely. It would take VO_2max values that are at least 15-20 ml/kg/min apart to make a safe assumption that an athlete with a higher VO_2 will be faster during an endurance event than another with a lower capacity [6]. The practical take-away point here is that VO_2max values among experienced endurance athletes do not change much during their racing career, and therefore offer very little benefit to a strength coach's programming unless the athletes possess a capacity notably below the general range of their competitive counterparts.

Anaerobic Threshold

When the body is at rest it can efficiently manage all systems, but exercise challenges the maintenance of homeostasis because force production of any type demands a higher rate of metabolism. During steady-state aerobic exercise, the body attempts to maintain an elevated physiological homeostasis where core temperature, pH, blood gases, blood glucose, and electrolyte balance are all maintained as close to normal levels as possible. Theoretically, since energy needs are being met, blood gas and pH concentrations are balanced, and body temperature is regulated, steady-state exercise should be possible to perform for a long period of time without fatiguing. But to win a race, endurance athletes must produce additional force to gain speed. These added demands surpass aerobic steady-state levels; forcing an athlete to recruit the anaerobic system for support, which accelerates disruption to homeostasis.

The anaerobic threshold represents the metabolic shift to supplement aerobic energy with higher amounts of anaerobic energy during exercise. This occurs due to the recruitment of faster, more glycogen-reliant muscle fibers. However, the exchange of efficiency for force is paid for by an inability to maintain internal homeostasis. The increased work rate and anaerobic energy contribution leads to a rate of ATP hydrolysis and glycolytic activity that supersedes the body's capacity to maintain homeostatic pH. Lactate formation, which has been identified as a marker of the body's means of buffering the acid residuals of sugar metabolism, exceeds clearance rates and begins to increase exponentially. However, the accumulation of lactate is not directly responsible for the promotion of acidic conditions; it is rather the free hydrogen byproducts that cause a reduction in the body's buffering capacity.

DEFINITIONS

Respiratory compensation –

Refers to the increase in respiration rate as a mechanism by which blood plasma pH can be altered to restore normal values in response to metabolic acidosis; it functions to maintain a steady-state condition during work intensities that range between the aerobic limit and anaerobic threshold

VO_2 slow component –

The point during exercise of increasing intensity where respiratory muscle work and fast-twitch muscle fiber contributions negate the ability to maintain a steady-state condition

Although the mechanisms behind the increased respiratory rates experienced during exercise are multifaceted, an athlete will quickly notice an increase in breathing effort while relying more on anaerobic energy. It will become difficult to speak and/or the athlete's breathing will become audible. This occurs because CO_2 is an acid, and the respiratory system will compensate for a decreasing pH by increasing pulmonary ventilation and CO_2 exhalation (**respiratory compensation**) [7]. The combined increase in respiratory muscle work and recruitment of fast-twitch muscle fibers causes a linear increase in oxygen consumption despite an unaltered training or racing speed; a point referred to as the **VO_2 slow component** [8]. At this point the athlete is no longer able to maintain a steady-state condition, which leads to performance compromise and fatigue within a relatively short period of time.

VO_2 Slow Component: The Upward Drift

The VO_2 slow component is an important acute predictor of endurance performance. Oxygen consumption and lactate production are in steady-state during lower-intensity exercise, and the athlete can take advantage of fat as the primary fuel source (~65% VO_2max; or 80% heart rate maximum [HRmax]). At this work rate, an athlete can continue for hours. In contrast, intense exercise above anaerobic threshold (≥85% VO_2max; or 92% HRmax), yields a steep upward drift in oxygen consumption and H^+ accumulation. As mentioned previously, this occurs because the body requires additional recruitment of (less-efficient) fast-twitch fibers to support force demands; which consequently increases the relative contribution of anaerobic energy pathways. The additional anaerobic support causes a deviation from steady-state as it places elevated demands on oxygen consumption. The heart responsively has to work harder to deliver more oxygen, leading to an upward drift in HR. This upward drift, or VO_2 slow component, will continue on a trajectory toward HRmax and VO_2max until the athlete is forced to slow down or stop.

The HR responses experienced during a 5K exemplify the VO_2 slow component. A 5K race will take most runners approximately 20 minutes to complete. In this situation the athlete is primarily relying on aerobic energy, but due to the relatively high intensity he or she will need to supplement energy production with anaerobic fuel to support fast-twitch muscle fiber contribution. At the end of the first mile an individual's HR may be 180 bpm. It may rise to 190 bpm by the end of the second mile, and climb to their maximal HR (perhaps 200 bpm) by the end of the race. This gradual rise in HR and oxygen consumption reflects the absence of a true aerobic steady state, and clearly illustrates the VO_2 slow component. This slow component can be equated to (or understood as) drag. The greater the drag, the faster an athlete will tire. Therefore, extending the level of work an athlete can perform before the VO_2 slow component emerges, or lowering its trajectory, can allow the athlete to compete for a longer duration before fatiguing.

Economy

A successful endurance athlete will be able to produce large quantities of sustainable energy over the duration of a competition using oxygen, and translate this energy into the fastest movement velocity. Movement economy (or muscular efficiency) has been defined in numerous ways, but for the purposes of this chapter it will be specified as the energy required (kcals) to maintain a constant velocity during steady-state exercise [9]. Therefore, evaluation of movement economy requires measurement of oxygen consumption at a constant power output. An athlete with good economy will have a high ratio of power production to oxygen consumption when engaged in a sport-specific movement. The sport specificity is important as it relates to economy, and differentiates the value of VO_2max independently. Consider a run, bike, and swim event; athletes who are well-practiced in a single modality will not be able to compete with those who train to proficiency in each sport movement. Therefore an elite runner will not be equally competitive in the other endurance events such as the swim, even though they may have the highest VO_2max of all the competitors. In fact, sport-specific economy may be the most important factor in determining the performance of an endurance athlete. For example, the oxygen consumption required to run a 6-minute mile pace can broadly range from 45-60 ml/kg/min. This indicates a range of relative economy. The best equations for measuring running economy calculate calories burned per minute of work; which involves determining oxygen consumption as well as fuel utilization, considering fat burns less calories per liter of oxygen than carbohydrate.

Sport-specific economy may be the most important factor in determining the performance of an endurance athlete.

Using indirect calorimetry a strength coach can measure this expenditure with the following formula:

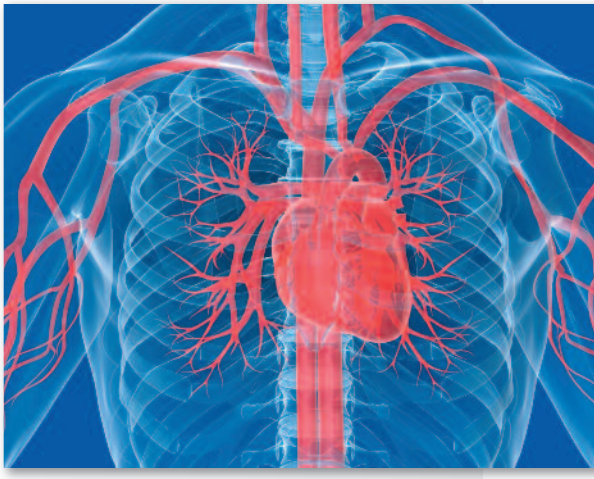
Oxygen (Liters) x minutes of work x RQ value x 5 = kcals expended per minute

The RQ, or **respiratory quotient**, is the volume of expired CO_2 divided by the volume of inspired O_2 [10]. A higher ratio indicates a greater reliance on glycolytic pathways, or carbohydrates for fuel (1.0). A lower ratio (0.7) suggests the majority of energy is coming from lipids. A number in between 0.7 and 1.0 (e.g., 0.85) suggests a mixture of energy is being relied upon to maintain the work rate.

DEFINITIONS

Respiratory quotient –

Indicates the relative contribution of macronutrients for fuel during work; is measured by taking the volume of expired CO_2 and dividing it by the volume of inspired O_2 (known as the R-value)



Enhancing VO_2max with Training

The specific training methods used to enhance VO_2max are equivocal in the literature, and will be discussed later in this chapter. Here underlying theoretical concepts will be briefly addressed.

Logically, it seems that training stresses for improving aerobic capacity must be applied to the variables that limit VO_2max. This means increasing stroke volume, capillary/mitochondrial density, and aerobic enzyme concentrations within muscle cells. For improving stroke volume, a common notion is that the training intensity must be high enough to overload the heart's tissue (myocardium) in order to promote compensatory increases in ventricular chamber size and strength. An example of this is the use of high-intensity interval training (HIIT) using work bouts that last longer than two minutes to reach a maximal aerobic steady-state. Intense interval training as well as long-distance running can benefit capillary density. Appropriate physiological stress during endurance training will lower skeletal muscle O_2 (partial pressure) and promote hypoxia; which is ideal for increasing the expression of vascular endothelial growth factor (VEGF), a hypoxia-responsive gene that induces increased capillary growth through **angiogenesis**. An increased number of functioning capillaries can in turn increase oxygen delivery to the mitochondria, improving the capacity of muscle to consume oxygen; or perhaps more importantly, better manage the increased delivery rate of oxygen associated with the concurrent adaptation gain in stroke volume. If these adaptations are matched it prevents the red blood cell transit time from becoming too brief to fully off-load oxygen. If stroke volume improvements occur without a concurrent rise in capillary density, circulating blood will flow through tissues too rapidly for adequate diffusion across the capillaries; limiting the amount of cellular respiration that can take place.

DEFINITIONS

Angiogenesis –

The process of creating new blood vessels (capillaries) from pre-existing blood vessels

Graded exercise test (GXT) –

Used to determine VO_2max; consists of incremental increases in intensity, causing the demand for energy to gradually increase while physiological indices are monitored

Training that elicits mitochondrial growth should increase oxygen consumption as well. This process, known as mitochondrial biogenesis, is promoted by various stimuli in response to endurance training such as contraction-mediated calcium release, increased reactive oxygen species activity, and an acute decrease in the ATP/AMP (adenosine monophosphate) ratio. These stimuli, among others, activate the expression of an important endurance "supergene" called PGC1-alpha [11]. This gene regulates key adaptations including glycolytic-to-oxidative muscle fiber conversions and the actual growth of mitochondria. Most evidence suggests that an energy crisis within the cell promotes the expression of this important metabolic regulator, which seems to be directed by glycogen depletion combined with significant training stress [11].

