

## 2.6.2 Oxygen consumption and fatigue

Fatigue induced by submaximal long duration exercise significantly increases the aerobic demand of running. Following prolonged activity, increases in  $VO_2$  have been associated with increases in heartrate, core temperature, fat catabolism and blood catecholamines levels as well as decreases in biomechanical efficiency, muscle glycogen and liver glycogen content (Zavorsky et al., 1998). The rise in  $VO_2$  indicated worsened running economy and the increase in heartrate is to compensate for a decreased stroke volume.

Zavorsky et al., (1998) reported a rise in  $VO_2$  by 5% during 3 hour steady state exercise in moderate environmental conditions. An increase in core temperature induces an increase in minute ventilation with accompanying oxygen cost for the respiratory muscles. Increased ventilation, enhanced oxygen extraction, or a combination of these mechanisms should account for the increase in  $VO_2$ . Billat et al. (1994) indicate that the average time to exhaustion at  $VO_2$  max ranges between 2 min 30 s and 10 min.

## 2.6.3 Lactic acid and fatigue

Fatigue caused by lactic acid accumulation has been suspected for many years. However, only recently has a relationship between intramuscular lactic acid accumulation and decline in peak tension been established (Fox et al., 1993). The accumulation of an excess amount of lactic acid in muscles under stress is a contributing factor to fatigue (Gupta et al., 1996). When an athlete starts a race too fast, lactate will accumulate to very high levels and muscle glycogen stores will be depleted early in the race. Costill (1967) found only a 2–3 times increase in lactate values after trained athletes completed a marathon. The fatigue experienced by these runners is therefore caused by factors other than high blood lactic acid levels. Other factors that could lead to fatigue are:

- low blood glucose levels owing to depletion of liver glycogen stores;
- local muscular fatigue owing to depletion of muscle glycogen stores;
- loss of water and electrolytes, which leads to a high body temperature; and
- boredom.

In addition, interindividual variability in the degree of fitness could affect the relationship between lactate concentration in capillary blood at a given exercise intensity during

incremental exercise and the resistance to exercise fatigue (Mognoni et al., 1990). Lactic acid, which causes the pH value in muscles to drop, causes extreme fatigue, which limits the usefulness of the anaerobic mechanism for ATP production. During the transmission of action potentials, potassium is lost from the muscle cells and excess sodium enters. As long as ATP is available to energize the Na<sup>+</sup> and K<sup>+</sup> pump, these slight ionic imbalances are corrected. However, in the absence of ATP, the pump is inactive, and ionic imbalances finally cause the muscle cells to become non-responsive to stimulation (Marieb et al., 1989). The lactate accumulation is represented as the ratio of lactic acid concentrations in fast twitch (FT) and slow twitch (ST) fibres. This means that as the ratio increases, more lactic acid is being produced in FT fibres in comparison with ST fibres. This greater ability to form lactic acid might be one contributing factor to the higher anaerobic performance capacity of the FT fibres. As the lactic acid FT : ST ratio increases, the peak tension of the muscle decreases. This may be interpreted to mean that the greater fatigability of FT fibers is related to their greater ability to form lactic acid (Foss & Keteyian, 1998).

Barstow et al. (1996) showed that the relative magnitude of the slow component during heavy exercise was significantly correlated with the proportion of FT muscle fibers. This study strongly suggest that the VO<sub>2</sub> slow component is related in some way to the recruitment of FT motor units during heavy exercise. Study of Foss & Keteyian (1998) indicate that the composition of fiber types varies within different regions of the same muscle, between different muscles within the same person, and certainly within the same muscles of different people. It is thus important to consider such distributions in athletes and their potential impact on performance.

#### **2.6.4 Time to exhaustion**

According to Kindermann et al. (1979) exercise characterised by a lactate concentration of 4 mmol/L may be carried out for 45-60 min and occasionally, longer. The results of Mognoni et al. (1990) also found the time to exhaustion 45-60 min with a lactate concentration of 4.3 mmol/L. The data of Stegmann & Kindermann (1982) are not in agreement with the above results. In fact, most of their athletes were no able to carry out a steady state lactate intensity equal to 4 mmol/L over 50 min. They were exhausted after 14 min. These results are probably the consequence of an overestimation of the threshold intensity.

Mognoni et al. (1990) conclude that the effect of blood and muscle lactate on resistance to fatigue decreases rapidly with time. The anaerobic threshold is very often determined in order to obtain the corresponding heart rate value which is used to set the exercise intensity in endurance training so that there is no, or little lactic acid accumulation. However, the exercise duration should also be kept in mind as lactate increase with prolonged exercise.

### **2.6.5 Differences between black and white runners**

In South Africa, black runners dominate all running distances greater than 3 to 5 km. Interestingly, black South African runners regularly dominate the annual world listings for the 15 and 21 km. For example black South Africans recorded 11 of the top 15 times at 15 km in 1990. This suggests that the same genetic pool for distance running excellence that exists in East and North Africa must also be shared by black South Africans (Noakes, 1992)

Bosch et al. (1990) showed that sub-elite black runners matched with white runners for best 42 km marathon time had slightly lower  $\text{VO}_2$  max values than white runners but compensated for this by sustaining a significantly higher %  $\text{VO}_2$  max during marathon races. Bosch et al. (1990) reported 89% of  $\text{VO}_2$  max for the black runners and 81% of  $\text{VO}_2$  max for the white runners in which both groups ran at the same percentage of their best marathon race speed. The black runners in Coetzer et al. (1993) also study reported that they trained at high average exercise intensity than the white runners. Thus, a better resistance to fatigue. When the very best white and black athletes, with the same  $\text{VO}_2$  max compete against each other, then the black runners were outperform the white runners in endurance events like marathons. Because of their greater capacity to run for longer at a higher percentage  $\text{VO}_2$  max and hence at a faster running speed (Noakes, 1992).

Despite the superior fatigue resistance of the black distance athletes, however, their skeletal muscle fiber composition did not show a preponderance of type I fibres as might have been expected. In both the black and white runners, there was a high proportion of FT fibres, similar to that described for middle-distance runners (Coetzer et al., 1993). However the FT fibers of the black runners are fundamentally different from those of the white middle-distance runners, and are characterised by extreme fatigue-resistance (Noakes, 1992).

The main anthropometric differences between the runners in Coetzer et al. (1993) study were that the black runners were significantly shorter and lighter than the white middle-distance track athletes and had a considerably smaller muscle mass and lean thigh volume. They also had smaller front thigh and medial calf skinfold thickness. Thus the inertia of the limbs would be less and so theoretically less energy would be expended when moving the limbs (Bosch et al., 1990).

Lower blood lactate concentrations were found in the black runners. The lower blood lactate concentration at any given running speed might have contributed to the superior fatigue resistance of the black athletes. The lower peak RER values in black athletes were due to a lesser hyperventilatory response to maximal exercise, which in turn was possibly related to their lower blood lactate concentration. Bosch however found that the difference in blood lactate was so small in black and white runners, that the physiological importance is questionable. Coetzer et al. (1993) also measured a large difference between the quadriceps strength in black and white runners. Strength was better in the white athletes and fatigue better in the black athletes.

Bosch et al. (1990) stated that during a marathon black runners had lower  $V_T$  but higher breathing frequency than white runners. This combination resulted in similar minute ventilation volume. The higher breathing frequency in the black runners is almost certainly due in part to a smaller  $V_T$  as a result of a smaller vital capacity compared to the white runners.

It seems very probable that these specific characteristics explain the remarkable dominance of distance running by black East Africans athletes, especially Kenyans. Whether they are the result of both a culture in which running is a natural daily activity and residence at altitude, or whether they are inherited traits, remains to be established (Noakes, 1992).

#### **2.6.6 Difference between male and female runners**

In the study by Ramsbottom et al. (1989) women demonstrated lower respiratory exchange ratios and lower blood lactate concentrations throughout the test. Thus at a running speed equivalent to a blood lactate concentration of 2 mmol/L the women were able to utilise a higher proportion of their maximal oxygen consumption than were the men. The ability to

maintain a high proportion of  $\text{VO}_2$  max has been suggested to be a better predictor of conditioning or training status than a determination of the maximal oxygen uptake alone (Noakes et al., 1990). Therefore using this criterion, the women appear to have a higher aerobic capacity than the men in this study of Ramsbottom et al. (1989).

## **2.7 VELOCITY**

### **2.7.1 Oxygen consumption and velocity**

There is no doubt that a high  $\text{VO}_2$  max constitutes a kind of membership card for entrance into the world of top level middle-distance and distance running excellence. But anaerobic aspects of performance also contribute to the difference between finishing first and second in a race, because they interact with  $\text{VO}_2$  max.

Noakes et al. (1990) found that peak treadmill velocity reached during the  $\text{VO}_2$  max test was a better predictor of running performance than  $\text{VO}_2$  max for all distances from 10-90km. Noakes et al. (1990) reported that race time at 10 km or 21 km is the best predictor of performance in both the 42.2 km marathon in specialist marathon runners and in the 90 km ultra-marathon in the specialist ultra-marathon runners. That indicates that in trained marathon and ultra-marathon runners are also the fastest over the shorter distances. Thus, in agreement with Hawley & Noakes (1992) the relation between power output and oxygen uptake is linear. Kuipers & Arts. (1994) reported that the relationship between the power output and oxygen uptake and heart rate is linear for the absolute values as well as the percentages of maximum power output,  $\text{VO}_2$  max, and maximum heart rate.

Thus, two important physiological variables are important in evaluating distance-running abilities. One is the velocity at anaerobic threshold – the pace at which blood lactate just starts to rise substantially. Marathon pace is slightly slower than this. The other is the velocity at  $\text{VO}_2$  max, which typically is close to 3000m race pace (Martin & Coe, 1997).

The larger the  $\text{VO}_2$  max, the smaller the runners total anaerobic contribution will be at any given pace, or the faster they can run before anaerobic effects start to impair performance. But once  $\text{VO}_2$  max has been elevated about as high as possible without inordinate additional training volumes, anaerobic development will make the additional difference between being

optimally fit and marginally fit. Noakes et al. (1990) study showed that the physiological variables determining success at distances from 10-90km are not different, at least in marathon and ultramarathon specialists. This suggests that with appropriate training for longer distance events, the fastest 10km runners will also be the fastest marathon and ultramarathon runners. Billat et al. (1994) reported that the subjects capable of sustaining the maximal aerobic speed for longer period of time were also those who displayed a marked increase in lactate concentration at a later stage of a progressive exercise test and those who run a 21.1 km race faster.

