# THE DETERMINANTS OF RUNNING PERFORMANCE IN MIDDLE DISTANCE FEMALE ATHLETES

**Matome Lieghtone Mpholwane**

**A dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, in fulfillment of the requirements for the degree Master of Science in Medicine**

**Johannesburg, 2007**

# DECLARATION

I **Matome Lieghtone Mpholwane** declare that this dissertation is my own work except to the extent indicated in the acknowledgements and the references. It is being submitted for the degree Master of Science in Medicine at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

Signature:.....

18th day of October 2007

MMatha

## DEDICATION

This Dissertation is dedicated to my father Ngwako Phineas Mpholwane and in loving memory of my mother Mmapula Gladys Mpholwane and my grandmother Mohlatjo Grace Mpholwane

# PRESENTATIONS ARISING FROM THE DISSERTATION

1. MPHOLWANE ML, KOETLE F AND ROGERS G. **PREDICTORS OF MIDDLE DISTANCE RUNNING PERFORMANCE**. 3RD INTERNATIONAL CONGRESS OF THE AFRICAN ASSOCIATION OF PHYSIOLOGICAL SCIENCES. POSTER PRESENTATION, PRETORIA, SEPTEMBER 2000.

2. MPHOLWANE ML, KOETLE F, SAUNDERS A, VON BORMANN G. FLETCHER R, WARD S AND ROGERS G. **THE CONTRIBUTION OF AEROBIC AND ANAEROBIC ENERGY CAPACITIES DURING 800M TREADMILL RUNNING.** 3OTH PHYSIOLOGICAL SOCIETY OF SOUTHERN AFRICA, POSTER PRESENTATION, STELLENBOSCH , SEPTEMBER 2002

3. MPHOLWANE ML, KOETLE F AND ROGERS G. **PHYSIOLOGICAL CORRELATES OF MIDDLE DISTANCE RUNNING PERFORMANCE IN YOUNG FEMALE ATHLETES,** SOUTH AFRICAN SPORT SCIENCES CONFERENCE, ORAL PRESENTATION, JOHANNESBURG, OCTOBER 2004

## ABSTRACT

Male subjects are invariably used to study the physiological determinants of middle distance running performance. Studies that do include females have examined only the aerobic contribution to middle distance running performance. The aim of the present study was to investigate aerobic, anaerobic and muscle function factors that could be used to predict middle distance running performance in female runners. This study was performed at an altitude of 1800m.

Eleven middle distance female runners aged 18-20 were selected for the study.

Aerobic capacity was assessed by measuring the maximal oxygen consumption ($VO_2max$), running velocity at maximal oxygen consumption ($vVO_2max$), running economy (RE) and onset of blood lactate accumulation (OBLA).

The blood lactate curve of each subject was constructed by relating the oxygen consumption, to the plasma lactate concentrations.

Anaerobic capacity was determined by measuring the maximum accumulated oxygen deficit (MAOD) on a treadmill. Muscle function was assessed by having the subjects cycle as fast as possible against changing brake weights ranging from heavy to light using a Monark cycle ergometer. The brake force (kg) was related to velocity (rpm).

A stepwise multiple regression model (SAS system) was used to determine the best predictors of 800m, 1500, 3000m and 10 000m running performance times (minutes) respectively.

The correlation between MAOD and 800m was -0.725 ($p = 0.027$). When the Iso force and MAOD were entered to predict the 800m running time; $r^2 = 0.700$ ($p= 0.0269$). The variable that made the greatest contribution to 1500m running performance was MAOD. The correlation coefficient for MAOD and 1500m running performance was -0.614 ($p = 0.079$). The latter correlation became significant when Iso Force was included with MAOD ($r^2 = 0.671$ ; $p = 0.036$).

The onset of blood lactate accumulation (OBLA) and the velocity of running at $VO_2max$ ($vVO_2max$) were the only two variables which correlated with 3000m and the 10000m running performances (3000m: OBLA, $r^2 = 0.947$ and $p = 0.027$ ; OBLA and $vVO_2max$ : $r^2 = 0.999$ and $p = 0.003$ ; 10000m : $vVO_2max$, $r^2 = 0.466$ and $p = 0.135$ ; vVO2max and OBLA : $r^2 = 0.832$ and $p = 0.069$). The combination of $vVO_2max$ and OBLA were marginally not significantly correlated to predicting 10000m performance possibly because of the smaller sample size.

It is concluded from the present study that isometric force was the best predictor of 800m running performance and MAOD was the best predictor of 1500m running performance in female athletes. The 3000m and 10000m running distances depend more on the aerobic factors, OBLA and vVO2max respectively.

## ACKNOWLEDGEMENTS

I would like to acknowledge the technical support and help of sister F Koetle for her assistance with the withdrawal of blood and the blood lactate analysis during the project.

I would like to acknowledge the late Dr Ben Eisenberg (Tshwane University of Technology, Research and Development) for his statistical services.

I would also like to thank the University of the Witwatersrand Research Fund and the Faculty of Health Science Research fund for financial assistance.

Last, I wish to thank my supervisor, Prof G Rogers, for his encouragement and guidance.

# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ABBREVIATIONS.

| | |
|---|---|
| **ATP** | Adenosine triphosphate |
| **MAOD** | Maximal accumulated oxygen defict |
| **OBLA** | Onset of blood lactate accumulation (Set at 4mmol) |
| **RE** | Running economy |
| **SD** | Standard deviation |
| **VO2max** | Maximal oxygen consumption |
| **vOBLA** | Velocity associated with OLBA |
| **vVO2max** | Velocity associated with maximal oxygen consumption |

# CHAPTER 1 INTRODUCTION

Male athletes have been used as subjects in most of the studies where physiological determinants and / or predictors of performance have been assessed. Physiological parameters such as maximal oxygen consumption ($VO_2$max), running economy (RE), onset of blood lactate accumulation (OBLA), fractional utilization of oxygen (F) and maximal accumulated oxygen deficit (MAOD), have been popularly and widely used to predict or determine athletic performances (Morgan *et al*, 1989b, di Prampero *et al*, 1986, Brandon, 1995, Fernhall *et al*, 1996).

Female athletes started to participate in track and field and distance running in the 1960s (Sparling, 1980). The majority of the data available to assess running performances were obtained from male athletes. A few studies have reported on the connection between running performances and physiological parameters using both male and female athletes as a combined group. Even fewer studies have described the relationship between some selected parameters and performance using female athletes as subjects. No study has been reported were the anaerobic capacity measured as MAOD was used to predict middle distance running performance in female athletes.

Weltman *et al* (1990) demonstrated on forty four female athletes that a 3200m time trial could be used to estimate $VO_2$ max and running velocity at lactate threshold (LT). Fay *et al* (1989) investigated the relationship between $VO_2$max and vOBLA (running velocity corresponding to 4 mmol/l blood lactate concentration) and running performances at 5km, 10km, and 16km distances. The latter used fifteen moderately to highly trained

female athletes and found that VO2max and vOBLA correlated closely with all the running distances (r > - 0.84)

Weyand *et a*l (1994) used twenty two male and nineteen female athletes and reported that peak oxygen deficit is strongly correlated with 100m, 200m, 400m, 800m, 1500m, and 5000m (r = -0.66, -0.67, -0.71, -0.62, -0.52 and -0.40). Fernhall *et al* (1996) in their study used eleven boys and ten girls and found that lactate threshold was the best variable to show a relationship with cross country running performance. Almarwaey *et al* (2003) used twenty three boys and seventeen girls to investigate the relationship between 800m and 1500m running time and peak $VO_2$, RE, $vVO_2$ peak, and velocity at fixed blood lactate concentrations (v2.0, v2.5 and v4 mmol/l). Their study indicated that v2.5 and $vVO_2$peak correlated with 800m and 1500m distances.

Billat *and* Koralsztein (1996) used fifteen males and fourteen females to investigate the effect of gender differences on the time limit (t-lim) in the minimum speed that elicits $VO_2$max (T-lim –$vVO_2$ max) and its correlation to performance speed. They observed that there is a gender difference were 1500m running velocity was predicted from $vVO_2$max, vOBLA, t-lim at 110% $vVO_2$max and RE. No bio-energetic parameters correlated with the 1500m running speed in the female athletes.

Of the studies cited, only Fay et al (1989), Weltman et al (1990) and Billat and Koralsztein (1996) included a group of middle distance female athletes that have been independently investigated. However these studies have not examined all the responses of

female middle distance runners that have been studied in some detail in males. The present study aims to evaluate the aerobic and anaerobic physiological variables and muscle strength variables that could be used to determine middle distance running performances (800m, 1500, 3000m and 10 000m) in female athletes.

In this study it is hypothesised that:

i) anaerobic capacity and leg strength will be the principal determinants of 800m and 1500m running performances

ii) aerobic capacity will be the principal determinants of 3000m and 10 000m running performances.

The study will be performed at an altitude of 1800m (Johannesburg, South Africa), which may result in responses different to what may be expected at sea level.

# CHAPTER 2. LITERATURE REVIEW

## *2.1. INTRODUCTION*

Successful running performance has been related to a number of physiological factors. Long distance events depend primarily on maximum oxygen consumption ($VO_2$ max), fractional utilization of $VO_2$ max, and running economy (Morgan *et al*, 1989b, di Prampero *et al*, 1986, Brandon, 1995, Fernhall *et al*, 1996, Tanaka *et al*, 1984a, Houmard *et al*, 1994). Factors like lactate accumulation and skeletal muscle fiber type influence endurance performance (Morgan *et al*, 1989b, Brandon, 1995). Short distance running performances (60m-400m) have been correlated with a high anaerobic capacity and maximal velocity of movement. Middle distance events are related to both a high anaerobic and aerobic capacity (Brandon, 1995).

The relative contribution of anaerobic and aerobic energy has become an important factor in determining middle distance running performance. While it is simple to assess aerobic capacity it is far less simple to measure anaerobic capacity. Recently the maximal accumulated oxygen deficit (MAOD) has been used and accepted as a measure of anaerobic energy capacity (Medbo *et al*, 1988).

Muscle contraction requires energy in the form of adenosine triphosphate (ATP). The main causes of the limitation of athletic performance are the ability for the body to meet the energy demands of the exercise. The source of energy at muscle contraction is ATP (Jones, 2004). Muscles contain small stores of energy (about 20 KJ). Continuous

activity of muscles requires a constant supply of ATP. The muscle cells are able to produce energy in three ways (Gastin, 2001; Powers and Howley, 2004; Brooks *et al*, 2000; Wilmore and Costill, 2004) :

i) formation of ATP (anaerobic) from the breakdown of phosphocreatine (PC).

ii) glycolysis (the anaerobic formation of ATP from glucose or glycogen).

iii) oxidative phosphorylation (aerobic formation of ATP),

The ATP-PC system is important in providing energy for high intensity, short duration activities such as the 100m sprint (less than 10 seconds, elite male). Phosphocreatine (PC) hydrolysis, becomes the principal mechanism to re-synthesise ATP (Jones, 2004, Powers and Howley, 2004, Brooks *et al*, 2000, Wilmore and Costill, 2004).

As the PC can only re-synthesise ATP for a few seconds, the other systems become more important to provide ATP as race time becomes longer (Jones, 2004; Powers and Howley, 2004; Brooks et al, 2000; Wilmore and Costill, 2004). Glycolysis is a more complex system than the ATP-PC system. The glycolytic process generates a net gain of two ATP's from each molecule of glucose used.

There are two limitations associated with glycolysis:

i) the system does not produce large amounts of ATP.

ii) glycolysis leads to an increase in the accumulation of muscle and blood lactate. The increased lactate inhibits further breakdown of glycogen as it impairs glycolytic enzymes and causes fatigue (Wilmore and Costill, 2004; Westerbald *et al*, 2002).

The ATP-PC and glycolytic systems can provide energy for events lasting up to two minutes (Wilmore and Costill, 2004). It takes approximately two minutes before the oxygen uptake can reach steady state. Running events which take less than two minutes (eg. 800m) will be completed before oxidative metabolism could become involved (Jones, 2004).

Oxidative phosphorylation is the most complex system for the synthesize of ATP of the three systems. This system has the capacity to produce large amounts of ATP (Powers and Howley, 2004; Brooks *et al*, 2000; Wilmore and Costill, 2004). The system depends on the ability of the body to deliver oxygen to the active muscles. The aerobic energy system generates a net of thirty six ATPs from one glucose molecule (Brooks *et al*, 2000; Wilmore and Costill, 2004).

The relative contribution of these systems differs with the duration of the exercise (Astrand and Rodahl, 1986 ; Brooks *et al*, 2000; Gastin, 2001 ). During medium intensity exercise, such as middle distance running, ATP is synthesized from both aerobic and anaerobic processes (Tabata *et al*, 1997)

Running which lasts up to one minute, (e.g. 400m) uses about 70-80% anaerobic energy and 20-30 % aerobic energy (Astrand and Rodahl, 1986). Serresse *et al* (1988) have reported that during a 10 seconds maximal ergo cycle test, about 50-60% of energy is derived from the creatine phosphate. They also reported on the energy contribution during a 30-second and 90 second cycle test. Their results show that in a 30 s test the

relative contribution of the energy systems is 23% phosphogenic, 49% glycolytic and 28% aerobic (oxidative) (Serresse *et al* 1988). This shows that the relative contribution of the energy systems to exercise depends largely on the duration of the exercise (Figure 1).