Assessing Aerobic Capacity

Interpreting VO_2max Values

To a coach, VO_2max best serves as a barometer for novice endurance athletes looking to improve their aerobic capacity, or for monitoring advanced training to determine caloric expenditure and glycogen utilization based on oxygen consumption. VO_2max is generally determined during a **graded exercise test (GXT)**, which consists of incremental increases in intensity, causing the demand for energy to gradually increase while physiological indices are monitored. Both oxygen delivery and uptake across mitochondrial membranes of muscle cells increase linearly; therefore VO_2 is directly proportional to the rate of muscular work. VO_2max is the point where oxygen consumption reaches a maximal plateau, which can usually only be sustained for a short duration of time. During cycling exercise, upper-body ergometry, or in certain disease conditions muscular fatigue prevents a plateau in maximal oxygen consumption; and therefore **VO_2peak** is reported [12].

It is important to realize that VO_2max or VO_2peak is not the highest exercise intensity that an individual can achieve. It is possible for athletes to perform intervals of work at intensities that surpass 100% of their VO_2max. Oxygen use during sprinting or weight lifting far exceeds VO_2max because the activities use anaerobic energy sources. An athlete may be able to sprint at 15 mph which reflects a 4-minute mile pace, but not be able to run a 4-minute mile. In this case, the sprint rate may represent 150% of his or her VO_2max, but will not be sustainable because it requires anaerobic energy to support the force demands. Similarly, it is important to recall that VO_2max does not singularly predict endurance performance, but merely reflects endurance potential. Endurance athletes typically compete below their VO_2max because maximal-intensity work can only be maintained for brief periods. The relative percentage of VO_2max an athlete can maintain for the duration of competition is more important. In essence, the efficient translation of aerobic energy into sport-specific muscular work dictates performance. For example, a runner with a VO_2max pace measured at 10.5 mph who is only capable of maintaining 9 mph for a 10K distance would actually lose a race to an athlete who can maintain 9.5 mph, even if their running speed at their VO_2max is lower. Therefore, both VO_2max and the highest tolerable sustained speed are relevant in endurance events; with the latter tending to be more critical to success.

DEFINITIONS

VO_2 peak –

Highest point of oxygen consumption during a given bout of maximal-intensity work; may not actually equal VO_2max due to limiting factors associated with the activity (muscle fatigue) or the participant (disease)

VO_2max Testing

Much like any physiological factor that may aid in programming exercise for athletic performance, measures of aerobic fitness provide relevant data in different forms. Many of the more common predictive field tests for VO_2max were developed for individuals with low levels of fitness; and consequently, are often less accurate for elite endurance athletes. A field test requiring an intense or maximal effort would be expected to be superior for athletes over modality-specific (e.g., treadmill) GXTs. Chapter 3 recommended the Yo-Yo intermittent recovery test(s) as a viable measurement tool to identify endurance capacity among athletes. This test involves intervals of work which eventually progress toward continuous running to keep up with a set pace; which may be of more interest to athletes and coaches over continuous treadmill tests.

Another viable test, also detailed in Chapter 3, is the 12-minute run test. It is useful for predicting VO_2max among athletes as it requires maximal effort and the equipment needed for proper implementation simply includes a measured track and stopwatch. The athlete must run as many laps as possible on the track in a 12-minute period. He or she is immediately stopped by the coach at the 12-minute mark and the track is marked just in front of their toes to attain an accurate distance covered. The strength coach should teach the athlete how to properly pace themselves for this test to increase validity. VO_2max is then estimated using the following formula:

$$VO_2max = 0.0278 \text{ x distance covered (m)} - 11.3$$

If a coach does not have access to a track, he or she may opt to use the Astrand test. During this assessment, the athlete starts running on a treadmill at 5 mph. At the 2-minute mark, the incline (grade) increases by 2.5%; this is continued at every subsequent 2-minute increment until volitional fatigue is reached. By the time the athlete voluntarily terminates the test, he or she should have attained their HRmax and VO_2max pace. VO_2max can be predicted using the following equation with the Astrand test:

$$VO_2max = (time \times 1.44) + 14.99$$

Regardless of the type of test selected, the data should be used for programmatic decisions to create an optimal matrix of adaptation-based stress. Identifying the contribution of the three relevant physiological variables (e.g., aerobic capacity, anaerobic threshold, economy) along with the best method for enhancing each should be applied to each training cycle.

VO_2max Associations to Age and Gender

After age 25, VO_2max decreases at an average rate of 1% per year among both sexes.

As previously mentioned, VO_2max is attributed to the amount of oxygen delivered by the cardiovascular system and metabolized by working tissues. In children and adolescents, the tissue uptake of oxygen (a-v O_2 difference) seems to be the greatest contributor to VO_2max; while in adults oxygen delivery is the primary determinant. VO_2max values, as shown in Table 17.1, are expressed in milliliters of oxygen consumption per kilogram of body weight per minute. Active boys and girls have a similar VO_2max up until age 12; boys typically benefit from hormone directed maturation at this point, attaining a 25% greater aerobic capacity than girls by age 14. After age 25, VO_2max decreases at an average rate of 1% per year among both sexes. VO_2max correlates with lifespan as well as quality of life, and is linked to all-cause mortality from various cardiovascular and metabolic diseases. The ability to live without assistance, for example, is estimated to require a VO_2max of 20 ml/kg/min. Competitive, world-class athletes will often have a VO_2max over 60 ml/kg/min. Lance Armstrong's greatest recorded VO_2max was reportedly 84 ml/kg/min; whereas the highest male VO_2max records include a cyclist measured at a university in 2012 at 97.5 ml/kg/min, and two cross-country skiers in the mid-90's. These values are impressive, but also accompanied by some controversy and skepticism.

Among the general population, aerobic capacity in females is about 15-30% lower than males (on average) due to smaller heart sizes, greater body fat percentages, and lower concentrations of circulating hemoglobin; most of which is related to relatively lower testosterone when compared to adult males. When male and female endurance athletes are compared, the difference in VO_2max is less pronounced (15-20%). This is due to the lower relative body fat percentages maintained by female athletes. Interestingly, body fat percentage as well as distribution has a significant impact on VO_2 values; however, men and women have nearly comparable VO_2max values when oxygen consumption is expressed per kilogram of fat-free mass. Sex-specific differences are more notable during comparisons of the circulatory system as larger heart sizes among males contribute to a greater cardiac output. Likewise, adult males typically have 15g of hemoglobin per deciliter of blood, whereas females maintain about 14g. Since hemoglobin is the major iron depot in the body, women are more prone to anemia and require nearly twice the daily iron intake (compared to men).

Table 17.1 General Population VO_2max Norms for Age and Gender

MEN							
Age	Very Poor	Poor	Fair	Average	Good	Very Good	Excellent
20-24	<32	32-37	38-43	44-50	51-56	57-62	>62
25-29	<31	31-35	36-42	43-48	49-53	54-59	>59
30-34	<29	29-34	35-40	41-45	46-51	52-56	>56
35-39	<28	28-32	33-38	39-43	44-48	49-54	>54
40-44	<26	26-31	32-35	36-41	42-46	47-51	>51
45-49	<25	25-29	30-34	35-39	40-43	44-48	>48
50-54	<24	24-27	28-32	33-36	37-41	42-46	>46
55-59	<22	22-26	27-30	31-34	35-39	40-43	>43
60-65	<21	21-24	25-28	29-32	33-36	37-40	>40

WOMEN							
Age	Very Poor	Poor	Fair	Average	Good	Very Good	Excellent
20-24	<27	27-31	32-36	37-41	42-46	47-51	>51
25-29	<26	26-30	31-35	36-40	41-44	45-49	>49
30-34	<25	25-29	30-33	34-37	38-42	43-46	>46
35-39	<24	24-27	26-29	32-35	36-40	41-44	>44
40-44	<22	22-25	26-29	30-33	34-37	38-41	>41
45-49	<21	21-23	24-27	28-31	32-35	36-38	>38
50-54	<19	19-22	23-25	26-29	30-32	33-36	>36
55-59	<18	18-20	21-23	24-27	28-30	31-33	>33
60-65	<16	16-18	19-21	22-24	25-27	28-30	>30

Table 17.2 Select VO_2max Values among Athletes Participating in Common Endurance Sports [13, 14, 15, 16, 17, 18, 19, 20]

Sport	Measurement Activity or Tool	Gender	VO_2max (ml/kg/min)
Marathon Running	Running	Both	~70-85 (women averaged 10% lower)
Elite Middle-distance Running (800-1500m)	Treadmill running	Male	72.1
Elite Long-distance Running (5000-10,000m)	Treadmill running	Male	78.7
Olympic Middle- and Long-distance Running	Treadmill running	Male	79.1
Olympic Middle- and Long-distance Running	Treadmill running	Female	66.1
Elite Cycling	Cycle ergometer	Male	~62.5-82.5 (average of ~72)
Elite Triathlon	Treadmill running	Male	78.5
Elite Triathlon	Cycle ergometer	Male	75.9
Elite Swimming	Swimming	Male	~68.0
Elite Swimming	Swimming	Female	57.9

DEFINITIONS

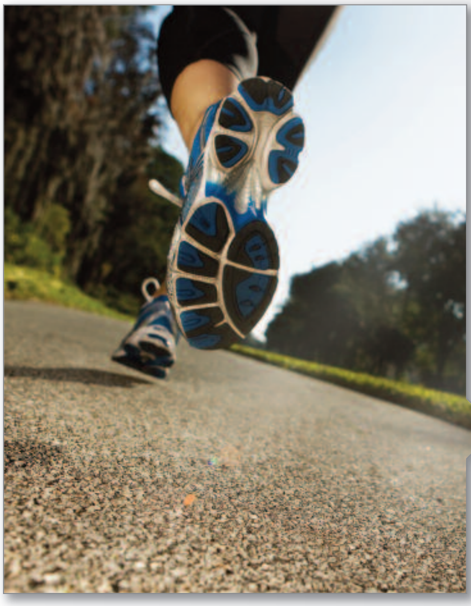
Aerobic limit (fat max) –

Point during exercise when lactate production begins to exceed clearance from muscle cells, which initiates lactate release into the bloodstream (and ultimate accumulation); is also referred to as fat max because it is a metabolic junction where fat utilization generally peaks before glycogen becomes the predominant source of fuel