Daniels (1985) suggested that the interplay of  $VO_2$  max and running economy could be expressed by calculating the predicted running velocity at  $VO_2$  max. According to Daniels, this derived variable may be useful in explaining performance similarities among competitive distance runners who differentially possesses the desirable attributes of  $VO_2$  max and running economy.

Research by Morgan et al. (1989) indicated that there is a significant relationship between 10 km run time and velocity at  $VO_2$  max and appears to be mediated to a large extent by running economy. This data from Morgan et al. (1989) suggest that velocity at  $VO_2$  max is a useful index of training status and therefore a non-invasive predictor of distance running performance. Nevill et al. (1992) stated that subjects with higher  $VO_2$  max values produced steeper regression lines (together with lower intercepts) than subjects with lower  $VO_2$  max measures.

### **2.7.2 Lactate levels and velocity**

Anaerobic metabolism may will occur among the Comrades athletes at the start, or while running up hills, but the lactic acid concentration in the blood immediately after a standard marathon (Costill, 1970) and the Comrades Marathon (Jooste et al., 1981) is fairly low. These facts emphasise the conviction that the Comrades Marathon is run mainly on aerobic energy. The pace of each athlete is thus limited largely by his lactic acid turning point and in such a way that this point is not exceeded (Jooste et al., 1981). Palmer et al. (1999) reported that marathon runners finished their races in a time 3 to 7 min faster if they had been running at

velocities above the maximal lactate steady state. This indicate that lactate may build during the race to reach a level above threshold by the finish.

## **2.9 RUNNING ECONOMY**

### **2.9.1 Definition**

Hawley (1995) defines economy of motion as the cost (i.e. oxygen uptake) required to produce a specific work rate or speed of movement. The best endurance athletes are usually the most efficient (Noakes, 1988). Better economy (i.e. lower oxygen cost) is advantageous during endurance exercise because it is associated with a slower rate of energy utilisation (i.e. muscle glycogen). Daniels & Daniels (1991) defines running economy as the relationship between oxygen consumption and velocity of running, or as the aerobic demands of running.

Previously published results show a decrease in energy cost of running across speed ranging from 40%-60%  $\text{VO}_2$  max and an optimal zone of energy cost between 60% and 80%  $\text{VO}_2$  max in trained runners (Brisswalter et al., 1996). This indicates that elite distance runners have a physiologically non-optimal speed (too slow a pace), and a physiologically optimal speed.

### **2.9.2 Factors that affect running economy**

The question that remains unresolved is why some individuals demonstrate markedly better economy when compared with counterparts exhibiting similar fitness and performance backgrounds. An alternative hypothesis is that successful long distance runners may have a structural or anatomical makeup, which genetically predisposes them towards better economy. Bailey & Pate (1991) introduced the concept of “external energy” – the energy needed to overcome external resistance, and “internal energy” the energy used in the production of external energy. In this way, running economy could, theoretically, be improved by reducing the demand for external energy, internal energy or both at any given submaximal running velocity. Previous research has indicated that the between-subject variation in running economy can be as much as 20-30% among trained male and female runners of similar ability (Williams et al., 1991).

There are many factors that affect running economy i.e. age, sex, training, stride rate and frequency, shoe weight, wind air resistance, including lower density found at altitude (Daniels & Daniels., 1991). Furthermore, clothing, footing, terrain, and possibly fatigue are additional factors that can change the cost of running. Brisswalter & Legros. (1994) indicate that elite runners display a wide range of daily variation in the energy cost of running that is independent of variation in stride rate or respiratory parameters. The application of this information should help coaches to design better training programs that will improve the running economy and endurance performance of both male and female athletes.

### **2.8.2.1 Age**

Children are less economical than adults are; running at common submaximal speeds elicits a greater relative demand for oxygen in children (Krahenbuhl & Williams., 1991). They also concluded that running economy improves steadily with age in normally active children. This improvement occurs with or without participation in formal running training programs. Some of the reasons why children are less economical than adults are that when compared with adults they exhibit higher resting metabolic rates, greater ventilatory equivalents for oxygen at a given running pace, and disadvantageous stride lengths. Cross-sectional research (Morgan et al., 1989) indicates that the gross energy cost of running increases 2% per year from 8-18 years of age.

### **2.8.2.2 Sex**

Daniels & Daniels. (1991) concluded that at absolute running velocities, men are more economical than women, but when expressed in ml/kg/min there are no gender difference at similar relative intensities of running. Also, when men and women of equal  $VO_2$  max or equal economy are matched, the men show a better aerobic profile. Some studies however showed that there are no differences in running economy (Pyne, 1994). Daniels & Daniels. (1991) recommended the economy data must be collected up to speeds equal to over 90% of  $VO_2$  max. Much of the variance in physiological parameters can be accounted for by differences in body composition and the proportions of fat free mass. Pyne (1994) proposed that smaller individuals possess a relatively greater amount of his or her body mass in the extremities, and would therefore perform a relatively greater amount of work moving body segments during running than larger individuals. Given that female runners are, on average, smaller than their



male counterparts, it is possible that this might be one explanation for the relatively poorer economy in female runners.

Morgan et al. (1989) speculated that the higher stride frequency and greater oxygen debt exhibited by the females might have contributed to the higher overall energy cost of running. Morgan & Craib (1992) also suggested that females may exhibit greater vertical displacement of the body during running, which would theoretically require a higher aerobic demand because of the added muscular effort needed to lift the body a greater vertical distance. Other factors observed were differences in stride frequency, running-experience and training intensity.

### **2.8.2.3 Training**

In a statistical sense, approximately 64% of the total variation in 10km running performance among athletes can be explained by the variations in running economy. (Morgan & Craib, 1992). Noakes et al. (1990) noted a relationship between peak treadmill running velocity and running economy; those athletes who reached the highest treadmill running velocities were also the most economical. This suggests that with appropriate training for longer distance events, the fastest 10km runners will also be the fastest marathon and ultramarathon runners. The positive correlation found between running economy and run times from Housh et al. (1988) further substantiates that the faster runner were also more metabolically economical. Morgan & Craib (1992) stated that athletes who specialists in shorter distance events have been shown to exhibit better economy at faster speeds, whereas long-distance specialists tend to be more economical at slower running speeds.

Krahenbuhl & Williams (1991) found that instruction on techniques of running, at least over a short term (2-3 months) is ineffective in bringing about improvements in running economy. However running training results in little or no improvement in running economy during childhood and adolescence. Over the longer term (years), improvements in running economy may be augmented through participation in running training programs (Krahenbuhl & Williams, 1991). Morgan et al. (1989) concluded that growth-related factors and training were likely causes for the enhancement in running economy.

There is no single biomechanical factor that accounts for individual differences in running economy (Martin & Morgan, 1992; McArdle et al., 1996). Significant variation in economy observed at a particular running speed occurs even among trained runners. (Conley & Krahenbuhl, 1980; McArdle et al., 1996). In general, improvements in running economy can result from long-term programme of running (Conley & Krahenbuhl, 1980; McArdle et al., 1996). Morgan et al. (1995) stated that trained distance runners are more economical compared with untrained subjects and that economy differences between trained and untrained subjects may be a function of repeated exposure to moderate training loads.

Ideally, runners are most concerned with being optimally economical at race pace. The longer the race and the smaller the anaerobic racing component, the greater will be the influence of running economy on performance quality. Thus marathoners can probably benefit most either from above-average running economy through genetic factors or from specific training to improve it. This has been offered as an explanation for the rather low  $VO_2$  max values recorded among some top-level marathon runners (Martin & Coe, 1997). Better running economy was associated with a lower heartrate and ventilation (Bailey et al., 1991). Training-induced reductions in heartrate and ventilation might produce an overall drop in total body  $VO_2$  leading to lower aerobic demands (Morgan & Craib, 1992).

#### **2.8.2.4 Stride rate and frequency**

Elite runners also appear to choose an optimal stride length at which they are most efficient and, when forced to take either longer or shorter strides for the same running velocity, they require an increased oxygen uptake, thus becoming less efficient (Hawley, 1995). Based on these results, Morgan et al. (1989) concluded that there is little need for a coach to dictate a particular stride length profile in most athletes since they tend to display nearly optimal stride lengths. They suggested that this phenomenon might be due to two mechanisms. The first states that runners may gravitate naturally toward an optimal stride length/stride rate combination over time an interactive process based on perceived exertion. A second possibility is that runners may adapt physiologically through repeated training at a particular combination of stride length and stride frequency for a given running speed.

In the study by Rowland et al. (1987) both adults and children elected to increase stride length rather than frequency as treadmill speed increased. This further supports the idea that greater running economy is achieved by increasing stride length rather than frequency. Bailey & Pate (1991) shown that stride length and running economy differ between experience and novice runners, with experienced runners possessing longer stride lengths and greater running economy. The results indicated that the most economical runners possessed a significantly lower force peak at heel strike, greater shank angle with vertical at heel strike, smaller maximal plantar flexion angle following toe off, greater forward trunk lean, and lower minimum velocity of a point on the knee during foot contact.

#### **2.8.2.5 Fatigue**

Economy takes on considerable importance during longer-duration exercise, where success depends largely on the aerobic capability of the individual and the oxygen requirements of the task (McArdle et al., 1996). Zavorsky et al. (1998) also stated that fatigue induced by submaximal long duration exercise significantly increases the aerobic demand of running. For exercises lasting more than two hours (e.g. marathon), it has been shown that the running economy decreased at the end of a long-distance run (Hauswirth et al., 1996). Thus fatigue affects economy in a negative way, increasing aerobic demand through the use of increasingly tired prime movers plus others brought into action to help maintain pace.

Following prolonged activity, increases in heart rate, core temperature, fat catabolism and blood catecholamine levels as well as decreases in biomechanical efficiency, muscle glycogen and lower glycogen content (Bailey and Pate, 1991). An increase in core temperature induces an increase in  $V_E$  with accompanying oxygen cost for the respiratory muscles. Increased ventilation, enhanced oxygen extraction, or a combination of these mechanisms should account for the increase in  $VO_2$  (Zavorsky et al., 1998).