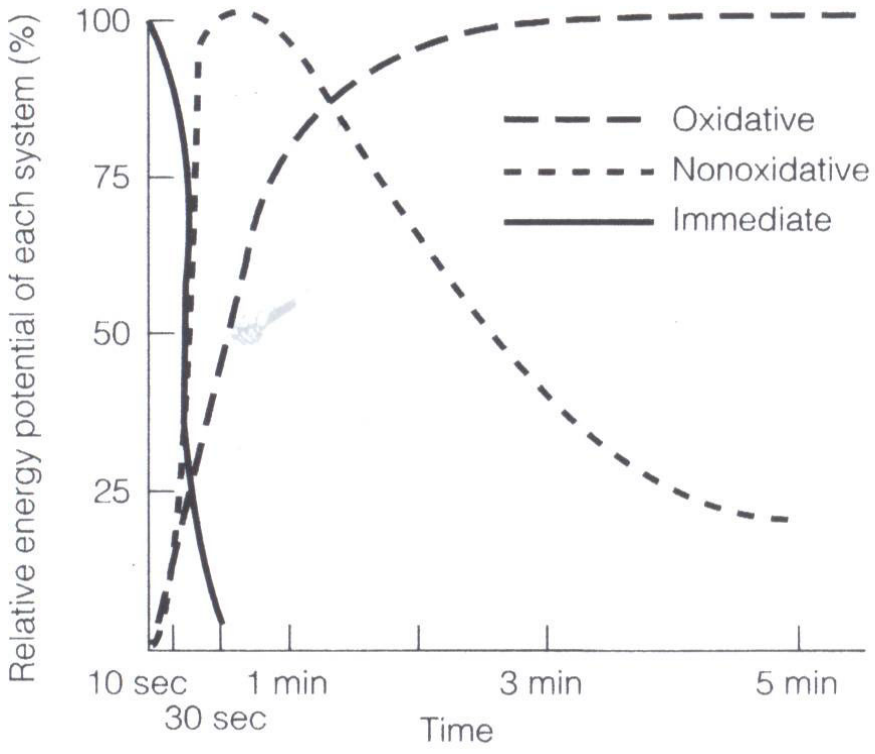


**Figure 1: The contribution of energy sources for muscle as a function of activity duration (Brooks *et al*, 2000).**

In a typical middle distance event (such as 800m running) about 65% energy is derived from the anaerobic system and about 35% energy from the aerobic system (Hill, 1999). However Lacour *et al* (1990) reported that 800m distance running derives 41% from

anaerobic and 59% from aerobic energy systems. The study by Weyand *et al* (1994) also has contradictory results for the 800m. They reported that about 19% and 24% anaerobic energy was used in female and male athletes respectively during an 800m event.

Similar discrepancies have been reported for 1500m running. Spencer and Gastin (2001) reported that 84% 0f the energy for 1500m is contributed by aerobic mechanisms while Foss and Keteyian (1998) indicated that aerobic energy contributes 51% of the energy needed for the 1500m. This differs somewhat to Weyand *et al* (1994) who found that only 10% of the energy for the 1500m running came from anaerobic sources.

The relative contribution of aerobic and anaerobic energy sources during middle distance running is therefore highly uncertain.

## *2.2. MIDDLE DISTANCE RUNNING*

There is no clear cut distinction between middle distance running events and long distance running events. di Prampero *et al* (1993) defines middle distance as events between 800m and 5 000m. This is similar to what has been defined by Brandon (1995) where he defined middle distance running events as between 800m and 3000m. This study defines middle distance running events as between 800m and 10 000m (Daniels and Daniels, 1992).

Middle distance running events require about two to fifteen minutes to complete. Middle distance runners are in most instances able to compete and perform well in either shorter or longer running events. Distances that require up to fifteen minutes to complete depend on both aerobic and anaerobic metabolism (Boileau *et a*l 1982; Mahon *et al*, 1996; Houmard *et al*, 1994). The ATP-CP energy system supplies energy during the first 10 second of exercise (Jones, 2004). From 10 seconds to about 3 minutes the major source of energy is derived from glycolysis. The aerobic energy system increases and predominates as the duration of exercise progresses (Spencer *et al*, 1996)

Eight hundred meters running depends on about 40% of aerobic energy for its total energy needs and 10000m running obtains about 80% of its energy need from aerobic sources (Boileau *et a**l***, 1982).

Studies have shown that long distance runners have higher maximal oxygen uptakes (> 70 $ml0_2kg^{-1}.min^{-1}$) compared to middle distance runners (> 60 $ml0_2\ kg^{-1}.min^{-1}$), (Boileau *et al*, 1982). This shows that the contribution of aerobic energy systems is necessarily greater for long distances compared to middle distances.

## *2.3. AEROBIC CAPACITY*

The physiological variables that are associated with aerobic function such as $VO_2$max, $vVO_2$max, blood lactate indices, and running economy are commonly used to determine running performance (Berg, 2003).

### 2.3.1. Maximal oxygen consumption

Maximal oxygen consumption ($VO_2$max) is defined as the maximal oxygen that can be used during exhaustive exercise (Bassett and Howley, 2000). $VO_2$max is a principal determinant of running performance (Ramsbottom *et al*, 1987). This establishes the limit of energy that can be produced aerobically (Evans *et al*, 1995). $VO_2$max describes the individual's capacity for the uptake and utilisation of oxygen (Duncan, 1997).

Hill and Lupton (1923), state in their study that:

i) "there is an upper limit to oxygen uptake",

ii) "there are interindividual differences in $VO_2$max",

iii) "a high $VO_2$max is a prerequisite in middle and long distance running" and

iv) "$VO_2$max is limited by the ability of the cardiorespiratory system to transport oxygen to the muscle".

Central factors that could limit the rate of maximal oxygen uptake (Basset and Howley, 2000) are:

i) maximal cardiac output and

ii) oxygen carrying capacity of the blood.

A number of criteria have been used to judge when the $VO_2$max has been reached. A number of researchers judge this test when at least two of the following criteria have been accomplished (Unnithan *et al*, 1995; Brisswalter *et al*, 1996; St Clair Gibson *et al*, 1999, Maldonado-Martin *et al*, 2004).

i) heart rate within ten beats of the age predicted maximum heart rate,

ii) respiratory exchange ratio of greater than 1.0,

iii) a plateau of VO2 values varying less than 2 $ml.kg^{-1}.min^{-1}$ with increasing load,

iv) blood lactate concentration greater than 10mmol/l and

v) exhaustion of the athlete.

Whereas $VO_2$max is highly correlated with distance running it is not the only physiological parameter related to running performance. Running economy and fractional utilisation of oxygen are also primary determinants of running performance (Bulbulian *et al,* 1986).

The study by Ramsbottom *et al* (1987) looked at factors that determine running performance over 5km in male and female runners. It was found that there was a significant contribution of $VO_2$ max in 5km running time in men (r=0.85) and woman (r=0.86). When the men and women were combined as a single group the correlation of $VO_2$ max to running performance improved (R=0.89).

The study by Conley and Krahenbuhl (1980) found a significant correlation (r=0.79) between $VO_2$ max and 10km race time. In the study of Abe *et al* (1998), a positive correlation between $VO_2$ max and running performance was found (1500m, 3000m and 5000m). Similarly the study by Boileau *et al* (1982), reported a significant correlation between $VO_2$max and running performance in middle distance running (r=0.7). These studies confirm that $VO_2$ max appears to be a major determinant of middle distance running performance. The high correlation of $VO_2$max with endurance running performance in adults has been associated with the same in pre-pubertal boys (age ± 12). Similarly Unnithan *et al* (1995) found that $VO_2$max correlated highly with middle distance running performance (3000m) in young boys.

### 2.3.2. v$VO_2$max as a Predictor of Running Performance

v$VO_2$max is the minimum velocity required to elicit VO2max (Hill and Rowell, 1996, Billat and Koralsztein, 1996). v$VO_2$max represents an interplay between running economy and VO2max. v$VO_2$max has been found to explain variation in 10km and marathon running performances (Grant *et al*, 1997).

v$VO_2$max has been suggested as a predictor of running performance by Daniels *et al,* (1986). Noakes *et al* (1990) have also demonstrated that v$VO_2$max can account for variance in endurance performances. Yoshida *et al* (1993) studied the relation of v$VO_2$max and 3000m running performance in females. Their study agrees with that of Daniels *et al* (1986) and Noakes *et al* (1990). In addition v$VO_2$max has also been

significantly related to 1500m, 3km and 5km track running events by Almarwey *et al* (2003). It was concluded that $vVO_2max$ could be used to predict running performance.

### 2.3.3. Running economy

Running economy (RE) is defined as the energy cost of work [aerobic demand for any given level of sub-maximal running at a constant velocity (Ramsbottom *et al*, 1987; Morgan *et al*, 1989a; Daniels and Daniels, 1992)]. This is similar to the definition of Williams et al (1991), "RE is the oxygen consumption for a given speed". RE is affected by a number of factors. Factors that are reportedly associated with RE are biomechanics of running, training level, $VO_2max$, substrate utilization, muscle power, muscle fiber type, temperature and flexibility (Morgan *et al*, 1989a; Berg, 2003; Daniels and Daniels, 1992).

Variation in distance running performance has been associated with RE and it plays an important determining role in endurance events (marathon and triathlon) (Hausswrith and Leheaff, 2001 Morgan and Mitchell, 1992). Running economy is determined from the steady state oxygen consumption at a given velocity of running (Morgan *et al*, 1989a and 1989b; di Prampero *et al*, 1993)

**Where**: **RE = [$VO_2$ (steady state exercise) - $VO_2$ (rest)] / speed of running**

**{RE (ml $O_2.kg^{-1}.km^{-1}$) = [$VO_2$ ($mlO_2.min^{-1}.kg^{-1}$) – $VO_2$ ($mlO_2.min^{-1}.kg^{-1}$)] / $km.min^{-1}$}**

With small differences in $VO_2$max between elite athletes, running economy becomes the differentiating factor in runners (Unnithan *et al*, 1995). Variations in performance of runners with similar $VO_2$max have been ascribed to differences in RE. Conley and Krahenbuhl (1980) confirmed this during a 10km race.

Boileau *et al* (1982) have reported that running economy was much better in long distance runners compared to sprinters. Most top runners seem to have a more efficient RE. RE therefore is a significant determinant of performance in events which derive a substantial portion of energy from aerobic sources (Sjödin and Svedenhag, 1985).

### 2.3.4. Blood lactate indices: blood lactate accumulation during exercise

At rest, the concentration of blood lactate is normally about 1-2 mmol/l of blood. During low intensity exercise, blood lactate concentration stays at about resting levels (Gollnick *et al*, 1986, Billat, 1996). During exercise the metabolic demands exceed the aerobic capacity. The anaerobic metabolism of glycogen to lactate is used to supplement the aerobic capacity. This will lead to an increase in the production of the lactate (Stainsby, 1986). However once a threshold is reached an exponential increase in the concentration of blood lactate occurs as exercise intensity increases (Gollnick *et al*, 1986, Billat, 1996).

The lactate levels start increasing above baseline levels at work intensities between 50%-90% of maximal oxygen consumption (Stanley *et al*, 1985. MacRae *et al*, 1992). The threshold at which blood lactate accumulation begins depends on physical fitness. The

type, frequency, duration and intensity of exercise leads to variability in the threshold for blood lactate concentration increase (Gollnick *et al*, 1986). In unfit individuals blood lactate increases at an exercise intensity of 50%-60% $VO_2$max. The highest exercise intensity which could be achieved for a given blood lactate concentration is related to the aerobic fitness level (Ramsbottom *et al*, 1989).

Trained runners can reach up to 90% $VO_2$max before there is a significant rise in blood lactate (McArdle *et al* 1991). A number of terms have been used to describe the lactate accumulation during sub-maximal exercise. These include: anaerobic threshold, lactate threshold and onset of blood lactate accumulation.

Blood lactate measurements during exercise and or after exercise has a number of uses in the laboratory and in field-testing. It could be used to assess performance during submaximal or supra-maximal exercise or as training tool (Jacobs 1986). More specifically, the level at which blood lactate rises is used to assess or predict exercise performance and monitor training response. The study of Allen *et al* (1985) demonstrated that the running speed at which lactate threshold occurs could be used to predict distance running performance and marathon running. Blood lactate at a given exercise intensity is also used to assess fitness during sub-maximal exercise, for a specific sport. Marathon runners are said to be utilizing at least 80% of the $VO_2$ max before lactate accumulates in the blood (Farrell *et al* 1979).

### 2.3.5. Anaerobic threshold / lactate threshold and performance

Anaerobic threshold (AT) is defined as the work intensity at which the concentration of blood lactate rises above resting levels (Wassermann *et al* 1973, Billat, 1996, Hagberg, 1984, Kindermann *et al*, 1979). This according to one school of thought refers to the onset of increased anaerobic glycolysis when oxygen uptake can no longer meet the requirements for energy production during exercise.

Anaerobic threshold (AT) is one of the physiological parameters other than $VO_2$max that is related to running performance. AT is critical in determining running pace during endurance running. AT showed a high correlation (0.8) with 10km running performance. Running velocity at AT is also significantly related to 10km running (Tanaka *et al*, 1984b). Effectively AT determines the fraction of $VO_2$max which can be utilized during submaximal running.

Maffulli *et al* (1991b) have reported on the relationship between anaerobic threshold and middle and long distance running performance. The study compared the relationship between the anaerobic threshold and 800m, 1500m, 3000m and 10km running performance in different age groups. They reported a correlation, which varied with age that could be because of metabolic differences between age groups. The study showed a correlation of anaerobic threshold with running speed for middle distance events (800m – 10km). Kenney and Hodgson (1985) found that AT accounted for 77% of the variance in 3000m-steeplechase performance.

Velocity at lactate threshold and velocity at 4mmol/l have been found to relate significantly with 3km running performance (Grant *et al*, 1997). Velocity at lactate threshold was found to be the best predictor of running performance for the 3km distance. This explained 87% of the variation in the running velocity.