Comparing the Aerobic Limit with the Anaerobic Threshold

Aerobic limit, lactate threshold, and anaerobic threshold are often used as interchangeable terms as the differences between them are commonly misunderstood. Developing a basic understanding of blood lactate hemodynamics will help clarify the differences between the three terms. During lower-intensity training the nervous system preferably recruits slow-twitch muscle fibers that can sustain work for prolonged periods of time. These fibers rely heavily on oxygen and utilize fat effectively as a fuel; giving an athlete the best "fuel mileage". These aerobic fibers can continue to contract perpetually since there is an abundance of fat available, and the low intensity allows the body to function at a metabolic steady state. However, if the exercise intensity increases, the recruitment of additional muscle fibers functioning at a faster work rate will begin to strain the homeostatic environment. Unlike aerobic fibers that use oxygen to strip energy substrates of their hydrogens, glycolytic fibers have a more rapid method of providing energy. Fast-twitch fibers strip glucose of H^+ using 10 enzymatic reactions as described in chapter 6 that allow for rapid ATP production. Since the ATP is being made outside of the mitochondria, it is immediately available in the areas of the muscle fiber that fuel contractions. But unlike aerobic metabolism, this pathway does not readily combine the H^+ byproduct with oxygen to form water (H_2O). Instead, the H^+ accumulates and lowers muscle pH; causing the fatigue-inducing metabolic milieu described earlier [21]. Conversely, when an athlete is well conditioned, the metabolic adjustment is properly managed and the H^+ are added to the remnants of glucose to form lactate. Lactate can then leave the working cell and be used by neighboring muscle cells, thereby thwarting the loss of aerobic steady state.

When an athlete trains at higher intensities, the anaerobic contributions quickly cause a decrease in pH and an increase in temperature which is picked up by local sensory receptors. These metabolic shifts are sensed in the brain and physically expressed as a localized burning-type of discomfort. Many people erroneously believe that the buildup of lactate is responsible for this acute discomfort and pain. Recall from previous chapters that lactate is actually a buffer that contributes to the removal of hydrogen; it is not a performance-inhibitor. In fact, muscle pain is not noticed at intensities where lactate concentrations begin to rise above resting. Also remember the soreness felt in the days following exercise is also not associated with lactate. It is largely attributed to inflammation and swelling caused by the infiltration of phagocytic immune cells that function to heal the tissue. By the time delayed-onset muscle soreness (DOMS) is felt, lactate has long been removed from the environment.



Aerobic Limit or Fat Max

Steady-state exercise is supported by lactate being shuttled from anaerobic to aerobic cells to help limit the negative impact of tissue acidity on exercise performance. This is an important component of exercise homeostasis as it allows the athlete to easily continue at the same intensity. However, when lactate production exceeds the ability of the muscle's aerobic fibers to draw it from the extracellular space, lactate begins to accumulate in the blood. Some exercise scientists refer to this as lactate threshold, but it is actually a metabolic junction where an athlete's fat metabolism usually peaks with an elevation in anaerobic muscle fiber contribution. This point of accumulation will typically occur at ~2.2 mmol/L; however, this is inconsistent among trained athletes. A better term to describe this transition is "aerobic limit" or fat max. At this point additional lactate is being released into the blood stream, and it marks the beginning of the linear relationship between work intensity and plasma lactate concentration. However, lactate concentrations at this level of work are still relatively unnoticeable to the athlete, and are easily regulated by aerobic metabolism to maintain steady state. This differs from the anaerobic threshold in that it represents the work rate where lactate production exceeds muscular disposal rates, not whole-body lactate clearance. Once the aerobic limit is reached, the rest of the body is recruited to assist in lactate removal to prevent acidosis. Lactate is consumed by the heart, liver, kidneys, brain, and other aerobic muscle fibers.

The aerobic limit, as the name implies, represents a metabolic environment by which the athlete can sustain continual force for a significant period of time. It should reflect the intensity used for long slow distance (LSD) training. A strength coach can predict the aerobic limit for an athlete using a target HR with the 180-Formula, introduced by Dr. Philip Maffetone [22].

Figure 17.2 Estimating an Aerobic Limit Heart Rate

Steps to calculate aerobic limit using HR:

Subtract the athlete's age from 180 (180 - age)

For athletes recovering from a major illness, disease, operation, or hospital stay, and any taking a regular medication, subtract 10

For novice athletes, those who have stopped exercising because of an injury, and those with a high susceptibility to upper respiratory tract infections (URTI) or allergies, subtract 5

For athletes who have trained at least four times a week without injury for up to two years, and have not suffered a cold or the flu more than once or twice a year, do not modify

For athletes exercising for more than two years without any injury, and/or those who have been making progress in your exercise program, add 5

Most runners will find their aerobic limit HR is sustained at a pace 1:00-1:30 minute per mile slower than their marathon pace or ~2:00 minutes per mile slower than their 10K pace. Breathing should be relaxed and talking should not be restrained by the required ventilation rate. A second indirect estimate of the LSD pace is to use 80% the athlete's HRmax; keeping in mind that this value varies from percentage of VO_2max. Eighty percent of HRmax translates to ~ 65% of maximum aerobic capacity. This LSD intensity optimizes lipid metabolism making it the ideal training threshold for prolonged training bouts.

Importance of the Aerobic Limit or Fat Max Point

The aerobic limit is often under-appreciated in endurance sports because it seems too easy. However, there are specific key adaptations associated with performing at this intensity. Therefore, despite the reduced effort to sustain the work rate, the aerobic limit may be the most critical intensity to accurately determine when putting together an endurance athlete's program. A problem both coaches (and athletes) often struggle with is to keep the athlete's pace slow enough during LSD training to properly maximize fat oxidation and increase the recruitment of energy-saving, slow-twitch muscle fibers.

Figure 17.3 Physiological Adaptations and Benefits Associated with Training at the Aerobic Limit

Key physiological events theorized to occur at the aerobic limit:

1. Blood flow is sufficient to supply muscle as well as circulate through adipose tissue to promote lipolysis
2. The nervous system is conditioned to preferentially recruit slow-twitch fibers to spare glycogen
3. Blood is flowing mainly through the capillary beds of aerobic fibers; leading to angiogenic adaptations that increase the fuel-delivering capacity to these fibers
4. Glycogen-sparing allows the athlete to perform for longer periods without fatigue; leading to greater hypertrophy of slow-twitch fibers
   - Larger slow-twitch fibers can increase lactate scavenging from the neighboring anaerobic fibers
5. The athlete is at their highest rate of fat metabolism, which may increase the individual's fat burning capacity (higher fat max)
6. The low plasma lactate level prevents re-esterification of fatty acids and inhibition of fat oxidation as seen in the presence of high lactate

Anaerobic Threshold – The Second Turning Point

Anaerobic threshold marks a transitional point where steady-state work becomes much harder to maintain.

Among trained athletes anaerobic threshold usually occurs at ~92% of HRmax, or 85% of VO_2max, but can vary based on an athlete's capacity to buffer H^+. Some exercise scientists have problems with the term anaerobic threshold. When first used in the 1960's it was based on the (inaccurate) notion that athletes run out of oxygen at a given point and (metabolically) shift to anaerobic energy; similar to shifting gears in a car. It is now known that oxygen consumption continues to rise, however the anaerobic threshold does mark a transitional point where steady-state work becomes much harder to maintain. This explains why a number of variables change at this juncture of exercise intensity, all of which can be used to define anaerobic threshold.

Figure 17.4

Physiological variables which indicate anaerobic threshold has been attained:

- A nonlinear rise in blood lactate concentration at a constant pace (~4.0 mmol/L)
- A nonlinear increase in ventilation rate compared to O_2 intake (ventilatory equivalent for O_2)
- A nonlinear rise in CO_2 content in air ventilated (ventilatory equivalent for CO_2)
- An elevation in the R-value, suggesting increased carbohydrate metabolism
- Deviation in linearity between HR and movement speed

If a coach or athlete attempts to use lactate concentration to assess training intensities and/or competition paces, concentrations of 2.2 and 4.0 mmol/L represent distinct markers for the aerobic limit and anaerobic threshold, respectively. Intensities between the two thresholds can be maintained at steady state since the body is still able to maintain equilibrium between lactate formation and lactate clearance; therefore the lactate formation is combatting muscle H^+ build-up (drop in pH).

The anaerobic threshold is recognized as the second "lactate and ventilatory turning point" (following the aerobic limit). This is why it is often referred to as the respiratory compensation point, or ventilatory threshold. As detailed in Figure 17.4, a non-linear increase in ventilation occurs and it corresponds with an increased removal of CO_2 from the lungs to raise pH. The anaerobic threshold is the point at which it becomes difficult to speak, and in contrast to the aerobic limit, occurs when the work rate is so high that lactate production in the blood exceeds total-body clearance capacity. At this level, serum lactate begins to rise exponentially with a corresponding decrease in plasma buffering capacity and subsequent systemic drop in pH. Exercise-induced metabolic acidosis triggers respiratory compensation, indicated as the athlete's ventilation rate begins to notably increase. Another good description of this intensity is **maximal lactate steady state**, or the onset of blood lactate accumulation (OBLA), since the blood lactate concentration will accumulate at intensities above this point, even if the intensity is held constant [23].

DEFINITIONS

Maximal lactate steady state –

The transition point during exercise of increasing intensity where a critical level of blood lactate accumulation occurs and concentrations will continue to increase even if the intensity is held constant

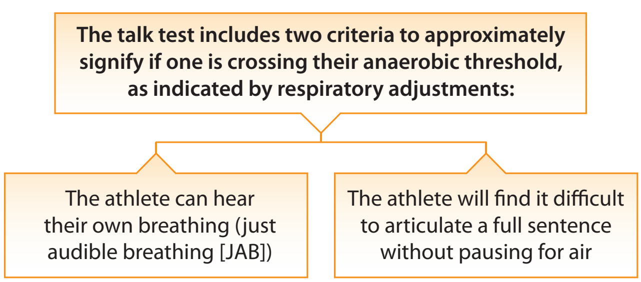
Exercise hyperpnea –

An increase in the depth and rate of breathing required to meet the metabolic demands of working tissues during exercise; not the same as hyperventilation

The Talk Test

Individuals have different buffering capacities and chemoreceptor sensitivity to pH changes in the blood and muscle due to genetic and training-related influences. **Exercise hyperpnea** and difficulty speaking while training may not precisely correlate with anaerobic threshold; but it works as a practical, non-invasive measurement strength coaches and athletes can use to gauge work.