Possible explanations of fatigue:

- include inadequate recovery time following intense training periods to permit proper nutrient, electrolyte, and fuel replenishment (Martin & Coe, 1997);

- use multiple muscle groups during exercise (running up hills with a vigorous arm swing to accompany leg motion), thereby diminishing the fall in muscle cell glycogen for any particular muscle groups (Martin & Coe, 1997);
- the contractile ability of the muscle falls progressively during prolonged exercise possibly on the basis of thermal damage to muscle (Davies and Thompson, 1986);
- increase stored fuel supplies in the working muscle before a major competition;
- inadequate fluid intake while running (Noakes, 1992)

Data obtained on elite and trained endurance runners performing longer runs have produced conflicting results, which one study reporting higher aerobic demands following a competitive distance race (Cavanagh et al., 1985), and others demonstrating no change in economy 1 day after a hard training workout (Martin et al., 1987). Morgan et al. (1990) replicated the Martin et al. (1987) study by expanding the experimental design. These findings suggest that an intense 30-min training run or a competitive 10 km race would not raise the aerobic demand of running by increasing dependence on fat metabolism or disrupting the gait pattern in subsequent submaximal runs over the short term. Viewed from a theoretical perspective, these results demonstrate the imperturbability of the metabolic and biomechanical profiles of trained runners following a prolonged maximal run. In a more recent study by Zavorsky et al. (1998) they conclude that running economy is worsened after repeated hard efforts, quantification of the time needed to re-establish baseline economy values would assist athletes in optimising training.

#### **2.8.2.6 Temperature**

A number of studies have documented the effect of increased core temperature (Q10 effect) on  $VO_2$ . Morgan et al. (1989) reported a 5% rise in  $VO_2$  during 3 hours of constant-load exercise under normal conditions. Variety of reasons for this rise in  $VO_2$ , including an increased energy requirement for peripheral circulation, increases sweat gland activity, hyperventilation and a decreased efficiency of energy metabolism. Bailey & Pate (1991) have suggested that training-induced adaptations to exercise in the heat, such as an increased plasma volume, may attenuate the magnitude of the thermoregulatory response and reduce attendant energy requirements.

### 2.8.2.7 Body mass

Davies (1980) found that children carrying 5% of their body weight on their trunk while running displayed a lower aerobic demand at faster speeds compared to unloaded running. Morgan et al. (1989) also observed a modest inverse relationship between body mass or weight and economy in elite female runners. However, greater body mass in the trunk area appears to be advantageous in terms of running economy. Conversely, those individuals who possess greater percentages of their body mass in the arms and legs may be able to obtain higher  $\text{VO}_2$  max values because a greater proportion of their lean muscle mass is active during running (Bailey & Pate, 1991).

### 2.8.3 Determination of running economy

Martin & Coe (1997) estimate the submaximal  $\text{O}_2$  demand (economy) at each pace as the average of three 20-s expired gas samples collected during the final minute of running at a pace. Using the statistical technique of regression analysis, an equation can be written using the pace and  $\text{VO}_2$  data that best describe each runner's  $\text{O}_2$  consumption with increasing work load. This regression equation determined from data obtained during level running permits extrapolation to the level-ground pace at which the athlete would be running at  $\text{VO}_2$  max intensity. Thereby, *velocity at  $\text{VO}_2$  max* or *v-  $\text{VO}_2$  max* can be calculated.

The question asked now is, is the relationship between running velocity and  $\text{O}_2$  consumption linear or curvilinear? The present evidence seems almost in favour of curvilinearity. If the relationship were linear throughout, the slope of the regression lines obtained by most workers who evaluate the economy of distance runners would be essentially parallel, differing only in that the more efficient runners would be positioned lower than the less efficient runners because of their decreased  $\text{O}_2$  cost at submaximal paces (Martin & Coe, 1997).

However, studies by Kearney & Van Handel (1989) state information from other published studies suggesting that a range of faster running velocities results in a steeper slope than does a range of lower running velocities. Thus, although some studies quoted frequently regarding the relationship whereby 1 kcal of energy is required per kilogram of body weight per kilometre of distance covered submaximally, this linearity may not necessarily be true for energy demands beyond the lactate/ventilatory threshold and approaching  $\text{VO}_2$  max.

Morgan et al. (1990) reported that a stable measure of running economy could be obtained in a single data collection session if the testing environment is controlled to minimise nonbiological variability. Also to maximise the likelihood of securing accurate baseline measures of running economy and running mechanics, it is recommended that subjects be evaluated at the same time of the day, in the same footwear and in a nonfatigued state (Williams et al., 1991). It appears that the importance of economy may be expressed only when performers are of comparable ability with similar maximal aerobic capacities (Conley & Krahenbuhl, 1980).

Costill (1979) provides the following information regarding oxygen uptake at set speeds:

Type of runner (running speed)	12 km/hr	14.5 km/hr	16 km/hr	19.2 km/hr
<b>VO<sub>2</sub> (mlO<sub>2</sub>/kg/min)</b>				
Very efficient	35	42	48	58
Average efficient	38	46	52	61
Inefficient	43	51	57	66

## 2.9 TRAINING

Over the past century, there have been massive assaults on athletic performance records. For example, the world's best running performance in the marathon and the 100 m, 400 m, and 1500 m races have all fallen sharply from the 1900s to the present, with an average of about 25% (Foss & Keteyian, 1998). Athletes who strive to compete at the highest levels must realise that it takes time to build the excellence required. Long-term goal setting permits an athlete to assign relative importance to the various aspects of a training year. The need to simply score points for the team or to be seen in a sponsoring firm's new line of sportswear without being prepared to do one's best is a very difficult pill to swallow for an athlete who desires excellence. Racing and training are very different entities and demand different mental attitudes. Nowadays, extreme pressures are placed on top-level athletes to disrupt their

development and overall goals by travelling to far-flung destinations and racing for huge sums of money to satisfy their sponsoring firms.

Martin & Coe (1997) said that it was important to focus on a career plan for an athlete with potential. A career plan is important to identify both the competitive event for which excellence can most likely be achieved and the age at which athletes typically will be at their best for that distance. The average age of career-best performance in marathon running is  $29,3 \pm 4,9$  for men and  $26,8 \pm 3,9$  for women (Martin & Coe, 1997). Thus, it is important to organise an athlete's career effectively.

Without question, improved training techniques and methods, resulting partly from our better understanding of the physiology of exercise, have played a pivotal role in improving athletes record breaking performances (Foss & Keteyian, 1998).

### 2.9.1 Principles of training

The objective of training is to bring an athlete to a peak fitness level at the proper time, with all the requirements for good performance brought along in balance.

The four primary aspects of an adaptation to training are:

- initial tissue catabolism that occurs from the load applied and causes an initial reduction in performance capabilities;
- adaptation to the stress of training as a result of tissue recovery and improved mental outlook from having successfully completed the work;
- retention and likely improvement in such performance characteristics following a tapering of training; and
- reduction in performance if training volume is decreased for too long a period (Martin & Coe, 1997).

Thus, the training life of an athlete is a constant cycle of hard work, recovery (regeneration), improvement in performance, and a brief layoff (for mental and physical rest) to permit another cycle to repeat. Martin & Coe (1997) define *multi-tier* training as the organisation of training around several levels of which builds on the preceding one. The effectiveness of multi-tier training is scientifically based. Multi-tier training continually exposes athletes to a

wide range of training stimuli with varying emphasis, thereby decreasing risk for injury or excessive fatigue.

### 2.9.1.1 Intensity

Training intensities are commonly defined as percentages of maximal oxygen uptake or maximal heart rate. But according to Meyer et al. (1999) should not only these parameters alone be used to determine exercise intensities. Individualised concepts based on lactate measurements are preferable.

McArdle et al. (1996) named seven ways to express exercise intensity:

- calories expended per unit time (kcal/min or kJ/min);
- power output (kg-m/min or W);
- relative metabolic level as a percentage of  $\text{VO}_2$  max;
- level of exercise below, at or above the lactate threshold;
- percentage of maximum heart rate;
- multiples of resting metabolic rate (METs)
- rate of perceived exertion (RPE)

Londeree (1995) provides the selected values for percent  $\text{VO}_2$  max and corresponding percentages of heart rate max:

Percent HR max	Percent $\text{VO}_2$ max
50	28
60	40
70	58
80	70
90	83
100	100

Gilman & Wells (1993) suggested that energy production is primarily aerobic when exercise intensity is below the ventilatory threshold. Ventilatory threshold is considered the upper limit for easy intensity exercise. Hard intensity exercise may be identified by fatigue in the legs after a few minutes. Gilman & Wells (1993) considered OBLA as the lower limit of hard



intensity. Physical activity requiring a metabolic rate between ventilatory threshold and OBLA is considered moderate intensity exercise.

The metabolic reference points occur not only at different percentages of  $VO_2$  max, but also at different percentages of maximal heart rate. Therefore, it may be possible to design individualised training programs based on heart rates at ventilatory threshold, OBLA, and  $VO_2$  max. These reference heart rates can then be used to monitor training intensity relative to metabolic factors.

Gilman & Wells (1993) study shown that the subjects in his study spent nearly all their training time performing easy to moderate intensity running where as the majority of their race time occurred at a high intensity level. Thus training prescriptions based on heart rate at designated metabolic markers with subsequent heart rate monitoring will enable coaches and athletes to accurately monitor training intensity. The question still remains whether there is a single best training intensity for promoting endurance performance.

#### **2.9.1.1.1 Long-duration, moderate intensity training**

This method of endurance training involves 30 min to 2 hr or more of continuous exercise, usually performed over relatively long distances and is often referred to as LSD training (Foss & Keteyian, 1998). The intensity of exercise generally increases heart rate to 75% to 85% of maximum or 60% to 70% of  $VO_2$  max. For most athletes this pace is below lactate threshold, and as a result, it is slower than race pace (Foss & Keteyian, 1998).

However, the optimum training intensity for improving endurance performance remains established; on theoretical grounds it has been suggested to be the maximum intensity that can be maintained in a steady state. Jacobs (1986) suggested that a blood lactate concentration of 4 mmol/L represent the optimum intensity. But according to Jacobs (1986) trained endurance runners lower than the optimum training intensity. According to Noakes & Granger (1995) the focus in the base training period should be on the time spent in the exercise zone, rather than the speed at which the athlete run. The intensity should be slower than race pace (85% to 95% of race pace), athlete should be able to do the talk test (Noakes & Granger, 1995). However, Sjodin et al. (1982) presented early evidence the training at an intensity approximating the maximal lactate steady state may be superior to other training.