The study by Yoshida *et al* (1987), found that LT/AT correlated significantly with 12min running distance (2356m) which falls within the middle distance category. The study showed that LT/AT and OBLA could both be used as indices of middle distance running performance. The correlation between LT/AT and $VO_2$ max is an indication that LT/AT is an index of aerobic capacity. Running velocities at given blood lactate concentrations (2.0, 2.5 and 4.0 mmol/l) have also been used to predict 3000m and 3200m running performance in trained and untrained runners (Yoshida *et al* 1993; Weltman *et al,* 1990).

On the other hand Iwaoka *et al* (1988) reported a low correlation between LT/AT and performances for 800m ($r = 0.228$), 1500m ($r = 0.501$), 5km ($r = 0.399$) and 10km ($r = 0.329$) in female athletes. Evans et al (1985) observed a relationship between LT/AT running velocity and performance in a 10km race in females of different ages. The LT/AT was strongly correlated to female performance in the study of Hoogeveen and Schep (1997). Nichols *et al* (1997) have reported that OBLA was the best predictor of performance in 13.5km ($r^2 = 0.83$) and 20km ($r^2 = 0.78$) races in female cyclists.

## 2.3.6. Onset of blood lactate accumulation (OBLA)

The onset of blood lactate accumulation (OBLA) i.e. the workload (speed, $VO_2$, $VO_2$ max %) at which blood lactate concentration reaches 4mmol.l$^{-1}$, has been used as a measure of physiological fitness (Jacobs, 1986; Ghosh, 2004). The point at which blood lactate accumulation occurs during exercise has been used as a significant and an important physiological determinant in sustaining high percent $VO_2$max during exercise (Iwaoka *et al* 1988).

Trained subjects with a higher aerobic capacity have a better OBLA than subjects with a low aerobic capacity (Bulbulian *et al,*1986). Long distance runners have a better OBLA than sprinters and middle distance runners. This could relate to endurance runners having high lactate removal rates. This could also relate to endurance runners having low glycolytic capacity (Taunton *et al*, 1981).

Endurance trained athletes could tolerate exercise for a longer period of time at a threshold of 4mmol.l$^{-1}$ lactate concentration (OBLA) (Heck *et al*, 1985). OBLA has been used as the best measure of marathon race performance in endurance athletes (Sjödin and Jacobs 1986, Yoshida *et al*. 1987). Blood lactate level during prolonged continuous exercise depends on the rate of its production and removal (Heck *et al* 1985). The exercise intensity (% $VO_2$ max) at which OBLA occurs has also been found to be an important determinant of endurance exercise by Evans *et al* (1995). Iwaoka *et al* (1988)

studied the age-related differences in blood lactate and a 5km run time. They found a significant correlation between OBLA and 5 km running performance in young, middle and old aged athletes.

## *2.4. ANAEROBIC CAPACITY*

The energy (ATP) derived from the catabolism of phosphocreatine and muscle glycogen during high intensity exercise has been referred to as anaerobic capacity (Medbo *et al*, 1988). Green and Dawson (1993) also had a similar definition: "Anaerobic capacity is defined as the maximal amount of adenosine triphosphate re-synthesised via anaerobic metabolism during the specific mode of short duration maximal exercise".

A number of tests to quantify anaerobic capacity has been explored (Green and Dawson, 1993). These tests include amongst others:

i) oxygen debt ( the amount of oxygen consumed during recovery),

ii) post exercise blood lactate levels

iii) oxygen deficit and

iv) muscle ATP degradation

### 2.4.1. Maximal accumulated oxygen deficit (MAOD)

Exhaustive high intensity exercise (e.g. sprinting), depends greatly on anaerobic metabolism. The amount of energy (ATP) derived anaerobically is very important for this type of exercise. This leads to the need for an accurate method of measuring anaerobic capacity (Green *et al*, 1996).

MAOD was first proposed by Medbo *et al* (1988) as a means of measuring anaerobic capacity in athletes. The measurement of MAOD agrees closely with the anaerobic energy supply calculated from changes in muscle and blood metabolites such as lactate (Bangsbo *et al* 1990). MAOD therefore is considered one of the more reliable non-invasive methods of estimating/measuring anaerobic capacity. Exercise requiring 2-10 minutes depends on both aerobic and anaerobic energy sources. A variable component (depending on the duration of exercise) of the energy needed for this type of exercise is derived from anaerobic sources (Astrand and Rodahl, 1986). Bangsbo et al (1993) found in their study that the anaerobic energy (MAOD) is related to muscle fiber mass and the muscle fiber distribution..

MAOD has been used as a measure of anaerobic capacity in a variety of studies (Medbo *et al* 1988, Gastin *et al* 1995, Weyand *et al*, 1994). The test involves all out exhaustive high intensity exercise such as sprinting or middle distance running (Gastin *et al* 1995). A linear relationship of $VO_2$ and power (speed) during sub-maximal exercise is defined initially. The linear regression line determined from the $VO_2$ and power (speed) relationship is used to estimate the energy demand during supra-maximal exercise at 110 - 125% of $vVO_2max$ (Medbo *et al* 1988; Medbo, 1996; Gastin *et al* 1995; Buck and McNaughton, 1999). Supra maximal exhaustive exercise at a speed (power) of 110%-125% of $vVO_2max$ is then performed.

To measure MAOD effectively, it has been suggested that at least 2 minutes of exercise to exhaustion is needed to use anaerobic sources successfully (Medbo et al, 1988; Weber and Schneider, 2001; Gastin *et al*, 1995; Ramsbottom *et al,*1994; Maxwell and Nimmo, 1996; Medbo and Tabata, 1993). MAOD is calculated as the difference between the total accumulated energy demand (cost) and the energy derived from aerobic sources measured during high intensity and exhaustive exercise (Green and Dawson, 1996, Buck and McNaughton, 1999).

As already mentioned, high intensity exercise lasting a few minutes depends on the anaerobic capacity, then a large component of the latter will be beneficial in these type of events. The proper application during training for anaerobic capacity becomes necessary. Medbo and Burgers (1990) found that appropriate training led to an increase in MAOD in males and females. In their study they used six untrained (physically active), six endurance trained and eight sprint trained male subjects. There were no differences in the anaerobic capacities of the untrained and endurance trained subjects, whereas the sprinter's anaerobic capacity averaged 30% higher.

Similarly Webber and Schneider (2001) measured MAOD in seven untrained men and seven untrained women. They determined MAOD at 110% and 120% of vVO2max during cycling. Although the times to exhaustion during the two trials were different, they obtained no significant differences in the amount of MAOD with 110% and 120% of vVO2max in both men and women. Their finding are similar to those of Medbo *et al,* (1988) who found that the amount of MAOD does not increase significantly irrespective

of the exercise intensity if the test is longer than two minutes. This suggests that MAOD can be determined successfully and reliably irrespective of the exercise intensity.

Spencer and Gastin (2001) studied the contribution of aerobic and anaerobic energy systems during 200m to 1500m simulated running performance. They observed a progressive increase in the contribution of the aerobic system to 200m (29 ± 4.4%), 400m (43 ± 1%), 800m (66 ± 2%) and 1500m (84 ± 1%) running. The absolute amounts of MAOD also increased with the 200m, 400m and 800m running events but did not increase further in the 1500m event (Spencer and Gastin, 2001). This indicates that the absolute amount of MAOD increases with event duration up to 1500m.

However a study by Spencer *et al* (1996) found no differences in absolute amounts of MAOD for simulated 400m, 800m and 1500m treadmill runs (despite the differences in duration of running). They reported that the aerobic energy system contributed 46 ± 4% for the 400m, 69 ± 4% for the 800m and 83 ± 3% for the1500m. This contradicts previous views that 50% of the energy required to complete an 800m running event is derived from aerobic sources (McArdle *et al*, 1991).

Ramsbottom *et al* (1994) found a strong correlation between running performances in 100m and 400m and MAOD determined in a laboratory set up. From the same study they reported a smaller but significant relationship of MAOD with 800m running performance. This is similar to the study by Scott *et al* (1991) who showed a correlation

of MAOD with 300m track times. The studies by both researchers indicate that the contribution of anaerobic capacity diminishes as the running distance increases.

## *2.5. LEG STRENGTH*

Muscle contraction refers to the activation of the force generating capacity of the muscle fibers. The muscle will shorten, lengthen or remain the same depending on the external load. When the muscle length does not change there is equilibrium between the external load and the amount of force produced. This type of muscle contraction is called isometric force (Brooks *et al*, 2000).

There are two types of muscle fibers. There is one type I (slow twitch) fibers and two type II (fast twitch) fibers,referred to as IIa and IIb. The biochemical and contractile properties of these muscles differ (Powers and Howley, 2004).

The type I or slow twitch fibers (ST) have a high level of aerobic endurance and are used during events which require oxygen usage (oxidative phosphorylation). These muscle fibers are very efficient in producing large amounts of ATP because of their high content of oxidative enzymes. The ST fibers are able to sustain muscle activities for prolonged duration, e.g. marathon running (Wilmore and Costill, 2004; Moss *et al*, 1997). It has been reported by Moss *et al* (1997) that heavy resistance training improves the maximal isometric strength of type I fibres.

The fast twitch fibers (FT) have relatively poor aerobic endurance and are better suited for anaerobic activities. These types of muscle fibres are used mainly during high intensity, short duration events (e.g. elite sprinters). The FT fibers have a high myosin ATPase activity and a high maximum power output (Wilmore and Costill, 2004; Jones, 2004).

The muscle characteristics of sprint and endurance runners have been studied. It has been documented that sprinters have a high percentage of the type II (FT) fibers as compared to endurance athletes who have a high percentage of type I (ST) fibers. This indicates that muscle enzyme profiles of these athletes are anaerobic for sprinters and aerobic for long distance runners. In contrast to sprinters and endurance runners, middle distance runners do not display a clear distinction of their muscle characteristics. They are represented by a wide range of muscle composition (Foss and Keteyian, 1998).

During muscle contraction, velocity of shortening is low initially and a high force can be produced resulting in high acceleration. As the velocity increases, the ability to generate force at high velocity is important. This is because muscle power is the product of force and shortening velocity (Moss *et al*, 1997). The peak power produced by muscles then is greatest in the FT fibers (Powers and Howley, 2004). It is expected therefore that power type events are associated with FT fibers.

The relationship between force and velocity is important (Moss et al, 1997). The force-velocity curve (F/V) (Figure 3) is a graphic representation of the relationship between

muscle tension and the velocity of shortening or lengthening of the muscle. It is used to analyze the effects of training and to identify muscle fiber types used during exercise. The velocity at which a muscle shortens is inversely related to the load it must move. Thus if a load is great, the velocity of shortening is slow, conversely, as the velocity of movement increases, the total tension produced by the muscle decreases (Douben, 1980, Foss and Keteyian, 1998). This translates that the greatest force will be produced at the slowest speed of muscle contraction and is regardless of the muscle type characteristics.

The most important function of muscle is to develop tension against a load. This leads to the muscle doing work. The relationship between the velocity at which the muscles contract and the force on the muscle is explained by the Hill equation (Douben, 1980):

$(P + a) V = (Po + P)b$

Where:

P = Tension developed during muscle contraction

Po = Maximal isometric force of muscle (maximal tension the muscle can develop during isometric contraction). This is the intercept of the F/V curve on the force axis (V =0).

V = velocity of contraction. The maximal shortening (contracting) velocity is determined by extrapolating the F/V curve to F = 0.

a = a constant and has the dimension of force related to the coefficient of the heat of shortening.

b = a constant depending on the intrinsic velocity of contraction of muscle and is numerically equal to about 25% of the maximum speed of shortening of an unloaded muscle.

# CHAPTER 3. MATERIALS AND METHODS

## *3.1. SUBJECTS*

Eleven female subjects (Caucasian) volunteered to take part in the study. The subjects were randomly recruited from athletic clubs around Gauteng (mainly Johannesburg). The subjects were all competitive runners in track and road running. The measurements were taken at the same time of the day for each subject. All the subjects gave written informed consent before any of the tests was performed. The protocol was approved by the Committee for Research on Human Subjects, University of the Witwatersrand.

Body mass was measured to an accuracy of 50g (Mettler TE/J, Zurich, Switzerland) and height was measured to the nearest 1mm (Seca Model 207b, Vogel and Halke, Hamburg, Germany) (Table 1).

The exercise testing was done on four separate days. The tests were done in the following order:

Day 1. Running economy and VO2max

Day 2. Onset of blood lactate accumulation

Day 3. Maximal accumulated oxygen deficit

Day 4. Leg strength

The test days were 24-48 hours apart and all the tests were completed in 14 days. The subjects were not allowed to perform any strenuous activity during the rest days.

**Table 1. Physical characteristics of subjects (mean ± SD) (n = 11)**

| | |
|---|---|
| Age (years) | 18.13 ± 3.46 |
| Weight (kg) | 56.08 ± 6.53 |
| Height (cm) | 168.93 ± 6.39 |
| BMI ($kg.m^{-2}$) | 19.60 ± 1.43 |

## *3.2. PRE-TESTING EXERCISE.*

The subjects were familiarized with treadmill running before any of the tests were performed (except for leg strength measurements). Each subject ran at$10km.h^{-1}$ on a level motorised treadmill (Powerjog, EG10, Sport Engineering Limited, Birmingham, England) for 10 minutes before each test as warm up.

## *3.3. HEART RATE*

During all the tests, (except for leg strength), the heart rate was monitored using a three chest ECG lead (Hewlett Packard 78351, Andover, Ma, USA).

## *3.4. MAXIMAL OXYGEN CONSUMPTION.*

Different laboratory protocols have been used to measure maximal oxygen consumption. Amongst those treadmill tests that have been explored (St Clair Gibson *et al*, 1999) include:

i) the speed is progressively increased,

ii) the treadmill gradient is progressively increased from horizontal or

iii) both speed and gradient are progressively increased until exhaustion.