Figure 17.5



Anaerobic Threshold and Fatigue

Lactate concentrations do not consistently predict anaerobic threshold in a manner that is especially meaningful to strength coaches and athletes. Also, as described earlier in this chapter, lactate in itself does not cause fatigue. Due to elevated concentrations in the blood this is often assumed, but it can clearly serve the opposite effect by providing energy and delaying fatigue. However, as athletes cross the anaerobic threshold point, exercise becomes notably harder to sustain as muscular work associated with breathing further increases oxygen demands. Although respiratory muscles are only working at ~50% of their maximum capacity at this intensity, they demand ~15% of total oxygen consumption. This represents

Figure 17.6 Anaerobic Fatigue

Cascade of Events Leading to Anaerobic Fatigue:

A high work pace/ intensity or reduced efficiency

↓

Fast-twitch glycolytic motor unit recruitment

↓

H+ accumulation and drop in plasma buffering

↓

Respiratory compensation

↓

Increased oxygen demand

↓

Additional glycolytic motor unit recruitment

↓

Increased rate of H+ accumulation

↓

Elevated respiratory compensation

↓

Loss of homeostasis and onset of VO_2 slow component

↓

Oxygen consumption on a trajectory toward maximum (VO_2max)

↓

Anaerobic Fatigue

a significantly greater amount of oxygen than the mere 3-5% used during moderate-intensity exercise. The increased work of breathing during vigorous exercise evokes a competition between the skeletal and respiratory muscles for the total cardiac output and available oxygen. This ultimately prevents maintenance of a steady-state condition, and will lead to fatigue as a vicious cycle emerges.

Training status and other physiological variables ultimately determine an athlete's fatigue rate relative to intensity, but all athletes will encounter fatigue soon after surpassing their anaerobic threshold. Therefore, anaerobic threshold is often thought of as the "performance threshold". Depending on the training status and glycogen stores of the athlete, it can usually be maintained for up to 30 minutes (or longer). Recently, it has been shown in elite cross-country skiers that high rates of glycogen breakdown (as occurs at the anaerobic threshold) can directly weaken muscle contractions when intramuscular glycogen levels fall below an optimal level; perhaps being another major cause of fatigue during endurance sports [24].

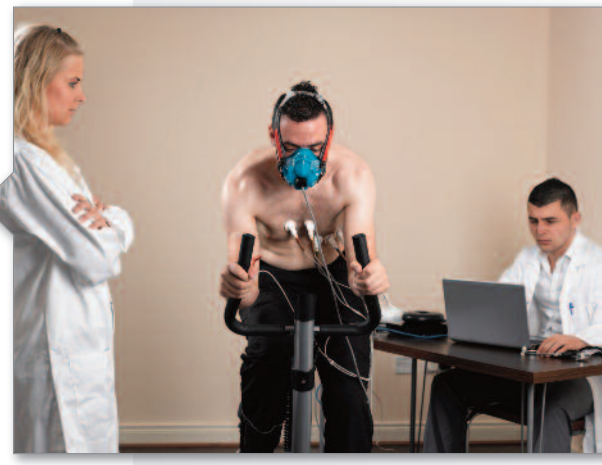
Variations in Lactate Concentration and Anaerobic Threshold

Similar to the aerobic limit, the anaerobic threshold does not always reflect the lactate production of working muscle fibers. A number of factors can be the source of changes in blood lactate concentration such as decreased clearance rates, changes in the ratio of glycolysis to mitochondrial respiration, reduced blood oxygen content, reduced blood flow to muscle, or various other metabolic fluctuations. Additionally, decreased liver glycogen and the associated endocrine response will promote a release of lactate from non-exercising muscles. Lactate concentration measured at anaerobic threshold will differ depending on the form of endurance exercise as well as the volume of muscle mass recruited. Cycling exercise for instance, requires a higher metabolic rate per unit of muscle mass recruited; causing anaerobic threshold to occur at a lower VO_2 than running.

Intensity Paradox: The Most Common Training Intensity is Least Useful (The Junk Zone)

A considerable irony in endurance training is that most people tend to train between their aerobic limit and their anaerobic threshold; that being about 80%-92% of their HRmax (or 65%-85% of their VO_2max). This intensity on the Borg scale of perceived exertion is between somewhat hard and very hard; so naturally an individual feels as though the intensity is not too easy or too hard. It makes sense that training between the aerobic limit and the anaerobic threshold is the most common training zone for recreational runners, and certainly for health purposes it has merit; but it may in fact be the least effective training zone for improving performance among competitive athletes. This intensity is referred to as the "junk zone" for endurance sports because it is too easy to provide optimal training adaptations associated with high-intensity training, but too hard to last long enough to get the benefits associated with LSD training. When an athlete trains above their aerobic limit, he or she will begin to utilize glycogen stores which should be conserved for high-intensity sessions, such as tempo runs and interval training. The exception to this guideline is when an athlete runs at their marathon pace considering this will reflect a given level of sport-specificity; and usually occurs in the upper-end of the junk zone (80% of VO_2max or 88% of HRmax). The junk zone may also serve as a comfortable middle ground for athletes in the off-season simply attempting to maintain fitness and caloric expenditure. The take-home message here is that strength coaches must recognize that most athletes will instinctively train at an intensity that is too fast for maximal endurance and fat-burning benefits, but too slow for maximal aerobic capacity improvements. Adjustments and education must be applied accordingly.

Understanding Lactate Testing



Conventionally, GXTs with blood samples are used in attempts to identify the athlete's optimal training zones. This stems from the notion that the point where lactate increases exponentially corresponds with critical power among cyclists, or roughly a 10K pace among runners. However, based on all the factors that can impact lactate concentrations it is hard to argue that the athlete's anaerobic threshold point is superior to simply using 92% of the athlete's HRmax. Rather, a coach should be educated on what he or she is trying to obtain. Studies on endurance athletes suggest that percentage of HRmax, despite its simplicity, may be a more consistent gauge of an athlete's exercise intensity than blood lactate responses. For example, cyclists seem to consistently maintain 90% and 85% of their HRmax for 30 and 60 minute time trials, respectively. Lactate responses on the other hand, do not appear to be linear and vary depending on the length of the effort [25]. Similarly respiratory compensation, or the ventilatory threshold, indicates the intensity where muscle acidosis begins to contribute to a systemic lowering of pH and a reduction in extracellular buffering. Since this pace is only sustainable for ~30 minutes as detailed earlier, the ventilatory threshold is of greater importance than any indirect measure of lactate. Certainly, lactate concentrations rise around the same time working muscles begin using greater amounts of glycogen, but each athlete has his or her own individual ability to clear lactate from circulation using other tissues. Since lactate is a blood marker of the muscle's reliance on glycogen, the higher the intracellular catabolism of glycogen, the more lactate is created. Furthermore, it is inaccurate to assume lactate is an acid (lactic acid) since it will only lower pH once the body has reached an acidity level far greater than what is physiologically possible (pKa <4.0). Adding to the potential for flawed assumption, an athlete's stress levels, liver metabolism, hydration status, and other factors can make this point somewhat inconsistent. Even when looking at lactate only, the anaerobic threshold point, referenced earlier at ~4.0 mmol/L can vary significantly across athletes. This variation can be even greater depending on the how an athlete's aerobic limit is determined. For example, Amann et al. found that the aerobic limit can vary from 1.2-6.4 mmol/L when examining 15 experienced road cyclists. Furthermore, their cycling power output varied greatly (220-363 Watts). In this study, the use of ~92-95% of a cycling 5K time trial speed (or ventilatory threshold) was far superior at estimating a cyclist's critical power than using lactate blood markers [26].

Using Serum Lactate Testing

Provided a strength coach is not trying to identify a theoretical performance threshold that remains constant throughout a training cycle, lactate, along with HR monitoring, can help identify energy system shifts including a greater reliance on glycolytic metabolism. This can indicate when the athlete recruits more type II muscle fibers and is experiencing elevated sympathetic nervous system activity. Changes in HR and lactate can also assist in understanding an athlete's level of recovery or risk of overtraining. These markers can be especially useful in differentiating between sympathetic and parasympathetic overtraining. For example, adrenaline increases the breakdown of glycogen; and therefore, sympathetically-overtrained athletes will have elevated lactate concentrations and higher HRs during sub-maximal efforts. During parasympathetic overtraining, lactate will be unusually low at sub-maximal as well as maximal workloads, recovery HRs will be relatively rapid, and the athlete will present with a reduced maximal HR.

Top athletes can rely on physiological testing such as HR, lactate, and blood pressure to monitor training stages, recovery, injury risk, and proper training distribution among the energy systems. In elite athletes, an advanced and effective form of coaching is to use lactate concentration at a given HR to indicate neuromuscular activation patterns. For example, a 5K runner with a lower than expected lactate concentration at a high HR may not be using enough of his or her fast-twitch fibers to excel; and should therefore engage in more anaerobic training. To the contrary, a marathon runner with higher than expected lactate concentration may be over-reliant on fast-twitch fibers; and therefore require additional LSD training. From this perspective, the greatest value in lactate testing is being able to determine the athlete's relative reliance on glycolytic pathways, and making decisions for training based on results.