#### **2.9.1.1.2 Moderate-duration, high intensity training**

This method of training is often referred to as pace or tempo training. Exercise intensity is set very near an athlete's lactate threshold – as heart rates that approach 85% to 90% of maximum (Foss & Keteyian, 1998). Exercise is still continuous in nature but duration is shortened (30 – 60 min). The approach is similar to interval training but differs in that the:

- length of the work interval is longer;
- and the degree of recovery between repetitions is shorter.

The main objective of aerobic interval training is to improve tolerance to racing at lactate threshold. This method of training is very effective for improving  $VO_2$  at lactate threshold and/or economy of movement (Foss & Keteyian, 1998). The heart rate method of determining intensity will establish a level of exercise stress for central circulation (for example stroke volume, cardiac output), whereas adjustment to lactate threshold are dictated by the capability of the periphery (local vasculature and active muscles) to sustain steady-rate aerobic metabolism (McArdle et al., 1996).

Heck et al. (1985) suggesting that elite runners who were stagnated in their performance improved only after decreasing the intensity of their training to that associated with the aerobic anaerobic threshold. Weltman et al. (1992) have demonstrated that at least some training above the lactate threshold is required for improvement. However, Lehmann et al. (1992) suggests that athletes respond better to increases in training intensity than training volume. If training at the maximal steady state was the “best” method to exercise one would have hypothesised that the increased volume study would have been tolerated better than increases in the homeostasis disturbing training intensity (Snyder et al., 1994). However if training intensity associated with maximal lactate steady state is not the best form to exercise in, it may be that this intensity simply represents the most time effective way of integrating training volume and intensity (Snyder et al., 1994). Yoshida et al. (1992) demonstrates the training-induced improvement in  $VO_2$  kinetics was more apparent for the OBLA exercise intensity than for the initial lactate threshold intensity. Robinson et al. (1991) found that the mean intensity of steady state running for the subjects in this study is considerable lower than the optimal training intensity.

### **2.9.1.1.3 Short-duration, very high intensity training**

This method of training involves a modification of interval training; in fact it is often called interval sprinting. The session involves for example a 50 m sprint then a 60 m jog over a distance of 4 – 8 km. Runners often incorporate hills into this type of training (Foss & Keteyian, 1998). Improvements in performance occur in trained runners when intensity of training increased and it is known that optimum improvements in cardiorespiratory fitness occur when training is at an intensity corresponding to 90-100 % of maximum oxygen uptake (Robinson et al., 1991). Noakes & Granger (1995) reported that high intensity training should never last longer than 14 weeks and this period should include at least three recovery weeks. Evidence of Noakes (1992) proves beyond doubt that the faster the athlete at short distances, the greater his or her potential in the marathon and ultimately in the ultramarathon. Matthews Temane, who has run the fastest mile at altitude, holds the world 21.1 km best; Bruce Fordyce had the fastest mile, 5 000 m and 10 000 m times of all finishers in the Comrades Marathon and Firth van der Merwe and Eleanor Adams are one of the fastest female ultra athletes and both also compete in shorter events (Noakes, 1992).

### **2.9.2 Methods of training**

The old question thus remains: How much training and what kind of training are ideal and sufficient? Optimal training can be defined as doing the least amount of the most specific work that will continually bring improvement in fitness (Martin & Coe, 1997).

Gustav Brink, Chairman of the Road Running Coaches Committee, reported a number of different training phases for a distance runner:

- base training phase;
- endurance training phase;
- speed phase;
- tapering phase; and
- racing phase (Brink, 1999).

A runner has to build a proper base before attempting to enter the next phase. It is preferable that the phases be followed in the order indicated above in order to peak for a specific event.

In the case of ultra distances, such as Comrades, there may not be sufficient time remaining after “loading” i.e. running extreme weekly distances, to properly incorporate a speed phase, and this phase may be done before the endurance phase.

### **2.9.2.1 Base training phase**

Base training should be at a comfortable level, i.e. it should not leave the athlete fatigued and the athlete should recover from any base training session within 24 hours. Base training for a 10km runner would differ considerably from that of an ultra runner. A 10km runner would do approximately 30-50km per week with strides once or twice a week. The long run would not exceed a maximum of 15 km. In the case of club running for the Comrades i.e. someone who would run 100 to 120km per week for a period of 4 to 6 weeks in the build-up to Comrades. The base training for this athlete should be at least 50 to 60km per week, incorporating a long run of at least 18 to 20km. Evidence from Hickson & Rosenkoetter (1981) suggest training frequency rather than training intensity is responsible for the increase mitochondrial enzyme concentration and endurance exercise capacity.

Martin & Coe (1997) question the benefit of more than 115 to 120 km a week at low intensity aerobic conditioning paces for distance runners seeking to improve their  $VO_2$  max. Although marathon runners are special cases in requiring very high training volumes in order to stimulate greater fuel storage abilities in their working muscles. Thus, once aerobic conditioning has provided the initial stimulus, it should then be followed by lower total weekly volume with higher-intensity aerobic capacity training sessions to bring  $VO_2$  max to its peak for that particular training period.

### **2.9.2.2 Endurance training phase**

Endurance exercise training leads to modest improvements in maximal oxygen uptake but large increases in the capacity to sustain submaximal exercise to exhaustion (Ramsbottom et al., 1989). The large increase in submaximal endurance capacity is thought to be closely related to the increases in muscle oxidative capacity. It is well documented that endurance training results in lowered blood lactate concentrations at the same absolute and relative exercise intensity after training which suggests an increased proportion of the energy supply derived from fat metabolism or greater aerobic catabolism of substrates *per se*.

Over the shorter events, most serious runners would train “over distance” i.e. runs longer than the end goal. Accordingly, a half marathon runner may run training runs of up to 25km, while a 5000m runner will occasionally train over distances of up to 15km. The great New Zealand coach, Arthur Lydiard, had even his 800m runners, such as Peter Elliot, occasionally run distances of up to the marathon during their endurance training. Long runs for the 5km to 21.1km runner will invariably be run at a pace 20 to 30 seconds/km slower than race pace. A marathon runner, mindful of the effect that very long runs have on the body and the recovery time required, may choose not to train beyond 35 to 38km in preparation for a hard marathon, although some of the elite athletes do train over distances of up to 45km. Serious Comrades runners invariably train over distances of up to 75km, but usually have just one or two runs, five or six 60-70km runs, and several shorter 40-50km runs. Even the serious Comrades runner would not train “over distance”. Most of the long runs are at a pace slightly slower than race pace, while the very long training runs (over 60km) would be run significantly slower than race pace (Brink, 1999).

Noakes (1992) stated that elite runners perform best in the marathon and ultramarathon races when they train between 120 to 200 km per week, with an increasing likelihood that they will perform indifferently when they train more than 200 km per week.

It is possible that increased volumes of aerobic training alone can improve fitness and provide a similar economy of motion. The studies of Scrimgeour et al. (1986), which report that athletes training less than 60 km a week have as much as 19% less running economy than athletes training more than 100 km a week, might support this suggestion. Martin & Coe (1997) report that as athlete became better trained, not only does the  $VO_2$  max rise, but so does the lactate/ventilatory threshold, both in absolute terms and as a percentage of  $VO_2$  max. These long runs are not just important for endurance development but also for mental preparation for the Comrades.

A good rule of thumb is to have run 5-6 runs during the endurance phase and to add another 2-3 such runs during the strength and speed phases of training. The last run should be 3-4 weeks prior to the race to give the body the opportunity to fully recover before the race. The distance

of long run should be at least 80% or more for the half marathon and shorter distances, and 60% of the distance in the case of a marathon and 50% for the Comrades (Brink, 1999).

Muscle endurance can also be increased through track work, by doing long repeats on the track at a pace slightly (5-10 seconds/km) faster than race pace. If the race goal is a marathon at a speed of 4 min/km, a sample track session in this phase would be 5x2000m at 3:50-3:55/km, with 1:00 passive or 400m active recovery. Muscle endurance can also be trained through cross training such as cycling, swimming, and gym, provided the sessions are done at a similar intensity and for reasonably long periods of time. In the gym the athlete would work with a lighter weight, and then do 2-3 sets of 20-40 repetitions with 60-65% of maximum weight (Brink, 1999).

#### **2.9.2.2.1 Strength training phase**

Resistance training is one component that will result in a stronger endurance runner. Runners who avoid resistance training fear it will compromise their performance but fail to realise that resistance training leads to physiological adaptations, both acute and long-term, that may actually improve performance. Dolezal & Potteiger (1996) named several physiological adaptations that take place when doing resistance work.

- ***Muscle enlargement***

Increased muscle size usually means increased strength, which can enhance performance.

- ***Muscle contraction time***

Research reveals that strength training does not affect a muscle's contraction time and therefore will not slow one down. In fact, many athletes have shown increases in speed of movement.

- ***Body composition changes***

Strength training increases lean body mass and decreases fat weight and the percentage of body fat. This improvement help maximise performance.

- ***Neural factors***

Initial strength gains may be attributed to the recruitment of additional motor units and reductions of inhibitory impulses. These changes enhance motor skill performance.

- ***Fuel availability***

Significant increase in the intramuscular stores of energy leads to increased performance and delayed fatigue response.

- **Enzymatic changes**

Increased enzymatic activity leads to more energy production and more efficient energy use.

- **Bone density**

There is strong evidence that strength training can increase bone mineral content, thus guarding against stress fractures or providing a safety factor in the case of falls.

- **Connective tissue**

Physiological adaptations in ligaments and tendons due to strength training may help prevent injuries.

Johnston et al. (1995) found that low volume training of moderate to high intensity, when incorporated in an endurance training programme will significantly improve upper and lower body strength as well as running economy. They stated that the benefits from increased upper body strength help delay fatigue in the arms and postural muscles during a race. As the muscles become fatigued, they may compromise the efficiency of movement and increase the oxygen demand for running because additional motor units are recruited. Oxygen cost at each running speed may be reduced if a more efficient pattern is induced through an increase in leg strength. However some studies showed no improvement in endurance performance after resistance training (Hawley, 1998). It appears that there is a minimal amount of muscle strength required performing well in any endurance event. This explains why the greater muscle power seen after most resistance training increases short-term endurance capacity in these athletes.