These protocols could be tested either continuously or discontinuously. The measurement of VO2max in this study is based on a discontinuous protocol. Duncan et al (1997) investigated the $VO_2$max criteria during discontinuous and continuous protocols. They found in their study that the achievement of VO2max criteria is independent of the test protocol.

Maximal oxygen consumption ($VO_2$max) therefore was measured using an intermittent (discontinuous) incremental method (Wyndham et al, 1959, Speechly *et al*, 1996). Each subject ran for 3-minute periods on the treadmill while speed remained constant at 13km.$h^{-1}$. The work intensity was increased by increasing the gradient by 1% after each completed 3 minute run. $VO_2$ was recorded after each 30 seconds. Steady state $VO_2$ measurements from 2 to 3-minute of exercise were averaged.. The subjects were allowed to rest (5-10 minutes) in between the runs. $VO_2$max was taken as the average when the $VO_2$ of two consecutive workloads differed by <1.0ml $min^{-1}kg^{-1}$ (Speechly *et al*, 1996).

$VO_2$ was measured using a pre-calibrated on-line metabolic cart (Oxycon-4 Mijnhardt, Bunnik, Holland). Inspired and expired air was separated using a low resistance two-way non-rebreathing valve (Hans-Rudolph 2700, Kansas City, USA) while the nose remained occluded (Maxwell and Nimmo, 1996). The metabolic cart was calibrated with known concentrations of $CO_2$ and $O_2$.

## *3.5. RUNNING ECONOMY*

Running economy (RE) was determined during steady state running (Conley *et al*, 1981). The subjects were asked to run 12km.h$^{-1}$ on a flat (0% gradient) treadmill for 5 minutes while measuring $VO_2$ (Brisswalter *et al*, 1996, Krahenbuhl *et al*, 1989). $VO_2$ was measured using the pre-calibrated on-line metabolic cart (Oxycon-4 Mijnhardt, Bunnik, Holland) described previously. The steady state $VO_2$ measured from 3 - 5 minutes was averaged to calculate RE. RE was measured on the same day and just prior to the determination of $VO_2$max. Running economy was calculated as:

RE = $VO_2$ (at 12km.h$^{-1}$) - $VO_2$ (at rest) / 0.2 km.min$^{-1}$ (di Prampero *et al*, 1986, Brisswalter *et al*, 1996.)

## *3.6. ONSET OF BLOOD LACTATE ACCUMULATION.*

The onset of blood lactate accumulation test was done on day 2. Subjects ran on a level (0% gradient) treadmill for 3-minute periods at progressive speeds. Running speed started at 4km.h$^{-1}$ with increments of 2km.h$^{-1}$ up to at least 90% $VO_2$max. Each subject performed at least 6 bouts of exercise.

Blood samples (2ml) were collected after each 3-minute run. Blood was collected into tubes containing an anticoagulant (potassium oxalate) and metabolic inhibitor (sodium fluoride) from a catheter inserted into a forearm vein. Lactate remains stable in potassium oxalate and sodium fluoride (Myburgh *et al*, 2001). Thin Teflon catheter (Jelco, Thicon, Pomeza, Italy) was inserted before the start of the test and was strapped on the arm for the duration of the test. This was flushed with heparinized saline after each blood withdrawal. The blood samples were kept on ice until the end of the test. The samples were centrifuged (5 minutes) and the supernatant stored at -20$^{o}$C until further analysis. An enzymatic method (Boeringer Mannheim Mannheim, Germany) was used to measure plasma lactate concentrations (Brisswater et al, 1996, Speechly et al 1996) (APPENDIX A.)

$VO_2$ was measured as described previously. The steady state $VO_2$ measured over 2 - 3 mins was averaged at each running intensity and represented the oxygen consumed at each work load. Morgan et al (1989a) and Hagan et al (1980) have reported that steady state oxygen consumption is reached within 2 minutes of a constant work load.

The oxygen consumption expressed as percent $VO_2$max was related to plasma lactate levels. The blood lactate curve of each subject was constructed by regression analysis and an exponential model [y = a + b exp (-x/c)], using an automated equation generator and data fitter (Tablecurve 2D for Windows, 32/BIT version, 1988-94). The OBLA was obtained from this curve, which was determined as the percentage $VO_2$max, at which plasma lactate level reached a level of 4 mmol/l (Figure 2.) (Speechly *et al,* 1996).

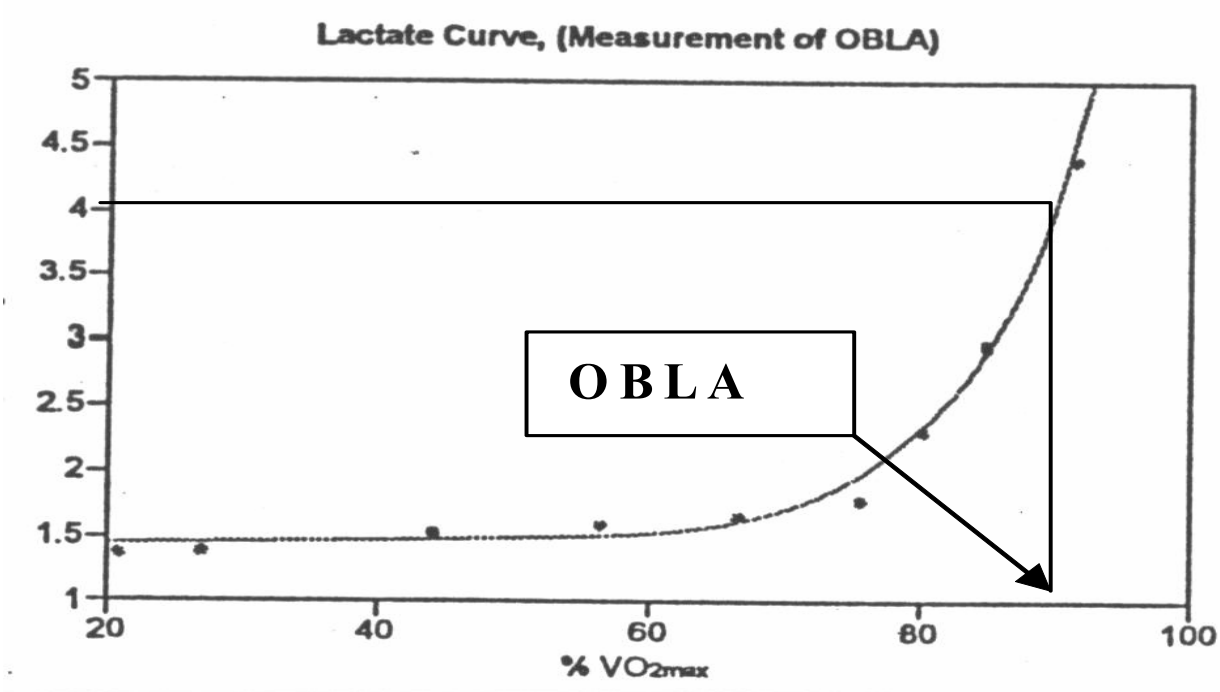


**Figure 2: Curve relating plasma lactate concentration (y-axis) to exercise intensity depicted as percentage of maximal oxygen consumption (x-axis). The figure shows the determination of the OBLA. (Powers and Howley, 2004, Mcardle at al, 1991)**

## *3.7. MAXIMAL ACCUMULATED OXYGEN DEFICIT*

This test was done on day 3. Maximal accumulated oxygen deficit (MAOD) has been proposed (Medbo et al, 1988) as a measure of anaerobic capacity. Subjects performed 6 - 9 sub-maximum 3-minute runs on a level treadmill. A level treadmill was used so that it became possible to re-use data from the different tests. This was done to minimise the stress and strain to which the subjects were exposed. This was far more preferable than a dubious attempt to simulate wind velocity or slavishly follow other protocols by changing gradients. The principal of the test remained unaltered.

Treadmill speed started at $4km.h^{-1}$ and increased after each run until a level giving 90% $VO_2max$ was reached. From the steady state $VO_2$ levels of the sub maximal runs, a linear regression curve was constructed to determine the running velocity at $VO_2max$ ($vVO_2max$) (Ramsbottom *et al*, 1997). Subjects performed at supra maximal levels (10% above $vVO_2max$) until voluntary exhaustion (>2,5 minutes) (Reis *et al*, 2005). $VO_2$ was measured as described previously. MAOD was calculated as the difference between total oxygen demand and actual oxygen consumption (Figure 3a and 3b.).