Determining the Athlete's Training Zones (Finding the Gears)

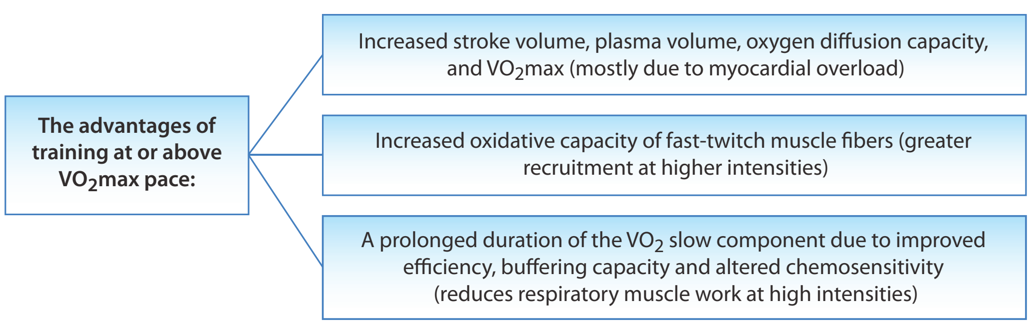
Figure 17.7

The aerobic limit (fat max) is associated with lower intensities, making it optimal for use as active recovery or for LSD training sessions. As mentioned earlier, associated benefits include (1) the ability to engage in a greater volume of training with minimized glycogen depletion, (2) hypertrophy of slow-twitch muscle fibers, (3) increased strength of postural muscles to improve movement economy, (4) increased vascularization of slow-twitch fibers, (5) neuromuscular adaptations leading to preferred recruitment of aerobic muscle fibers as well as asynchonized firing patterns, (6) an increased fat oxidation capacity to further contribute to glycogen sparing, (7) greater lipolytic activity in fat cells, (8) increased fatty acid transport and oxidative capacity in skeletal muscle, and (9) a decrease in glycolytic enzyme expression (also helping to thwart rapid glycogen depletion). Disadvantages of excess training using this intensity includes a loss of power, speed, and fat-free mass, endocrine disruptions leading to reduced testosterone, and musculoskeletal imbalances due to a high volume of repetitive movement. In the beginning of a macrocycle this type of training represents the bulk of the athlete's regimen with efforts to build a conditioning base that promotes glycogen sparing and slow-twitch muscle fiber strength and mass.

Anaerobic threshold is usually attained at an intensity of ~85% of VO_2max, or 92% of HRmax. Training at this intensity is used for tempo-run sessions as well as short intervals of work lasting 30 seconds to 2 minutes, using a ~3:1 work:rest ratio. A conventional coaching rule is to not exceed 60 minutes of training at this intensity per week (for a given modality) due to physiological stress that can lead to non-functional over-reaching or overtraining. It is generally recommended that this type of workout should attempt to *average* near the anaerobic threshold pace by performing brief intervals above the threshold, interspersed with brief recovery intervals.

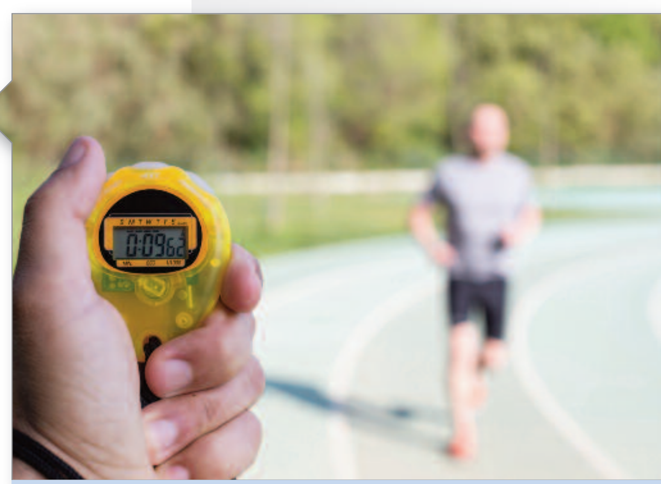
The VO_2max interval pace is roughly equal to the velocity an athlete can maintain for 3,000 m, or about 1.5-2.0 miles. Training status, sport-specificity, and other variables that affect conditioning at this exercise intensity will cause some variance between athletes, but this pace can normally be sustained for 5-10 minutes. During a GXT, an athlete will maintain his or her VO_2max pace for 5-30 seconds before volitional failure. If the athlete does not use the prolonged, gradual build-up associated with testing and begins running at VO_2max pace he or she may be able to last for a few minutes. A VO_2max interval pace can be implemented up to about 125% of VO_2max pace. VO_2max pace intervals will involve passive recovery periods of relatively longer duration so that each effort is of high-quality and can be performed at a maximal or supra-maximal intensity. The following figure illustrates primary benefits associated with training using VO_2max pace intervals.

Figure 17.8



How to Determine the Three Zones

A coach has a number of options when creating training zones for an endurance athlete including the use of running speed, HR, percentage of max power output, or rate of perceived exertion (RPE). Usually the first step is to find the athlete's HRmax and/or their VO_2max pace. The Astrand test, as discussed earlier, can be used to find both values. However, strength coaches still must keep in mind that confounding variables such as hydration status, environmental temperature, anxiety, medications, and some nutritional factors can alter HR responses during exercise.



Many coaches and athletes prefer to use movement speed, as opposed to monitoring HR, to measure workout intensities.

To determine HR zones for the three major intensities, strength coaches can use the following guide:

First step: Obtain HRmax from Astrand test, or add 5 beats to the highest HR observed during a race. Then, estimate VO_2max pace by using the Astrand test or by multiplying the athlete's 5K pace by 0.985

Zone 1: Aerobic limit/fat max: ≤80% of HRmax, use the 180-formula, or 75% of VO_2max pace

Zone 2: Anaerobic threshold: ≤92% of HRmax, use the talk-test, or 90% of VO_2max pace

Zone 3: VO_2max interval pace: 0-5 beats lower than HRmax, or a pace determined by dividing VO_2max pace by 1.12 (i.e., 6-minute mile pace ÷ 1.12 = 5:35 mile pace)

Using an Athlete's Speed to Determine Training Intensity Zones

Many coaches and athletes prefer to use movement speed, as opposed to monitoring HR, to measure workout intensities. The disadvantage with this method is that the speeds will be influenced by environmental factors (e.g., heat, wind) and terrain (e.g., hills, dirt roads). But, an experienced coach should be able to adjust the speeds to be suitable for various conditions. The most important marker to base training speeds on should be VO_2max pace. Since the treadmill excludes wind resistance and has a different surface than running outdoors, the pace obtained upon fatigue at the end of the Astrand test is not the best predictor of VO_2max pace outdoors. This measure is best determined by having an athlete perform a 3,000 m time trial on the track; which should reflect 100% of VO_2max pace for most athletes. An estimate of VO_2max pace can also be attained by multiplying the athlete's 5K pace by 98.5% as illustrated earlier. For example, if a runner completes a 5K in 19:00, his pace was 6:07 minutes per mile and 9.8 mph. Using 98.5%, the coach would estimate this runner's VO_2max pace to be 10.00 mph or 6:00 per mile. Using this conversion, a coach can create a spreadsheet from an athlete's 5K time (Table 17.3)

Zone 1 – Easy Pace or Aerobic Limit/Fat Max

Among all of the training zones, percentage of HRmax calculations best apply to lower intensities as the economy of a runner can vary significantly between low and high speeds. A runner's gait will change significantly as faster fibers and other muscles are recruited. The aerobic limit, as mentioned earlier, occurs rather consistently across endurance athletes at 80% of their HRmax, 65% of their VO_2max and ~75% of their VO_2max pace. For most athletes this pace feels uncomfortably slow. Usually a coach will have to stress to the athletes that they need to slow down, as the emphasis here is to place the muscular system under tension for a long duration to promote specific metabolic enhancements. The slow pace is necessary to improve glycogen sparing via increased fat oxidation. Athletes often find that due to the labored postural adjustments to run "slow" there is a significant need for increased muscular endurance. When HRs are not used, a strength coach should set 75% of the athlete's VO_2max pace as the limit for his or her LSD training. Again, elite marathon runners spend approximately 80% of

Table 17.3 Training Zones Estimated From 5K Time

5K time	Minutes per mile	Miles per hour (mph)	Estimated VO_2max pace (mph)	VO_2max minutes per mile	VO_2max seconds per mile	VO_2max pace	Half-marathon pace	Marathon pace	10K pace	Anaerobic threshold pace	Aerobic limit pace	Mile-interval pace	800m-interval pace	800m time	400m-interval pace	400m time	200m-interva pace	200m time
16:00	5:09	11.66	11.84	5.068	304.051	5:04	5:46	5:58	5:30	5:38	6:45	5:17	5:01	2:30	4:54	1:14	4:44	0:31
16:30	5:18	11.31	11.48	5.226	313.553	5:14	5:56	6:09	5:41	5:48	6:58	5:27	5:10	2:35	5:03	1:16	4:53	0:32
17:00	5:28	10.98	11.14	5.384	323.055	5:23	6:07	6:20	5:51	5:59	7:11	5:37	5:20	2:40	5:13	1:18	5:02	0:33
17:30	5:38	10.66	10.83	5.543	332.556	5:33	6:18	6:31	6:01	6:10	7:23	5:47	5:29	2:44	5:22	1:20	5:11	0:34
18:00	5:47	10.37	10.52	5.701	342.058	5:42	6:29	6:42	6:12	6:20	7:36	5:57	5:38	2:49	5:31	1:23	5:20	0:35
18:30	5:57	10.09	10.24	5.859	351.559	5:52	6:39	6:54	6:22	6:31	7:49	6:07	5:48	2:54	5:40	1:25	5:29	0:36
19:00	6:07	9.82	9.97	6.018	361.061	6:01	6:50	7:05	6:32	6:41	8:01	6:17	5:57	2:59	5:49	1:27	5:38	0:37
19:30	6:16	9.57	9.71	6.176	370.563	6:11	7:01	7:16	6:43	6:52	8:14	6:27	6:07	3:03	5:58	1:30	5:46	0:38
20:00	6:26	9.33	9.47	6.334	380.064	6:20	7:12	7:27	6:53	7:02	8:27	6:37	6:16	3:08	6:08	1:32	5:55	0:39
20:30	6:35	9.1	9.24	6.493	389.566	6:30	7:23	7:38	7:03	7:13	8:39	6:47	6:25	3:13	6:17	1:34	6:04	0:40
21:00	6:45	8.89	9.02	6.651	399.068	6:39	7:33	7:49	7:14	7:23	8:52	6:56	6:35	3:17	6:26	1:37	6:13	0:41
21:30	6:55	8.68	8.81	6.809	408.569	6:49	7:44	8:01	7:24	7:34	9:05	7:06	6:44	3:22	6:35	1:39	6:22	0:42
22:00	7:04	8.48	8.61	6.968	418.071	6:58	7:55	8:12	7:34	7:45	9:17	7:16	6:54	3:27	6:44	1:41	6:31	0:43
22:30	7:14	8.29	8.42	7.126	427.572	7:08	8:06	8:23	7:45	7:55	9:30	7:26	7:03	3:31	6:54	1:43	6:40	0:44
23:00	7:24	8.11	8.24	7.285	437.074	7:17	8:17	8:34	7:55	8:06	9:43	7:36	7:12	3:36	7:03	1:46	6:49	0:45
23:30	7:33	7.94	8.06	7.443	446.576	7:27	8:27	8:45	8:05	8:16	9:55	7:46	7:22	3:41	7:12	1:48	6:57	0:46
24:00	7:43	7.78	7.89	7.601	456.077	7:36	8:38	8:57	8:16	8:27	10:08	7:56	7:31	3:46	7:21	1:50	7:06	0:47
24:30	7:53	7.62	7.73	7.76	465.579	7:46	8:49	9:08	8:26	8:37	10:21	8:06	7:41	3:50	7:30	1:53	7:15	0:48
25:00	8:02	7.46	7.58	7.918	475.08	7:55	9:00	9:19	8:36	8:48	10:33	8:16	7:50	3:55	7:40	1:55	7:24	0:49
25:30	8:12	7.32	7.43	8.076	484.582	8:05	9:11	9:30	8:47	8:58	10:46	8:26	7:59	4:00	7:49	1:57	7:33	0:50
26:00	8:22	7.18	7.29	8.235	494.084	8:14	9:21	9:41	8:57	9:09	10:59	8:36	8:09	4:04	7:58	1:59	7:42	0:51
26:30	8:31	7.04	7.15	8.393	503.585	8:24	9:32	9:52	9:07	9:20	11:11	8:45	8:18	4:09	8:07	2:02	7:51	0:52
27:00	8:41	6.91	7.02	8.551	513.087	8:33	9:43	10:04	9:18	9:30	11:24	8:55	8:28	4:14	8:16	2:04	8:00	0:53
27:30	8:51	6.79	6.89	8.71	522.588	8:43	9:54	10:15	9:28	9:41	11:37	9:05	8:37	4:18	8:26	2:06	8:09	0:54
28:00	9:00	6.66	6.77	8.868	532.09	8:52	10:05	10:26	9:38	9:51	11:49	9:15	8:46	4:23	8:35	2:09	8:17	0:55