Runners are much less out of breath during a marathon, particularly during the latter stages, but are far more fatigued in their legs after a 10km. This indicates the importance of muscle endurance. Muscle endurance is the ability of a muscle to endure a sub-maximal workload over an extended period of time. The impact on an athlete's legs when running on a level surface is four times the athlete's bodyweight. The impact on a downhill can increase as much as eight times the athlete's bodyweight (McGee, 1998). Therefore the importance of eccentric contraction exercises to improve muscle endurance and decrease risk of injury.

### 2.9.2.3 Speed training phase

Running at faster speeds demands the utilisation of a greater proportion of the maximal oxygen uptake and an increased contribution to the energy supply from anaerobic metabolism. The end result is that lactate accumulates in the blood in increasing concentrations (Ramsbottom et al., 1989). A strong correlation has been reported between the onset of plasma of blood lactate accumulation and distance running performance (Rieu et al., 1990; Seip, 1991; Foxdal et al., 1996).

Long-distance racing is about endurance and speed together. Jenkins & Quigley (1992) reported that endurance training appeared to induce a fall in the y-intercept (anaerobic capacity), and although the change was not significant, the implication is that the improved endurance ability diminished the capacity of high-intensity exercise. Thus, endurance athletes have higher anaerobic thresholds than non-athletes, where the anaerobic threshold is expressed as a fraction of  $VO_2$  max (Haffor et al., 1991). Endurance will get a runner to the finishing line, but speed will get a runner there quicker. This means that speed and varying degrees of speed must be practised to be done well.

### 2.9.2.4 Tapering phase

Endurance runners often reduce training volume for 5 – 21 days prior to an important competition in an effort to enhance performance. Houmard et al. (1990) found that a 70% reduction in training volume, while maintaining training intensity, resulted in unchanged aerobic power and 5 km race performance. In a more recent study by Houmard et al. (1994), reported that a 7 day systematic reduction in training volume of low intensity (60%  $VO_2$  max) did not improve treadmill time to exhaustion at a fixed pace (1 500m race pace). In contrast a 7 day high intensity taper improved this index of performance by 22% (Shepley et al., 1992). Hickson (1981) found that one of two thirds reduction in training frequency or duration had no affect on  $VO_2$  max over 15 weeks as long as training intensity was maintained. However, the ability to sustain a high percentage of this oxygen uptake appears to have been diminished based on elevated RER and blood lactate levels during submaximal exercise (McConnel et al., 1993). Shepley et al. (1992) findings suggest that a high-intensity taper provides an unique stimulus that may lead to enhanced distance running performance.



Intense distance running has been demonstrated to decrease muscular power (Houmard et al., 1994), however muscular power is positively associated with distance running performance. Therefore any effort to maximise power should be made. A 7 day taper consisting of high-intensity running increased muscle citrate synthase activity by 18% in well-trained distance runners (Shepley et al., 1992). An elevation in mitochondrial capacity could minimise lactate production and any corresponding inhibition of the contractile process and thus improve both performance and running economy. Mode-specific training during taper is necessary for performance enhancement (Houmard et al., 1994).

Top-level marathon runners who remain injury free with excellent general fitness can work well with a cycle that repeats every four to five months. There are 10 to 12 weeks of intense preparation, a few weeks of tapering, then the race, and a month of mental and physical recovery (Lenzi, 1987). This is why the world's healthiest and most consistent marathoners typically compete no more than two to three times a year.

Newton's tapering approach was to reduce his training by 15% the third week before the race, and by a further 10% in the second week before the race, so that still running 75% of his usual mileage only seven days before the race. By comparison, Bruce Fordyce rests much more during the last ten days before Comrades than did Newton, despite the fact that Fordyce runs less total mileage. This suggests that Newton probably did not rest sufficiently before races and this might have explained the occasions when his performance was not optimal (Noakes, 1992).

### **2.9.2.5 Training summary**

Endurance training is the most crucial element in any long distance training programme and becomes more important the longer the goal race distance is. A runner can, within the limits, still run a reasonable marathon or Comrades without doing strength or speed work, but without the necessary endurance work, the athlete will fail to finish the race.

### **2.9.3 Physiological consequences of training**

#### **2.9.3.1 Effect of endurance training on the $VO_2$ parameters**

It has been well documented that cardiorespiratory and metabolic responses to exercise may be modified rapidly by exercise training. The study by Ramsbottom et al. (1989) demonstrated a decrease in the ventilatory equivalent for oxygen with endurance training. This decrease represents a more efficient utilisation of oxygen and, may reflect an increased mechanical efficiency of the running action. Therefore increased aerobic capacity of human skeletal muscle. Wasserman et al. (1986) suggest that lactate production during exercise depends mainly on the availability of oxygen in the active tissue. Therefore the decrease in blood lactate concentrations with endurance training.

The well-documented adaptation within endurance trained muscle suggest greater perfusion and an increased transit time for blood through muscle after training. Such adaptations would facilitate an improved availability of oxygen and substrates to the active muscle cell while promoting the rapid removal of metabolic waste products (Ramsbottom et al., 1989). Such adaptations within human skeletal muscle may be especially important during marathon and ultra running events like the Comrades Marathon.

Yoshida et al. (1992) named three factors that contribute to the improvement of  $VO_2$  parameters after training, i.e.:

- an improved capacity for mitochondrial respiration in muscle;
- an increased availability of blood and / or muscle  $O_2$  stores; and
- an elevation of cardiac output and / or an increase in muscle blood flow.

In this context, Yoshida et al. (1992) documented that endurance training induces an improvement of mitochondrial respiratory function resulting in a reduced production of lactate during heavy exercise.

#### **2.9.3.2 Can $VO_2$ max be raised by training?**

The answer relates to inherent genetic endowment, but the level of fitness at which one begins the training programme also plays a role. Recent studies of Makrides et al. (1985) have shown that untrained people over a broad age range who embark on a serious aerobic fitness

development programme can raise their sedentary-lifestyle  $\text{VO}_2$  max values by as much as 40% or more. Among already established top-level runners, this percentage increase is considerably less.

Although some researchers claim that  $\text{VO}_2$  max among elite-level runners changes little over the course of a year, Martin & Coe (1997) find substantial differences as either training load or training emphasis shifts. As an example, the  $\text{VO}_2$  max of one of their male middle-distance runners increased by 18%, from 4,695 ml/min to 5,525 ml/min, over a seven-month period. Ramsbottom et al. (1989) stated that training status could be better explained in terms of the highest proportion of the  $\text{VO}_2$  max at which a steady-state could be achieved rather than  $\text{VO}_2$  max alone. Earlier investigations all demonstrated that training induced improvements in endurance capacity were accompanied by an increase in exercise intensity at which blood lactate accumulates and at which ventilatory threshold was achieved. Weltman (1990) reported that it is possible to increase velocity and  $\text{VO}_2$  at OBLA without changing  $\text{VO}_2$  max.

Housh et al. (1988) has reported that trained males exhibited lower submaximal steady-state  $\text{VO}_2$  responses than untrained males. Therefore, while short term endurance training may not be effective in modifying running economy, it is possible that prolonged training could result in improved biomechanical efficiency and therefore lower submaximal steady-state  $\text{VO}_2$  values.

### **2.9.3.3 Effect of training on heart rate response**

It has been well documented that heart rate at a given exercise intensity decreases significantly after endurance training. Yoshida et al. (1992) demonstrated that as well as a reduction in heart rate during constant exercise test; the increase of heart rate at the onset of exercise was speeded up by the endurance training. Furthermore, since endurance training has been shown to increase stroke volume during constant exercise, it is postulated that cardiac output kinetics at the onset of exercise might be improved by endurance training.

### **2.9.3.4 Interval training versus long slow distance training**

Interval training appears to enhance running economy, and improvements seem to occur when the number of interval sessions per week is increased (Douglas et al., 1981). It is probably best to include some interval work at speeds equal to or slightly faster than the pace at which

optimal economy is desired. Endurance training has little effect on  $\text{VO}_2$  max, whereas interval training brings about greater, more rapid improvement. It appears, therefore, that interval training is essential for the development and maintenance of maximal aerobic capacity.

### **2.9.3.5 Effect of training on lactate and ventilatory threshold**

Training at or slightly above OBLA has been found to be the most effective way to develop aerobic fitness (Spurway, 1992). It is well established that exercise of differing durations, number of repetitions, or levels of severity can bring about different degrees of glycogen depletion in the active muscles. Glycogen depletion was shown to cause depression of glycolysis and lactate production, resulting in a rightward shift in the lactate response curve and OBLA point (Dotan et al., 1989). Yoshida et al. (1990) reported that in distance runners and competitive walkers, blood lactate variables such as lactate threshold ( $\text{VO}_2$  at threshold, and velocity at threshold) and OBLA ( $\text{VO}_2$  at OBLA, velocity at OBLA), and running velocity were significantly improved after extra endurance training, but  $\text{VO}_2$  max was not significantly improved. Yoshida et al. (1992) also stated that during the first few weeks of training decreases have been observed in blood lactate concentration and heart rate during submaximal exercise, and increases in lactate threshold.

### **2.9.3.6 Effect of endurance training on weight loss**

Chad & Wenger (1985) reported that the duration of activity rather than the intensity have a greater effect on the post-exercise oxygen consumption. The implications of the metabolic after-effects of exercise making a contribution in a weight reduction program, is in considering the total energy expenditure of prolonged exercise and the importance of extending the work time for elevating energy expenditure. Hagberg (1980) found that rectal temperature is significantly higher following longer duration exercise (20 minutes versus 5 minutes) at work intensities of 50% to 80% of  $\text{VO}_2$  max and elevated temperatures after exercise are associated with elevated post exercise  $\text{VO}_2$ . Previous studies indicated that lower fat-free body weight is one of the variables primarily characterising the faster endurance runners (Costill, 1967; Housh et al., 1988).

### 2.9.3.7 Fast (FT) and Slow twitch (ST) fibres

Recent research studies involving comprehensive physiological evaluation of male Kenyan distance runners have been quite illuminating in helping to explain whether it is genetics (FT/ST muscle fiber ratios) or lifestyle (altitude residence, a hard lifestyle in younger years), or both that make the Kenyans such good distance runners. As seen by recent studies from Saltin et al. (1995), from a physiological perspective, the most important characteristic of these runners is their slightly higher running economy, higher anaerobic threshold, and higher  $VO_2$  max. These physiological advantages most likely are developed from the utilization of running as a part of their childhood lifestyle, before they begin more structured training intended to improve fitness for competitive racing. Thus it may be simply the situation of successful accommodation to stress loading in the formative years, rather than genetic factors, that sets the stage for their success (Noakes, 1992).