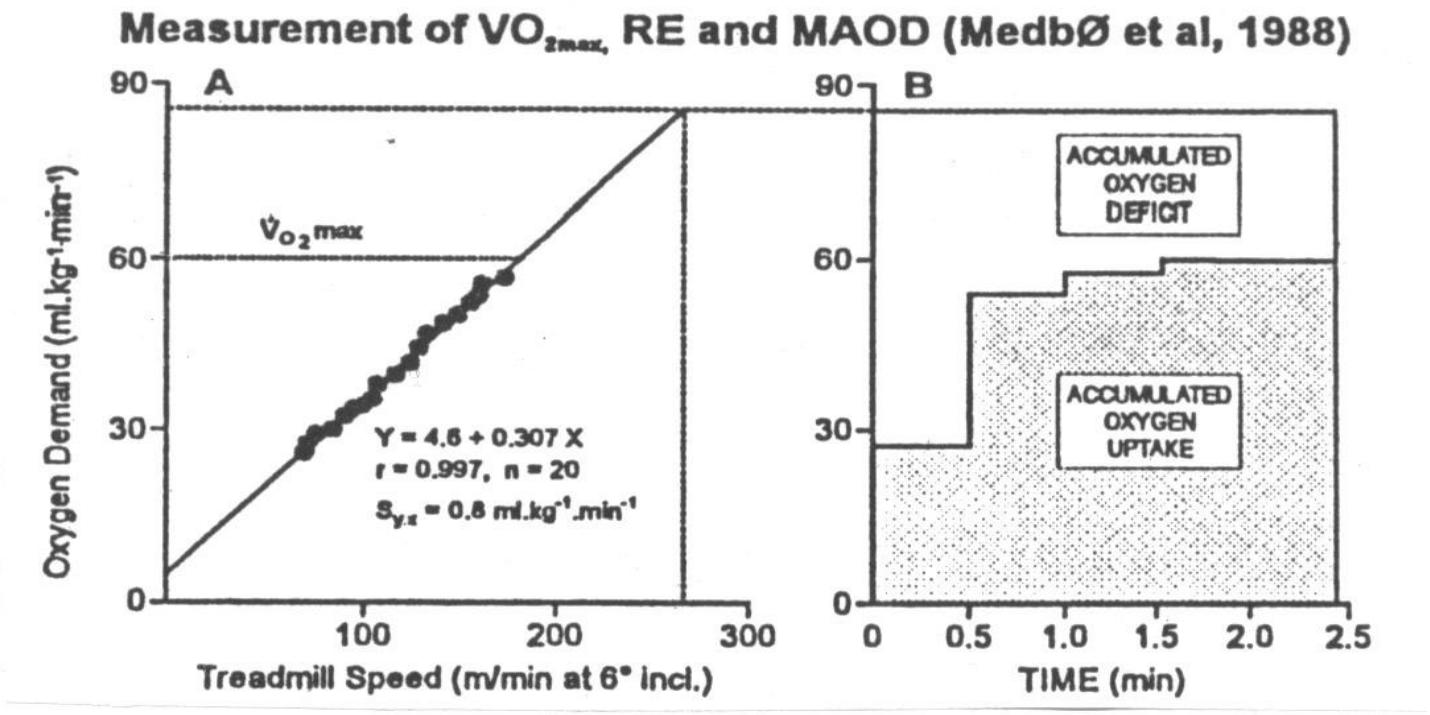


**Figure 3a: The graphic determination of MAOD taken from Medbø et al (1988)**

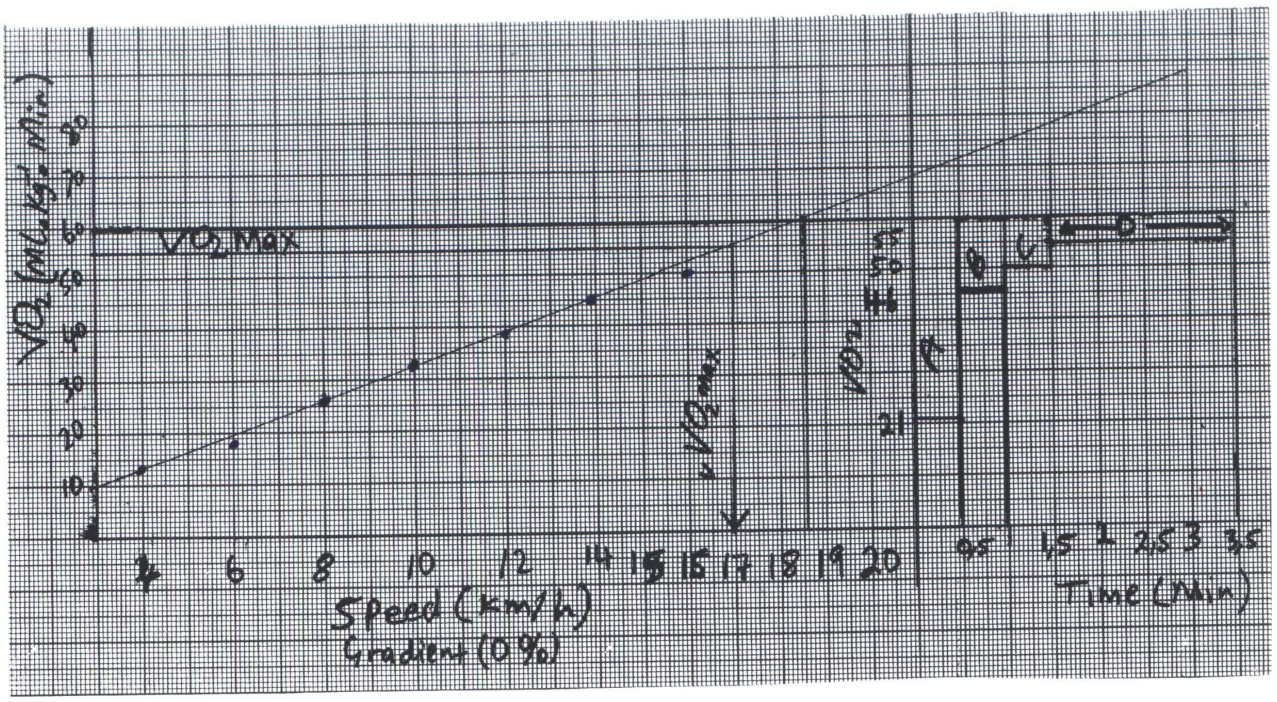


**Figure 3b: The graphic determination of MAOD used in this study.**

**Calculation.**

Total MAOD = Area A + Area B + Area C = Area D = 41.5 $mlO_2.kg^{-1}$

Area A = 39 $mlO2.kg^{-1}.min^{-1}$ X 0.5 min = 19.5 $mlO_2.kg^{-1}$

Area B = 14 $mlO2.kg^{-1}.min^{-1}$ X 0.5 min = 7 $mlO_2.kg^{-1}$

Area C = 10 $mlO2.kg^{-1}.min^{-1}$ X 0.5 min = 5 $mlO_2.kg^{-1}$

Area D = 5 mlO2.$kg^{-1}$.$min^{-1}$ X 2.0 min = 10 $mlO_2$.$kg^{-1}$

## *3.8. ISOMETRIC STRENGTH AND CONTRACTILITY OF LEG MUSCLES*

The maximal muscle strength is the measure of the maximum amount of force produced by a muscle at a specified velocity of muscle contraction. This is related to the sport related fitness level. The measurement of muscle strength is used to assess neuromuscular and musculoskeletal function. Isokinetic dynamometry has been used and found to be a favoured method to assess muscle function in sports and clinical environments (Gleeson and Mercer, 1996, Diesel *et al*, 1990).

The use of the Monark cycle ergometer (Ergomedic 834E, Monark Bodyguard AB, Vardberg, Sweden) was then explored in this study. The Monark cycle ergometer is an instrument that has an adjustable weight brake system where the brake force can be set (kg). When peddling, the subject supplies the flywheel with kinetic energy and the cycling revolutions can be measured per unit time (rpm). The Monark cycle ergometer has been used extensively in assessments of high intensity short duration exercise not necessarily related to cycling. The best known of these is the Wingate test.

The leg strength test was done on day 4. No warm-up was done for this test. The subjects were informed about the test. They were instructed to sit on the Monark Exercise Ergometer and the seat height adjusted for optimal pedalling. The subjects cycled as fast as possible against a brake weight for 30 seconds. With recovery periods of 10 mins interspersed, each subject pedalled at 6 – 9 loads ranging from heavy to light. A force

velocity curve (Figure. 4) was constructed using the equation $y = a + b (\ln x)^2$ where y = brake weight (kg) and x = velocity (rpm) generated from Tablecurve 2D For Windows, 32/BIT version, 1988-94 . Maximal isometric force (Y intercept) and velocity max (X intercept) were determined by extrapolation of the curve.

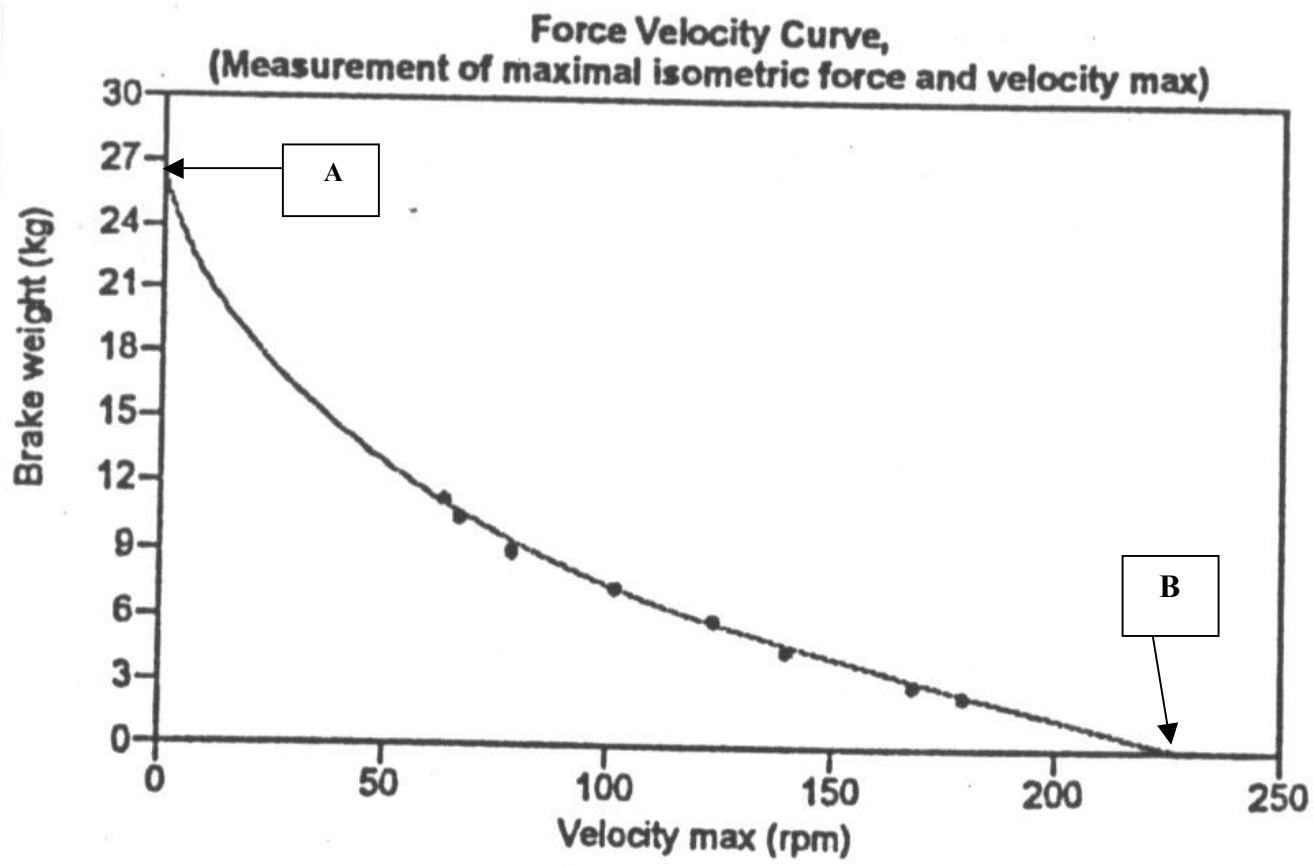


**Figure 4: The force-velocity curve obtained using the Monark cycle ergometer. The curve was used to determine the maximal isometric force (point A) and the maximal velocity ($V_{max}$) (point B) (McArdle et al, 1991, Brooks et al 2004)**

## *3.9. STATISTICAL ANALYSIS.* [1]

A stepwise multiple regression model (SAS system) was used to determine the best predictors of 800m, 1500, 3000m and 10 000m running performance times (minutes) respectively. The measured variables which included maximal oxygen consumption ($VO_2max$), running velocity at $VO_2max$ ($vVO_2max$), running economy (RE), onset of blood lactate accumulation (OBLA), maximal accumulated oxygen deficit (MAOD), isometric muscle force (Iso force) and maximal velocity of muscle shortening (V max), were entered into the stepwise programme. The stepwise multiple regression procedure operates by inclusion and elimination to determine the best variable/s to predict the dependent variable, which in this case are performance times. Statistical significance was set at $p \leq 0.05$.

[1] The Statistics were done with the assistance of a qualified statistician, Dr Ben Eisenberg, PhD (Research and Development, Tshwane University of Technology) who took into consideration factors such as multiple comparisons and sample sizes. His field of expertise was considered beyond reproach by persons with a more limited statistical background.

# CHAPTER 4 RESULTS

## *4.1. INTRODUCTION*

In this study two subjects were not able to complete the leg strength tests. In addition only 6 and 8 subjects participated in the 3000m and 10000m respectively. Table 2 gives the responses during maximal and sub-maximal exercise in the group of middle distance female runners. Table 3 shows middle distance performance times for the subjects.

**Table 2. Exercise dynamics in female runners (mean ± SD and sample size)**

| Variable | Mean ±SD | 95% Confidence Interval | | n |
|---|---|---|---|---|
| | | Lower level | Upper level | |
| $VO_2$max ($ml/O_2.kg^{-1}.min^{-1}$) | 52.27± 4.59 | 49.18 | 55.35 | 11 |
| v $VO_2$max ($km.h^{-1}$) | 15.59 ± 1.51 | 14.57 | 16.60 | 11 |
| Running Economy ($ml/O_2.kg^{-1}.km^{-1}$) | 185.50 ± 7.31 | 180.58 | 190.41 | 11 |
| MAOD ($ml/O_2.kg^{-1}$) | 31.64 ± 6.82 | 27.06 | 36.21 | 11 |
| OBLA (%$VO_2$max) | 86.85 ± 5.56 | 83.12 | 90.59 | 11 |
| Max Isometric Force (kg) | 9.97 ± 1.32 | 8.96 | 10.99 | 9 |
| Velocity (V) max (rpm) | 209.64 ± 10.09 | 201.88 | 217.39 | 9 |

**Table 3. Performance times for middle distance female runners (mean ± SD and sample size)**

| Distance (m) | Time (min) | n | World record | Current 2007 |
|---|---|---|---|---|
| 800 | 2.39 ± 0.17 | 11 | 1:53.28 | 2:00.71 |
| 1500 | 4.92 ± 0.36 | 11 | 3:50.46 | 4:05.25 |
| 3000 | 10.61 ± 0.49 | 6 | 8:08.11 | 8:58.67 |
| 10 000 | 41.80 ± 2.98 | 8 | 29:31.78 | 31:35.15 |

The table above show the female performance times from the present study, the world records and the current (2007) world leading times (International Association of Athletics Federations, www.iaaf.org, 2007/04/09).

**Table 4. Colinearity of the physiological variables measured in this study**.

| Variable | $VO_2$ max | $vVO_2max$ | RE | OBLA | MAOD | Iso force | V max |
|---|---|---|---|---|---|---|---|
| **$VO_2max$** | 1.0000 | 0.5069 | 0.5020 | -0.2777 | -0.0010 | -.5998 | 0.3859 |
| **$vVO_2max$** | 0.5069 | 1.0000 | 0.5262 | -0.6513 | 0.5758 | -0.3430 | 0.7985 |
| **RE** | 0.5020 | 0.5262 | 1.0000 | -0.6927 | -0.1930 | -0.0024 | 0.5740 |
| **OBLA** | -0.2777 | -0.6513 | -0.6927 | 1.0000 | 0.0318 | 0.2306 | -0.6079 |
| **MAOD** | -0.0010 | 0.5758 | 0-0.1930 | 0.0318 | 1.0000 | 0.0240 | 0.4245 |
| **Iso Force** | -0.5998 | -0.3430 | -0.0024 | 0.2306 | 0.0240 | 1.0000 | -0.3038 |
| **V max** | 0.4959 | 0.7985 | 0.5740 | -0.6079 | 0.4245 | -0.3038 | 1.0000 |

Table 4 represents the inter-correlations (associations) between the measured (predictor) variables. Variables which had a similar (colinear) influence on performance were:

$VO_2max$ and $vVO_2max$, r = 0.5069

RE and OBLA, r = -0.6927

## *4.2. PREDICTING 800M RUNNING TIME (N = 11).*

For 800m running time, the best variable to predict running performance was isometric force. The $r^2$ for Iso force and 800m performance was 0.5254, (p = 0.0271) demonstrating that Iso force explained 53% of the variance for 800m running performance.

**Table 5. Results of stepwise multiple regression between the most appropriate physiological variables and 800m running performance.**

| | Variable | $r^2$ | p | significant |
|---|---|---|---|---|
| Step 1 | Iso force | 0.5254 | 0.0271 | * |
| Step 2 | MAOD | 0.7004 | 0.0269 | * |

* $p < 0.05$

**800m model 1 (Iso Force)**

| | Parameter Estimate | SE |
|---|---|---|
| a (intercept) | 3.37081 | 0.36308 |
| b (slope) | -0.10057 | 0.03613 |

The 800m running time could be estimated from:

$Y = a + bx$

800m time = 3.371 – 0.101(Iso Force)

The next variable, which made a significant contribution to 800m running performance, was MAOD. The correlation coefficient for MAOD was -0.4356. When the Iso force and MAOD were entered to predict the 800m running time, $r^2$ was 0.7004 (P = 0.0269). This demonstrated that 70% of the variance for 800m running time was explained through the contribution of MAOD and Iso Force.

**800m model 2 (Iso Force and MAOD)**

| | **Parameter Estimate** | **SE** |
|---|---|---|
| a (intercept) | 3.732167 | 0.36637 |
| $b_1$ (MAOD) | -0.1137 | 0.00607 |
| $b_2$ (Iso Force) | -0.09918 | 0.03101 |

The equation that could best predict the 800m running performance was:

$y = a + b_1x_1 + b_2x_2$

800m time = 3.732 – 0.114(MAOD) –0.099(Iso force)

## *4.3. PREDICTING 1500M RUNNING TIME (N = 11).*

The variable that made the greatest contribution to 1500m running performance was MAOD. The $r^2$ for the MAOD and 1500m running time was 0.3767, (p = 0.0787) demonstrating that MAOD contributed 38% to the prediction of 1500m running performance.