their total training time at this pace because it preserves glycogen for higher-intensity training and racing.

For example, an athlete with a 5K time of 19:00, and a VO_2max pace of six minutes per mile, would perform Zone 1 training at an 8-minute mile pace or slower. Unfortunately, it is difficult for a strength coach to convince the athlete that 7:30 is too fast, because slowing to the desired pace will feel unnatural. If the athlete is successful at reducing the running pace, distance, intensity, and session quality will increase.

Marathon Pace - Zone for Running Races >10 Miles or Endurance Events >90 Minutes

The marathon pace is equal to ~85% of VO_2max pace or 88% of HRmax. It represents a running gear not recognized in this text as one of the three key intensities; however, it is useful for runners competing in events greater than 10 miles. Elite athletes may also use it as an

Although elite marathon runners spend most of their training in Zone 1, it is important that they integrate some marathon-pace training as it is specific to improving racing speed.

interval recovery pace over short distances (1,500 m). Although elite marathon runners spend most of their training in Zone 1, it is important that they integrate some marathon-pace training as it is specific to improving racing speed. A perilous flaw would be training to run 26.2 miles (or even a half marathon) without ever working at the actual racing pace. The motor unit recruitment and movement patterns associated with the racing speed must be familiar to the athlete so movements during the event are performed with optimal economy. Most coaches understand that marathon runners should progress their LSD runs to 18-22 miles, and perform 4-6 runs of that distance before the competitive event. However, another important goal should be to perform 2-4 runs of 12-16 miles, at the desired race pace. A few miles of marathon pace can also be inserted into the middle of a long run to break the monotony. Suitable nutrient intake, rehydration, and sleep are needed to reduce the risk of overtraining and injury.

Zone 2 – Anaerobic Threshold Pace

Anaerobic threshold pace occurs at ~90% of VO_2max pace or 92% of HRmax. This pace represents the point at which an athlete performs aerobic work at a metabolic level beyond possible exercise homeostasis. This suggests that at this point, even if the athlete maintains the pace, his or her oxygen consumption will drift upward on a trajectory toward maximum, eventually causing fatigue. This is the pace used for tempo runs; it should also be the average intensity of workouts that include repeated short intervals of work. When monitoring an athlete's training volume, the rest intervals for anaerobic threshold workouts are brief and therefore should be included in the calculated duration. As a general rule, endurance athletes should try to limit anaerobic threshold pace work to ~10% of their total training volume. Multisport athletes, such as triathletes, increase the risk for overtraining when their combined anaerobic threshold training exceeds 60 minutes per week. It is important for athletes and coaches to watch for signs of overtraining. The benefits/goals of this training zone are to increase power at one's anaerobic threshold, reduce muscle and peripheral sensitivity to acidity (lessens respiratory muscle work), increase the relative composition of oxidative muscle fibers (type II fibers become more fatigue-resistant), and burn additional calories. However, glycogen insufficiency, non-functional overreaching/overtraining, and a reduced capacity for fat oxidation are potential adverse effects of excess training at this pace.

Zone 3 – VO_2max Interval Pace

VO_2max pace (and above) should be reserved to ~8% of total training volume, and is not added into the program on a weekly basis until the athlete has been introduced to anaerobic threshold training sessions for at least four weeks. When VO_2max interval workouts are introduced to long-distance runners competing in races over 5,000 m, strength coaches should first aim to strategically place them in the program every other week to allow for sufficient recovery. Once the athlete demonstrates physical acclimation to Zone 3 training, the frequency of this pace can be increased to one session each week. These intervals are performed usually above VO_2max speed for 2-5 minutes, using a 1:1 work:rest ratio. For example, a runner performing an 800 m run in three minutes on the track at 110% of their VO_2max pace would then recover for three minutes before performing their next 800 m effort. Since the recovery is passive, the recovery periods in this zone should not be computed in the estimation of an athlete's training volume. There are numerous benefits to training at an intensity equal to or above VO_2max pace as detailed in Figure 17.8 (page 17.6). This intensity will overload the myocardium eliciting modifications in heart morphology, such as larger ventricular chambers without significant changes in wall mass. This in turn improves overall cardiac function and output; the most significant component of VO_2max. Furthermore, type II muscle fibers will become more oxidative and movement economy at levels over anaerobic threshold will improve; thus thwarting the onset of the VO_2 slow component. Training in this zone will also accelerate the rate at which an individual's fitness improves, but if performed too early the athlete may peak prematurely.

Rate of Perceived Exertion

The Borg's Rate of Perceived Exertion (RPE) Scale is often used to determine cardiovascular training intensity [27]. This scale is useful for individuals on medications that may alter normal HR responses, those without a HR monitor, or those who do not care to measure and calculate their HR during exercise. The original, and most common, scale begins at six (6) and goes up to 20. If you add a zero to the numbers it loosely reflects beats per min (HR). A modified scale, also created by Borg, includes values from zero to 10, with zero being no exertion at all.

Despite the subjectivity involved, the RPE scale can be effective for coaches, trainers, athletes, and functions within research. An individual's RPE may be a great predictor of fatigue as it is centrally-mediated; meaning it is largely psychological. For example, motivating and cheering on an individual in a race may encourage them to to work harder. Distractions, such as music, can also greatly prolong time to fatigue. Essentially, when an individual's exertion and discomfort exceeds his or her desire to continue (motivation), fatigue ultimately sets in at a rapid rate. Monitoring RPE with the Borg scale can therefore be very useful. If an athlete rates running 9 mph a value of 14 on the scale a month ago, and now registers the pace as a value of 12, some factors are progressing in his or her program.

Non-athletes, beginning a cardiovascular program should use 11 (fairly light) on the scale to reflect ~50% of their VO_2max; being the minimum intensity shown to provide cardiovascular benefits. The aerobic limit, which occurs at ~65% of VO_2max, corresponds with a RPE value no higher than 14 (just below hard). The anaerobic threshold, which occurs at ~85% of VO_2max, should be a 17 (very hard), while RPE values during very-intense short intervals of work (or by the end of a race) will range from 18-20 (>very hard to exhaustion).

Table 17.4
Traditional Borg RPE Scale

RPE Rating	Description
6	Rest
7	Very, Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, Very Hard
20	"Exhaustion"

Closer Look at the Work Rates during each Training Zone

Table 17.5 Summary Work Rate Determination during each Training Zone

	Minimum Cardiovascular Benefit	Aerobic Limit Pace (Zone 1)	Anaerobic Threshold Pace (Zone 2)	VO_2max Interval Pace (Zone 3)
RPE Values	11 (fairly light)	14 (between somewhat hard and hard)	17 (very hard)	18-20 (just above very hard to exhaustion)
% VO_2max	50%	65%	85%	>85%
% HRmax	70%	80%	92%	95-100%
"Expected" Lactate Level	~1.0-2.0 mmol/L	~2.2 mmol/L	~4.0 mmol/L	Usually >8-10 mmol/L
Ventilatory Responses	V_e/VO_2 proportional with work rate Unnoticeable change in ventilation rate	First increase in V_e per consumed O_2 Increase in ventilation but still barely noticeable	Second increase in V_e per consumed O_2 Another increase in ventilation rate making prolonged speech difficult (talk test)	Exercise hyperpnea Individual cannot speak due to ventilation rate

**V_e = quantity of gasses inhaled/exhaled from the lungs in one minute*

Apart from the variables presented in Table 17.5, the pace of movement can also be used to predict work rates. The running speed of a trained individual is consistent with their relative HR; and based on the fact that HR corresponds linearly with VO_2, they are all interrelated. Coaches can refer to Table 17.6 which takes into account running speed and an equation developed by David Swain {%HRmax = (0.64 x %VO_2max) + 37} that predicts the %VO_2max from HR [28].