Studies by Costill et al. (1973) have demonstrated a strong relationship between ST fibres in the lateralis muscle and distance running performance. The fastest runners were found to possess 70-80% ST fibres while slowest runners had 40-45% ST fibres. It is possible therefore, that the lower blood lactate values observed in the better distance runners might be a function of fibre population and/or the oxidative-glycolytic qualities of the running musculature.

Rice et al. (1988) also demonstrated that the lateral head of the gastrocnemius muscle of 14 elite male long-distance runners showed a range of 50% to 98% ST fibers compared to a range of 50% to 64% among the untrained population. However, because the ST fibers in the elite runners were 29% larger than the FT fibers, on the average 82% of the muscle cross-sectional area was composed of ST muscle. Thus training can selectively increase the size of muscle fibers (Rice et al., 1988).

Jenkins & Quigley (1992) used critical power (CP), that was determine in exhaustive tests at different outputs, to measure a athletes aerobic and anaerobic capacity. CP as proposed by Jenkins & Quigley (1992), is the power represented by the coefficient of linear regression of maximum work on maximum time. As hypothesised, the slope of the CP function increased as a result of continuous training at or near CP without any significant change in the y-

intercept. This confirms now the well-established finding that continuous training results in increases in endurance performance, the percentage of maximal oxygen uptake that can be maintained continuously, and the lactate and ventilatory thresholds, all of which exceed the increase in maximal oxygen uptake.

#### **2.9.4 Overtraining**

Competitive endurance athletes typically undergo large increases in training volume and intensity early in their competitive season. Training stress during this period can exceed the athlete's ability to adapt, leading to decrements or stagnation in performance, injury, and complex of symptoms commonly referred as the overtraining syndrome (Pizza et al., 1994). Morgan & Craib (1992) defined overtraining as an imbalance between exercise and recovery, resulting in severe and prolonged fatigues. A problem exists in attempting to steadily increase aerobic and anaerobic capabilities through training. The greater the increase in such performance indicators as  $VO_2$  max, lactate / ventilatory threshold pace, and whatever maximal anaerobic work indicators are used, the greater the subsequent intensity and volume of training required for any further increases. Kuipers & Keizer (1988) have hypothesised that inadequate recovery from a rapid increase in training volume would increase the aerobic demand of running at any given workload due to changes in the stimulation and recruitment of motor units.

Thus, higher volumes of aerobic running bring so little performance benefit that the increasing risks of overuse injury or development of symptoms of overtraining outweigh the potential performance gains (Martin & Coe, 1997). In other words, the risk-benefit ratio becomes excessively high.

Coaches and athletes commonly use an elevation in resting heart rate as an indicator of training stress. However, Pizza et al. (1994) reported that moderate to large increases in training intensity and volume have failed to produce significant elevations in resting heart rate despite changes in other indices of training stress. Therefore, in highly conditioned endurance athletes, monitoring resting heart rate may not be a useful indicator of training stress.

### **2.9.5 Cross training**

In an attempt to minimise the potential detrimental effects of a large increase in training stress via the same training mode (overtraining), endurance athletes are currently implementing cross training regimens into their training. The popular media has endorsed cross training as a means of improving total body fitness and performance in runners (Pizza et al., 1994). However, in the presence of well-developed literature on the principle of specificity of training, the idea that the practice of non-running training alternatives in improving running performance is tenuous and potentially detracts from training time that could be spent more specifically on running needs to be investigated.

Walker et al. (1993) reported that cross training does not exhibit this optimisation of stride length due to the detracting influence of:

- interaction of training methods, specifically running and cycling that utilise the leg musculature in quite a different range of motion; and
- inadequate volume of running specific training relative to their other training necessary to produce an optimal running economy.

However, Mutton et al. (1993) support the use of cross training as an alternative to increasing performance while adding variety to the training program and perhaps reducing the potential for injuries due to overuse or high intensity activity. They showed improvements in running speed, %  $VO_2$  utilised and a decrease in blood lactate values with the cross training group. Cross training could be advantageous to an athlete with smaller increases in training volume or during the “off season” by creating variety in their workouts, training accessory muscles, and by providing a training stimulus when an injury may not permit them to train in their competitive mode. However, in the “high volume phase” of a competitive season, the athlete may benefit more from reducing the volume and increasing the intensity of training, as opposed to, increasing their training volume via the same training mode or by cross training (Pizza et al., 1994).

### **2.9.6 Middle distance and long distance running**

There is no doubt that a high  $VO_2$  max constitutes a kind of membership card for endurance into the world of top level middle and long distance running excellence. But anaerobic aspects

of performance also contribute to the difference between finishing first and second in a race, because they interact with  $VO_2$  max (Martin & Coe, 1997). It is thus important to measure two physiological variables in evaluating long and middle distance runners. One is velocity at anaerobic threshold. Marathon pace is slightly slower than this. The other is velocity at  $VO_2$  max, which is close to 3 000 m pace (Billat & Koralsztein, 1996).

Middle distance runners have lower  $VO_2$  max values than long distance runners but complete at a higher percentage of  $VO_2$  max and incur a greater energy cost for unit distance run. They have the ability to compete at intensities up to 110% of  $VO_2$  max for a duration of as long as 10 or 11 minutes, while long distance runners typically compete at intensities of between 75% and 90% of  $VO_2$  max (Brandon, 1995). Athletes attempt to compete at the fastest sustainable aerobic pace, through the 800-m, where they must cope with additional large anaerobic accumulation over a few minutes time. The larger their  $VO_2$  max, the smaller their total anaerobic contribution will be at any given pace, or the faster they can run before anaerobic effects start to impair performance. But once  $VO_2$  max has been elevated about as high as possible without inordinate additional training volumes, anaerobic development will make the additional difference between being optimally fit and marginally fit (Martin & Coe, 1997).

The energy requirements and metabolic support for optimal run performance are functions of the length of the race and the intensity at which it is completed (Brandon, 1995). The energy requirement for long distance running can, to a great extent, be supplied by the aerobic metabolism, as the rate of energy production necessary to sustain the run velocity is less at longer than at shorter distances (Lacour et al., 1990). Brandon (1995) found that distances requiring up to 10 minutes to complete are quite dependent on both aerobic and anaerobic metabolism.

Many studies have shown that the muscles of outstanding athletes show specific and predictable patterns of muscle fibre content according to the sports in which they excel. Middle distance runners, cyclists and swimmers tend to have equal proportions of both FT and ST fibers. In long distance runners and cross-country skiers, on the other hand, the percentage of ST fibers is high (Noakes, 1992).



Since anaerobic threshold occurs at 60% to 90% of  $\text{VO}_2$  max it is important factor in long distance run performance, as distance running is associated more with submaximal efforts. On the other hand, middle distance runners run for shorter time periods at higher velocities and apparently are less sensitive than long distance runners to high lactate levels. Middle distance runners are able to maintain high velocities in races lasting 8 to 11 minutes with relatively high levels of lactic acid (Brandon, 1995).

## 2.10 ENVIRONMENTAL STRESS

### 2.10.1 Altitude

The density of air decreases progressively as one ascends above sea level. The barometric pressure at sea level averages 760 mm (Hg), whereas at 3048 m, the barometer reads 510 mm Hg; at an elevation of 5486 m, the pressure of a column of air at the earth's surface is about one-half its pressure at sea level. Ambient air at both sea level and altitude contains 20,93% oxygen, the  $\text{PO}_2$  or density of the oxygen molecules in air is reduced in direct proportion to the fall in barometric pressure upon ascending to higher elevations. Ambient  $\text{PO}_2$  averages approximately 150 mm Hg at sea level, and 107 mm Hg at 3048 m. At the summit of Mount Everest (8848 m), the alveolar  $\text{PO}_2$  is 25 mm Hg. This represents only approximately 30% of the oxygen available in air at sea level. It is this reduction in  $\text{PO}_2$  that precipitates the immediate physiologic adjustments to altitude as well as the longer-term process of acclimatization (McArdle et al., 1996).

The relatively poor performances of men and women in middle-distance and distance running and swimming during the 1968 Olympics in Mexico City (altitude 2300 m) have been attributed to the small reduction in oxygen transport at this altitude. Acute exposure to 4300 m causes a 32% reduction in aerobic capacity, compared with sea level values. At extreme altitudes (8848 m),  $\text{VO}_2$  max will reduce by approximately 70% (Groves, 1987).

Classification of altitude elevation (Curtis, 1998)

<b>Low</b>	1000 – 1500 m
<b>Moderate</b>	2300 – 3000 m
<b>High</b>	3100 – 4000 m
<b>Extreme</b>	5300 – 8800 m

## 2.10.2 Acclimatization

The adaptive responses in physiology and metabolism that improve one's tolerance to altitude hypoxia are broadly termed acclimatisation (McArdle et al., 1996). Rapid ascent to high altitudes may be associated with acute mountain sickness, a syndrome including various combinations of headache, anorexia, vomiting, fatigue, insomnia, dyspnoea, ataxia, oliguria and oedema (Berrè et al., 1999). There are many uncertainties about when to have an athlete go to an area of high altitude to compete. Some believe that 2 – 3 weeks before competition provides the best adjustment period, whereas others believe that, for psychological as well as physiological reasons, three days before competition is enough time (Arnheim & Prentice, 1993).

The length of the acclimatisation period depends on the altitude. As a broad guideline, approximately 2 weeks are required to adapt to altitudes of up to 2300 m. Thereafter, for each 610 m increase in altitude, an additional week is necessary to fully adapt up to an altitude of 4600 m. The benefits of acclimatization are lost within 2 – 3 weeks after a return to sea level (McArdle et al., 1996).

Bailey & Pate (1991) stated that the economy of heat stress environment should be improved by heat acclimatisation. Acclimatisation, accompanied by exercise training, can increase plasma volume up to 12%. Increased plasma volume assisted in the maintenance of stroke volume and consequently minimises myocardial work in a heat stress environment. Further, an increased plasma volume improves sweating capacity and enables the body to tolerate greater internal heat production.

According to Levine & Stay-Gundersen (1992) 2200-2500 m is approximately the “altitude threshold”. It is thus unlikely that physiological adaptations that might improve exercise performance would develop at altitudes below this range. Above 2500 m however, such adaptations are likely to increase linearly with increasing altitude unless acute mountain sickness intervenes or extreme hypoxia (above 5500 m) causes frank deterioration. It would appear that as far as altitude acclimatisation for sea level performance is concerned, within a reasonable range between 2200 m – 4000 m, “higher is better”

### 2.10.3 Adjustments to altitude

- ***Acid-Base Readjustment***

Although hyperventilation at altitude favourably increases alveolar  $PO_2$ , it has the opposite effect on carbon dioxide. During a prolonged stay at high altitude, the pressure of alveolar carbon dioxide falls to as low as 10 mm Hg. This control of respiratory alkalosis is accomplished slowly, since the kidneys excrete base through renal tubules (McArdle et al., 1991).

- ***Reduced Buffering Capacity***

A general depression in maximum lactate concentration is apparent during maximal exercise at altitudes above 4000 m. This reduction in exercise blood lactate levels during chronic high-altitude hypoxia is not accompanied by an increase in  $VO_2$  max or by an increase in oxygen delivery to active tissues after acclimatization (McArdle et al., 1991). It seems that lactate threshold is better maintained in males than females with increasing altitude. Comparing the same active, untrained altitude residents from above, increasing hypoxia detrimentally influenced lactate kinetics in females. This difference was independent of the reductions in  $VO_2$  max (Seiler, 1997).

- ***Hematological Changes***

The most important adaptation for the endurance athlete is an increase in the number of red blood cells, which are produced in response to greater release of the hormone erythropoietin (EPO) by the kidneys (Baker & Hopkins, 1998). An increase in the blood's oxygen-carrying capacity is the most important longer-term adaptation to altitude. The two factors that are responsible are the initial decrease in plasma volume and the increase in the erythrocytes and haemoglobin. After one week at an altitude of 2300 m, the plasma volume decreased by 8%, haematocrit increase by 4% and haemoglobin increased by 10%. During the 1973 Mount Everest Expedition, a 40% increase in haemoglobin concentration and a 66% increase in haematocrit were noted for climbers acclimatised at 6500 m. This probably approaches the upper limit of a beneficial concentration of red blood cells. Any further erythrocyte packing would increase the blood's viscosity and probably restrict blood flow and oxygen diffusion to the tissues. Athletes with low iron stores may not respond to the acclimatisation process as well as individuals who arrive at altitude with

iron reserves adequate to sustain an increase in red blood cell production (McArdle et al., 1996).

- ***Cellular Adaptations***

Increasing red cell mass is recognised as a potent means of improving athletic performance (Buick et al., 1980). Numerous studies have shown that red blood cell production is stimulated during exposure to very high altitude - 4 000 m or higher (Ashenden et al., 1999). An increase in the concentration of erythropoietin (EPO), which is one of the hormones that stimulate red blood cell production, has been documented in athletes living at simulated altitudes of between 2500 and 3000 m and training at near sea level (Laitinen et al., 1995). Ashenden et al. (1999) found no increase in the reticulocyte production of elite female cyclists following 12 nights of sleeping at a simulated altitude of 2650 m compared to control subjects undertaking the same training loads but sleeping near sea-level conditions. The reticulocyte parameters are known to reflect an increase in red blood cell production.

Muscle biopsies from humans living at high altitude indicate an increase in myoglobin by as much as 16% after acclimatisation. Such adaptations increase the “storage” of oxygen in specific muscles and facilitate intracellular oxygen release and utilisation at low  $PO_2$ . Adaptations that depend on oxygen delivery to peripheral tissues increase linearly with oxyhemoglobin desaturation. Thus, red cell mass does not increase until  $PaO_2$  decreases below approximately 65mmHg (Levine & Stay-Gundersen, 1992).

- ***Changes in Body Mass and Composition***

A substantial increase in heart rate when the athlete stands up may be an early warning of the onset of overtraining and a sign that the athlete should return to sea level (Rusko, 1996). A related sign of living to high may be wasting of muscles. Athletes living at 3000 m or higher would be wise to include some form of monitoring for overtraining: feelings of fatigue during training, reduction in performance of criterion tests, and possibly changes in heart rate, body mass or muscle mass (MacDougall et al., 1991). Long-term exposure to high altitude produces a significant loss in lean body mass and body fat. The higher basal metabolic rate also plays a role in weight loss. Severe high altitude is thus catabolic. In

fact the decrease in muscle fiber size may be directly responsible for increasing capillary density and reducing effective diffusion distance to muscle mitochondria (Green et al., 1989).

Baker & Hopkins (1998) named various methods to get altitude exposure:

- Use of a mountain and a valley;
- stay high and train hard with oxygen;
- live in a nitrogen house;
- rest and sleep in a nitrogen tent;
- breathe through a nitrogen mask intermittently;
- live in a large barometric chamber;
- rest and sleep in a personal barometric chamber; and
- use erythropoietin or blood doping.

However the ethics of altitude exposure should also be taken in consideration. Altitude chambers, nitrogen houses and nitrogen tents would be dangerous if the simulated altitude was high enough and long enough to raise the thickness of blood to an unsafe level (Baker & Hopkins, 1998).

#### **2.10.4 Altitude training and performance**

From a theoretical viewpoint, training at altitude could produce more rapid and even greater physiological changes than could training at sea level only. The reason is that altitude hypoxia is a stress that produces physiological changes similar to those caused by physical training. To a certain extent, this research has been supported experimentally. (Roskamm et al., 1969; Banister & Woo, 1978), but most of the research indicates that enhancement in performance is more apparent in unconditioned non-athletic individuals.

Although some adaptations during acclimatisation to altitude should enhance aerobic capacity and endurance performance upon return to sea level, research results do not support this effect (Banister & Woo, 1978). This is probably the result of the altitude-related decrease in both maximum heartrate and stroke volume. For the highly trained athlete, the training intensity required for maintenance of peak performances cannot be achieved at altitude. In contrast,

probably the most important adaptation that might improve sea level performance is an increase in hemoglobin and hematocrit which improves the oxygen carrying capacity of the blood (Levine & Stay-Gundersen, 1992).

Despite the fact that there is very little scientific evidence showing that altitude training improves sea-level performance, the prevailing opinion among coaches, athletes and many uninformed sports administrators is that it works for all athletes, irrespective of their event or ability. Special altitude training centres are usually located in exotic mountainous regions and the athletes who attend these camps do not have too many distractions. They are there to train. Life at altitude consists of running, eating sleeping and more of the same. Athletes are highly motivated and usually working towards a common competitive goal, an environment highly conducive to quality living and training. John Hawley stated in the Runners World magazine that it may well be that the isolation of these altitude camps is the main reason that many athletes improve their performance when they return to sea level. Therefore Hawley reported that isolated sea-level training camps would probably have just the same positive effect whether the camp is at altitude or not (Hawley, 1997). However Baker & Hopkins (1998) found that living and training at altitude is less effective than living at altitude and training near sea level, because the lack of oxygen at altitude results in detraining through reduction in intensity of training

Trained runners have revealed lower aerobic demands during treadmill running at altitude compared with sea-level treadmill running, despite a greater ventilatory effort at altitude (Morgan & Craib, 1992). Levine & Stay-Gundersen (1992) study showed that athletes train faster and at greater oxygen uptakes near sea level than at altitude. A lowered overall work of breathing due to the reduced air density at altitude an environmental differences in anaerobic energy contribution may partly account for enhance treadmill running economy at altitude. Sea level aerobic demands measured in trained runners during track running are also significantly greater when compared with track running at altitude. A potential explanation for this finding is that a decreased energy demand is required to move through the less dense air of altitude (Morgan & Craib, 1992). Kayser et al. (1993) stated that high-altitude natives are also characterised by low levels of lactic acid at exhaustion, although the underlying mechanism that might be different from that for acclimatised lowlanders. Levine & Stay-

Gundersen (1992) stated that the substrate utilisation also improved by increasing mobilisation of free fatty acids and increasing dependence on blood glucose thus sparing muscle glycogen. This is manifested by decreased accumulation of metabolites such as lactate or ammonia during submaximal exercise.

Muscle pH after exhaustive exercise is higher at altitude than at sea level. As a consequence, decreases in intra- and extracellular buffer capacities do not appear to be responsible for the decrease in low lactate values at maximum intensity. It is important however, that altitude training is not a substitute for a focused, well designed training program and must be undertaken with specific attention to adequate nutrition, particularly ensuring adequate iron stores (Levine & Stay-Gundersen, 1992). Stay-Gundersen et al. (1992) demonstrated that runners, who begin a period of altitude training with low iron stores, do not increase their red cell volume after a month living and training above 2500 m.

#### **2.10.4.1 Training intensities at altitude**

During high intensity interval workouts, absolute workloads, peak heart rate, and blood lactate concentrations were lower during training at altitude than near sea level. Thus interval training at high altitudes is unlikely to be as effective as interval training at lower altitudes (Levine & Stay-Gundersen, 1992).

It seems that lactate threshold is better maintained in males than females with increasing altitude (Seiler, 1997). Base training near sea level will allow relatively normal training intensity and may prevent the loss of plasma volume that often accompanies altitude acclimatisation (Withey et al., 1983). In contrast, base training at altitude, as long as it occurs at a low enough altitude to maintain similar running speeds and absolute workloads as at sea level, may facilitate an increase in mitochondrial aerobic enzyme activities and maximise peripheral oxygen utilisation.

The shortage of oxygen at higher altitudes appears to be a stressor that these athletes cannot adapt to. The result is inability to sustain previous training may loads and gradual loss of fitness. A substantial increase in heart rate when the athlete stands up may be an early warning of the onset of such overtraining and a sign that the athlete should return to sea level. Thus it would be wise to include some form of monitoring for overtraining: feelings of fatigue

during training, reduction in performance of criterion tests, and possibly changes in heart rate, body mass, or more sophisticated measures of muscle mass (Baker & Hopkins, 1998).

### **2.10.5 Alternative approaches**

The optimal approach to altitude training would be to acclimatise to altitude, but train as close to sea level as possible thereby maximising running speed and maintaining aerobic fitness (Levine & Stay-Gundersen, 1992). Especially high intensity and interval workouts should be conducted as close to sea level as possible, preferable below 1500 m, to maximise running speed and training intensity. However, Ashenden et al. (1999) found no increase in the erythropoietic stimulus when the athletes participate in a “live high, train low” experiment.

## **2.11 USE OF HEARTRATE MONITORS**

Yamaji et al. (1992) found excellent correlation between heart rate monitors and heart rate readings as computed from the ECG using chest electrodes. These findings support thus the accuracy of the use of pulse monitors. Today, heartrate monitors are widely used by amateur and professional athletes in many different sports in an effort to guide training, optimise race performance and monitor recovery. Heartrate monitoring allows a more precise control of intensity than would be possible from subjective monitoring of effort alone. During running competitions, it has become common practice for athletes to guide pace by setting relatively narrow heartrate limits (10 bpm) on their heartrate monitors. (Toole et al., 1998). They attempt to stay within these limits by continually adjusting pace throughout the course of the race. Thus, heartrate monitoring provides the key to regulate the quantity and intensity of workouts and racing performance by providing accurate and immediate biofeedback data.

### **2.11.1 Factors that affect heart rate response**

One of the major problems is determining the degree of similarity between the laboratory test used to establish the heartrate – oxygen uptake line and the specific activity to which it is applied. Comrades Marathon star Nick Bester said after the 1997 Comrades that in the last few kilometres he was unable to keep his heart rate up at the remarkable 170 beats per minute he had sustained the whole race, “because my legs were too tired, I just couldn’t move any faster” (Comrades Marathon update, 1997).



Many factors have an effect on a person's heartrate response and therefore need to be considered when training. The increased heart rate found in warm conditions is probably the result of increased body temperature rather than any tendency for the subjects to push themselves harder in warmer weather. Increased fluid loss through sweating might also contribute to the increased heart rate in warmer conditions (Robinson et al., 1991; Seiler, 1997). Heartrate increases from 5-10 beats per minute at any speed when the ambient temperature increases to about 25°C. Heartrate is the lowest in the morning and increases by about 10 beats per minute by late afternoon, thus time of the day is also a factor to consider when training. Dehydration affects the heartrate response by an increase in heartrate (about 7 beats per minute) at any speed for every litre of fluid lost while training. Heart rate decreases as a result of an improvement in an athlete's fitness level (Robinson et al., 1991). Daily heat exposure of ten days is superior to intermittent exposure for inducing acclimatisation (Seiler, 1997)

Yamaji et al. (1992) report a direct linkage between central and cardiovascular fatigue, and respiratory and peripheral sensations. Robinson et al. (1991) named other factors that produced significant correlations with heart rates were distance, duration, willingness to train, number of companions, temperature, terrain and wind. They stated that the higher heart rates recorded in steep terrain and wind conditions may have been the result of subjects attempting to maintain a constant pace during periods of increased work load. Also the effect of running with companions may reflect a tendency of elite athletes to compete against each other even on training runs.

#### *Why use a heartrate monitor:*

- to give a precise measurement of the exercise intensity
- to individualise the training program
- to monitor progress, and witnessing improvement is motivation
- to introduce objective observation

#### **2.11.2 Different heart rate formulas for exercise intensity prescription**

Several formulas are routinely used to determine an individual's exercise intensity and are based upon maximal heart rate, either measured directly during a graded exerciser test or

estimated for age ( $220 - \text{age}$ ). The Karvonen method, which is the most widely accepted, the resting heart rate is a second variable used in the calculation of the targeted heart rate intensity (DiCarlo et al., 1991; Foss, & Keteyian, 1998). By doing an incremental maximum oxygen consumption test, the lactate and ventilatory threshold can be used to determine target exercise zones.

Conconi developed a method by which it was possible to establish the anaerobic threshold without measuring lactate. Conconi made use of the existing correlation between activity intensity and pulse rate. He found that at very intensive activity pulse rate and intensity no longer parallel. The straight line at the onset deflects at high intensities. In other words, the intensity may be increased but the increase of pulse rate lags at a certain point. This point is the PR point. The workout intensity corresponding to this point is the maximum activity that can be done with aerobic energy supply (Janssen, 1987).

For each person, heart rate and oxygen uptake tends to be linearly related throughout a wide range of aerobic exercises (McArdle et al., 1996). If this precise relationship is known, the exercise heart rate can be used to estimate oxygen uptake during similar forms of physical activity. This approach has been used when the oxygen uptake could not be measured during actual activity. Each athlete's heart rate increased linearly, with an increase in oxygen uptake being accompanied by a proportionate increase in heart rate. However, even though both heart rate and oxygen uptake lines are linear, the same heart rate does not correspond to the same level of oxygen uptake. The slope or rate of change of the line differs considerably from person to person (McArdle et al., 1996).

Heart rates generally rise quickly to a steady-state heart rate that is maintained early in exercise (i.e. up to approximately 30 minutes), followed by gradually increasing heart rates if exercise is continued for prolonged periods (Toole et al., 1998). Although specific reasons for slowing pace during prolonged exercise may vary among individual athletes, potential contributing reasons include substrate depletion, altered muscle efficiency, fluid and electrolyte imbalances, thermoregulatory problems, cardiac fatigue and psychological factors (Toole et al., 1998). The ability, then, to sustain high heart rates during prolonged exercise could be hypothesised to be necessary for fast paces and fast finish times.

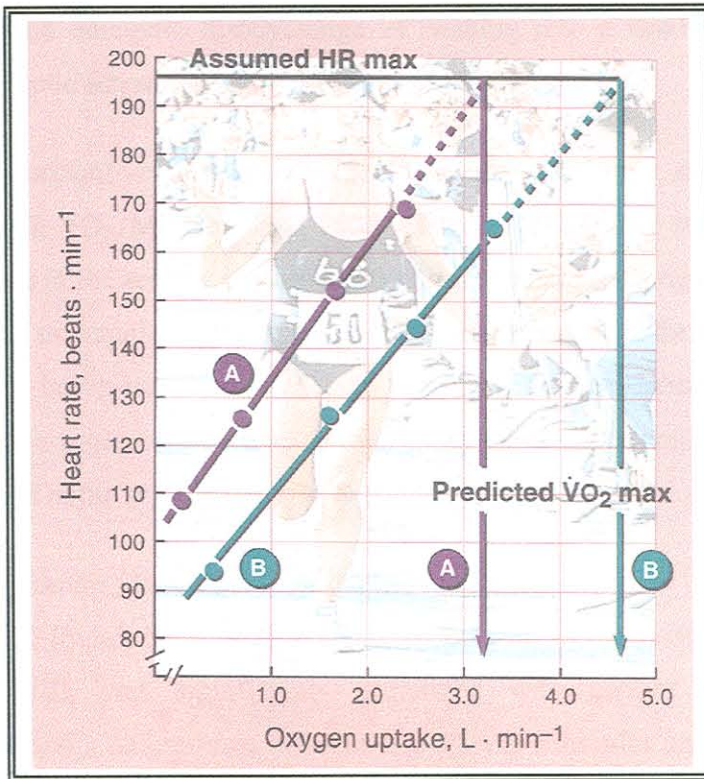
### 2.11.3 Relationship between oxygen consumption ( $VO_2$ ) and heart rate

Heart rate is recognised as the most useful method for determining training intensity, because it displays a fairly linear response to increasing work loads and normally reaches maximum values at the same exercise intensity that produces maximum aerobic power (Astrand & Rodahl, 1986). Thus, by simultaneously measuring maximum aerobic power and exercise heart rate in the laboratory, the scientist can estimate the relative intensity of exercise in the field on the basis of heart rate alone and indirectly determine maximum aerobic power (MacDougall et al., 1991).

Common tests to predict  $VO_2$  max use exercise heart rate during a standardised regimen of submaximal exercise performed either on a bicycle ergometer, a treadmill or a step test. Using the linear relationship between oxygen consumption and heartrate,  $VO_2$  max can be determined. Although each person's heartrate- $VO_2$  line tends to be linear, the slope of the individual lines can differ considerably (McArdle et al., 1996). Also heart rate reflects the relative difficulty or intensity of the exercise rather than the absolute work being performed. This explained the fact that the lower body usually represent a larger proportion to the total body mass and, in the case of equal fitness in upper and lower body musculature, is capable of achieving a higher work rate before the aerobic production of ATP becomes limiting (MacDougall et al., 1991).

Londeree (1995) provides the selected values for percent  $VO_2$  max and corresponding percentages of heart rate max:

Percent HR max	Percent $VO_2$ max
50	28
60	40
70	58
80	70
90	83
100	100



**Figure 8: Heart rate in relation to oxygen uptake during upright exercise in endurance athletes (brown line) and sedentary college students before (blue line) and after (green line) 55 days of aerobic training (McArdle et al., 1996).**

## 2.12 TREADMILL VS OVERGROUND CONDITIONS

Due to the difficulty of obtaining metabolic data in field situations, measurements have typically been made indoors on treadmills. Since air and wind resistance are not factors during indoor testing, caution must be used in applying treadmill data to overground conditions (Morgan et al., 1989).

While most studies have indicated that overground running is more costly than indoor treadmill running, some investigators have reported no significant differences between the two conditions. Morgan et al. (1989) estimated that 2% to 8% of the total energy demands of long- and middle-distance track running is expended overcoming air resistance. Results from Daniels (1985) indicated that at fast running speeds, the cost of overground running in calm air was 7.1% greater compared to indoor treadmill running. It was observed that as wind

velocity increased, the energetic disadvantage of running into a headwind was relatively greater than the energetic advantage gained by running with a tailwind.

Interestingly, when running velocity and tailwind velocity were equal, overground  $VO_2$  was equivalent to treadmill  $VO_2$  (Morgan et al., 1985). Bassett (1985) also stated that there is no measurable difference in the aerobic requirements of submaximal running on the treadmill and track, or between the maximal oxygen uptakes measured during both forms of exercise. It is still possible that at faster running speeds the impact of air resistance on a calm day is considerable and the oxygen cost of track running may be greater compared to “stationary” running on a treadmill at the same speed (Bassett, 1985).

### **2.13 Psychological factors influence running performance**

Bailey & Pate (1991) found that a more positive mood state, as measured by the Profile of Mood States (POMS), was significantly correlated with greater running economy. Furthermore, correlation's determinate between the POMS subscales and running economy indicated that tension held the strongest association. Mood state during exercise and running economy may be similarly affected by changes in heartrate, ventilation, running mechanics and substrate utilisation.