**1500m model 1 (MAOD)**

| | Parameter Estimate | SE |
|---|---|---|
| a (intercept) | 5.95669 | 0.54682 |
| b (slope) | -0.03351 | 0.01629 |

The next most appropriate variable entered into the regression was the Iso force. When the Iso force and MAOD were entered to predict the 1500m running time, the $r^2$ was 0.6705 and statistical significance was at P = 0.0358. This demonstrated that 67% of the variance for 1500m running time could be explained from MAOD and Iso Force

**Table 6. Results of stepwise multiple regression between the most appropriate physiological variables and 1500m running performance.**

| | Selected | $r^2$ | p | significant |
|---|---|---|---|---|
| Step 1 | MAOD | 0.3736 | 0.0787 | |
| Step 2 | Iso Force | 0.6705 | 0.0358 | * |

* $p < 0.05$.

**1500m model 2 (MAOD and Iso Force)**

| Variable | Parameter estimate | SE |
|---|---|---|
| a (intercept) | 7.44109 | 0.77215 |
| $b_1$ (MAOD) | -0.03280 | 0.01280 |
| $b_2$ (Iso Force) | -0.15118 | 0.06536 |

This is shown in the following equation:

$y = a + b_1x_1 + b_2x_2$

1500m time = 7.441 – 0.033(MAOD) – 0.151(Iso Force)

## *4.4. PREDICTING 3000M RUNNING TIME (n=6).*

From the variables that were measured, the best that could predict 3000m running performance was OBLA The correlation coefficient when relating OBLA and 3000m running time was 0.9731 (P = 0.0269). The $r^2$ for the OBLA and 3000m running time was 0.9469. This demonstrated that OBLA contributed 95% to the prediction of 3000m running performance.

**3000m model 1 (OBLA)**

| | Parameter Estimate | SE |
|---|---|---|
| a (intercept) | -10.73867 | 3.55316 |
| b (slope) | 0.23775 | 0.03980 |

The equation that can be used to predict the 3000m running performance from OBLA is:

**y = a + bx**

**3000m time = -10.739 + 0.238(OBLA)**

From stepwise regression the next variable entered which made a significant contribution, was the velocity at $VO_2$max ($vVO_2$max). When the OBLA and $vVO_2$max were entered to predict the 3000m running time, the $r^2$ was 0.9991 and statistical significance was at P = 0.0296. This demonstrated that 99% of 3000m running time could be predicted from OBLA and $vVO_2$max.

**Table 7. Results of stepwise multiple regression between the most appropriate physiological variables and 3000m running performance.**

| | Variable | $r^2$ | p | significant |
|---|---|---|---|---|
| Step 1 | OBLA | 0.9469 | 0.0269 | * |
| Step 2 | $vVO_2$max | 0.9991 | 0.0296 | * |

* $p < 0.05$

**3000m model 2 (OBLA and $vVO_2$)**

| | Parameter estimate | SE |
|---|---|---|
| a (intercept) | -31.44287 | 2.76307 |
| $b_1$ ($vVO_2max$) | 0.42726 | 0.05544 |
| $b_2$ (MAOD) | 0.39332 | 0.02144 |

The equation that could predict the 3000m distance running time for both variables was:

$y = a + b_1x_1 + b_2x_2$

3000m time = -31.443 + 0.427($vVO_2max$) + 0.393(OBLA)

## *4.5. PREDICTING 10000M RUNNING TIME (n=8).*

The variable that could best predict the 10000m running performance was the $vVO_2max$ The correlation coefficient when relating $vVO_2max$ and 10000m running time was –0.6829 (P = 0.1349). The $r^2$ was 0.4663.

**10000m model 1 ($vVO_2$ max)**

| | Parameter Estimate | SE |
|---|---|---|
| a (intercept) | 82.36937 | 22.00153 |
| b (slope) | -2.58129 | 1.38127 |

The next variable entered in the equation was OBLA. The coefficient when correlating between OBLA and 10000m running time was –0.2970. When vVO2max and OBLA were both entered into the system the $r^2$ was 0.8323 (P = 0.0687). However this relationship was just not statistically significant and has a greater than 5% probability that it occurred by chance.

**Table 8. Results of stepwise multiple regression between the most appropriate physiological variables and 10000m running performance.**

| | Variable | $r^2$ | p | significant |
|---|---|---|---|---|
| Step 1 | $vVO_2max$ | 0.4663 | 0.1349 | |
| Step 2 | OBLA | 0.8323 | 0.0687 | |

**10000m model 2 ($vVO_2max$ and MAOD)**

| | Parameter Estimate | SE |
|---|---|---|
| a (intercept) | 140.19750 | 26.71332 |
| $b_1$ ($vVO_2max$) | -3.53154 | 0.96801 |
| $b_2$ (MAOD) | -0.49178 | 0.19220 |

# CHAPTER 5. DISCUSSION

The aims of the study were to determine aerobic and anaerobic variables that are related to 800m, 1500m, 3000m and 10000m running performance in young female runners and it was hypothesized that:

i) anaerobic capacity and leg strength will be the principal determinants of 800m and 1500m running performances

ii) aerobic capacity will be the principal determinants of 3000m and 10 000m running performances.

Conley *et al* (1981) used 14 trained and competitive female runners. The performance time for 10000m from this study (43.7 minutes) was similar to that of the present study (41.8 minutes). In the study by Yoshida *et al* (1990) they reported: 2.30 minutes for 800m, 4.79 minutes for the 1500m and 10.45 minutes for the 3000m running distances. These performances are all similar to the present study of 2.39 minutes (800m), 4.92 minutes (1500m) and 10.61minutes (3000m). The performance times from this study are not comparable to the world records and the current (2007) world leading times. This illustrates that the female athletes from this study are not world class runners.

MAOD has been used as a reliable measure of anaerobic capacity in runners (Medbo *et al,*1988). Ramsbottom *et al* (1994) reported a significant correlation (r = -0.61) between MAOD and 800m running performance. However Olesen *et al* (1994) and Craig and

Morgan (1998) related MAOD to 800m running performance and both studies observed that MAOD was not a significant predictor of 800m running performance. In the present study MAOD and the maximal isometric force were significantly related to 800m running performance. These results suggest that muscle force, measured as the maximal isometric force and anaerobic capacity, measured as the MAOD, play a significant role during 800m running in young female athletes. Eight hundred meter running performance demands more from isometric force and the anaerobic energy system (Scott *et al*, 1991) than longer events. This is probably even more the case when 800m is run at an altitude of almost 2000m (Johannesburg, South Africa).

The importance of muscle force and anaerobic energy is greatest in the shorter running distances (Spencer and Gastin, 2001). This could explain the contribution of the maximum isometric force and MAOD to 800m and 1500m running in the present study. The maximum isometric force and MAOD did not show any relationship with the other distances (3000m and 10000m).

$VO_2$max has been shown to be one of the best aerobic variables to predict longer distance running time (Evans *et al*, 1995). Evan's *et al* (1995) found in their study that $VO_2$max correlated significantly with 10km running performance in female athletes. Results from the present study indicate that $VO_2$max did not show any significant contribution to the 800m running event perhaps because of the reduced availability of aerobic energy at an altitude of 1800m compared to sea level. Similar responses were observed by Williams *et al* (1987).

Running economy is one of the aerobic variables that have been shown to correlate significantly with running performance particularly in samples of athletes who have homogenous $VO_2$max levels (Morgan and Mitchell, 1992). The result from the study by Housh *et al* (1988**)** showed that RE was a valuable determinant of middle distance running performance. The present study does not support these previous findings. In this study RE does not correlate or contribute significantly to any of the running distances (800m, 1500m, 3000m and 10000m) in female middle distance athletes. The latter data support previous findings by Craig and Morgan (1998) who also found that RE does not correlate significantly with 800m running time. Similarly Evans *et al* (1995) found also that RE does not correlate with 10km running performance in female athletes. In the present study RE did not improve the level of correlation with stepwise regression for all four running performances. Our athletes had heterogenous $VO_2$max levels which may have limited the influence of RE under the conditions of this study and contributed to the findings.

Running velocity at $VO_2$max ($vVO_2$max) has shown to be a good predictor of performance during middle and long distance running (Morgan et al, 1989a, Cunningham 1990). Cunningham (1990) found $vVO_2$max related with 5km running performance. $vVO_2$max incorporates both maximal aerobic power and RE (Morgan et al, 1989a). In their study Morgan et al, 1989a reported that $vVO_2$max was closely related to the 10km event. The results from the present study show that $vVO_2$max correlates with longer distances i.e. 3000m ($r = -0.8388$) and 10000m ($r = -0.6829$). These results are similar to those reported in previous studies indicating that $vVO_2$max is a relatively sensitive index

of aerobic energy production and therefore is closely related to longer distance running events. Our results show no statistically significant relationship existed between $vVO_2max$ and the shorter running events (800m, r = 0.0035 and 1500m, r = 0.0327). In contrast Craig and Morgan (1998) reported that $vVO_2max$ correlated significantly (r = -0.54) with 800m running performance.

During 10000m running, $vVO_2max$ was the variable that contributed most (but not significantly) to the running time. Morgan *et al* (1989a) found that $vVO_2max$ correlated significantly with 10km running performance. Other studies which reported significant correlations with $vVO_2max$ included Billat and Koralsztein (1996) (21.1km), Noakes et al, (1990) and Scrimgeour *et al*, (1986) (21.1km and 42.2km). Although the correlation coefficient between $VO_2max$ and 10000m running time exceeded 0.55, the relationship was not statistically significant. The possibility cannot be excluded that the smaller sample size resulted in a type 2 statistical error.

Previous studies have shown that blood lactate variables such as OBLA ($\%VO_2$ max at blood lactate concentration of 4mmo/l), $\%VO_2$ max at other fixed blood lactate levels (2mmol/l, 2.5mmol/l) and lactate threshold have been found to be good predictors of long distance running performance and fitness level in athletes (Duggan and Tebbutt, 1990; Weltman *et al*, 1990; Sjodin and Jacobs, 1985; Yoshida *et al*, 1981; Maffulli *et al*, 1991b; Fernhall *et al*, 1996; Tanaka and Matsuura, 1984a)

In the present study apart from vVO2max, OBLA was significantly correlated with 3000m running time (r = -0.9731 P = 0.0269). For the 10000m, it was the second best variable to predict performance and together with $vVO_2max$ accounted for 83% of 10000m running performance variance (P = 0.0687). The combined relationship was marginally not statistically significant probably because of the smaller sample size. This is similar to the study by Yoshida *et al*, 1993, where they reported that blood lactate variables vOBLA, $VO_2$ at lactate threshold and running speed at lactate threshold account for 73.2% in 3000m running performance.

Unlike this study, Yoshida *et al* (1981) reported a significant correlation between OBLA and 800m running time. Similar to this study Yoshida *et al* (1990) observed that OBLA was also significantly correlated to 3000m running performance. It could be concluded that OBLA is a significant predictor of longer distance running performance.

This study has also demonstrated that blood lactate variables are good predictors of distance running performance. This confirms the findings of a variety of previous studies. The study by Sjodin and Jacobs (1991) confirmed that running speed at 4mmol/l (vOBLA) was closely related with distance running performance in marathon running. Weltman *et al* (1990) used 3200m running performance to predict running speed at fixed blood lactate concentrations (2mmol/l, 2.5mmol/l and 4mmol\l). They identified which blood lactate concentrations could be used best to predict 3200m running time and could also be used as training monitors.

Duggan and Tebutt (1990) reported that vOBLA is a good predictor of 4000m running performance. Evans *et al* (1995) found that lactate threshold was highly correlated with 10km running performance. The study by Maldonado-Martin *et al* (2004) assessed physiological variables that could be used to compare running performances between males and females. They found out that lactate threshold correlated (r=0.59, p,0.05)with running performance (1500m) in male athletes and female athletes. Brandon and Boileau (1987) used 29 male well conditioned recreational runners to assess the contribution of aerobic and anaerobic (Wingate bicycle ergometer protocol) variables to 800m, 1500m and 10000m running performances. From their study they observed that the aerobic variable ($VO_2$max), contributed to all the running distances and was far the best for the 10000m distance. This is in contrast to our present study where VO2max did not show any major significant contribution even in the 10000m running distance.

Housh *et al* (1988) reported on the contribution of physiological variables to middle distance running performance. They used 39 male novice runners, competitive runners and intercollegiate competitive middle distance runners. They used the stepwise regression analysis and found that VO2max, RE and ventilatory threshold provided the most effective prediction of 3.22km running performance. This is different from the present study where OBLA and vVO2max were the best variables to predict 3000m running performance. It may be that differences in altitude between the two studies account for this difference.

## CONCLUSION

At an altitude of 1800m the performance in the shorter middle distances like 800m and 1500m are best predicted by measurements of leg strength (isometric force) and anaerobic capacity (maximal accumulated oxygen deficit). Studies done closer to sea level have shown that performance in the shorter middle distance events is effectively predicted by measurements of aerobic capacity. Performance in the longer middle distance events at an altitude of 1800m are best predicted by measurements of aerobic capacity specifically OBLA and $vVO_2max$. The study has identified the specific measurements that best predict performance in the different middle distance events for female athletes competing at an altitude of 1800m.

The results from this study suggest that 800m and 1500m runners at an altitude of 1800m should concentrate on the development of leg strength (Isometric force) and anaerobic capacity (MAOD) in their training and longer distance runners should spend more of their training time on improving their aerobic capacity.

The results from the present study are inconclusive when comparing the contribution of physiological variables during middle distance exercise performed by males and females. Available literature has demonstrated that very little information exists on specific female responses during middle distance running. One may expect differences in response between males and females based on differences in strength. It is concluded and

recommended that a study looking at gender differences in the contribution of these physiological variables and middle distance running performance be explored.