Table 17.6 Relationship between VO_2max Intensity, HR Intensity and Running Speed

% VO_2max	% HRmax	Running Speed
50	70	Very slow (warm-up, cool down, recovery)
60	75	Slow running (early measure of an LSD training session)
70	82	Steady running (off-season work or challenge during an LSD run)
80	88	Half marathon pace; just above marathon pace
90	95	10K speed
95	98	5K speed
100	100	3K speed
110	100	1,500 m speed

Building the Endurance Athlete's Program

A full program for a 10K race will be illustrated in the following section. Recalling the previous periodization chapter, a macrocycle has typically been viewed as a full year of training; but like some other year-round sports, endurance athletes may have two or three major events (and numerous minor) to prepare for throughout the year. Each event should have a separate training program which progresses up to the race; consisting of applicable micro and mesocycles. Therefore, for the purposes of this chapter "macrocycle" and "program" will be used interchangeably. Since training stresses are usually increased in three-week intervals, it may be optimal to have the total number of mesocycles be divisible by three. Mesocycles of six or nine weeks is the easiest time-frame to use when developing this type of endurance program.

Figure 17.9

The macrocycle in the following practical example consists of four mesocycles:

- **Foundation phase**
- **Speed phase**
- **Pre-competition phase**
- **Peaking phase**

Similar to the phasic techniques used in anaerobic programs, aerobic training regimens are constructed in a way that optimally balances training volume. A mesocycle of an endurance program is dictated by the athlete's **TRIMP score**, or TRaining IMPulse score [29]. The TRIMP score is defined as training volume (time) x training intensity (Zone). As a rule of thumb the TRIMP score should not vary by more than 10-20% every three weeks. The first week the TRIMP score is increased serves as an intentional over-reaching stimulus for the athlete; therefore, the following two weeks it would stay consistent to allow for adaptations and adequate recovery.

DEFINITIONS

TRIMP score –

Calculated by multiplying training volume (time) and training intensity (zone 1-3); used as a stress and volume management technique within endurance sport programs

Calculating an Athlete's TRIMP Score [30]

The use of training zones allows for intensity to be determined using a TRIMP score calculation. Each of the three zones are used to calculate the value as the zone number is used as a multiplier. The total weekly TRIMP score can be calculated using the cumulative time spent in each training zone.

- **Zone 1:** Aerobic limit pace and below = total minutes x 1
- **Zone 2:** Anaerobic threshold (tempo pace or short intervals with recovery periods) = total minutes x 2
- **Zone 3:** VO_2max interval pace = total minutes x 3

Examples:

- An athlete trains for 40 minutes in Zone 1
  - TRIMP score = training volume (time) x training intensity (zone)
  - TRIMP score: 40 minutes x 1 = 40
- An athlete trains for 25 minutes in Zone 3
  - TRIMP score: 25 minutes x 3 = 75

Foundation Phase

The goal of the foundation phase is to promote tissue adaptations within the sport-specific musculature, increase postural muscle endurance, and promote metabolic proficiency that maximizes fat oxidation. This phase generally lasts 4–8 weeks and includes a progressive LSD run performed at or below the aerobic limit as well as 3-4 easy runs per week. However, no Zone 2 or Zone 3 workouts should be used. If an athlete has a conditioning base established from a previous macrocycle, the phase may be reduced to 3-4 weeks; if he or she is coming off a previous peak than a one-week taper should be implemented prior to this shortened period. Conversely, if the athlete is coming off a period of rest it is recommended to use a 6-8 week foundation phase. Clearly the condition of the athlete dictates the length of the phase relative to need. A year-round competitor can peak up to three times per year. If an athlete is attempting to peak multiple times, the first program should last five months while the other two can be limited to approximately three months as the foundational base was established during the first training cycle. As mentioned earlier, a common struggle in the foundation phase is keeping the athlete from running too fast as they need to remain in Zone 1. So it should be made clear that the pace is extremely relevant.

Strength and conditioning work during this phase will emulate the goals of the preparation and anaerobic endurance phases used for anaerobic sports. Endurance athletes will benefit from improved trunk stability, hip/ankle ROM, and muscle balance across all joints (particularly in the sagittal plane). It is important to prevent lower-cross syndrome, with a particular emphasis on hip flexor and hamstring ROM, as well as ensure proper mechanics at the foot to prevent knee and lower back issues. Adjunct ROM work focused on the quadratus lumborum and IT band is also relevant as frontal plane musculature should not be overlooked. In preparation for the speed phase, and to maintain neural residuals from prior training, some short-distance sprints (50-100 m) and landing drills (e.g., depth drops) should be used. Stability and ROM improvements while performing a limited volume of weight room work requires the use of combination exercises that include rotational actions and overhead reaches/swings.

If races are used as part of the training, the athlete should not taper or alter other aspects of the program in preparation for these session-replacing races.

Speed Phase

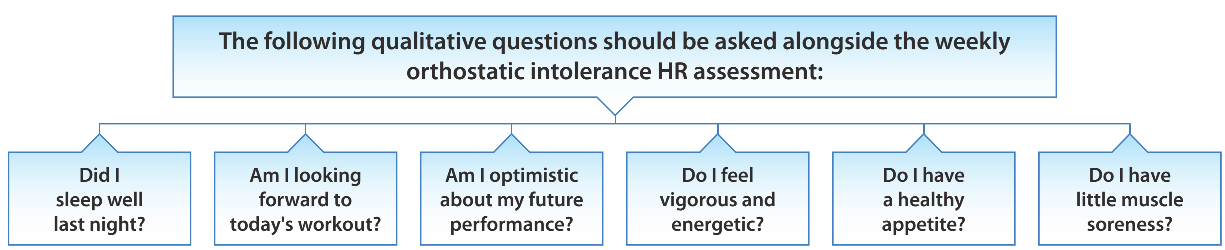
The speed phase will usually last 6-8 weeks. Each week will consist of an LSD run that progresses to a distance 200-300% longer than the race length (unless the event is >10 miles). Training weeks will alternate two Zone 2 workouts with one Zone 2 and one Zone 3 workout. Resistance training will morph from the foundation phase into an emphasis on compound lifting and enhanced strength across the kinetic chain. The speed phase is consistent with the hypertrophy/strength phases of anaerobic periodization models. Clean pulls or DB jump shrugs, deadlifts, front squat to presses, axial-loaded reverse lunges, and single-leg presses are all commonplace activities. Considering enhanced strength across the kinetic chain is a key component, exercises that incorporate total-body work will make the most sense. The use of ballistics and plyometrics increase during this phase as well. The use of medicine ball ballistic throws for the hip and trunk serve as excellent supplements to isolated trunk work to enhance running posture efficiency. The speed phase will still promote the residuals of the prior phase but should result in improved overall strength and power.

Pre-competition Phase

The bulk of the training time and most intense efforts occur during the pre-competition phase. This phase may span 5-12 weeks, and will consist of a progressive LSD run that plateaus at ~200-300% of the race distance as well as one Zone 2 and one Zone 3 workout each week. The other run days will be easy runs to facilitate adequate recovery. A competitive race, preferably shorter than the goal race, can be used in place of a track workout during this phase. If races are used as part of the training, the athlete should not taper or alter other aspects of the program in preparation for these session-replacing races. For example, a 5K race on a Saturday may replace a normal Saturday track workout, but should be treated in the same manner as if the track workout was to be performed. The last week of the pre-competition phase will be the hardest training period of the cycle. The peak phase to follow will coincide with a 20% reduction in the TRIMP score.

Due to the intensity of the pre-competition phase, the coach should assess the athlete for non-functional over-reaching and overtraining by (1) looking for signs and symptoms, (2) using a validated overtraining questionnaire, and/or (3) implementing an orthostatic intolerance test. The orthostatic intolerance test is employed by the athlete on the first morning of each week. He or she must first measure their resting HR after lying in bed for 15 minutes. The athlete will then stand up, wait 15 seconds and reassess their HR to get a comparative score. The 2nd heart rate should be between 10-15 beats above the first measurement. If it is >15 beats from rest, he or she may be sympathetically over-stressed. In this case, their HR would take longer to recover following a workout or between work bouts during interval training. It is also sometimes associated with a loss of appetite and elevated blood pressure. Conversely, if his or her HR increases only slightly (<7 beats) upon standing, it may indicate the verge of parasympathetic overtraining. This is increasingly likely if the athlete's training HR is also lower than usual, and if their HR recovers quickly between intervals and after workouts.

Figure 17.10 Qualitative Questioning to Help Indicate Overreaching or Overtraining



The athlete should answer yes to all to all of the statements in Figure 17.10. If the athlete answers no to any of these questions in conjunction with an abnormal HR response to the orthostatic tolerance test, the coach should:

1) Give the athlete a day off of training.

2) Reduce the TRIMP score for the week by 20%. In the case of parasympathetic overtraining this can be done by reducing LSD mileage. With sympathetic overtraining it is more effective to skip Zone 2 and Zone 3 workouts for the week.

3) Be sure the athlete consumes a predominantly plant-based diet, consumes quality carbohydrates and protein with every meal, reduces their alcohol intake, and focuses on drinking enough water so that their urine is clear. With sympathetic overtraining he or she should reduce overall sodium intake and avoid caffeine. With parasympathetic overtraining sodium and caffeine intake does not need to be modified.

The concerns of overreaching in the pre-competition phase should be considered within the resistance training program. This will reflect a reduction in the total time-under-tension with a greater emphasis placed on function and neural improvements. Combination-based functional exercises performed through a full ROM are useful in reducing restriction, and can aid in muscle balance. The strength and power developed over the pre-competition phase can be maintained by using low-volume plyometrics and ballistics. An increase in sets with a corresponding reduction in the reps can help maintain neural residuals without creating as much of a need for muscle recovery. Each muscle group should be trained at least once each week with favor given to functional groups over isolated muscle work.

Peaking Phase

In the final peaking phase (if multiple peaks) the goal will be to preserve the athlete's glycogen and prevent overreaching by reducing the TRIMP score by 20% (or more if the athlete is showing signs of overtraining). This phase lasts one to two months, with weekly training consisting of one shortened LSD run, one Zone 2 run, and one Zone 3 run. Some coaches may choose to use a marathon pace in lieu of Zone 1 training to keep the intensity high. However, strength coaches and athletes should remember that a key benefit of training in the Zone 1 intensity is that it spares glycogen for subsequent high-intensity training and racing.

The last week of the peaking phase will consist of a pre-competition taper to assure that the athlete is as fresh and as "glycogen-replenished" as possible. The weekly TRIMP score is now reduced by about 50%. Typically, training is reduced by 40-60% by decreasing Zone 1 training and the duration of Zone 3 workouts. Race-pace Fartlek runs in Zone 2, with 3-4 short intervals in Zone 3, will preserve neuromuscular activation patterns required for racing as well as prevent detraining without wasting large quantities of glycogen.

During the peaking phase a few total-body exercises and plyometric drills should be used on a weekly basis. Many athletes forgo any resistance training during this phase, but this is not particularly warranted until the last week. Again, using exercises that focus on functional muscle groups are advantageous as no particular muscle should be emphasized; the focus is on movement. Likewise, the strength coach should limit plyometric jumping drills to 30-50 landings per week. Box jumps and other concentric-only ballistics will help reduce connective tissue stress. Therefore, the removal of rebounds and eccentric loading should be considered across this phase.

Athlete Example: Practical Coaching Steps to Program Development

Subject: Experienced athlete preparing for a 10K race

Step 1: Athlete Assessment - Predict VO_2max Pace	Treadmill test: • Speed: 9.2 mph at a 1% grade (accounts for missing wind resistance); HR: 172 bpm; RPE: 17 • Predicted HRmax (add 5 beats to the athlete's recent 5K HR): 178 bpm • Treadmill pace represents ~96% of the athlete's max - predicting 9.6 mph or 6:17 per mile (9.2 mph x 104%) on a track • Predicted VO_2max pace can be calculated by using 98.5% of the athlete's recent 5K pace, being 6:16 per mile • **Predicted VO_2max pace: 6:12 per mile**
Step 2: Estimate the Goal Time	Estimating goal time: • A 10K is typically raced at ~92% of VO_2max pace • A reasonable 10K goal to aim for is an increase in pace by ~5% (97% of VO_2max) • Calculating 97% of a 6:12 pace places the athlete at 6:24 per mile and 39.41 min for a 10K • **10K goal time: ~40 minutes**
Step 3: Calculate the Gears - Aerobic Limit/ Zone 1	Aerobic limit: • 80% of HRmax: 143 bpm (≤65%VO_2max) • 75% of VO_2max pace: ≤8:20 per mile • Runs should begin a HR of ~125-130 bpm to account for the upward drift as the duration increases during the workout
Step 4: Calculate the Gears - Threshold Pace/ Zone 2	Threshold pace - tempo runs/short intervals: • ~92% of HRmax: 165 bpm • 90% of VO_2max pace: ~6:55-7:00 per mile Short intervals: • 10-15% faster than VO_2max pace, for the example athlete, ~5:35 per mile • Typically ≤3 min with short periods of recovery • Perform 400 m runs in 82 sec; 200 m runs in <42 sec • Example for 400 m repeats: ~80-83 sec with rest intervals of ~40 sec Setting the proper pace for Zone 2 intervals: • Use Zone 3 pace interspersed with brief periods of recovery; this keeps the athlete's intensity at an average around Zone 2 • The recovery periods are calculated in the TRIMP score, and are about half the duration of the work interval
Step 5: Calculate the Gears - VO_2max Interval Pace/ Zone 3	VO_2max interval pace/longer, more intense intervals: • Zone 3 intervals are typically 2-5 min, using a 1:1 work-rest ratio (unless the pace is used for 100-200 m repeats) • HR nears maximum as the intensity is ~12% faster than VO_2max pace (~5:35 per mile) Examples: • 800 m intervals would be performed in ~2:47, with 3-min recovery periods • 600 m intervals would be performed in ~2:05, with 2-min recovery periods Zone 3 considerations: • HR will not plateau (steady state) until the athlete reaches their max at ~178 bpm • HR will approach maximum until the athlete fatigues; depending on the length of the interval he or she will come within 4-6 bpm of their HRmax • If the HR plateaus before fatigue and never reaches HRmax, this suggests that 1) the athlete's HRmax might need to be re-calculated, 2) the pace was too fast, and/or 3) the athlete may be over-trained (need to reduce training volume)

Training Cycles	
Step 6: Mesocycle One - Foundation Phase	**Foundation phase:** • Will last 6 weeks • Will include one LSD run and three easy runs per week <u>Weeks 1-5:</u> • Weekly TRIMP score will begin at 199 • All runs will be performed in Zone 1 • HR should be ~142 bpm, but lower during the first mile of each run • At week 4 the TRIMP score increases 15% to 228 <u>Week 6:</u> • One LSD run of 10 miles and 3 easy days involving 6-mile runs
Step 7: Mesocycle Two - Speed Phase	**Speed phase:** • Will last 6 weeks • Each week will include one LSD run, one short interval day (Zone 2) and/or one tempo day (Zone 2) • Alternate each week with one long interval bout (Zone 3) in place of a short interval (Zone 2) session • Each Zone 2 and Zone 3 workout should include at least a one-mile warm-up and a half-mile cool down (this is calculated as Zone 1 training time) <u>Week 1:</u> • Weekly TRIMP score will start at 263 • One 10-mile LSD run and one easy 7-mile run • Two Zone 2 sessions: a 1.5-mile tempo run at a 6:55 pace, and a track session including 400 m repeats (400 m at 1:20 sec with 1:20-sec recovery periods) • Total Zone 2 time is 40 min (this intensity should never exceed 60 min/week) <u>Week 2:</u> • One 12-mile LSD run • The same tempo run as week one • One Zone 3 track day including 800-m repeats in ~2:48 with 3-min recovery periods • One easy 5-mile run in order to keep the TRIMP score at 263 <u>Weeks 4-6:</u> • Weekly TRIMP score will increase 10% to 290 during week 4 • Phase will finalize with one 16-mile LSD run, one tempo run and one Zone 3 track session
Step 8: Mesocycle Three - Pre-competition Phase	**Pre-competition phase:** • Will last 9 weeks • LSD run will plateau at 200-300% of race distance • Each week consists of one Zone 3 track session and one Zone 2 day which can be a tempo run, Fartlek run, or repeated short intervals <u>Week 1:</u> • Weekly TRIMP score increases 15% from the previous phase to 334 • One 14-mile LSD run • One 7-mile easy run • One 30-min Fartlek run at a Zone 2 pace • One 20-min Zone 3 track session (600 m repeats in ~2:05 with 4-min recovery periods) <u>Progression considerations:</u> • TRIMP score increases by 10% every 3 weeks; increases should never exceed 20% • By the end of the pre-competition phase, the athlete will reach a peak TRIMP score of 404 <u>Week 9:</u> • One 14-mile LSD run • One 50-min tempo run • One 30-min Zone 3 track session (800 m repeats in <2:50 with 5-min recovery periods)

Training Cycles (continued)	
Step 9: Mesocycle Four - Peaking Phase	**Peaking phase:** • Will last 4 weeks • One shorter LSD run (compared with later speed phase LSD runs) • No easy days • One tempo run at a Zone 2 pace • One Zone 3 track session (or race)
Step 10: Pre-Competition Taper	**Pre-competition taper:** • Will last 1 week • One 6-mile LSD run at Zone 1 pace • One 10-min Zone 2 Fartlek run • One 15-min track session including 200 m repeats at a Zone 3 pace • Weekly TRIMP score is reduced by 50% to 161

Table 17.7 Sample Periodized Plan for Endurance-Sport Training (Using the Athlete Example)

Foundation Phase: One long run and 2-3 easy runs per week; total of 4-8 weeks										
Week	LSD miles	LSD minutes	Tempo/ interval days	Total Zone 2 minutes	Total Zone 3 minutes	Easy/recovery run days	Easy miles	Total Zone 1 minutes	TRIMP score	TRIMP progressions
March 3	6	50	0	0	0	3	18	199	199	
March 10	7	58	0	0	0	3	17	199	199	
March 17	6	50	0	0	0	3	18	199	199	
March 24	8	66	0	0	0	3	20	228	228	+15%
March 31	9	74	0	0	0	3	19	228	228	
April 7	10	83	0	0	0	3	18	228	228	
Speed Phase: One long run, one short interval session, and one tempo day each week; alternate each week with one long interval in place of short interval; total of 6-8 weeks										
Week	LSD miles	LSD minutes	Tempo/ interval days	Total Zone 2 minutes	Total Zone 3 minutes	Easy/recovery run days	Easy miles	Total Zone 1 minutes	TRIMP score	TRIMP progressions
April 14	10	83	2	40	0	1	7	140	263	+15%
April 21	12	99	2	20	15	1	5	138	263	
April 28	10	83	2	40	0	1	7	140	263	
May 5	14	116	2	10	10	1	7	170	290	+10%
May 12	12	99	2	30	0	1	11	180	290	
May 19	16	132	2	10	10	1	7	170	290	

Pre-competition Phase: Long runs plateau (200-300% of competition distance) or decrease; one tempo or short/long interval session each week; any races take place of long interval day										
Week	LSD miles	LSD minutes	Tempo/ interval days	Total Zone 2 minutes	Total Zone 3 minutes	Easy/recovery run days	Easy miles	Total Zone 1 minutes	TRIMP score	TRIMP progressions
May 26	14	116	2	30	20	1	7	174	334	+15%
June 2	12	99	2	30	25	1	7	158	334	
June 9	14	116	2	30	20	1	7	174	334	
June 16	12	99	2	40	24	1	9	174	367	+10%
June 23	14	116	2	40	30	1	5	158	367	
June 30	14	116	2	45	35	1	2	133	367	
July 7	14	116	2	45	30	1	8	183	404	+10%
July 14	12	99	2	50	38	1	6	149	404	
July 21	14	116	2	50	30	1	4	153	404	
Peaking Phase: No slow days, interval session can be replaced with races										
Week	LSD miles	LSD minutes	Tempo/ interval days	Total Zone 2 minutes	Total Zone 3 minutes	Easy/recovery run days	Easy miles	Total Zone 1 minutes	TRIMP score	TRIMP progressions
July 28	12	99	2	30	40	0	0	102	323	-20%
August 4	12	99	2	45	30	0	0	102	323	
August 11	12	99	2	30	40	0	0	102	323	
August 18	12	99	2	45	30	0	0	102	323	
RACE WEEK	6	50	2	10	15	0	1	56	161	-50%

*TRIMP score calculations must include the intermittent rest periods as well as the warm-up and cool down segments associated with Zone 2 training.
**This example program includes 20 minutes of Zone 1 training on each interval day to account for the warm-up and cool down periods.
***Coaches must recognize that the TRIMP scores are meant to be a close estimate of total volume. The values can be slightly off from a strict calculation to accommodate environmental and other stress-related factors. Like other forms of programming it is not an "exact science" implemented in a clinical setting.

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