## REFERENCE LIST


1. Abe D., Yanagawa K., Yamanobe K., Tamura K. *Assessment of middle-distance running performance in sub-elite young runners using energy cost of running*. Eur. J. App1. Physiol., 77; 320-325, 1998.
2. Allen,William K., Douglas R. Seals, Ben F. Hurley, Ali A. Ehsani, and James M. Hagberg. *Lactate threshold and distance-running performance in young endurance athletes*. J. Appl.Physiol., 58(4) 1281-1284,,1985.
3. Almarwaey O.A., Jones A.M. and Tolfrey K. *Physiological correlates with endurance running performance in trained adolescents*. Med. Sci. Sports Exerc., 35 (3): 480-487, 2003.
4. Astrand P.O. and Rodahl K. Textbook of work physiology. New York, McGraw-Hill, 1986.
5. Bangsbo J. , Dollnick P.D., Graham T.E., Juel C., Kliens B., Mizuno M. and Saltin B. *Anaerobic energy production and $O_2$ deficit-debt relationship during exhaustive exercise in humans*. J Physiology, 422: 539-559, 1990.
6. Bangsbo J., Michalsik L. and Petersen A. *Accumulated 02 deficit during intense exercise and muscles characteristics of elite athletes*. Int. Sports Med., 14 (4): 207-213, 1993.
7. Bassett D.R. and Howley E.T. *Limiting factors for maximum oxygen uptake and determinants of endurance performance*. Med. Sci. Sports Exerc., 32(1) pp. 70-87,2000.
8. Berg K. *Endurance training and performance in runners*. Sports Med., 33(1): 59-73, 2003

9. Billat L.V. and J. Koralsztein P. *Significance of the velocity at $VO_2$max and time to exhaustion at this velocity*. Sports Med, 22(2): 90-108, 1996.

10. Billat L.V. *Use of Blood Lactate Measurements for Prediction of Exercise Performance and for Control of Training Recommendation for Long Distance Running*. Sports Med, 22(3): 157-175, 1996.

11. Boileau, R.A., Mayhew, J.L. Riner, W.F., and Lussier, L. *Physiological characteristics of Elite Middle and Long Distance Runners*. Can. J. App1 Sport. Sci., 7(3): 167-173, 1982.

12. Brandon J.L. *Physiological factors associated with middle distance running performance*. Sports Med., 19(4): 268-277, 1995.

13. Brisswalter J. Legros P and Durand M. *Running economy, preferred step length correlated to body dimensions in elite middle distance runners*. J. Sports Med. Phys. Fitness. 36: 7-15, 1996.

14. Brooks G.A., Fahey T.D., White T.P. and Baldwin K.M. *Exercise physiology: Human bioenergetics and its applications*. 3rd edition. McGraw-Hill, Boston, 2000

15. Buck D. and Mcnaughton L. *Maximal accumulate oxygen deficit must be calculated using 10-min time periods.* Med. Sci. Sports Exerc. 31. (9); 346-1349, 1999.

16. Bulbulian R., Jeong J.W. and Murphy M. *Comparison of anaerobic components of the wingate and critical power tests in males and females*. Med. Sci. Sports Exerc., 28 (10): 1336-1341, 1996.

17. Bulbulian R., Wilcox A.R. and Darabos B.L. *Anaerobic contribution to distance running performance of trained cross-country athletes*. Med. Sci. Sports. Exerc. 18(1): 107-113, 1986.

18. Conley D.L. and Krahenbuhl G.S, Burkett L.N. and Millar A. L. *Physiological correlates of female road racing performance*. Research Quarterly for Exercise and Sport, 52(4): 441-448, 1981.

19. Conley D.L. and Krahenbuhl G.S. *Running economy and distance running performance of highly trained athletes*. Med. Sci. Sports Exerc., 12(5): 375-380, 1980.

20. Craig I.S. and Morgan D.W. *Relationship between 800-m running performance and accumulated oxygen deficit in middle-distance runners*. Med. Sci. Sports Exerc., 30(11): 1631-1636, 1998.

21. Cunningham L.N. *Relationship of running economy, ventilatory threshold and maximal oxygen consumption to running performance in high school females*. Research Quarterly for Exercise and Sport. 61(4): 369-374, 1990.

22. Daniels T.J. and Daniels S. *Running economy of elite male and elite female runners*. Med.Sci. Sports Exerc. 24 (4): 483-489, 1992.

23. Daniles J.T., Scardina N. and Hayes J. *Elite and subelite female middle and long distance runners.* In: Landers D.M. (ed). Sport and elite performers, Human Kinetics, Champiagn, 1986.

24. di Prampero P.E, Atchou G., Bruckner J.C. and Moia C. *The energetics of endurance running*. Eur. J. Appl. Physiol. 55: 259-265, 1986.

25. di Prampero P.E. Capelli C. Pagliaro P. Antonutto, G. Girrardis M. Zamparo P. and Soule R.G. *Energetics of best performances in middle distance running*. J. Appl. Physiol. 74(5): 2318-2324, 1993.

26. Diesel W., Noakes T.D., Swanepoel C. and Lambert M. *Isokinetic muscle strength predicts maximum exercise tolerance in renal patients on chronic hemodialysis*. Am. J. Kidney Dis. 7: 386-395, 1990.

27. Douben R.M. *Contractility: with special reference to skeletal muscle*, in Medical Physiology Volume 1 of 2, 14th ed, Edited by Mountcasle V. B. C V Mosby company, St Louis , 1980.

28. Duggan A. and Tebbutt S.D. *Blood lactate at 12km/ and vObla as predictors of run performance in non-edurance athletes*. Int. J. Sports Med., 11(2): 111-115,1990.

29. Duncan G.E., Howley E.T. and Johnson B.N. *Applicability of VO2max criteria: discontinuous versus continuous protocols*. Med .Sci. Sports Exerc. 29(2); 273-278, 1997.

30. Evans S.L., Davy K.P., Stevenson E.T. and Seals D.R. *Physiological determinants of 10-km performance in highly trained female runners of different ages*. J. App1 Physiol.,. 78(5); 1931-1941, 1995.

31. Farrell P.A., Wilmore, J.H., Coyle E.F., Billing J.E. and Costill D.L. *Plasma lactate accumulation and distance running performance*. Med. Sci. Sports. 11(4): 338-344, 1979.

32. Fay L., Londeree B.R., LaFontaine T.P. and Volek M.R. *Physiological parameters related to distance performance in female athletes*. Med .Sci. Sports Exerc., 21(3) 319-324, 1989.

33. Fernhall B., Kohrt W., Burkett L.N. and Walters S. *Relationship between the lactate threshold and cross-country run performance in high school male and female runners.* Ped. Exerc. Sci., 1: 37-47, 1996.

34. Foss M.L. and Keteyian S.J. *Fox's Physiological basis for exercise and sport*. 6th ed, Dubuque, McGraw-Hill, 1998.

35. Gastin P. B., Costill D. L., Lawson D. L., Krzeminsi K. and McConell G. K. *Accumulated oxygen deficit during supramaximal all-out and constant intensity exercise*. Med.Sci.Sports Exerc.,.27. (2): 255-263, 1995.

36. Ghosh A.K. *Anaerobic threshold: Its concept and role in endurance sport*. Malaysian J. Med. Sci. 11(1): 24-36, 2004.

37. Gleeson N.P. and Mercer T.H. *The utility of isokinetic dynamometry in the assessment of human muscle function*. Sports Med. 21(1): 18-34, 1996.

38. Gollnick P.D., Bayly W.M. and Hodgson D.R. *Exercise intensity, training, diet, and lactate concentration in muscle and blood*. Med. Sci .Sports Exerc. 18(3):334-40, 1986.

39. Grant S., Craig I., Wilson J. and Aitchison T. *The relationship between 3km and running performance and selected physiological variables*. J. Sports Sci., 15:403-410, 1997.

40. Green S and Dawson B. *Measurement of Anaerobic Capacities in Humans Definitions,Limitations and Unsolved Problems*. Sports Med, 15(5): 312-327,1993.

41. Green S. and Dawson B.T. *Methodological effects on the $VO_2$-power regression and the accumulated $O_2$ deficit.* Med. Sci. Sports. Exerc., 28(3): 392-397, 1996.

42. Green S., Dawson B.T., Goodman C. and Carey M.F. *Anaerobic ATP production and accumulated $O_2$ eficit in cyclis*t. Med. Sci. Sports Exerc. 28(3) 315-321, 1996.

43. Hagan R.D., Strathman T., Strathman L. and Gettman L.R. *Oxygen uptake and energy expenditure during horizontal treadmill running*. J. Appl. Physiol. 49(4): 571-575, 1980.

44. Hagberg J. M. *Physiological implications of lactate threshold*. Int. J. Sports Med., 5:106-109 (supp),1984.

45. Hausswirth C. and Lehenaff D. *Physiological demands of running during long distance runs and triathlons*. Sports Med., 31(9): 679-680, 2001.

46. Heck H., Mader A., Hess G., Mucke S., Muller R., and Hollman W. *Justification of the 4-mm1/1 lactate threshold*. Int. J. Sports Med., 6: 117-130, 1985.

47. Hill A.V. and Lupton H. *Muscular exercise, lactic acid and the supply and utilization of oxygen*. Quart. Med. J. 16: 135-137, 1923.

48. Hill D.W. *Energy System Contributions in Middle-distance running events*. J Sports Sci, 17: 477-483, 1999.

49. Hill, D.W. and Rowell A.L. *Running velocity at $VO_2max$*. Med.Sci. Sports Exerc., 28 (1): 114-119, 1996.

50. Hoogeveen A.R. and Schep G. *The plasma lactate response to exercise and endurance performance: Relationships in elite triathletes*. Int. J. Sports Med. 18: 526-530, 1997

51. Housh T J, Thorland W G, Pohnson G O, Hughes R A and Cisar C J, *The contribution of selected physiological variables to middle distance running performance*. J Sports Med Phys Fitness, 28(1): 20-26, 1988.

52. Iwaoka I., Fuchi T., Higuchi M. and Kobayashi S. *Blood lactate accumulation during exercise in older endurance runners*. Int. J. Sports Med. 9(4): 253-256, 1988.

53. Jacobs I. *Blood Lactate, Implications for Training and Sports Performance*. Sports Med, 3: 10-25, 1986.

54. Jones A. *Physiological determinants of success in track athletics*. Physiology News. 54:8-10. 2004.

55. Kenney W.L. and Hodgson J.L. *Variables predictive of performance in elite middle-distance runners*. Brit. J. Sports Med., 19(4): 207-209, 1995.

56. Kindermann W, Simon G and Keul J. *The signicance of the aerobic-anaerobic transition for the determination of work load intensities during endurance training*. Eur. J. Appl. Physiol., 42: 25-34, 1979.

57. Krahenbuhl G.S., Morgan D.W. and Pangrazi R.P. *Longitudinal changes in distance-running performance of young males*. Int. Sports Med., 10(2): 92-96, 1989.

58. Lacour J. R., Padilla-Magunacelaya S., Barthelemy J.C. and Dormois D.*The energetics of middle distance running*. Eur J App1 Physiol. 60:38-43, 1990.

59. MacRae, Holden S.H., Dennis S.C., Bosch A.N. and Noakes T.D. *Effects of training of lactate production and removal during progressive exercise in humans*. J. App1. Physiol., 72(5): 1649-1656, 1992.

60. Maffulli N, Capasso G and Lancia G A. *Anaerobic threshold and performance and long distance running*. J Sports Med Phys Fitness, 3(3): 332-338, 1991a.

61. Maffulli, N., Testa V., Lancia A., Capasso G. and Lombard S. *Indices of sustained aerobic power in young middle distance runners*. Med. Sci. Sports. Exerc., 23 (8): 1090-1096, 1991b.

62. Mahon A.D., Del Carral P., Haowe C.A., Duncan G.E. and Ray D.A.. *Physiological correlates of 3- kilometre running performance in male children*. Int. J. Sports Med., 17(8): 580-584, 1996.

63. Maldonado-Martin S, Mujika I and Padilla S. Physiological variables to use in the gender compatison in highly trained runners. J. Sports Med. Phys. Fitness. 44(1): 8-14, 2004.

64. Maxwell N.S. and Nimmo M.A. *Anaerobic capacity: a maximal anaerobic running test versus the maximal accumulated oxygen deficit*. Can. J. Appl. Physiol. 21(1): 35-47, 1996.

65. McArdle W.D., Katch F.L. and Katch V.L. *Exercise Physiology, Energy, Nutrition and Human Performance*. 3dr Edition Lea and Febiger, Philadelhphia, 1991.

66. Medbo J.I, Mohn A.C, Tabata I, Bahr R. Vaage O. and Sejersted O.M. *Anaerobic capacity determined by maximal accumulated O2 deficit*. J. Appl. Physiol. 64: 50-60, 1988.

67. Medbo J.I. and Burgers S. *Effect of training on the anaerobic capacity*. Med. Sci. Sports Exerc. 22(40): 501-507, 1990.

68. Medbo J.I. and Tabata I. *Anaerobic energy release in working muscles during 30s to 3 min of exhausting bicycling*. J. Appl. Physiol. 75(4): 1654-1660, 1993.

69. Medbo. J.I. *Is the maximal accumulated oxygen deficit an adequate measure of the anaerobic capacity?* Can.J.Appl.Physiol. 21(5): 370-383, 1996.

70. Morgan D.W and Mitchell C.. *Physiological aspects of running economy*. Med. Sci. Sports Exerc., 24(2):456-461, 1992.

71. Morgan D.W. Baldini F.D. Martin P.E. and Kohrt W.M. *Ten kilometre performance and predicted velocity at $VO_2$max among well trained runners*. Med Sci. Sports Exerc. 21(1): 78-83, 1989a.

72. Morgan D.W., Martin P.E. and Krahenbuhl G.S. *Factors affecting running economy*. Sports Med., 7:310-330, 1989b.

73. Moss B.M., Refsnes P.E., Abildgaard A., Nicolaysen K. and Jensen J. *Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional are, load-power and load-velocity relationships*. Eur. J. Appl. Physiol. 75: 193-199, 1997.

74. Myburgh, K.H., Viljoen A. and Tereblanche S. *Plasma lactate concentrations for self-selected maximal effort lasting 1 h*. Med. Sci. Sports Exerc. 33(1): 152-156, 2001.

75. Nichols J.F., Phares S.L. and Buono M.J. *Relationship between blood lactate response to exercise and endurance performance in competitive female master cyclist*. Int. J. Sports. Med. 18: 458-463, 1997.

*76.* Noakes T.D., Myburgh K.H and Schall H. *Peak treadmill running velocity during the VO2 max test predicts running performance.*J. Sports Sci., 8(1): 35-45, 1990.

77. Olesen H L, Raabo E, Bangsbo J and Secher N H . *Maximal oxygen deficit of sprint and middle distance runners*. Eur J Appl Physiol, 69: 140-146, 1994.

78. Powers S.K. and Howley E.T. *Exercise physiology: theory and application to fitness and performance*. 5th edition, McGraw-Hill, Boston. 2004

79. Ramsbottom R., Nevill A M, Nevill M E, Newport S and Williams C. *Accumulated oxygen deficit and short-distance running performance*. J Sports Scie,12: 447-453, 1994,

80. Ramsbottom R., Nevill M.E., Nevill A.M. and Hazeldine R. *Accumulated oxygen deficit and shuttle run performance in physically active men and women*. J. Sports Sci., 15: 207-214, 1997.

81. Ramsbottom R., Nute G.L. and Williams C. *Determinants of running performance in active men and women*. Brit. J. Sports Med. 21(2): 9-12, 1987.

82. Ramsbottom R., Williams C., Boobis L. and Freeman W. *Aerobic fitness and running performance of male and female recreation runners*. J. Sports Sci., 4(1): 9-20, 1989.

83. Reis V.M., Silva A.J., Ascensao A. and Duarte J.A. *Inclusion of exercise intensities above lactate threshold in VO2 running speed regression does not improve the precision of accumulated oxygen deficit in endurance trained runners*. J. Sports Sci. Med. 4: 455-462, 2005.

84. Scott C.B., Roby F.B., Lohman T.G. and Bunt J.C. *The accumulated oxygen deficit as an indicator of anaerobic capacity*. Med. Sci. Sports Exerc. 23(5): 618-624, 1991.

85. Scrimgeour A.G., Noakes T.D., Adams B. and Myburgh K. *The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultramarathon runners*. Eur. J. Appl. Physiol. Occup. Physiol. 55: 202-209, 1986.

86. Serresse G., Bouchard L.C. and Boulay M.R. *Estimation of the contribution of the various energy system during maximal work of short duration* . Int. J. Sports Med., 9(6): 456-460, 1988.

87. Sjodin B and Svedenhag J. *Applied Physiology of Marathon Running*. Sports Med, 2: 83-99 (1985).

88. Sjodin B. and Jacobs I. *Onset of blood lactate accumulation and marathon running performance*. Int. J. Sports Med., 2(1). 1981.

89. Sparling P.B. *A meta-anaylysis of studies comparing maximal oxygen uptake in men and women*. Research Quarterly for Exercise and Sport, 51(3): 542-552, 1980.

90. Speechly D.P., Taylor S.R. and Rogers G.G. *Differences in ultra-endurance exercise in performance-matched male and female runners*. Med. Sci. Sports Exerc., 28(3): 359-365, 1996.

91. Spencer M. R, Gastin P B and Payne W R. *Energy system contribution during 400 to 1500 metres running.* Med. Sci. Sports Exerc . New Studies in Athletics. 11(4): 59-65, 1996.

92. Spencer M.R. and Gastin P.B. *Energy system contribution during 200-to 1500-m running in highly trained athletes*. Med. Sci. Sports Exerc., 33 (1): 157-162, 2001.

93. Stainsby W.N. *Biochemical and physiological bases for lactate production*. Med. Sci. Sports Exerc., 18 (3): 314-343

94. St Clair Gibson A., Lambert M.I., Hawley J.A., Broomhead S. and Noakes T.D. *Measurement of maximal oxygen uptake from two different laboratory protocols in runners and squash players*. Med. Sci. Sports Exerc. 31(8): 1226-1229, 1999.

95. Stanley W.C., Gertz W.E., Wisneski J.A., Morris D.L., Nesse R.A. and Brooks G.A. *Systemic lactate kinetics during graded exercice in man*. Am.J. Physiol., 249.1985.

96. Tabata I., Irisawa K., Kouzaki M., Nishimura K., Ogita F. and Miyachi M. *Metabolic profile of high intensity intermittent exercises*. Med. Sci. Sports Exerc. 29: 390-395, 1997.

97. Tanaka K. and Matsuura Y. *Marathon performance, anaerobic threshold and onset of blood lactate accumulation*. J. Appl. Physiol. 53(3): 640-643, 1984.

98. Tanaka K., Matsuura Y., Matsuzaka A., Hirakoba K., Kumagai S., Sun S.O. and Asano K. *A longitudinal assessment of anaerobic threshold and distance running performance*. Med. Sci. Sports Excer. 16(3): 278-282, 1984.

99. Taunton J.E., Maran H. and Wilkinson J.G. *Anaerobic performance in middle and long distance runners*, Can. J. App1.Sport Sci., 6(3): 109-113, 1981.

100. Unnithan V.B., Timmons J.A., Paton J.Y. and Rowland T.W. *Physiologic correlates to running performance in pre-pubertal distance runners*. Int. J. Sports Med., 16 (8): 528-533, 1995.

101. Wassermann K., Whipp B.J., Koyal S.N. ans Beaver W.L. *Anaerobic threshold and respiratory gas exchange during exercise*. J. Appl. Physiol. 35: 236-239, 1973.

102. Weber C.L. and Schneider D.A. *Reliability of MAOD measure at 110% and 120% of peak oxygen uptake for cycling*. Med. Sci. Sports Exerc., 33.(6): 1056-1059, 2001.

103. Weltman A., Seip R., Bogardus A.J. and Snead D*., of lactate threshold(LT) and fixed blood lactate concentrations (FBLC) from 3200-m running performance in women*. Int J Sports Med, 11(5): 373-378, 1990.

104. Westerbald H., Allen D.G. and Lannergren J. *Muscle fatigue: lactic acid or inorganic phosphate the major cause*? News Physiol. Sci. 17:17-21, 2002.

105. Weyand P.G., K.J. Cureton D.S., Conley M.A., Sloniger, and Y. L. Liu. *Peak oxygen deficit predicts sprint and middle-distance track performance*. Med. Sci. Sports Exerc., 26 (9): 1174-1180, 1994.

106. Williams K.R. and Cavanagh P.R. *Relationship between distance running mechanics, running economy, and performance*. J. App. Physiol., 63(3): 1236-1245, 1987

107. Williams T.J., Krahenbuhl G.S. and Morgan D.W. *Daily variation in running economy of moderately trained male runners*. Med. Sci. Sports Exerc., 23(8): 944-948, 1991.

108. Willmore J.H. and Costill D.L. *Physiology of sport and exercise*. 3rd edition, Human Kinetics. 2004.

109. www.iaaf.org, 2007/ 04 /09

110. Wyndham C. H., Strydom J. S., Maritz J. F., Morrison J. and Potgieter Z. U. *Maximal oxygen intake and maximum heart rate during strenuous work*. J. Appl. Physiol. 14: 927-936, 1959.

111. Yoshida T., Udo M., Iwai K. and Yamaguchi T. *Physiological characteristics related to endurance running performance in female distance runners*. J. Sports Sci., 11: 57-6, 1993.

112. Yoshida T., Udo M., Iwai K. Chida M., Ichiola M., Nakadomo F. and Yamaguchi T. Significance of the contribution of aerobic and anaerobic components to several distance running performances in female athletes. Eur. J. Appl. Physiol. 60: 249-253, 1990.

113. Yoshida T, Nagata A, Muro M, Takeuchi N, Suda Y. *The validity of anaerobic threshold determination by a Douglas bag method compared with arterial blood lactate concentration*. Eur. J. Appl. Physiol. Occup. Physiol.,46(4): 423-30, 1981.

114. Yoshida T., Chida M., Ichioka M. and suda Y. *Blood lactate parameters related to aerobic capacity and endurance performance*. Eur. J. Appl. Physiol. 56: 7-11, 1987.

# APENDIX A LACTATE ASSAY

Lactate Assay

Assay without deproteinisation.

Boehringer Mannheim, Germany.
Cat. No. 256773 fro 3 x 100ml.

Method

Model from Noll, F. (1974). L-(+)-Lactate. Determination with LDH, GPT and NAD. Page 1475 ff.in H.U. Bergmeyer, ed. Methods of enzymatic analysis, 2nd edition (translated from 3rd German edition) Verlag Chemie Weinheim and Academic Press, Inc., New York and London. 4 volumes.

Test principle

$$\text{L-lactate} + NAD^+ \xrightarrow{\text{LDH}} \text{pyruvate} + NADH + H^+$$

$$\text{Pyruvate} + \text{L-glutamate} \xrightarrow{\text{GPT}} \text{L-alanine} + \alpha\text{-oxoglutarate}$$

Sample material: plasma
Reagents:

1. NAD
2. Enzyme suspension
3. Ammonium sulfate

**Procedure**

Spectrophotometer: 340nm

Cuvette: 1cm light path

Incubation temperature: 20-25$^{o}$C

| Pipette into test tubes | | |
|---|---|---|
| | Sample Blank (SB) | Sample |
| Reagent solution<br>Plasma | 5.00ml<br>0.05ml | -<br>- |
| Mix well | | |
| Pipette from sample blank | | 2.50ml |
| Add: | | |
| Suspension 2<br>Solution 3 | -<br>0.05ml | 0.05ml<br>- |
| Mix immediately and after 10-15 minutes read absorbance of sample blank ($A_{SB}$) and sample ($A_S$) in same cuvette in immediate succession. | | |

Calculation:

[lactate] mmol/l = 16.3 x As – ASB

## APPENDIX B Individual Physiological Variables Of The Subjects.

| Subject | $vVO_2max$ ($kmh^{-1}$) | $VO_2max$ ($mlO_2.kg^{-1}.min^{-1}$) | RE ($m/O_2.kg^{-1}.km^{-1}$) | OBLA (%) | Iso Force (kg) | Vmax (rpm) | MAOD ($mlO_2.kg^{-1}$) | 800m | 1500m | 3000m | 10 000m |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 16.42 | 54.45 | 192 | 87.04 | 10.99 | 201.9 | 32.65 | 2.14 | 4.45 | 9.8 | 37.03 |
| **2** | 14.91 | 44.9 | 175 | 81.27 | | | 22.9 | 2.53 | 5.28 | 10.92 | 41.67 |
| **3** | 13.01 | 47 | 184 | 97.69 | | | 28.42 | 2.5 | 5.2 | 10.8 | 45 |
| **4** | 16.95 | 53.85 | 184.5 | 87.43 | 10.05 | 221.2 | 45.03 | 2.13 | 4.47 | 10.2 | 38.96 |
| **5** | 15.13 | 50.6 | 195.5 | 83.57 | 12.26 | 213.36 | 25.89 | 2.25 | 4.97 | | 46.01 |
| **6** | 13.83 | 55.35 | 179.2 | 91.28 | 10.06 | 192.17 | 27.02 | 2.5 | 5.13 | | |
| **7** | 18.5 | 58.95 | 192.5 | 80.68 | 9 | 222.91 | 38.39 | 2.58 | 5.2 | | |
| **8** | 14.83 | 46.07 | 173 | 91.89 | 11.16 | 199.48 | 37.96 | 2.27 | 4.3 | 11.05 | 42.88 |
| **9** | 15.74 | 53.2 | 185.6 | 83.22 | 8.15 | 210.13 | 24.66 | 2.58 | 5.35 | | |
| **10** | 15.64 | 57.13 | 189 | 90.67 | 8.73 | 213.71 | 30.63 | 2.53 | 4.93 | 10.88 | 40.42 |
| **11** | 16.49 | 53.42 | 190.2 | 80.66 | 9.36 | 211.87 | 34.44 | 2.33 | 4.87 | | 42.42 |
| **Mean** | 15.59 | 52.27 | 185.5 | 86.85 | 9.97 | 209.64 | 31.64 | 2.39 | 4.92 | 10.61 | 41.80 |
| **SD** | 1.51 | 4.59 | 7.31 | 5.56 | 1.32 | 10.09 | 6.82 | 0.17 | 0.36 | 0.49 | 2.98 |

# APENDIX C Ethics Clearance Certificate

**UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG**

Division of the Deputy Registrar (Research)

**HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)**
R14/49 Mpholwane

| | |
|---|---|
| **CLEARANCE CERTIFICATE** | **PROTOCOL NUMBER M060735** |
| **PROJECT** | Physiological Match Male and Female Runners (previously M990419 Prof G Rogers) |
| **INVESTIGATORS** | Ms M Mpholwane |
| **DEPARTMENT** | School of Physiology |
| **DATE CONSIDERED** | 06.07.17 |
| **DECISION OF THE COMMITTEE*** | |

**Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.**

**DATE** **CHAIRPERSON** .....
(Professor A Dhai)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Prof G Rogers

---

**DECLARATION OF INVESTIGATOR(S)**

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES