# PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES TO EXERCISE AND TRAINING IN ADOLESCENT RUNNERS

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## Abstract

This thesis aims to identify physiological and biochemical variables, comparing sex, training status, age and maturity in sub-elite, endurance trained adolescents. Maximal lactate steady state was investigated and the effects of endurance training programmes measured. The first study assessed the reliability of absolute running speed, $\dot{V}O_2$, and HR that correspond to the fixed blood lactate reference values of 2.0 and 2.5 mmol.$L^{-1}$ and the lactate threshold (LT) and found these measures to be reliable after endurance-trained adolescent runners completed two identical incremental treadmill tests within a 7-10 d period The second study was designed to determine the relationship between physiological variables and endurance running performance in this age group. Track-based, running performance times were available for 18 boys and 14 girls for the 800 m, and 16 boys and 13 girls for the 1500 m. The participants were tested using a step-wise incremental treadmill test and a Wingate anaerobic power test (WAnT) on separate occasions. The results from this study found that for the 1500m, running speeds corresponding to the fixed [$BLa^-$] were a useful measure for assessing performance in endurance trained boys and girls. Unlike previous studies, peak $\dot{V}O_2$ was not a significant physiological predictor of 1500m performance in either boys or girls. For the 1500 m performance in girls the anaerobic measure was no longer significant once variations in size or age had been taken into consideration. Whereas v$\dot{V}O_2$ peak and running economy may prove to be of some value when considering the 800m for boys, the running speed corresponding to a [$BLa^-$] of 2.5 mmol·$L^{-1}$ was the only meaningful physiological predictor variable for girls once differences in age and body size had been accounted for. The third study had three main objectives: (1) to identify the exercise intensity that corresponds to the (MLaSS) in adolescent, endurance trained runners, (2) to examine possible between sex differences, and (3) to compare the MLaSS with commonly cited fixed blood lactate reference variables. The participants were first tested using a step-wise incremental treadmill test to establish the blood lactate profile and peak $\dot{V}O_2$. The running speed and % peak $\dot{V}O_2$ at the MLaSS were not significantly different to those corresponding to the fixed [$BLa^-$] of 2.0 and 2.5 mmol·$L^{-1}$ ($P>0.05$). The % HR max at 2.5 mmol·$L^{-1}$ was also not different to that at the MLaSS, whereas at 2.0 mmol·$L^{-1}$ it was slightly lower ($P<0.05$). The running speed, % peak $\dot{V}O_2$, and % HR max at the fixed [$BLa^-$] of 4.0 mmol·$L^{-1}$ were significantly higher than those at the MLaSS ($P<0.05$). In conclusion, it is clear that the MLaSS corresponded to the relatively high exercise intensity in this sample of athletes. It would appear that the running speed, % peak $\dot{V}O_2$, and % HR max at the MLaSS lies somewhere between the fixed [$BLa^-$] of 2.0 and 2.5 mmol·$L^{-1}$. These results confirm earlier work that has suggested a fixed [$BLa^-$] of 2.5 mmol·$L^{-1}$ may be used with young people[1] to assess and monitor endurance running performance in place of the more commonly used 4.0 mmol·$L^{-1}$ that has received so much attention in adult-based studies.

The fourth study examined the effect of exercise training on endurance performance, blood lactate profile in relation to running speed (RV) and cardio respiratory function (peak $\dot{V}O_2$) in adolescent runners. This study demonstrated that resting HR, LT and


[1] Use of the expression young people is increasingly common since the publication of the text, *Young People and Physical Activity* by Armstrong and Welsman in 1997. It is used within this document to generically represent the 6 to 18 year age group.

RV, HR, $\dot{V}O_2$ and peak $\dot{V}O_2$ at LT were significantly influenced by endurance training. When running time, running velocity and run performance time pre and post-intervention were included in the analysis, the intervention did not have a significant effect on peak $\dot{V}O_2$. When percentage body fat was included as a covariate, there was a positive association with pre and post-training for all groups. The conclusion from these data is that maturity and training both have an effect, especially at supra suggested training levels.

The results of the four inter-linked studies support an age-related increase in endurance in aerobic and anaerobic performance and indicated significant differences between boys and girls. From a coaching viewpoint the results reveal that, from the age of 14 to 18 years, runners should be introduced to high intensity training and that changes to the format of middle distance running performance in adolescent competition are recommended.

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# DEDICATION

I dedicate this thesis to my Father, Mother, Brothers, Sisters, Wife, and my Children in Makkah and Jeddah in Saudi Arabia, for their personal support, encouragement, and for sharing the happiness and anguish throughout my life time with their everlasting love.

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# GLOSSARY

**Absolute** $\dot{V}O_{2max}$ the amount of oxygen consumed over a given time period; expressed as liters per minute ($L \cdot min^{-1}$).

**Acidosis** is an abnormal increase in blood hydrogen ion concentration (i.e. arterial pH below 7.4).

**Adolescence** is a stage of development characterised by unprecedented physiological changes in the musculoskeletal, cardiorespiratory and reproductive systems of the body.

**Aerobic threshold (AT)** The running speed and/or $\dot{V}O_2$ just below that at which metabolic oxidative and the associated changes in gas exchange occurs.

**Anaerobic threshold** a commonly used term to describe the onset of anaerobiosis (Wasserman et al., 1973) detected either by the initial increase in blood lactate or by a rapid increase ventilation or certain gas exchange parameters during exercise.

**Catecholamines** organic compounds that include epinephrine and norepinephrine (see glossary).

**Children-** <11 years old (prepubescent).

**Epinephrine** a hormone secreted by medulla of the adrenal gland that has effects on the heart, the blood vessels metabolism, and the central nervous system; also, called adrenaline.

**Lactate threshold (LT)** a commonly used term to describe either the initial increase in blood lactate above resting levels or an abrupt increase during graded exercise. Also, is defined as the running speed and/or $\dot{V}O_2$ at which there is a sudden and sustained increase in blood [lactate] above baseline.

**Lactate acid** an intermediate metabolite representing a means of distributing carbohydrate energy sources resulting from incomplete breakdown of either glucose or glycogen.

**Lysed blood lactate** a means of determining the lactate concentration in blood following centrifuge of the blood sample to break down the red blood cell walls. This process results in the release of intra-cellular lactate into the extra-cellular fluid.

**Maturity** refers to distinct biological activities that include both tempo and timing of progress towards the biological state and consequently varies with the biological system that used to assess this state.

**Maximal lactate steady state (MLaSS)** is defined the highest steady state exercise intensity that can be sustained whilst maintaining equilibrium between the processes of blood lactate accumulation and elimination. Also, is defined as the running speed above which [lactate] will rise until fatigue runs during prolonged exercise.

**Maximal oxygen uptake** ($\dot{V}O_{2max}$) greatest possible rate of oxygen uptake (consumption) by the body measured during severe dynamic exercise, usually on a cycle ergometer or treadmill. The most common employed indicator is a plateau in the oxygen uptake-exercise curve. This term can be expressed in several ways absolute, mass related or relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$).

**Norepinephrine** a hormone and neurotransmitter; released from the postganglionic nerve ending and the adrenal medulla. Also, called noradrenaline.

**Onset of blood lactate accumulation (OBLA)** the running speed and/or $\dot{V}O_2$ when blood lactate concentration [La] reaches 4 mM reference value.

**Peak** $\dot{V}O_2$ the greatest possible rate of oxygen uptake (consumption) by the body measured during severe dynamic exercise where a plateau in the oxygen uptake-exercise curve is not demonstrated. Several other subsidiary criteria are used to indicate a maximal effort during the exercise.

**Relative** $\dot{V}O_2$ oxygen uptake (consumption) expressed in relation to the peak or maximal value attained during a graded exercise test; expressed as a percentage in this dissertation (e.g. % peak $\dot{V}O_2$).

**Steady-State** describes when a control system (e.g. respiratory) achieves balance between supply and demand during exercise over a time period.

**Ventilatory threshold (VT)** a commonly used term to describe an abrupt increase in ventilation during graded exercise. Also, defined as the running speed and/or $\dot{V}O_2$ at which the fast loss in the $V_E$ - $\dot{V}O_2$, relationship is observed.

**Weight related** $\dot{V}O_2$ oxygen uptake (consumption) expressed per unit body mass (e.g. $ml \cdot kg^{-1} \cdot min^{-1}$).

**Whole blood lactate** a means of determining the lactate concentration in blood without treatment of the sample (i.e. no need for protein precipitant, glycolytic inhibitor or centrifuge).

**Young people** is used to describe individuals who are ≤ 18 years of age.

# Chapter One
# Introduction

## 1.0 Introduction

This introductory chapter provides a brief overview to examine the physiological and biochemical indices and correlates with endurance running performance in trained adolescent runners and the effects of training programme on these variables. Then to understand the limitations of the correlated indices with running performance in this group of population before addressing either aerobic or anaerobic running performance programme. The aims and objectives are presented, and experimental plans in the thesis are explained.

## 1.1 Overview

The highest speed that can be maintained over a set distance, or over time, will determine the relative success of an endurance athlete (Billat, 1996). Several physiological measurements have been used to predict endurance running performance in adults, including peak oxygen uptake ($\dot{V}O_2$), running economy (sub-maximal $\dot{V}O_2$), blood lactate threshold (LT), and fractional utilisation of peak $\dot{V}O_2$ (Unnithan et al., 1995). Longitudinal research has suggested that between 14 and 21 years of age, superior running performance may be associated with high absolute, rather than peak $\dot{V}O_2$ relative to body mass, i.e. $L.min^{-1}$ not $mL.kg^{-1}.min^{-1}$ (Murase et al., 1981). In another study, ventilatory threshold (VT) was related to 3000 m time trial performance in prepubertal boys (Unnithan et al., 1995) although the authors concluded that peak $\dot{V}O_2$ ($mL.kg^{-1}.min^{-1}$) appeared to be the single most important factor associated with success at 3000 m. Within a group of eight child cross-country runners, anaerobic capacity and running economy were closely related to best career mile (BCM) run time, whereas peak $\dot{V}O_2$ was not (Mayers and Gutin, 1979). However, the inter-subject variability for the time period between the measurement of BCM and peak $\dot{V}O_2$ may have affected the results. Moreover, mile run time, which was measured at the same time as peak $\dot{V}O_2$, was significantly correlated with peak $\dot{V}O_2$ ($r = -0.88$). In contrast to these findings, it has been suggested that in mature populations the measurement of blood lactate (BLa), when used in conjunction with maximal $\dot{V}O_2$ or running velocity, may provide the best method to predict and monitor endurance running performance (e.g. Nichols et al., 1997). This is especially relevant when attempting to differentiate performance within a homogenous trained group of athletes. Whether blood lactate can be similarly used to predict endurance performance in adolescent children has yet to be fully elucidated.

Increases in blood lactate concentration in response to sub-maximal exercise in adults have been described using an assortment of terminology. This may have led to some confusion in deciphering the main practical uses of blood lactate for monitoring and predicting endurance performance. Disparity in research findings involving children and adolescents may have resulted from differences in procedures in the measurement of blood lactate. It is clear, however, that considerable age-related differences in the blood lactate response to exercise between children/adolescents and adults (Tolfrey and Armstrong, 1995). Therefore, it would be prudent to assess the way in which lactate measurements taken during exercise might be employed to predict and monitor endurance performance in children and adolescents.

It has been suggested that the maximal lactate steady state (MLaSS), the point of equilibrium between lactate production and removal, may represent the highest constant exercise intensity that can be performed for prolonged periods of time (Heck et al., 1985; Beneke and Von Duvillard, 1996; Jones and Doust, 1998). Hence, it may be used to quantify, monitor and predict endurance performance (Heck et al., 1985). Studies of the MLaSS with pediatric populations are rare and have presented equivocal results. In one of the earliest reported studies (Mocellin et al., 1990), the MLaSS for 10-12 year old boys was 4.6 ± 1.3 mmol.$L^{-1}$. In stark contrast, MLaSS concentrations of only 2.3 ± 0.6 and 2.1 ± 0.5 mmol.$L^{-1}$ were reported for 13-14 year old girls and boys respectively (Williams and Armstrong, 1991b). The differences between the above values indicated that double values were obtained by Mocellin et al., (1990). These differences may be partially ascribed to variations in protocol and blood assay techniques. Identification of the physiological predictor variables for endurance running performance and the MLaSS in adolescent children are significant for three reasons: (1) it should be possible to improve future competition and training strategies with this population; (2) a valid measurement of endurance fitness can be used to predict athletic potential; and (3) MLaSS is considered by many to be the criterion measure of cardiorespiratory fitness.

### 1.1.1 Aims and objectives

### 1.1.2 Aims

The aims of this thesis are:

i) To identify physiological and biochemical correlates of middle distance performance time in adolescent runners.

ii) To investigate the effects of high intensity of MLaSS throughout training programme on running performance time and correlated issues.

Attainment of these aims will help improve our understanding of adolescent's endurance trainability and provide insights into suggested levels of exercise intensities and physiological and biochemical responses to the % of maximal aerobic performance running speed This determination will help coaches develop more precise training programmes for adolescents middle distance runners.

### 1.1.3 Objectives

The **Objectives** of this thesis are:

1) To compare the test-retest reliability of the identified physiological and biochemical variables those are most strongly associated with endurance running performance in sub-elite, endurance trained, adolescent children.
2) To identify the physiological and biochemical [predictor] variables that are most strongly associated with endurance running performance in sub-elite, endurance trained, adolescent children. Differences in subject characteristics will allow for a number of important comparisons to be made, these include comparisons by (a) sex; (b) training status; and (c) age or physical maturity.
3) To investigate the maximal lactate steady state (MLaSS) in adolescent children using a series of prolonged constant load exercise stages. The relationship between MLaSS, the predictor variable(s) outlined in the second aim above, and a variety of different endurance based running tasks would be assessed absolute, body mass relative and fractional utilisation oxygen uptake values ($L.min^{-1}$, $mL.kg^{-1}.min^{-1}$, and % peak $\dot{V}O_2$ respectively), and running velocity that correspond to the MLaSS would also be determined. The % peak $\dot{V}O_2$ and velocity at which the MLaSS occurred would then be compared to that seen during a standard step-wise incremental running test.
4) To study the effect of endurance training programme in adolescent children on the predictor variable(s) identified in the first aim above and also on the MLaSS. This would be achieved via a longitudinal, prospective research design providing original data regarding the endurance trainability of adolescent children. This study would include both girls and boys, allowing a between sex comparison.

### 1.1.4 Experimental plans

The research programme will consist of a series of inter-linked studies. Latter stages of the programme will build upon the findings of those that precede them.

**Stage I.** The reliability of blood lactate variables used to assess and monitor endurance performance does not appear to have been reported with the paediatric population. Therefore, the primary predictor variables identified at previous programme stage 1 (above) will be assessed for the reliability of the absolute running speed ($km \cdot h^{-1}$), $\dot{V}O_2$ ($L \cdot min^{-1}$), and HR($beat \cdot min^{-1}$) that correspond to fixed blood lactate reference values of 2.0 and 2.5 $mmol \cdot L^{-1}$, and the lactate threshold (LT) in 20-25 endurance trained adolescent runners. Participants will complete two identical incremental treadmill tests within a 7-10 d period. The blood lactate profile and peak $\dot{V}O_2$ will be determined during each test. Diet and exercise training 48 h before each test will be replicated. Intra-class correlation coefficient (ICC), 95% limits of agreement (LoA), and typical errors (standard error of measurement, SEM) will be calculated to assess the level of reliability.

**Stage II.** Permission has been granted to recruit the intermediate (14-18 year old) 800 m and 1500 m finalists from the Cheshire and Staffordshire County Athletics Championships. A total pool of at least 64 subjects will be available. The performance times from the 800 m and 1500 m events will be used as the field-based performance measures in this study. From a step-wise incremental treadmill test to exhaustion, peak and submaximal $\dot{V}O_2$, BLa (arterialised capillary sampling), ventilatory threshold (VT), and running economy variables will be determined. Breath-by-breath respiratory gas exchange data will be used. In addition, standard anthropometric and body composition measurements will be made. Physical maturity will be self-assessed by the subjects from secondary sexual characteristics. Anaerobic power and capacity will be determined using a modified Wingate (WAnT) test and a standard vertical jump test. Local Research Ethical Committee Approval has been granted (Approval number 99 05 02). It is hypothesised that BLa based indices will have the strongest relationship with endurance performance, as determined by multiple regression techniques, although this may be partially affected by anaerobic and anthropometric measurements. Between sex comparisons for the physiological variables will be assessed using ANCOVA analyses accounting for potential body size and composition differences.

**Stage III.** A small group (n=20-25) of sub-elite, endurance trained, adolescent children will be recruited from local running clubs and secondary schools. If necessary, it may be

possible to include some of the subjects who volunteered for Stage 1 above. In addition to the procedures listed above (Stage 1), a series of 20-30 min exercise stages with serial capillary BLa sampling would take place. No more than two exercise bouts would be completed on any one day. These prolonged stages would be separated by at least 3 days to allow sufficient recovery between bouts. The BLa data would be used to calculate MLaSS for each subject. Paired-Sample Student's T-tests would be used to compare the BLa data from the step-wise and prolonged tests at the % peak $\dot{V}O_2$ corresponding to MLaSS.

**Stage IV.** The influence of endurance training programme on the primary predictor variables and MLaSS identified at previous programme stages (above) will be examined using a prospective training study. The study will be at least 12 weeks in duration and will be have a repeated measures design to reduce inter-subject variability whilst also reducing the required sample size. Projected sample size will be approximately 20-25 well trained and 20-25 normally trained boys for the experimental groups. A comparative group of 10-15 untrained adolescent children will be recruited from local secondary schools. Using identical experimental procedures to those listed above, it would be possible to compare the $\dot{V}O_2$, % peak $\dot{V}O_2$, BLa, and running economy responses between the trained and untrained adolescents. The untrained group would complete 800 m, 1500 m and 3000 m time trials on separate occasions. This allows a comparison of predictor variables between the trained and untrained groups. Data will be analysed using factorial ANCOVA controlling for changes in body size and composition.

# Chapter Two

# Review of Literature

## 2.0 Literature review

### 2.1 Physiological and biochemical responses at endurance performance.

The physiological responses are important indicators to help the body minimize and detect the changes in homeostasis under different type of stresses such as physical performance. Many of these responses prove useful in gaining a clearer insight into human performance and adaptations. A simplified general pattern of physiological responses to repeated bouts of exercise over a period of time can cause improve performance in that exercise activity (Jones and Carter, 2000). The indicators of performance responses depends on the exercise which take into account the mode, intensity, frequency, duration and progression of exercise (The American College of Sports Medicine, 1991), parallel with the participant's initial training status, age, gender and genetic potential (Wenger and Bell, 1986) and relative exercise intensity (Baldwin et al. 2000). Also, it is important to specify the training stimulus in terms of the type of exercise performed (continuous/intermittent endurance, muscle strength/endurance or speed) and exercise modality used (Pierce et al., 1990). Insufficient recovery following a training overload may cause overtraining (Mckenzie, 1999) and inappropriate recovery may lead to lack of progress or detraining (Neufer, 1989). There are a number of factors that affect endurance performance and a number of these will be discussed as follows:

#### 2.1.1 Running speed at peak $\dot{V}O_2$ and endurance performance.

The running speed at peak $\dot{V}O_2$ ($v\dot{V}O_2$), a composite measure of peak $\dot{V}O_2$ and running economy, can be calculated by dividing peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) by running economy ($ml \cdot kg^{-1} \cdot km^{-1}$), and has been shown to be a powerful predictor of performance in adult runners (Morgan et al., 1989; Noakes et al., 1990; Jones and Doust, 1998). The relationship between $v\dot{V}O_2$ peak and running performance time has been shown to be an important physiological variable of determining endurance performance (Hill and Rowell, 1996). In a study by Cunningham (1990) he found a significant relationship between $v\dot{V}O_2$ peak and running performance in 22 female, high-school 5000 m runners, mean age 15.9 years. Also, Billat (1996) reported that $v\dot{V}O_2$ peak was closely related to 800 m running performance in adult runners. And Morgan et al., (1989) indicated that the running speed at $\dot{V}O_{2max}$ strongly correlated to 10 km running performance in a group of well adults' trained male runners.

### 2.1.2 Running economy and endurance performance.

Bailey and Pate, (1991) indicated that running economy is associated with anthropometric, (including segmental mass distribution), physiological, metabolic, biomechanical and technical factors. Jones and Carter, (2000) suggested that the improvement of neuromuscular control resulting from the training could have improved running economy by allowing a tighter regulation of muscle stiffness and better utilisation of muscle elasticity. It has been indicated that there is a possibility of improving running economy by strength training using maximal velocity contraction which allow for a better recruitment of motor units or reducing the antagonistic muscle group contractions (Sale, 1992; Hoff et al., 1999).

### 2.1.3 Blood lactate and endurance performance.

The measurement of the blood lactate response to exercise is increasingly regarded as the most acceptable criterion of endurance capacity, and is widely used to assess and train athletes and non-athletes in different sports (Wakayoshi et al., 1993; Jones and Carter, 2000; Naughton et al., 2000). It has been reported that the exercise intensity corresponding to the accumulation above resting levels of the blood lactate which is known as lactate threshold (LT) and the corresponding changes in gas exchange which is known as ventilatory threshold (VT) are strongly correlated predictors of physical endurance performance (Coyle et al., 1991; Zoladz et al., 1993; Jones and Doust, 1998). Moreover, endurance performance at an intensity higher than LT is highly correlated with a nonlinear increase in metabolic, respiratory and perceptual stress (Katch et al., 1978; Simon et al., 1983; Zoladz et al., 1993) and more rapid fatigue (Sahlin, 1992), and has been attributed to muscle glycogen depletion (Boyd et al., 1974). Therefore, adaptation of physiological and biochemical responses can result from appropriate endurance training programme (Wells and Pate, 1988; Jones and Carter, 2000). However, the ability to sustain a high fractional utilization of $\dot{V}O_{2max}$ at the lactate or ventilatory thresholds have revealed that the lactate breakpoint is a good predictor of distance running performance (Matsuura, 1984; Tanaka et al., 1984; Sjodin and Svendenhag, 1985; Weltman et al., 1992; Carter et al., 1999) and ventilatory breakpoint (Power et al., 1983; Rhodes and McKenzie, 1984; Peronnet et al., 1987).

## 2.2 Variability of blood lactate and cardiorespiratory measurements.

Measurements of physiological variables are often used to interpret their responses to experimental procedures. Most of these variables such as submaximal oxygen consumption, pulmonary ventilation and blood lactate have been investigated in adult fitness programs to assess the effects of physical training assuming stability of those values from day to the next, but ignoring the variation of the equipment or the intra-individual factors (Faulkner, et al., 1970; Key et al., 1975; Wilson and Hoare, 1980). Previous studies have examined the biological variability of maximal treadmill oxygen consumption whereas; the variability in repeated measures of submaximal exercise has not been investigated (Katch et al., 1982; Unnithan et al., 1990). A study of measuring daily heart rate reproducibility during field studies to estimate day-to-day submaximal oxygen consumption values from heart rate data was conducted in Norwegian coastal fishermen (Rodahl et al., 1974). It has been reported that the majority of many different endurance test protocols have been used in the past were not validated (Asker et al., 1996).

The validity and reliability of methods to evaluate aerobic and anaerobic power of adult athletes have been studied ( Krebs and Powers, 1989; Storer et al., 1990; Coyle et al., 1991), and reliability of max $\dot{V}O_2$ in children (Anita et al., 1995; McVeigh et al., 1995). Also, variability of aerobic performance of physiological responses in adult has been investigated (Daniels et al., 1984; Armstrong and Costill, 1985; Unnithan et al., 1990). However, there is only scarce literature available on the reproducibility of endurance performance tests in children (Asker et al., 1995; Unnithan et al., 1995). It has been reported that no specific "endurance performance test" is available to predict endurance performance (Asker et al., 1995). Furthermore studies have indicated that, intra-individual variability across repeated trials is comprised of technological and biological components (Pereira et al., 1994) with $\dot{V}O_2$max ranging from 4.1 to 5.8% of variations (Katch et al., 1982; Kyle et al., 1989).

Many studies have reported intra-individual variations during submaximal running test examining the problem of day-to-day variability in oxygen consumption (Armstrong and Costill, 1985; Frederick et al., 1986; Morgan et al., 1991; Williams et al., 1991). These studies indicted variability ranging from 1.32 (Morgan et al., 1991) to 4.1% (Armstrong and Costill, 1985), and variability across subjects ranges from 0.30 to 4.40% (Morgan et al., 1991), and 1.20 to 5.8% (Williams et al., 1991). Moreover,

variability was accounted for the technological error of intra-individual variations during running and cycling but did not quantify technological variation (Armstrong et al. 1985). Also, Pereira et al (1994) demonstrated that intra-individual variation in $\dot{V}O_2max$ during steady rate graded treadmill running is small. They do not control the extrinsic factors that may affect running economy and administering the same relative workload for all subjects to minimize within subjects variation from day-to-day. In addition, many investigators have studied the variability of submaximal running performance and have found significant differences in the submaximal energy cost of running in both between and within moderately and well trained runners on repeated measures (Armstrong and Costill, 1985; Daniels et al., 1984; Morgan et al., 1987; 1991; Williams et al., 1991a). It has been indicated by Daniels, (1985) that the term "efficient" refers to the relationship between work done and energy expended, and minimizing or eliminating unwanted or counter-productive muscular movement is a desirable goal for any distance runner. There are many different issues that may affect submaximal treadmill running performance (Morgan et al., 1991; Williams et al., 1991a). However, most of previous studies in children did not focus on reproducibility and reliability of $\dot{V}O_2max$ (Unnithan et al., 1995). Therefore, the first aim of this thesis is to examine the variability and to estimate the stability of selected physiological variables in adolescent trained athletes' boys and girls.

## 2.3 Physiological and biochemical responses in children at rest.

Studies of physiological and biochemical responses in children were extensively based on previous conducted investigations since the last three decades on children of 11 to 16 year old by (Eriksson et al., 1971; 1973; 1974; Eriksson., 1972; Eriksson and Saltin, 1974). These studies found different levels of PFK activity in the vastus lateralis, succinate dehydrogenase and lower levels of peak lactates in children compared with adults. In addition, Fournier et al. (1982) investigated the concentration of the enzyme PFK in adolescent children aged 16 to 17 years and reported similar results to those reported earlier (Eriksson et al., 1973). Whereas, similar levels in children compared to adults were reported (Haralambie, 1979; 1982; Berg et al., 1986).

It has been suggested that the above indications of 'change levels of PFK activities' could be related to reduced production of lactic acid which may increased oxidation of lactate or both. Also, it has been indicated that lactate is continuously produced by skeletal muscle during rest (Stainsby and Brooks, 1990). Furthermore, Brooks, (1991)

reported that production and consumption of lactate can be occur simultaneously by skeletal muscle, but the net lactate output does not mean that the whole blood lactate concentration produced by the skeletal muscle. However, the exact mechanisms to be accounted for the previous responses in children are unclear.

Moreover, there is a low concentration level of lactate in muscle and blood during rest, and may be similar in both children and adults with normal values of 1 to 2 mmol·L (Eriksson, 1972; Medelli, 1985; Gollnick et al., 1986), when exercise intensity increases, the rise in lactate concentration of blood and muscle becomes exponential and rise to significant differences ($P<0.05$). The lower level of blood lactate may be due to the low resting metabolic rate of muscle that occurs with a low blood flow and the fact that erythrocytes also have a low and constant metabolism that has been known as the metabolic end product of which is lactate (Gollnick et al., 1986; Berg and Keul, 1988; Cooper and Barstow,1996). Moreover, it was observed that muscle glycogen levels at rest during adolescence are similar to these levels observed in adults (Boisseau and Delamarche, 2000).

## 2.4 Physiological and biochemical responses in children at exercise.

It was indicated that anaerobic metabolism is age-dependent and it is limited in children compared to adults, such as lower peak blood lactate accumulations (Eriksson, and Saltin, 1974; Atomie et al., 1986) and less ability of anaerobic performance than in adults (Saavedra et al., 1991; Falk, and Bar-Or, 1993). However, most of these studies related to muscle metabolism in children were conducted using muscle biopsy techniques back to more than 30 years ago in young boys of 11 to 16 year old (Eriksson et al., 1971; 1973; Eriksson and Saltin, 1974). The investigators observed a relationship between maturity and anaerobic enzyme activity regarding of limited anaerobic metabolism in children. Due to the ethical limitations of using biopsy techniques in children, the metabolic enzymes of muscle in children, metabolic pathway and responses during physical performance would not be well improved.

Therefore, phosphorus nuclear magnetic resonance spectroscopy ($^{31}$P-MRS) is a powerful, noninvasive method of evaluating selected aspects of muscle metabolism in vivo providing valid measures for anaerobic metabolic during exercise (Cooper 1995; Cooper and Barstow, 1996) in both, adults (McCann et al., 1995; Cooke et al., 1997; Harber et al., 1997) and children (Zanconato et al., 1993; Kuno et al., 1995; Taylor et al., 1997) and gives the opportunity to address some of the physiological and

biochemical questions. However, Boisseau and Delamarche, (2000) indicated that ATP and PC stores are not age-dependent in prepubertal and adolescents, but there are smaller reductions in intramuscular pH in prepubertal children and adolescents during high intensity exercise when compared to adults. Also, they stated that the immaturity of anaerobic metabolism in children seems to be affected by anatomical structural reasons causing the reduction of glycolytic activities, such as higher proportions of slow twitch (type I) fibers in the vastus lateralis muscle in children than in untrained adults.

## 2.5 Maturation and endurance performance in children.

It has been known that some youngsters mature faster than others. For example, if two children are the same age and sex, but one is physiologically older (advanced skeletal maturation), the more mature child usually performs better on tests than does the less mature child (Pangrazi, and Corbin,1990). Physiological variables that correlate with sports performance of young people are an important concern for physiologists and must be taken into account (Malina, 1979; Berg and Keul, 1988; Grumbach and Styne, 1998). Tanner (1978) described the five stages of puberty from childhood to full maturity (Pubertal stage 1 to 5; P1 to P5). Malina and Bouchard, (1991) suggested that growth and maturation are characterised by individual variation and controlled by genetic and neuroendocrine control, environmental factors or sport. The corresponding median age for onset of stage 2 in girls is 10.38 years for breast development and 10.57 years for pubic hair development (Sun et al., 2002). The variation in the age of onset between the two indicators for boys and girls makes the definition of puberty using Tanner stages difficult. Age at menarche is also a pubertal landmark in girls and there is considerable population variation in the age at onset. The current average age at onset for girls in the USA is 12.43 years, with the ages at onset of menarche for Caucasian, African-American and Mexican-American girls being 12.55, 12.06 and 12.25 years, respectively (Chumlea et al., 2003).

Malina, (1991) observed that, late maturation is associated with exceptional motor performance. Also, growth characteristics in 123 children were measured after three years of growth into adolescence and indicated that, children who gained the greatest amount of muscle tissue (including cardiac muscle) experienced the greatest improvements in aerobic fitness, and concluded that measures of aerobic fitness prior to puberty tended to predict fitness during puberty (Janz and Mahoney, 1996). It has been observed by Malina, (1994) that the maturity differences among young female athletes

are most apparent during the transition from childhood to adolescence, and particularly during the adolescent growth spurt. Cacciari et al. (1990) found that competitive football players demonstrated early onset of pubertal growth and increased levels of serum testosterone and growth hormone compared with age-matched controls. Studies by Elias and Wilson (1993) and Hackney (1989) on adults both found that endurance training resulted in decreased resting levels of circulating serum testosterone. Recent data showed that, although a 22% increase in training intensity caused a 9% increase in testosterone, after 2 wk of tapering, testosterone was significantly reduced to pre training levels in 20-yr-old rowers (Maetsu et al., 2003). Carli et al., (1983) found results that were in agreement with Maetsu et al., (2003) and after 43 wk of swim training, pubertal athletes had testosterone levels that dropped below pre training levels. Rich et al., (1992) also found evidence of lowered testosterone with training after only 3 days of training in young gymnasts, and they did not examine hormonal factors.

## 2.6 Children's blood lactate responses to exercise and maturation.

Blood lactate responses to exercise have been used to evaluate the aerobic capacity of sedentary and active individuals as well as competitive athletes (Weltman 1995). Being a submaximal parameter, the blood lactate response to exercise is more appropriate than maximal oxygen uptake ($VO_{2max}$) for evaluating the effects of training, because of its strong correlation with endurance performance, and it can be used to prescribe individuals' intensity of aerobic training (Sjödin et al 1982; Coyle et al 1988). Much of work in studying children's metabolic responses to exercise in the early of 1970s indicated that anaerobic metabolism is related to physical maturity and thus is limited in children relative to adults. Also, lower peak blood lactate concentrations and substantially reduced phosphofructokinase (PFK) activity in children than in adults were observed (Macek and Vavra, 1971; Eriksson et al., 1973; Eriksson and Saltin., 1974; Atomie et al., 1986). Moreover, to support the contention that maturation influences anaerobic development, lower anaerobic power in children were compared with adults (Inbar and Bar-Or, 1986; Saavedra et al,. 1991; Falk and Bar-Or, 1993).

However, there are a number of methodological explanations for the low blood lactates, due to differences between studies in blood assessment procedures, inappropriate components of training programme (e.g. intensity of exercise) used to induce peak lactate values, motivation of the subjects, measurement techniques, and muscle size

(Pifitzinger and Freedson, 1997). These studies were performed using different exercises protocols (treadmill and cycle ergometer). During exercise performed at submaximal intensity, children have lower blood lactate concentrations than adults (Denadai et al. 2000). The factors responsible for this in boys aged 6-17 years; were increasing age, an increase in the activity of the glycolytic enzymes and a decrease in the activity of the oxidative enzymes (Eriksson and Saltin 1974; Berg et al 1986). This suggests that there is a lower ratio of glycolytic to oxidative enzyme activity in children, which could be related to a reduced production of lactate, increased oxidation of lactate, or both (Brooks, 1991; Brooks et al, 1994; Miller et al, 2002).

Denadai et al. (2000) indicated that, the blood lactate response to exercise in children can explain the difference between the mean values of critical speed and the speed at a blood lactate concentration of 4mmol·$L^{-1}$. They found that both the beginner and trained groups recorded mean speeds at a blood lactate concentration of 4 mmol·$L^{-1}$ that were significantly faster than those for critical speed. However, critical speed was defined as the swimming speed that could theoretically be maintained without exhaustion (Wakayoshi et al 1992a). The blood lactate concentration at the critical speed in the beginner and trained groups (Denadai et al. 2000) was 2.7 and 3.1 mmol·$L^{-1}$ respectively. These values are higher than those reported by Williams and Armstrong (1991a) who suggested a fixed value of 2.5 mmol·$L^{-1}$ instead of 4 mmol·$L^{-1}$ as the reference point for maximal lactate steady state in children of this age.

However, the results of Williams and Armstrong (1991a) should be treated with caution, since higher blood lactate concentrations corresponding to maximal lactate steady state (4-5 mmol·$L^{-1}$) have been reported for children of a similar age (Mocellin et al 1990, 1991; Beneke et al 1996a). In contrast, this is not in agreement with studies performed with adults (Wakayoshi et al 1992b, 1993) under similar exercise conditions. Also, it differs from the study of Denadai et al. (2000) in swimming which might affect the blood lactate concentration corresponding to maximal lactate steady state (Beneke and von Duvillard 1996). In addition, there is no evidence of increased maximal blood lactate being influenced by the stage of sexual maturation in humans (Falgairette et al., 1991; Paterson et al., 1985; 1986; Williams and Armstrong., 1991a; Pfitzinger and Freedson, 1997).

Several studies have been investigated the relationship between peak blood lactate concentration and stage of sexual maturation or chronological age, Paterson et al. (1987)

Williams and Armstrong (1991a), Fellmann et al. (1994). They concluded that changes correlated with age or sexual maturation and provided an indication of the interrelationship between growth and development with children's glycolytic capacity changes.

In addition, Mero (1988) investigated blood lactate production and removal during anaerobic exercise in trained and untrained boys; he concluded that blood lactate production in prepubescent boys was related to serum testosterone level and muscle type II fiber area. The influence of type II muscle fiber area also may be related to the higher content of muscle lactate dehydrogenase enzyme in type II fibers that regulates the reduction of pyruvate to lactate. Paterson et al. (1987), conducted longitudinal study to investigate peak blood lactate to age or sexual maturation. They were measured $\dot{V}O_{2max}$ and blood lactate throughout five years in 11- to 15 year-old boys. $\dot{V}O_{2max}$ lactate concentrations have been gradually increased up to 44% during the five years test period. The participants in this study were highly athletic and most of them improved their training status over the five years of study.

However, the effects of training, age and maturation are interrelated due to training status over time. It has been reported, that $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) remain relatively stable over this age span in boys (Armstrong and Welsman, 1994). For the participants in Paterson's study, the relative $\dot{V}O_{2max}$ increased by 11.8% over time of study suggests that the boys' level of aerobic fitness increased modestly throughout this time period. Peak $\dot{V}O_2$ and AT are major determinants of endurance exercise performance. An increase in either variable improves the athlete's ability to sustain a higher rate of aerobic energy expenditure. Absolute peak $\dot{V}O_2$ (litres/min) increases with age in both boys and girls, although the increase in girls is somewhat less, particularly after puberty (Mirwald and Bailey, 1986).

The influences of age and sexual maturation on lactate concentration at peak $\dot{V}O_2$ and the lactate threshold in 100 boys and 91 girls, aged 11 to 16 years, $\dot{V}O_{2max}$ lactate was found to be significantly higher for girls than boys, (Williams and Armstrong, 1991a). The mean $\dot{V}O_{2max}$ lactates were 5.3, 5.0, 4.7, 5.8 and 5.8 $mmol \cdot L^{-1}$, for the boys at Tanner Stage 1 through 5, respectively. While the means recorded for the girls were, 5.8, 5.7, 6.6 and 5.7 $mmol \cdot L^{-1}$, at Tanner Stages 2 through 5, respectively. The relatively low $\dot{V}O_{2max}$ lactates reported in this study could be related to the use of the whole-blood method, which measures only the lactate in the blood plasma and not in the

erythrocytes. $\dot{V}O_{2max}$ lactate was not significantly related to Tanner stage of sexual maturity or chronological age in either boys or girls.

Fellmann et al. (1994) investigated blood lactate after maximal and supra-maximal exercise in 10- to 12 year-old boys from Bolivia. The authors reported lower lactate concentrations in children from high altitude than in children from low altitude, and lower lactate concentrations in children from low socioeconomic status than in children from high socioeconomic status following both maximal and a 30-s Wingate test. The authors attribute these differences to lower gonadal maturation measured as lower testosterone levels in the children from high altitude, low socioeconomic status or both.

A longitudinal study in 8 boys' runners conducted to examine submaximal and maximal responses to exercise over 8-year period which began when the participants were 12 years of age. It was observed that, while submaximal blood lactate responses decreased throughout the period of the study in well trained boys, maximal blood lactate did not differ between the trained and sedentary groups (Sjodin and Svedenhag, 1992).

Beneke et al. (1996a) investigated the highest steady state lactate responses in 34 adolescent boys 15.4 $\pm$ 2.8 years of age. The blood lactate levels ranged from 15 to 30 $mmol \cdot L^{-1}$ and corresponding with the highest workload at which steady state could be maintained was independent of age and was more related to training status. It has been observed that the absence of a difference in maximal plasma lactate levels among trained and untrained adolescents possibly reflects the insensitivity of blood lactate as a marker of physiological change following maximal exercise in the second decade of life. Therefore, the sensitivity of blood lactate levels to the training status of this age population appears to be greater under submaximal rather than maximal exercise stimuli.

## 2.7 Blood lactate reference values and children's endurance performance.

The most common term used to describe the blood lactate response during exercise is the anaerobic threshold (AT). This represents the highest intensity of exercise at which a balance between the production and removal of lactate occurs (Heck et al 1985). Methods for the determination of the anaerobic threshold use either a direct or an indirect protocol. With direct protocols, fixed 4 mmol $l^{-1}$ (Heck et al 1985) or variable (Stegmann et al 1981; Tegtbur et al 1993) concentrations of blood lactate are used. The lactate threshold (LT) has been widely accepted as a predictor variable of endurance performance in adults. However, blood lactate levels probably reflect the balance

between lactate production and elimination rather than the onset of cellular anaerobiosis. Williams and Armstrong (1991a) identified the anaerobic threshold as the intensity corresponding to a lactate value of 4.0 mmol $l^{-1}$ (valid for adults) to be closer to peak $\dot{V}O_2$ in children (Williams and Armstrong 1991a; Washington, 1993). The identification of the threshold point has been circumvented by the use of fixed blood lactate reference levels; although it should be acknowledged that the specific theoretical underpinning of the use of the 4.0 mmol $l^{-1}$ level in adults is quite different from that of the classical AT (Armstrong and Welsman, 1996; Beneke et al. 1996). Some studies use fixed blood lactate concentrations of 2.5 or 4.0 mmol/L to represent LT (Fay et al., 1989). As children can exercise close to exhaustion without exceeding a blood lactate of 4.0 mmol/L, an alternative 2.5 mmol/l level is considered to be more appropriate (Hagberg and Coyle, 1983; Armstrong and Welsman, 1996). The cut off age for when this level is applicable in children is uncertain. Although fixed lactate concentrations of 2.5 and 4.0 mmol/l increase the objectivity of the anaerobic threshold determination, such a criterion does not respect the individuality of the inflexion point that occurs at different lactate values. This is particularly true for children because the peak percent $\dot{V}O_2$ corresponding to 2.5 mmol $L^{-1}$ decreases from about 90% to 80% from 12 to 15 years (Williams and Armstrong 1991b), suggesting lower lactate values at the inflexion point for younger children. However, it has been observed that MLSS occurs around 2.2 mmol $L^{-1}$, in 13 to 14 year-old participants (Williams and Armstrong, 1991a).

Several investigators focused on the relationship between the LT and chronological age or stage of sexual maturation such as Weymans et al. (1985) which investigated the effects of age and gender on VT in children aged 11.6 and 14 years. The results indicated that 14 year olds may have metabolic profiles that are more similar to those of adults than those of younger children. These results indicated that decreases in VT with age may be related to sexual maturation. Also, VT was assessed longitudinally in children aged 11 to 15 year olds and the findings indicated that, the percentage of $\dot{V}O_{2max}$ at VT was increased with age (Paterson et al.1987), which conflicts with other studies (Weymans et al. 1985; Atomi et al. 1988; Washington, 1989; 1993; Beneke et al. 1996b).

Beneke et al. (1996a) examined the relationship between the maximal lactate steady state (MLSS) and age, and found no relationship between lactate concentration at MLSS and age or between MLSS as a percentage of $\dot{V}O_{2max}$ and age. The authors concluded that neuromuscular development may have more influence than changes in oxidative

metabolism or glycolysis in determining age related changes in exercise responses in children.

Lactate threshold was measured as a percentage of $\dot{V}O_{2max}$ at different fixed lactate references of 2.5 and 4.0 mmol·$L^{-1}$. No significant differences were found between boys and girls at a 4.0 mmol/l LT as a percentage of $\dot{V}O_{2max}$ at each Tanner stage. A higher percentage of $\dot{V}O_{2max}$ at 2.5 mmol/l lactate concentration was observed in boys than girls (Williams and Armstrong, 1991a). The results of the previous studies, except those of Paterson et al. (1987) confirmed the hypothesis that found a negative relationship between LT as a percentage of $\dot{V}O_{2max}$ and age or stage of sexual maturation in children. Therefore, it is may not be possible to find a relationship if the 4 mmol/l lactate concentration was used to define LT in children. Because the effect of age independent of sexual maturation, on LT as a percentage of $\dot{V}O_{2max}$ remains unclear.

## 2.8 Body composition, maturation and endurance performance.

Body composition is a key component of an individual's health and physical fitness profile. It has become a major field of interest for many exercise and sport scientists as well as clinicians who specialize in the prevention and rehabilitation from hypokinetic diseases (Wilmore, 1984). Durnin and Womersley, (1979) observed that body fat tends to increase with age. However, some body fat is required and is important to serve as an insulator to conserve body heat as a metabolic fuel for the production of energy (ATP) and as padding for protection. Excessive body fat leads to obesity and enhances the risk of developing coronary heart disease, causing fatigue and hinders performance in many physical activities. Also, it does not contribute to the force production capabilities of musculoskeletal system. In addition, it has been indicated, that, the leaner is the greater and better physical performance potential (Wilmore and Haskell, 1972; Wilmore, 1976). However, in studies related to children, Malina and Bouchard (1991) found that fat deposition of the extremities declines and truncal fat slowly increase, while in females, it increased concomitantly in both truncal and extremities. These observations revealed that, girls gained faster fat distribution than boys. Also, they observed that the distribution of body fat during this stage may be due to best interaction of biological inheritance, nutritional status, energy expenditure, GH, leptin and sex hormones. In addition, it seems to be chosen as central deposition and independent of total body fat in pubescent boys, whereas, in pubescent girls, the increase of abdominal fat is occurs frequently during the increasing of total body fat as a result of lack activities.

Also, body mass and fat mass do not appear to differ between maturity groups at the age at PHV in either sex (Iuliano-Burns et al., 2001). At a given chronological age, children who are more mature tend to be taller and heavier than less mature children. Indeed, children who have a more rapid rate of sexual maturation tend to have a higher risk of obesity in adulthood (Garn et al. 1986; Van Lenthe et al., 1996). A negative association between age at menarche, BMI and body fatness in girls has been shown (Buckler 1990; Van Lenthe et al., 1996). It is still unclear, however, whether increased early childhood adiposity induces an earlier onset of puberty, if rapid maturation and early puberty induce an increase in body fat later in life, or whether both of these phenomena occur. Fatness and body mass index (BMI) have been found to be more closely correlated with maturation stage (or development age) than chronological age among girls (Daniels et al., 1997; Kaplowitz et al., 2001).

It has been indicated, that lack of aerobic fitness may also play an important role in the development of obesity, because of its significant association with physical activity in young children (Pate et al., 1990). Lack of aerobic fitness is also a marker of later cardiovascular disease (CVD), with greater aerobic fitness being associated with a reduction in risk of later CVD (Despres et al., 1990; Gutin et al., 1990; Young et al., 1995). Maximum oxygen consumption ($\dot{V}O_{2max}$) is one estimate of aerobic fitness that has been associated with lower levels of risk factors in a longitudinal study from adolescence to early adulthood (Andersen and Haraldsdottir, 1993).

It should be known that obese children seldom perform a good level of physical performance as much as leaner children due to the greater metabolic cost of the obese children's exercise. Moreover, obese child require a high level of oxygen uptake capacity to perform a required tasks and obesity affects a child's endurance performance because their $\dot{V}O_{2max}$ values lower than those of lean comparative children who are less reserve capacity and perceive higher exertion (Bar-Or, 1983., Bar-Or and Ward, 1989., Rowland, 1991).

## 2.9 Biological maturity and endurance performance.

The foremost procedural concerns in research on teenage years are in determining the exact year of the greatest height gain which is occurred at earlier stages of puberty stages in girls and boys during maturity and its progresses were calculated (Malina, 1991., 1994., 1997., Cheng et al. 1999). Common procedures of maturation include sexual maturation indicators (e.g. Tanner stages and age at menarche), measures of bone

growth and epiphyseal fusion (e.g. skeletal age evaluation), and landmarks of physical growth (e.g. age at peak height velocity [PHV]). Growth and maturation expressions are frequently used interchangeably to distinguish among biological activities, whereas several physiological mechanisms are involved to verify physical performance alterations with growth (Malina, 1994; Baxter-Jones, 1995). However, children's growth is referred to the size increases in their bodies as whole (Malina and Bouchard, 1991) or specific parts of their bodies (Faulkner, 1996), while children's maturation status is recognized as their biological age that includes components progressing toward biological status, timing and tempo (Malina and Bouchard, 1991). Therefore, biological maturation ought to be considered when estimating physical performance and fitness levels of children in physical fitness tests for the same chronological age (Malina, 1994; Jones et al. 2000). Furthermore, it was indicated that advanced maturation positively influences physical fitness components as well as motor skill and intelligence (Baxter-Jones, 1995). Accordingly, growth, maturation, and development occur simultaneously and interchangeably, whereas, growth and maturation are characterised by different variables which although under the influence of genetic, neuroendocrine control, and environmental factors (Malina, 1991). Biological maturity systems are very essential to the growth and development of the childhood status mainly thus who have a compartment on athletic performance, and these systems can be classified as morphological, skeletal and sexual maturity (Malina, 1997; Baxter et al., 1995).

## 2.10 Morphological maturity and endurance performance.

Although morphological maturation differences among immature athletes are most perceptible throughout the transition from childhood to adolescence, especially during the adolescent growth spurt, there is no reported effect of sport training on age at peak height velocity or growth tempo of height throughout the adolescents spurt (Malina, 1994). In addition, there is also a size difference between those who continue in sport compared to those who drop out (Tonz et al. 1990). Moreover, several recent studies concluded that training does not cause alterations in anthropometric variables (Geithner et al., 1998; Bass et al., 2000; Damsgaard et al., 2000; 2001). However, it should be noted that biological maturation augments both body mass and stature during puberty and adolescence due to the effect of hormones (Rogol, 1994., Abbassi, 1998., Demerath

et al.1999) However, the effect of body mass and stature on physical performance is observable in the majority of sports during adolescence, whereas fewer sex differences occur during the earlier stages especially before the beginning of growth spurt (Malina et al., 1997; Fogelholm et al. 2000).

## 2.11 Skeletal maturity and endurance performance.

Comparatively, skeletal age (i.e. skeletal age - chronological age) can be used to assess the degree to which an individual is skeletally advanced or delayed for their age (Malina and Bouchard, 1991). Measurement of skeletal maturation is conceivably the most valid indicator of biological age or maturity status, for the reason that its development spans the entire period of growth (Roche et al., 1988; Tanner et al. 1983). Skeletal maturation is interrelated with body composition and can be used to classify slow- and fast-maturing children (Roger et al. 2003). Age at PHV is inversely related to the magnitude of PHV in both sexes (Iuliano-Burns et al. 2001) in that children with an early adolescent growth spurt demonstrate a higher PHV than children with a later spurt. Boys who have a later growth spurt have been reported to accumulate more bone mineral and lean mass and are taller at the age of PHV, compared with boys with earlier growth spurts (Iuliano-Burns et al. 2001).

A significant influence of testosterone was observed among boys who have a positive increase in growth of bone and muscle and a simultaneous loss of fat in the limbs (Tanner, 1989). Furthermore, it was indicated that the maximal loss of fat and increase in muscle mass in the upper arms corresponds to the time of peak height velocity. In boys, the significant increase in lean body mass exceeds the entire increase in body mass because of the affiliated loss of adipose tissue. Therefore, as height velocity declines, fat gathering resumes in both sexes but is twofold as quick in girls, whereas as adults, males have 150% of the lean body mass of the average female and double the number of muscle cells (Cheek, 1974). The increase in skeletal volume and muscle mass leads to augmented strength in males. Together androgens and estrogens endorse deposition of bone mineral, and more than 90% of peak skeletal mass is in deposited by 18 years of age in adolescents who have undergone customary pubertal development. In girls, nearly one-third of total skeletal mineral is accumulated in the three to four years period instantaneously after the commencement of puberty (Bonjour et al., 1991; Slemenda et

al. 1994). Adolescents with delayed puberty or secondary amenorrhea may fail to accumulate bone mineral normally and have reduced bone mineral density as adults.

## 2.12 Sexual maturity and endurance performance.

Tanner stages of sexual maturation are based on pubic hair growth for boys and girls, breast development for girls and genital enlargement for boys. The stages progressive are from pre-puberty (stage 1), through puberty (stages 2-4) to post-puberty (stage 5). The median age at onset of stage 2 (the beginning of puberty) varies depending on the maturity characteristic and sex of the child. Sun et al., (2002) observed in the United States' children that the median age at onset of stage 2 in boys is 10.03 years for genital development and 11.98 years for pubic hair growth. The consequent median age for onset of stage 2 in girls is 10.38 years for breast expansion and 10.57 years for pubic hair accomplishment (Sun et al. 2002). The discrepancy in the age of onset between the two indicators for boys and girls makes the definition of puberty using Tanner stages difficult. Age at menarche is also a pubertal marker in girls and there is significant population discrepancy in the age at onset. Therefore, The current average age at onset for girls in the USA is 12.43 years, with the ages at onset of menarche for Caucasian, African-American and Mexican-American girls being 12.55, 12.06 and 12.25 years, respectively (Chumlea et al. 2003).

Puberty is characterised by huge hormonal changes consequentially in sexual maturation (growth of pubic hair and development in the genitalia). Concentrated training has been found to interrupt the onset of puberty in female individuals by varying normal hormonal development (Malina, 1994). In contrast this may led to delayed pubertal onset, delayed age at first menarche, and disappointment to enhance maturity of skeletal structure (Roche et al. 1988; Baxter-Jones and Helms, 1996). Furthermore, few of the longitudinal studies for girls active in sport were available to be compared with non-athletic girls obtained no influence of physical exercise programme on the timing and progress of secondary sexual characteristics (Malina et al. 1997). Despite evidence that physical activity can also have consequences in hormonal changes in boys; there have been a small number of studies that essentially examined the association between training and the onset of puberty.

Jones et al. (2000) sought to investigate the importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years and the effect sexual maturity had upon performance in physical fitness tests. They found that sexual maturity has a huge influence on physical fitness assessing in boys but a smaller amount outcome in girls. Rating of physical fitness, predominantly for boys should take into account biological maturity. Also, at a prearranged chronological age, children who are further mature have a tendency to be taller and heavier than smaller mature children. In fact, children who have a more rapid rate of sexual maturation have a tendency to have a higher risk of obesity in adulthood (Garn et al., 1986; Van et al. 1996).

## 2.13 Additional potential factors affecting children's endurance performance

In spite of the challenge of the finding the most accurate testing procedures, researchers have acknowledged some possible factors that affect children's endurance performance. These factors my include substrate availability, muscle fibers type and both aerobic and anaerobic performance, children's muscle maturity, and children's neuromuscular activation and maturation are associated to the characteristics of the children being tested or participated in the competitions. It ought to be noted that age and gender related differences in anaerobic performance throughout childhood and adolescence may be related to discrepancies in muscle mass (Martin and Malina, 1998).

### 2.13.1 Substrate availability in children's endurance performance.

Variation in substrate accessibility has been found to affect endurance performance in adults (Ivy et al., 1981; Yoshida, 1986) and children (Hebestreit et al; 1993; Duncan and Howley, 1999). In contrast, Goran et al., (1998) conducted a study in prepubertal girls and suggested a gender dimorphism in the maturational changes in energy expenditure before adolescence with a preservation of energy use in girls accomplished in the course of a marked reduction in physical performance. Significant different metabolic responses from the soleus muscle assessed with either head of the gastrocnemius muscle during calf exercise were reported (Zhu et al. 1993). It was observed that the mean gastrocnemius muscle thickness in the pubescent group was approximately 44% greater than that in the pre pubescent group (13 vs. 9 mm) (Zhu et al. 1993). This is not astonishing, because it is well accepted that the soleus is composed essentially of type I and gastrocnemius essentially of type II muscle fibers. It is also recognized that

gastrocnemius muscle is the primary supplier of muscle power during powerful plantar flexion work (Weineck, 1986), and strong association between gastrocnemius region, plantar flexor muscle, soleus muscle and blood lactate accumulation through running performance in both trained and untrained children (Atomi et al. 1987).

Also, alterations in circulating levels of blood glucose and insulin have been presented to stimulate glycolysis and augment blood lactate concentration, while increased dependence on lipid oxidation and decreased levels of circulating free fatty acids throughout muscular exercise specify increased dependence on lipid oxidation and decreased blood lactate concentrations (Ivy et al., 1981; Yoshida, 1984b; Green and Dawson, 1993). It was stated that these conclusions can led several investigators to contemplate that alteration in substrate availability might affect LT and consequently endurance performance (Ivy et al., 1981; Hughes et al; Yoshida, 1984b; Green, 1994).

### 2.13.2 Children's muscle fiber types and endurance performance.

Even though the common structural distinctiveness of muscle fibers is alike, differences can be renowned in their functions. Functional differences exhibited by fibers have been distinguished according to speed of contraction, aerobic capacity, anaerobic capacity, number of mitochondria present, number of capillaries present, and strength of contraction, ATPase activity and fatigability. Skeletal muscle of the human is principally consisted of two muscle fiber types; slow twitch (ST) or type I and fast twitch (FT) or type II. The involvement and the contribution of fiber types fluctuate across different muscle groups (Colling-Saltin, 1980). Type II fibers encompass further distinguished into three subtypes; type IIa, IIb and IIc fibers. Type II fibers superior fixed toward brief bursts of anaerobic activity at high power output, than type I fibers where metabolic distinctiveness give them a capacity for continuous exhaustion-resistance activity.

In addition, it appears with the intention of this typology, based on conservative histochemical discoloration, is somewhat deceptive because there survives a continuum in most, if not all contractile and metabolic possessions (Colling-Saltin, 1980). This originated in human's skeletal muscle in three isoforms; type I (slow), type IIA (fast), and a third type IIX (the fastest). It should be noted that this last type is highly related with another fiber type previously designated as type IIb (Ennion, et al. 1995). Few studies are available concerning muscle fiber types distribution in young population due to the ethical limitations of the biopsy techniques. Some of those studies specified that

the proportions of Type I fibers (slow twitch oxidative) to Type IIa (fast oxidative glycolytic) and Type IIb (fast glycolytic) are comparable in children and adults (Costill et al. 1976; Van Praagh, 1998).

However, the discrimination of muscle fiber type's appears to be present principally throughout the years following birth. Bell et al., (1980) found that by the age of six years a histochemical report is comparable to that of a young adult. However, the proportion contribution of type IIa fibers seems to be lower during the early childhood than in adulthood (Colling-Saltin, 1980), and reach adult's percentage through late adolescence state (Hedberg and Jansson, 1976; Fournier et al. 1982). It was observed that type IIa exemplified by superior predominance than type IIb for the periods of childhood and adolescence, whereas there do not appear to be any comprehensible sex discrepances in fiber type giving out through childhood (Jansson and Hedberg, 1991; Van Praagh, 2000).

Furthermore, muscle fiber dimension increases by means of size up to 75 % from birth to the first year of age, whereas this increase carries on through the early childhood in the direction of adolescence by means of size pertaining to 3.5 fold in girls and 4.5 fold in boys (Colling-Saltin, 1980; Oertel, 1989), and significantly superior standard fiber areas in boys than girls (Jansson and Hedberg, 1991). The lower limb muscle fibers area has been to increase about 20 fold, while the upper limb muscle fiber area increases by about 7-12 fold during the same period (Aherne et al. 1971). In girls, the fiber diameter reaches its peak during adolescence, while boys only achieve their peak size during early adulthood (Oertel, 1988).

Moreover, boys tend to exhibit relatively greater size increase in type II fibers, and more specifically type IIb fibers, than girls (Glenmark et al. 1992). Simoneau et al. (1986) showed the same type of gender difference in 25 year-old subjects (Table 2.1). These differences in the patterns of muscle mass development are said to account for both the age and sex associated variations in strength and force development during childhood and adolescence (Malina and Bouchard, 1991). Comparisons between children and adults in terms of active muscle mass and power output have revealed significantly lower power outputs in children compared to adults, even after the data have been normalised for active muscle mass, and the force individually optimised (Van Praagh, 1998).

**Table 2.1** Physiological characteristics of muscle fiber types and performance

| Fiber types | Speed of contraction | Aerobic capacity | Anaerobic capacity |
|---|---|---|---|
| Slow, oxidative (SO) | Slow | High | Low |
| Fast, oxidation glycolytic (FOG) | Fast | Medium | Medium |
| Fast, glycolytic (FG) | Fast | Low | High |

## 2.14 Principles of training for children and adolescents.

The most common principle of training for both athletes and non-athletes are to concentrate on metabolic systems used in the physical performance. This resulted as an incorporating the principle of specificity of training theory that involves the determination of the type, duration, frequency and intensity of its various components. The integration of these dimensions with knowledge of metabolic systems may guide the coach or teacher to decide the system's to be applied (oxygen, ATP-PC, lactate) and fraction time to be committed to each (Fox and Mathew, 1974; 1981). However, these metabolic systems can be changed by applying the principles of specificity, overload and progressive resistance and incorporating time for warm-up and cool-down. These components ought to be manipulated to adapt training to the metabolic system and the needs of the event.

The principles specificity of training theory impacts several body systems, including muscular, endocrine, skeletal, metabolic, immune, neural, and respiratory. An understanding and appreciation of basic scientific principles interconnected to resistance training is necessary in order to optimize training responses. Moreover, providing variety in programme variables to imitate sports-specific movements is required for the most favorable gains made between training and competition (Kraemer et. al. 1998). Furthermore, exercise period to rest period ratio should be taken into account that rest period is twice as long as the exercise period (Knuttgen et al. 1973; Wilmore et al. 1980; Kraemer et. al. 1998). Consequently, whether athletes involve for the most part eccentric, isometric, slow-velocity, or high-velocity strength or power in their athletic event will say aloud the time commitment to each element and form the basis for designing individual workouts. Series discrepancy over a training time is important to take full advantage of gains and avoid overtraining.

### 2.14.1 Aerobic trainability and children's maturation.

Endurance exercise fitness can be described as the ability to participate in prolonged endurance events that requires the ability to consume large amounts of oxygen to produce energy at high work rates. Therefore, the cardiorespiratory functions of young endurance athletes are an important determinant of endurance performance (Coyle, 1995). Four parameter laboratory measures of cardiorespiratory fitness contribute to the ability to succeed in endurance sport; maximal oxygen consumption, anaerobic threshold, and economy of movement and oxygen uptake kinetics (Whipp et al., 1982; Coyle, 1995). Maximal oxygen consumption ($\dot{V}O_{2max}$) is the maximal ability to take up, deliver, and utilize oxygen to produce energy via aerobic metabolism.

It is not a surprise that endurance athletes possess high values for $\dot{V}O_{2max}$. Eisenmann and Cumming, (1999) indicated that, highly-trained adolescents 15 to 19 year old endurance athletes have a $\dot{V}O_{2max}$ of 60 to 75 $mL.kg^{-1}.min^{-1}$. Values for pre-adolescent 8-12 years children are slightly lower 55-65 $ml.kg.min^{-1}$. Jones et al. (2000) investigated if performance in physical fitness tests differed between children of different sexual maturity stages irrespective of mass and stature. Stage of sexual maturity was significantly correlated with all physical fitness measures (boys: r=0.56 to 0.73; girls: r=0.24 to 0.46). When stature and mass were taken into account, significant differences were evident between sexual maturity stages in boys but not girls. This suggests that increases in mass and stature are primarily responsible for variation in girls' physical performance throughout maturation, whereas in boys there are some qualitative differences in performance due to other factors. It was concluded that sexual maturity has a large influence on physical fitness measures in boys but less effect in girls. Ratings of physical fitness, particularly for boys should take into account biological maturity.

Studying the aerobic responses to endurance exercise training in adolescence indicated that the cardiorespiratory benefits were apparent early in life (Rowland and Boyajian, 1996). Other physiological distinctiveness that refer to increased endurance performance in adolescent children were acknowledged by Pate and Ward (1996) including a high peak oxygen uptake ($\dot{V}O_{2peak}$), a lower lactate threshold and efficient economy of energy expenditure throughout submaximal performance.

Fournier et al. (1982) investigated the effects of a training regime consisting of intermittent aerobic (endurance) and anaerobic exercise (sprint) on the vastus lateralis muscle fiber area and the activities of glycolytic (phosphofructokinase, PFK) and oxidative (succinate dehydrogenase, SDH) enzymes of adolescent boys using running as the mode of training over a 12 week period. The boys were divided into two training-groups, a sprint-training group and an endurance-training group. The endurance-training group exercised for 2 intervals of 10 min and 2 intervals of 30 min followed by 5 min rest between each bout. They exercise 4 times per week at an intensity of a 60 to 90% heart rate. The sprint-training group ran distances ranging from 50 to 250-m and ran upstairs, using the same duration. The intensity of training and the rest period were not considered in the study. The training-groups were tested both before and after the training period using a treadmill protocol. Only the effect on $\dot{V}O_{2max}$, ventilation and heart rate will be reported here.

The authors indicated that $\dot{V}O_{2max}$ increased significantly by 10% in the endurance training group when a comparison was made within groups. The sprint training group showed an insignificant increase of 6%. The maximum ventilation of the sprint group decreased by only 4% after training, but the endurance group showed a significant increase of 6%. The heart rate of the sprint group decreased by only a 5 beats.min$^{-1}$ at sub-maximal exercise after training, but the endurance group showed a significant decrease of a 13 beats.min$^{-1}$ after 12 weeks of training. Both the sprint and the endurance groups decreased their maximum RER significantly, by 5% and 6% respectively after training. The maximum heart rate of the endurance group decreased significantly by a 9 beats.min$^{-1}$ after 12 weeks of training, while the sprint group showed a decrease of a 6 beats.min$^{-1}$ which was not significant. Neither group showed any change in % body fat, body mass or body height after 12 weeks of training.

Rotstein et al. (1986) considered the effects of an intermittent training regime on anaerobic threshold, maximal aerobic power and anaerobic performance of preadolescent boys over a 9 week period. The participants were divided into a training group and a control group. Both groups were tested in four ways before and after training using anthropometric measurement, a Wingate anaerobic test on a cycle ergometer, treadmill running to test $\dot{V}O_{2max}$, and a field test of a 1200-m run. The training group ran for a duration of 45 min per session, 3 times per week. The training

session consisted of warming-up and movement games lasting from 15 to 20 min. Several series of 600, 400 and 150-m runs were performed followed by a rest periods of 2.5, 2 and 1.5-min respectively. The intensity of training was freely chosen.

The authors found that in 10- to 11-year-old boys, a 9-week interval training increased the indices of anaerobic capacity: mean power by 10% and peak power by 14%. No change was found in percent fatigue. The training also increased $\dot{V}O_{2max}$ by 7% in absolute terms and by 8 % / kg body mass. A significant increase was also found in the running velocity at the anaerobic threshold (running velocity at inflection point of lactate accumulation curve), but in relative terms (percent of $\dot{V}O_{2max}$), the anaerobic threshold decreased by approximately 4.4%. It is concluded that proper training may improve maximal aerobic power and anaerobic capacity of preadolescent boys. Both the training group and the control group showed a significant increase in body height of 1.14 and 0.94-cm over the training period. In lean body mass, the control group increased significantly by 2%, but the training group remained unchanged after training. In the 1200-m run, the training group reduced their performance time significantly by 10% and the control group showed no change. The maximum heart rate of the training group decreased significantly by a 4 beats.min$^{-1}$ while no change was observed in the control group. It was also concluded that anaerobic threshold measures are less sensitive to the training regimen than $\dot{V}O_{2max}$ and that the 1200-m running performance is strongly associated with both aerobic and anaerobic capacities and less with the anaerobic threshold, which in preadolescent boys seems to be higher than in adults. This improvement confirmed other findings about the effects of a training regime consisting of intermittent aerobic (endurance) and anaerobic (sprint) on the vastus lateralis muscle and the activities of glycolytic and oxidative enzymes of adolescent boys using running as the mode of training over a 12 week period (Fournier et al., 1982; Rotstein et al., 1986).

There are conflicting data with regard to the effect of endurance training in children. On the basis of this information, Mahon and Vaccaro, (1989) investigated the effects of 8 weeks of run training on ventilatory threshold (VT) and $\dot{V}O_{2max}$ of eight male children. Participants ranged in age from 10 to 14 year, with a mean age of 12.4 year. All subjects were previously untrained. Training consisted of running 4 times per week for a period of 8 weeks. Continuous running was performed 2 times per week for 10-30 min at 70-

80% of $\dot{V}O_{2max}$. Interval running was performed the remaining 2 times per week. Repeated intervals of 100-800 m at 90-100% of $\dot{V}O_{2max}$ were used in this phase of the training. The total distance run for this type of training was 1.5-2.5 km. Incremental treadmill testing prior to and after the training period indicated a 19.4% increase in VT from 30.5 to 36.4 $mL.kg^{-1}.min^{-1}$ ($P< 0.05$). When VT was expressed as a percentage of $\dot{V}O_{2max}$, there was a significant ($P< 0.05$) increase from 66.6% to 73.8%. $\dot{V}O_{2max}$ increased 7.5% from 45.9 to 49.4 $mL.kg^{-1}.min^{-1}$ ($P< 0.05$). None of these changes was noted in eight age- and size-matched children who served as control subjects. The results of this study indicate that 8 weeks of endurance running training which is of sufficient frequency, intensity, and duration can significantly improve VT and aerobic power in male children.

### 2.14.2 Trainability of selected physiological issues for middle distance runners.

Katch, (1983) stated that exercise-induced changes in muscular and cardiovascular function in pre and post pubescent children proposing in terms a physical conditioning theory called "Trigger Hypothesis." This hypothesis predicts that, prepubertally, there will be only small training-induced biological alterations because of the lack of hormonal control. It is suggested, therefore, that prominence be placed on talent attainment rather than physiological conditioning during prepuberty. Postpubertal exercise-induced changes are well documented and follow predictable patterns. The principles that govern physiological adaptations to exercise are discussed in terms of energy convey and the factors that affect training. Duration, intensity, and frequency of performance are detailed. It is recommended that highlighting be placed on these factors when designing a physiologically sound physical training program. Greene et al. (2004) indicated that the impact of high training volumes on musculoskeletal adaptations of male adolescents is poorly understood, but their results from high training volumes in middle distance running are not unfavorable to musculoskeletal fitness and were coupled with positive body composition profiles in elite adolescent male athletes.

Mahler and Rostan (1990) indicated that, there is a prevalent practical improvement in monitoring of exercise instruction performance, perceived effort (PE) may be used as an supplementary indicator in the determination of the AT in an incremental AT-test and can be useful in the instruction of an implement program. Furthermore, the importance of the adjusting for age and gender and considering the confounding effects of growth

and maturation were taking into the account throughout a training programme. Also, the improvements of cardiovascular health were an indication as a result of increases in physical fitness during adolescence (Janz et al. 2002). The most frequent term used to explain the blood lactate response during work out is the anaerobic threshold. This represents the peak intensity of exercise at which is the equilibrium between the production and elimination of lactate occurs (Heck et al. 1985). Methods for the determination of the anaerobic threshold use either a direct or an indirect procedure. With direct procedures a fixed (4 mmol $l^{-1}$; Heck et al 1985) or variable (Stegmann et al 1981; Tegtbur et al 1993., Almarwaey et al. 2003., 2004) concentrations of blood lactate are used. Therefore, it is important to verify the ability of serious speed to calculate approximately the speed at a blood lactate concentration of 4 mmol·$l^{-1}$ in children, who tend to have a lower blood lactate concentration than adults at submaximal and maximal intensities (Eriksson and Saltin 1974; Almarwaey et al. 2003., 2004), because of lower glycolytic enzymes concentrations and the increased concentration of oxidative enzymes.

## 2.15 Summary.

The literature review state that, there is no relating studies on MLSS and adolescent athletics or children area. Also, there is a lack of studies to detect the most important physiological responses related to endurance performance and trained adolescent runners. Furthermore, there are no studies involving the effects of endurance training programme and adolescent middle distance runners. A few studies involve growth hormones and development throughout stages 1-5 but not adolescent runners. Little data available on threshold and haematological profile but none related to our population groups. Moreover, it is difficult and not promising to achieve straight measurements of muscle fiber types to detect the muscle ability and energy metabolism throughout this population group's performance. Therefore, investigators applied to add the WAnT as indirect measures to look at the improvement of anaerobic performance.

# CHAPTER THREE
# METHODOLOGY

## 3.0 Methods

This chapter includes outlines methods and procedures used in the four studies conducted and subsequent modifications prepared to the equipments and protocols used to estimate sub-maximal $\dot{V}O_2$, peak $\dot{V}O_2$, anaerobic performance, levels of flexibility, vertical jump. Details of the anthropometric measurement and secondary sexual maturation assessment (the self-assessment of maturation questionnaire) to evaluate the biological status of the participants are also included.

## 3.1 Participants

Participants for this thesis were adolescent boys and girls aged 14-18 years. The total numbers of participants was One hundred and 13 boys and 40 girls representing this population of age group for both countries of United Kingdom and Saudi Arabia Kingdom. They consisted of 89 sub-elite, endurance trained, adolescent children, 49 boys and 40 girls who volunteered to participate in the first three studies. They were the 800 m, 1500 m and 3000 m finalist from the 1999 Cheshire and Staffordshire County Athletics Championships. In addition 64 boys volunteered to participate in fourth study, 25 boys as well trained athletes, 25 normal trained athletes representing an experimental groups and 14 untrained boys as control group. They were the 800 m, 1500 m and 3000 m finalist from the 2001 Alwehda Club, Heraa Club, Intermediate and High Schools Athletics Championships of Makkah City at Saudi Arabia Kingdom. The running performance times were used as the field-based performance measure in this study. The participants were tested within four weeks of the Championships. Approvals for the studies procedures were obtained from the Manchester Metropolitan University Research Ethics Committee for the first three studies, and from Liverpool John Moores University Research Ethics Committee for the fourth study (Appendix 1).

All participants and at least one of their parents received a written explanation of the nature of the studies and general health was assessed using a pre-test questionnaire. All participants were asked to cease from training during the day of the testing, and instructed to eat according to their eating habits but no less than two hours before testing. Also, they were told to do their normal daily activities throughout the testing sessions. The investigator discussed the exact details of the testing procedures with the participants at their Clubs, Schools and before testing at the physiological lab at the Universities. Both the participant and at least one parent completed an informed consent

form prior to any active participation in the studies (Appendix 2). Each participant or parent/guardian were free to consent without any way of convenience and have the right to withdraw form any aspect of the studies (Appendix 2).

### 3.2 Anthropometric Measures

Stature was measured to the nearest 0.1 cm (Seca stadiometer 208), each participant was stretched according to the protocols described by Norton et al. (1996) to avoid diurnal variation (Reilly et al., 1984). Performing the stretched out stature technique requires the participant to stand with feet jointly extended, while the heels buttocks and the upper back touching the scale or the wall. The participant required to take and hold a deep breath whereas the head must be placed in Frankfort plane, and gentle upward pressure to the mastoid processes applied then the measurement of accurate stature should be taken. Body mass was assessed to the nearest 0.1 kg (Seca beam balance 710). Participants were dressed in T-shirt and shorts without shoes. All participants' ages were calculated from their date of birth to the test date to the nearest tenth of a year.

### 3.3. Body composition

Skinfold measurement were taken from the right side of the body using a Harpenden caliper (John Bull, England) and recorded to the nearest 0.1 mm. The average of three measurements was used to represent the value for the triceps and subscapular sites. Percent body fat (%BF) was then calculated using maturity and sex appropriate equations (Slaughter et al., 1988).

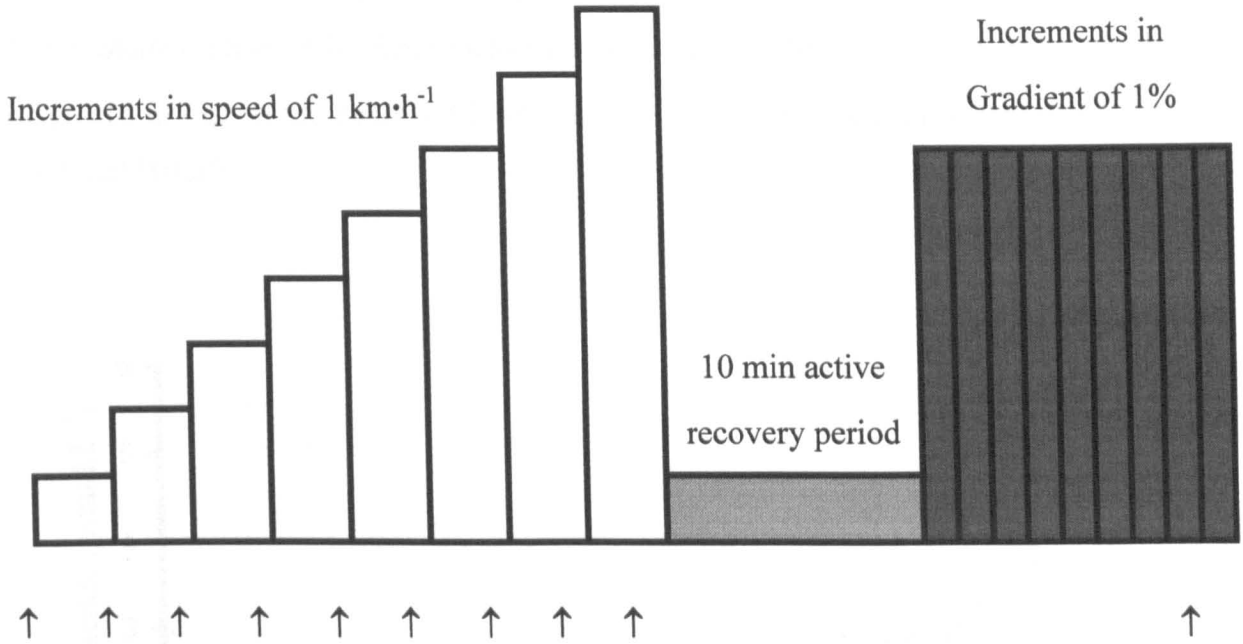
**Boys:** $\%BF = 1.21 \cdot (\text{triceps} + \text{subscapular}) - 0.008 \cdot (\text{triceps} + \text{subscapular})^2 - 5.5$

**Girls:** $\%BF = 1.33 \cdot (\text{triceps} + \text{subscapular}) - 0.013 \cdot (\text{triceps} + \text{subscapular})^2 - 2.5$

### 3.4 Treadmill (TM) protocol and test procedures

Each participant completed a two-phase treadmill (Powerjog EG30) test following habituation to treadmill walking and running. Phase one was a discontinuous incremental running test (Figure 3.1) with increments in running speed of 1 $km \cdot h^{-1}$ at the beginning of each stage. The incremental test consisted of six to eight 3-min stages following a 5 min warm-up of walking and running up to 7 $km \cdot h^{-1}$. The speed at the beginning of the actual test (8-11 $km \cdot h^{-1}$) was determined according to each participant's running performance time. Each stage was separated by a one-minute rest

period for finger-tip capillary blood sampling. Following a 10-min active recovery period, phase two was completed. This phase involved running at a fixed speed with the treadmill gradient being increased by 1% each min (Figure 3.1) until volitional exhaustion.




↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑

**↑= Capillary blood samples, heart rate, and $\dot{V}O_2$ measured at the end of each stage.**

**Figure 3.1 Treadmill test protocol**

### 3.5. Blood sampling

Blood sampling and analysis procedures throughout the studies and prior to any type of exercise test, were explained and demonstrated in more details to familiarise each participant with the process. It was indicated that blood lactate concentration and samples may influenced by different biochemical factors such as an increased catecholamine circulation levels, plasma adrenaline and noradrenaline (Mazzeo and Marshall, 1989; Stainsby and Brooks, 1990) or diet (Yoshida, 1986). A resting fingertip, capillary blood sample was taken to determine the whole blood lactate concentration prior to the start of the test. Whole blood samples were also taken during the test at the end of each stage (Figure 3.1). The fingertip was wiped with a mediswab saturated with 70% v/v Isopropyl alcohol and dried with a tissue. The blood samples were collected in heparinised capillary tubes after discarding the first drop of blood. The blood was analysed immediately in duplicate for whole blood lactate concentration using an automatic analyzer (YSI 1500 Sport; Yellow Springs, USA). The analyzer was

calibrated with a known standard of 5 mmol·L$^{-1}$ prior to testing and after every 20 samples.

Running speeds corresponding to 2.0, 2.5, and 4.0 mmol·L$^{-1}$ fixed whole blood lactate concentrations [BLa$^{-}$] (v2.0, v2.5, and v4.0) and the lactate threshold (vLT) were calculated via linear interpolation (Figure 3.2). The lactate threshold was defined as the first sustained increase in blood lactate concentration above the baseline value, the level of precision was to the nearest 1 km·h$^{-1}$ for the LT and to the nearest 0.1 mmol·L$^{-1}$ for the fixed [BLa$^{-}$].

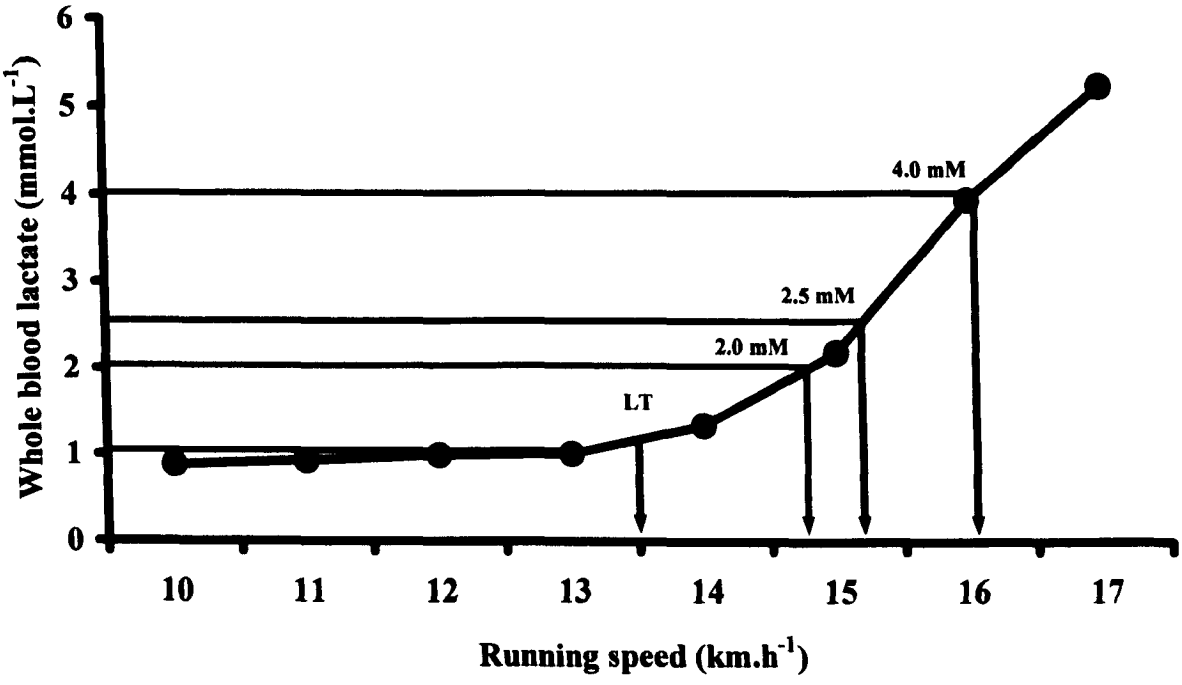



**Figure 3.2 Interpolation of fixed blood lactate reference values.**

### 3.6 Determination of sub-maximal and peak $\dot{V}O_2$

Heart rate (HR) was recorded using short-range radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland) whilst rating of perceived exertion (RPE) was recorded at the end of each stage using the Borg scale (Borg, 1982). During phase one of the test, expired air was collected into Douglas bags during the last min of each exercise stage. These measurements were also taken for consecutive 1 min stages at the end of phase two of the test to determine peak $\dot{V}O_2$. The concentration of oxygen and carbon dioxide in the expired air samples was determined using a paramagnetic oxygen analyser

(Servomex, Sussex, UK) and an infrared carbon dioxide analyser (Servomex, Sussex, UK). Expired air volumes were measured using a dry gas meter (Harvard Apparatus, Kent, UK) and corrected to standard temperature and pressure (dry). Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), expired minute ventilation, and respiratory exchange ratio (RER) were calculated for each Douglas bag. The analyser was calibrated with standard gases of known concentration before each test session. The running speed that corresponded to peak $\dot{V}O_2$ ($v\dot{V}O_2$ peak) was estimated by linear interpolation of the sub-maximal running speeds and $\dot{V}O_2$ values collected during phase one of the test (Daniels et al., 1984; Billat et al., 1994b; Jones and Carter, 2000). The level of precision for $v\dot{V}O_2$ peak was to the nearest 0.1 $km \cdot h^{-1}$ for each athlete. In addition, an on-line computerised, expired air analysis system (Jaeger, Oxycon Alpha) was used rather than the Douglas bag method for all sub-maximal and peak $\dot{V}O_2$ measurements throughout the last three studies.

### 3.7 Determination of maximum lactate steady state (MLaSS).

During a single laboratory visit participants completed two separate constant speeds, 20 min treadmill runs. Each run was separated by a 30-45 min active recovery period. During each 20 min run, fingertip capillary blood samples were taken at 5 min intervals, following an initial baseline sample for the determination of whole blood lactate concentration (i.e. 0, 5, 10, 15 and 20 min). For the safety of the athlete, the run was interrupted for 30s each time a blood sample was required. An interruption in the exercise of this duration does not affect the heart rate, running speed, or $\dot{V}O_2$ that correspond to a variety of blood lactate variables (Gullstrand et al., 1994). This interruption was strictly standardised to reduce the variability within the data. Participants completed four 20 min constant speed runs in total. At least two days of rest, but no more than five days, separated the two constant run tests. Rating of perceived exertion (RPE), heart rate (HR) and expired air were also recorded at 5 min intervals. The initial running speed for the first 20 min run was determined from the participant's blood lactate profile from the aforementioned incremental treadmill test. The MLaSS was defined by analysing the [$BLa^-$] between the 10th and 20th min of each constant speed test. It was defined as the highest [$BLa^-$] that increased by no more 0.5 $mmol \cdot L^{-1}$ during the last 10 min (Figure 3.3).

This increase in lactate per unit time is similar to that defined by numerous authors (e.g.Beneke and von Duvillard, 1996; Jones and Doust, 1998). The [BLa$^-$] at 20 min was accepted as the MLaSS concentration. The running speeds, $\dot{V}O_2$, and HR that corresponded to the MLaSS were recorded and used in subsequent analyses. The definition of MLaSS was used to determine the change in running speed across the four different constant speed runs. Over the four runs, running speed was manipulated to attain the upper boundary of MLaSS to a precision of 0.5 km.h$^{-1}$ (vMLaSS). Although it was not possible to randomise the speeds at which the participants completed the four runs, a visual analysis of the change in speed across the runs revealed that it did not appear to be related to the MLaSS. During this study, some participants did not complete the last stage of their fastest 20 min run. When this occurred, a blood lactate sample was taken two minutes after the run was terminated. In this instance, if the difference between the last sample and the final blood lactate concentration (i.e. between 10 and 20 min) was more than the 0.5 mmol.L$^{-1}$ criteria then the preceding running speed was used to represent the participant's MLaSS.

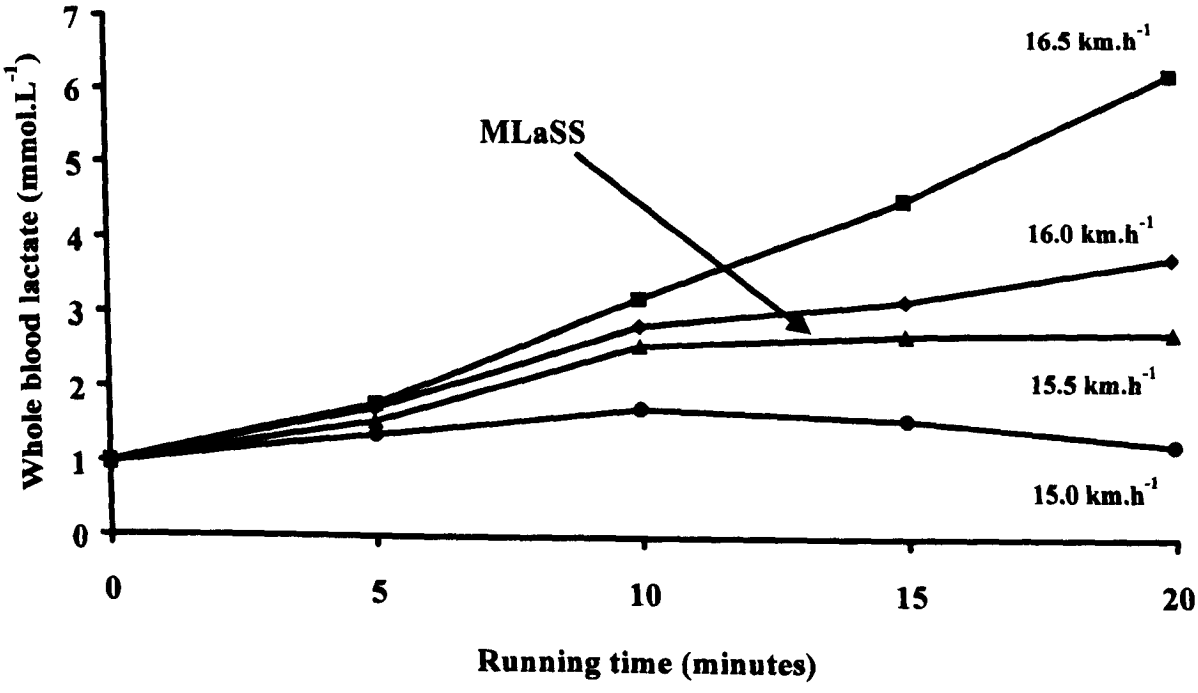



**Figure 3.3 Example of a maximum lactate steady state (MLaSS) profile.**

## 3.8 Measurements of Anaerobic Power

### 3.8.1 Wingate anaerobic test (WAnT)

The 30-second Wingate Anaerobic Test (WAnT) was designed by Ayalon et al. (1974) based on work by (Cumming, 1970s) and to assess the anaerobic power of both adults and children (Bar-Or, 1987., Mercier et al. 1992). The validity and reliability of the WAnT were investigated by the authors of the original papers and other researchers. Ayalon et al. (1974) found correlations ranging from r = 0.67 to 0.94 when compared with Margaria, Step Test, leg and arm 'explosive power'.

Furthermore, significant correlations ranging from r = 0.60 to 0.90 between WAnT indices and different measures of anaerobic power have found (Inbar and Bar-Or, 1977; Bar-Or, 1981; Inbar et al. 1981), thus indicating that the WAnT is a valid test of anaerobic power. The test-retest reliability of the WAnT was found with correlation coefficients of 0.91 and 0.93 for legs and arms respectively (Ayalon et al. 1974). Other authors reported relatively, similar findings of high correlation coefficients ranging from r = 0.91 to 0.98 (Bar-Or, 1981; Patton et al., 1985; Vanderwalle et al. 1987). The WAnT become the best alternative indirect test procedure of assessing anaerobic metabolism instead of muscle biopsies multiple techniques, which are painful and unsuitable for young population age group (Bar-Or, 1989; Lakomy, 1994; Green, 1995; Armstrong and Welsman, 2000). Also, peak power (W) was assessed using a 30 s Wingate anaerobic power test (WAnT) (Bar-Or, 1987; 1996; Armstrong and Welsman, 1997).

Therefore, Peak (PP) and 30 s mean power (MP) outputs (W) were assessed using a standard. Wingate anaerobic power test (WAnT) performed on a Monark 814 E (Monark-Cresent AB, Varberg. Sweden) interfaced to a computer. The cycle ergometer was calibrated according to the manufacturer's recommendations before each test. A standardized warm-up, which consisted of 5 min of pedaling at 30W interspersed with three maximal sprints of 3-4 second followed by static stretches of the leg muscles, was completed before each test. The test involved a maximal exertion sprint lasting 30 s, during which the participant seated throughout. The braking force was 0.74 $N \cdot kg^{-1}$ bodies mass. Power output was calculated each second throughout the duration of the test. The power values were corrected to account for the work required to accelerate the flywheel (Lakomy, 1986). The anaerobic test was completed within a week of the

treadmill test (above). The highest PP and MP values from the two trials were included in the analyses for the boys and girls.

The participants performed two trials interspersed by an active recovery period of 30 minutes. Capillary blood samples were taken prior to the start, directly at the end of the first trial, and three minutes later (Duche et al. 1992; Williams et al. 2000). These procedures were repeated for the second WAnT trial. The anaerobic test was completed within a week of the treadmill test. The best trial was recorded for both the boys and girls.

### 3.8.2 Vertical jump

A standard vertical jump test was measured using an electronic vertical jump mat. Each participant performed three trials and the best trial was recorded to the nearest 0.1 cm.

### 3.8.3 Flexibility.

Flexibility was assessed from a basic sit and reach position and the best trial out of three was recorded to the nearest 1.0 cm.

## 3.9 Assessment of Sexual Maturation

Tanner stages of sexual maturation were used based on no more than two criteria for both boys and girls (Tanner, 1962). These criteria are including pubic hair indications and genitalia development for boys and pubic hair indications and breast development for girls throughout the five stages progress from pre-pubertal (stage 1) through pubertal (stages 2, 3 and 4) to the fifth stage as post-pubertal (Tanner, 1975). The above descriptions of the secondary characteristics rating of pubertal children were pictured by Morris and Udry, (1980) for more explanation, self-examination, saving time and to reduce young people concerns (Faulkner, 1996) (Appendix 3). Therefore, a copy of complete Tanner's stages of self-assessment maturational questionnaire was given to each participant and at least one of his/her parents/guardian at the lab during the first visit in close envelop after discussed it to be assessed and returned a week later during second visit.

Comparing the self-assessment rating by children and adolescents with the pediatrician's assessment, were accurate, valid and highly reliable (Duke et. al.1980; Matsudo and Matsudo, 1993). Also, children can take more time to make their best assessment at homes and freely examine the diagrams and perform an excellent

comparison regarding to their personal concerns (Morris and Udry, 1980; Peterson et al. 1983). However, all participants in this thesis range between stages 2 and 5, and their ages between 13 to 18 years old, which had been known as adolescents (Bale et al. 1992).

# Chapter Four

## The reliability of blood lactate variables in endurance trained adolescent runners

## 4.0 The reliability of blood lactate variables in endurance trained adolescent runners

### 4.1 Estimation of the reliability

This chapter will concentrate on aims 2-4, that is to establish test retest reliability of measures to be used in subsequent studies in this thesis. In this section the reliability of the absolute running speed (km · $h^{-1}$), $\dot{V}O_2$ (L · $min^{-1}$), and HR (beat · $min^{-1}$) that corresponds to fixed blood lactate reference values of 2.0 and 2.5 mmol · $L^{-1}$, and the lactate threshold (LT) will be assessed.

### 4.2 Introduction

The reliability of any assessment may be defined as the degree of consistency with which a measuring device may be applied twice or more, a highly reliable assessment acquiesce the same or approximately the same scores when administered more than once to the same participants, when circumstances and issues are fundamentally the same (Safrit and Wood, 1989; Vincent, 1995; Nelson, 1997). Unfortunately, numerous factors may affect reliability. The situations of the subjects may not be identical every time, the assessments may be taken across different days or times, sex differences, psychological or individuality status (Hopkins et al., 2001) and the contradictory modes of the investigators or their objectivity (Thomas and Nelson, 1990).

A number of methods have been used to establish methods of assessing reliability in sports science (Atkinson and Nevill,1998; Williams and Bale, 1998; Hopkins, 2000).These are used to establish the extent of error believed satisfactory for the efficient use of a measurement apparatus (Atkinson and Nevill, 1998.,Watt et al. 2002). Inconsistency in measures can be split into 2 forms, random error and systematic bias. Random error is the biological and mechanical discrepancy, while systematic bias refers to the direction of potential learning, training, and/or fatigue (Atkinson and Nevill, 1998). In addition, Hopkins et al. (2001) indicated that reliability may be affected by numerous supplementary issues, such as participant's fitness status and gender. Trained subjects who will participate in studies in this thesis are reported to produce more reliable test-retest results than untrained people (Hopkins et al. 2001).

However, variations in the blood lactate response to physical performance in young people[1] and adults have been reported since the early pioneering work of Robinson (1938) and Åstrand, (1952). In order for a physiological variable or parameter to be valid, it must first demonstrate it can provide reliable results. That is, the total variability associated with the measurement should be small enough to allow alterations in physiological status to be detected following a prescribed intervention (e.g. exercise training). The magnitude of variability that researchers deem to be acceptable will depend upon the reason for measuring the blood lactate response to exercise in the first instance (Kirwan, 2001).

Some subsequent reports have indicated that young people demonstrate a 'blunted' blood lactate response when compared to their mature and older adult counterparts (Armstrong and Welsman, 1994; Boisseau and Delamarche, 2000) although this difference has not gone uncontested (Cumming et al., 1980). Moreover, it is not clear whether the child-adult differences are more closely aligned to chronological age or biological maturation (Tanaka and Shindo, 1985; Williams and Armstrong, 1991; Welsman et al., 1994; Tolfrey and Armstrong, 1995). The mechanisms underpinning the varying responses may include differences in, (1) both glycolytic and oxidative enzyme activities (Eriksson et al., 1973; Haralambie, 1979), (2) muscle fibre type recruitment (Atomi et al., 1987), (3) the catecholamine response to exercise (Lehmann et al., 1981; Mácek, 1986), and/or (4) oxygen uptake ($\dot{V}O_2$) kinetics (Armon et al., 1991; Fawkner et al., 2002).

However, all of these potential factors require further clarification. It is clear from the literature that a number of different lactate parameters have been employed or studied (Pfitzinger and Freedson, 1997). Numerous studies indicated that the blood lactate concentration responded to incremental exercise and it was positively associated with different types of endurance performance (Heck et al., 1985; Weltman, 1995; Grant et al., 1997). The exercise intensities that correspond to the lactate threshold (LT) and fixed blood lactate concentrations such as 2.0 and 2.5 $mmol \cdot L^{-1}$ have all been reported in young people (Tanaka and Shindo, 1985; Tanaka, 1986; Tolfrey and Armstrong, 1995; Almarwaey et al., 2003).

[1] Young people is used to describe individuals who are ≤ 18 years of age

There are a small number of studies that have studied the reproducibility of the lactate response to physical performance have been characterised by a numeral limitations, such as the studies by Aunola and Rusko (1984) and Weltman et al. (1990) they tested only adults male subjects, did not standardise diet or prior physical activity, and established limited statistical analyses. However, as far as the author is aware, no study has reported the variability of repeated measurements of these blood lactate parameters in young people. Therefore, the purpose of our study was to estimate the reliability of the running speed, oxygen uptake, and heart rate (HR) that corresponded to the LT and fixed blood lactate concentrations of 2.0 and 2.5 $mmol \cdot L^{-1}$ in endurance trained, adolescent athletes.

## 4.3 Methods

### 4.3.1 Subjects

### 4.3.2 Adolescent runners

Fourteen girls and 10 boys volunteered to participate in the study. All participants were endurance trained, adolescent runners who had been tested in the laboratory on at least two occasions and were considered to be well habituated to all of the procedures. The participants had been active members of an athletic club for at least one year leading up to their involvement in the study. They were all competing regularly in track-based events at club level or above (i.e. County and English Schools). The total weekly training distance, per athlete, ranged from 25 to 53 km. This was comprised of two or three track sessions that focused on interval and sprint-based work. The rest of the time was spent on continuous aerobic-type running on the road or cross-country. Approval for the study procedures was obtained from the Local Research Ethics Committee. All participants and at least one of their parents received a written explanation of the nature of the study and overall general health was assessed by a pre-test questionnaire. Both the participant and at least one of their parents completed an informed consent form prior to any measurements being made.

### 4.3.3 Research Design

Participants completed two incremental running tests on a calibrated motorised treadmill (Woodway ERGO ELG2, Germany) separated by exactly seven days. The second test was completed within ± 1 h of the time that the first one had occurred in an effort to avoid a circadian rhythm effect (McConnell, 1988). Nutritional intake and physical activity were recorded in a diary by the athletes 48 h before the first test; this was replicated over the same period leading up to the second test. In addition, the participants were asked not to consume products containing caffeine or any food 3 h before each test, to arrive at the laboratory well hydrated with plain water, and to avoid all physical training in the preceding 24 h. Each participant wore the same running shoes and sports clothing for both tests that were conducted in an air-conditioned laboratory (20 ± 1°C, 35 ± 3 %RH).

### 4.3.4 Anthropometric Measurements.

Stature was measured to the nearest 1.0 cm (Seca stadiometer 208) and body mass to the nearest 0.1 kg (Seca beam balance 710). Participants were dressed in running vest and shorts without shoes. Skinfold measurement were taken from the right side of the body using a Harpenden caliper (John Bull, England) and recorded to the nearest 0.2 mm. The median of three measurements was used to represent the value for the triceps and subscapular sites. Percent body fat (%BF) was then calculated using maturity and sex appropriate equations (Slaughter et al., 1988).

Boys: $\%BF = 1.21 \cdot (\text{triceps} + \text{subscapular}) - 0.008 \cdot (\text{triceps} + \text{subscapular})^2 - 5.5$

Girls: $\%BF = 1.33 \cdot (\text{triceps} + \text{subscapular}) - 0.013 \cdot (\text{triceps} + \text{subscapular})^2 - 2.5$

### 4.3.5 Treadmill Test

The treadmill tests consisted of two phases; phase one was a discontinuous incremental running test with increases in running speed of 1 $km \cdot h^{-1}$ at the beginning of each stage. The incremental test consisted of six to eight 3-min stages following a 5 min warm-up of walking and running-up to-7 $km \cdot h^{-1}$. The speed at the beginning of the test varied (8-11 $km \cdot h^{-1}$) according to each participant's peak $\dot{V}O_2$ determined during a previous visit to the laboratory (Almarwaey et al., 2003). Each stage was separated by a 60-s rest period for fingertip capillary blood sampling (Gullstrand et al., 1994). Following a 10-min active recovery period, phase two was completed. This involved running at a fixed speed with the treadmill gradient being increased by 1% each min until volitional exhaustion was reached. On average this second phase took 7 ± 2 min to complete. However, treadmill test protocol has been explained in more details at chapter three and (Figure 3.1).

### 4.3.6 Blood Lactate

Prior to each test, the athlete's whole hand was immersed in warm water (~42°C) for 5 min, dried throughly, and then the fingertip was wiped with a mediswab saturated with 70% v/v Isopropyl Alcohol and dried with a tissue. A resting fingertip, capillary blood sample was taken to determine the whole blood lactate concentration [$BLa^-$] after the skin had been pierced with an autolancet. During phase one of the treadmill test, whole blood samples were taken at the end of each exercise stage. The blood samples were collected in heparinised capillary tubes after discarding the first drop of blood. The

blood was analysed immediately in duplicate for whole blood lactate concentration using an automatic analyser (YSI 1500 Sport; Yellow Springs, USA). The analyser was calibrated with a 5 $mmol \cdot L^{-1}$ lactate standard prior to each individual test and after every 20 samples. Oxygen uptake ($L \cdot min^{-1}$) corresponding to the 2.5 $mmol \cdot L^{-1}$ fixed [$BLa^-$] was calculated via linear interpolation. The procedures described by Beaver et al., (1985) were used to calculate the LT for each athlete. In short, the [$BLa^-$] and $\dot{V}O_2$ data were log transformed. Then a two-phase regression model was used to estimate the inflection point of the lactate profile (i.e. LT, see Grant et al., 2002). The first phase of the model represented the baseline [$BLa^-$] while the second phase represented the incremental increase in [$BLa^-$]. The intercept of the separate linear regression lines for the two phases was used to estimate the LT. The $\dot{V}O_2$ that corresponded to the 2.5 $mmol \cdot L^{-1}$ fixed [$BLa^-$] and LT was calculated to the nearest 0.01 $L \cdot min^{-1}$ ($2.5_{VO_2}$ and $LT_{VO_2}$ respectively). These procedures were repeated to determine the running speed (precision = 0.1 $km \cdot h^{-1}$; $2.5_V$ and $LT_V$ respectively) and HR (precision = 1 $beat \cdot min^{-1}$; $2.5_{HR}$ and $LT_{HR}$ respectively) that corresponded to the LT and 2.5 fixed [$BLa^-$]. For some athletes the [$BLa^-$] was higher than 2.5 $mmol \cdot L^{-1}$ throughout the tests or it was not possible to objectively calculate the LT. Therefore, for some of the parameters complete data were not available for all 14 and 10 of the girls and boys who took part in this study respectively (girls LT n = 13, boys 2.5 [$BLa^-$] n = 9).

### 4.3.7 Oxygen Uptake ($\dot{V}O_2$)

Heart rate (HR) was recorded continuously using short-range radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland). During both phases of the treadmill test, pulmonary gas exchange and minute ventilation were measured using an on-line computerised system (Oxycon Alpha, Jaeger, Netherlands). Participants wore a nose-clip and breathed through a low dead space (35 mL), low resistance (< $0.1 kPa \cdot L^{-1} \cdot s^{-1}$ at 16 $L \cdot s^{-1}$) mouthpiece and volume sensor assembly. Gases were drawn continuously from the mouthpiece assembly through a capillary line and analysed for oxygen ($O_2$) and carbon dioxide ($CO_2$) concentrations by fast-response analysers ($O_2$: differential paramagnetic; CO2: infra-red absorption). The system was calibrated prior to each test with gases of known concentration. Expiratory volumes were determined using a triple V turbine volume sensor which was calibrated before each test with a 3 L graduated gas syringe (Hans Rudolph Inc., Kansas City, USA) according to the manufacturer's instructions. The concentration and volume signals were integrated by personal

computer and pulmonary gas exchange and ventilation variables were calculated and displayed for each 10-s period. During phase one of the treadmill test, the participants breathed through the mouthpiece for the final 90-s of each 3 min exercise stage. The average $\dot{V}O_2$ of the last 30-s was used to represent each stage. For phase two of the test, the participants signaled when they could only run for a further 2 min. From hereon they breathed through the mouthpiece. The highest 30-s rolling average of the $\dot{V}O_2$ data was taken to be the peak $\dot{V}O_2$. A maximum effort was deemed to have been given if the participant satisfied two of the three criterion upon termination of each test due to volitional exhaustion: (1) a plateau in $\dot{V}O_2$ ($< 2.1$ mL·kg$^{-1}$·min$^{-1}$), (2) a plateau in HR or peak HR within 10 beats·min$^{-1}$ of age predicted maximum, and (3) peak RER $\geq 1.10$. All participants satisfied these criteria.

### 4.3.8 Data analyses

All statistical analyses were conducted using SPSS for Windows (SPSS, Chicago, USA – version 11.0) and a priori alpha of $P \leq 0.05$ was chosen for statistical significance. Independent Student's t-tests were used to compare the data shown in Table 4.1 between the girls and boys. For the six performance parameters, the Shapiro-Wilk's W test and normal probability plot were used to check the normality of the residuals (test 2 minus test 1 value). Pairwise plots of individual residuals (test 2 minus test 1 values) were plotted against the mean of the two tests to check for heteroscedasticity visually. Pearson product moment correlations, between the absolute residuals and the mean of the two tests for each of the variables, were used to check more formally for heteroscedasticity (Atkinson and Nevill, 1998). This procedure was repeated after the data had been transformed using a natural logarithm function. The data were used for subsequent analyses to assess the variability because most of the parameters showed signs of heteroscedasticity (Hopkins, 2000; 2002; Nevill and Atkinson, 1997; 1998). The 95% limits of agreement (LOA) method was used in this study as the most suitable test for evaluating reproducibility in sports medicine and exercise science (Bland and Altman, 1986) and more recently (Nevill and Atkinson, 1997; Atkinson and Nevill, 1998). Student's paired t-tests were used to examine the data for systematic bias (change in the mean) by comparing the mean values from the two tests. The 95% confidence intervals (CIs) around the change score provided the range that might be expected in the population (i.e. the "true" mean difference). Mean differences between

consecutive pairs of measurements and the typical error from test to test are presented. The mean differences are expressed as a percentage change in the mean. This was calculated via the back-transformation of the mean pairwise differences between the two tests using the formula: percentage change in the mean = $100 \cdot (e^{x} - 1)$, where x is the mean difference between tests for the log transformed parameters (Phillips et al., 2004). The typical error is presented as a percentage coefficient of variation (CV) dervied from the formula: $\%CV = 100 \cdot (e^{s} - 1)$, where s is the typical error (Hopkins, 2000; 2002; Phillips et al., 2004).

### 4.4 Results

Standard descriptive (mean ± SD) of the participants' physical and physiological characteristics are shown in Table 4.1. On average, the boys were significantly heavier, taller, and leaner and had a higher peak $\dot{V}O_2$ than the girls. Two-tailed, independent Student's t-tests were determined to compare data between the sexes. The significant differences were found between boys and girls in relation to body mass, t = 2.43 at ($P \leq 0.05$) and in relation to stature t = 3.53, body fat % t = -6.6, and Peak $\dot{V}O_2$, t = 5.4 all were at ($P \leq 0.01$). However, there was no significant difference between boys and girls in relation to age at ($P \geq 0.05$). In addition, there was no significant difference between test 1 and test 2 in relation to age, body mass, stature, body fat % and Peak $\dot{V}O_2$ tests at ($P \geq 0.05$). Moreover, there was no significant difference in the peak heart rate between boys and girls or between the two tests. Peak heart rates (defined as > 95% age predicted maximum) were attained by 21 children (88%) during both tests.

**Table 4.1 Physical and physiological parameters for girls and boys.**

| Parameters | Boys (n=10) | | | Girls (n=14) | | |
|---|---|---|---|---|---|---|
| | Mean | | SD | Mean | | SD |
| Age (y) | 15.5 | ± | 0.99 | 15.9 | ± | 1.04 |
| Body mass (kg) | 57.8 | ± | 5.4 | 52.5 | ± | 4.9* |
| Stature (cm) | 171.8 | ± | 6.04 | 164.6 | ± | 4.0** |
| Body fat (%) | 7.63 | ± | 1.97 | 17.0 | ± | 4.2** |
| Peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 64.3 | ± | 3.83 | 53.8 | ± | 5.2** |

***Between sex difference ($P \leq 0.05$) **Between sex difference ($P \leq 0.01$).**

The running velocity (RV), blood lactate concentration (BLa), heart rate (HR) and oxygen uptake ($\dot{V}O_2$), at lactate threshold (LT), and peak (BLa) for the boys and girls are shown in Tables 4.2. There was no significant difference between boys and girls other than for peak BLa. Also, there were no significant differences in both tests for these parameters except for HR @ LT which indicated greater variance between test 1 and test 2 ($t = 4.59$; $P \leq 0.01$).

There were no significant differences in peak heart rate between girls and boys or tests 1 and 2. Within the treadmill tests, one adolescent did not complete the test due to failure to meet the specified criteria for peak $\dot{V}O_2$. Relationships among peak $\dot{V}O_2$ (expressed both as an absolute measure, $L \cdot min^{-1}$, and relative to body mass, $mL \cdot kg^{-1} \cdot min^{-1}$) and selected parameters were determined for both sexes.

**Table 4.2 Physiological parameters for girls and boys.**

| Parameters | Boys (n=10) | | | Girls (n=14) | | |
|---|---|---|---|---|---|---|
| | Mean | | SD | Mean | | SD |
| RV @ LT | 15.96 | ± | 1.78 | 13.55 | ± | 1.13** |
| BLa @ LT | 1.19 | ± | 0.38 | 1.71 | ± | 0.40* |
| HR @ LT | 169 | ± | 7.0 | 176 | ± | 7.0* |
| $\dot{V}O_2$ @ LT | 64.3 | ± | 3.83 | 53.8 | ± | 5.21** |
| Peak BLa | 7.48 | ± | 1.03 | 6.72 | ± | 1.07 |

***Between sex difference ($P \leq 0.05$)** ****Between sex difference ($P \leq 0.01$).**

The running speed, $\dot{V}O_2$, and HR at 2.5 [$BLa^-$] and LT for the boys and girls are shown in Tables 4.3 and 4.4 respectively. Furthermore, the variability of each of the six parameters measured in the current study was displayed in these tables. The LT (v, $\dot{V}O_2$, and HR) – running speed ($km \cdot h^{-1}$), oxygen uptake ($L \cdot min^{-1}$), and heart rate ($beats \cdot min^{-1}$) respectively, were corresponded to the lactate threshold. The 2.5 (v, $\dot{V}O_2$, and HR) – running speed ($km \cdot h^{-1}$), oxygen uptake ($L \cdot min^{-1}$), and heart rate ($beats \cdot min^{-1}$) respectively that corresponded to the 2.5 $mmol \cdot L^{-1}$ fixed whole [$BLa^-$]. These data revealed a significant difference in HR at 2.5 $mmol \cdot L^{-1}$ fixed whole [$BLa^-$] between test 1 and test 2 for boys and girls ($P = 0.019$) Differences also existed between test 1 and test 2 at ($P = 0.039$ and $P = 0.005$ for $2.5_{VO_2}$ and $2.5_{HR}$ respectively) in girls. Percentage

of coefficients variation did not show a significant variation throughout the parameters in test 1 and test 2 for the boys in table 4.3 and for the girls in table 4.4 at 95% of confidence interval. Two participants did not meet the criteria for demonstrating the interpolation of the 2.5 mmol·L$^{-1}$ fixed blood lactate due to (that both participants had very low level of blood lactate concentration during both tests and at all stages).

**Table 4.3 Tests and variability data for the boys**

| Parameter | n | Test 1 | Test 2 | % Change in mean (95% CI) | %CV (95% CI) |
|---|---|---|---|---|---|
| LTv (km·h$^{-1}$) | 10 | 13.9 ± 0.6 | 13.9 ± 0.6 | 1.3 (-1.8 to 4.5) | 3.1 (2.2 to 5.9) |
| 2.5v (km·h$^{-1}$) | 8 | 15.9 ± 1.1 | 14.6 ± 1.7 | 0.5 (-3.6 to 4.5) | 3.1 (2.0 to 6.8) |
| $LT_{VO_2}$ (L·min$^{-1}$) | 10 | 2.74 ± 0.4 | 3.2 ± 0.4 | -0.9 (-5.5 to 3.9) | 4.8 (3.4 to 9.2) |
| $2.5_{VO_2}$ (L·min$^{-1}$)† | 8 | 3.1 ± 0.4 | 3.2 ± 0.4 | 1.6 (-2.7 to 6.2) | 3.4 (2.2 to 7.8) |
| $LT_{HR}$ (beats·min$^{-1}$)† | 10 | 171 ± 7 | 166 ± 7 | -2.1 (-4.9 to 0.6) | 2.7 (1.9 to 4.9) |
| $2.5_{HR}$ (beats·min$^{-1}$)† | 8 | 187 ± 5 | 183 ± 8 | -2.6 (-4.5 to -0.6)* | 1.6 (1.0 to 3.5) |

**† - parameter data were log transformed; CI – confidence interval, *Difference between test 1 and test 2 (P = 0.019).**

Reliability of all measures across the two tests was demonstrated for all parameters had an intraclass correlation coefficient (ICC) greater than 0.96. Measures for specific parameters are shown in Table 4.5 and the assessment of the level of variability for boys and girls were highly significant in relation to those parameters except for HR @ 2.0 mM, which was less stable in boys only, with non significant intraclass correlation coefficient of (ICC = 0.39, $P \geq 0.05$). Although variances between the two tests were detected in relation to the previous parameters in the boys were observed only in relation to the heart rates during the tests but no significant difference was observed between the group means for any of the two tests.

**Table 4.4 Tests and variability data for the girls**

| Parameter | n | Test 1 | Test 2 | % Change in mean (95% CI) | %CV (95% CI) |
|---|---|---|---|---|---|
| LTv ($km \cdot h^{-1}$) | 13 | 13.0 ± 0.8 | 13.0 ± 0.8 | 0.02 (-0.18 to 0.22) | 2.0 (1.5 to 3.4) |
| 2.5v ($km \cdot h^{-1}$) | 14 | 14.1 ± 1.0 | 14.2 ± 1.2 | 0.12 (-0.13 to 0.38) | 2.1 (1.5 to 3.4) |
| $LT_{VO_2}$ ($L \cdot min^{-1}$) | 13 | 2.1 ± 0.2 | 2.05 ± 0.2 | -1.2% (-3.0 to 0.7) | 2.2 (1.6 to 3.7) |
| $2.5_{VO_2}$ ($L \cdot min^{-1}$)† | 14 | 2.4 ± 0.3 | 2.5 ± 0.3 | 2.1% (0.1 to 4.1)* | 2.4 (1.7 to 3.9) |
| $LT_{HR}$ ($beats \cdot min^{-1}$)† | 13 | 167 ± 10 | 162 ± 11 | -5.5 (-11.0 to 0.1) | 4.0 (2.9 to 6.6) |
| $2.5_{HR}$ ($beats \cdot min^{-1}$)† | 14 | 184 ± 7 | 181 ± 5 | -1.9% (-3.1 to -0.7)* | 1.5 (1.1 to 2.4) |

**† - parameter data were log transformed; CI – confidence interval *Difference between test 1 & test 2 (P= 0.039 & P= 0.005 for $2.5_{VO_2}$ & $2.5_{HR}$ respectively).**

**Table 4.5 Tests and variability data for assessing the level of reliability.**

| Parameter | ICC | | 95% LoA | | Typical Error | |
|---|---|---|---|---|---|---|
| | Boys | Girls | Boys | Girls | Boys | Girls |
| RV @ LT | 0.91 | 0.93 | 0.3 ± 1.4 | 0.0 ± 0.7 | 0.4 | 0.2 |
| RV @ 2.0 mM | 0.96 | 0.97 | 0.4 ± 1.5 | 0.2 ± 0.8 | 0.5 | 0.3 |
| RV @ 2.5 mM | 0.86 | 0.96 | 1.0 ± 1.4 | 0.1 ± 0.9 | 0.6 | 0.3 |
| $\dot{V}O_2$ @ LT | 0.97 | 0.97 | -0.03 ± 0.4 | -0.02 ± 0.12 | 0.5 | 0.4 |
| $\dot{V}O_2$ @ 2.0 mM | 0.89 | 0.98 | 0.1 ± 0.3 | 0.06 ± 0.16 | 0.1 | 0.06 |
| $\dot{V}O_2$ @ 2.5 mM | 0.92 | 0.97 | 0.06 ± 0.3 | 0.05 ± 0.16 | 0.11 | 0.06 |
| HR @ LT | 0.82 | 0.82 | -3 ± 12 | -5 ± 18 | 6 | 3 |
| HR @ 2.0 mM | 0.39* | 0.81 | -3 ± 16 | -3 ± 7 | 6 | 2 |
| HR @ 2.5 mM | 0.60 | 0.81 | -5 ± 8 | -4 ± 9 | 5 | 3 |

*** Non-significant ($P \geq 0.05$)- all other ICCs are significant at ($p0 \leq 0.01$). 95% LoA is bias (error), Running velocity (RV) ($km \cdot h^{-1}$), Lactate threshold (LT), Oxygen uptake ($\dot{V}O_2$) ($L \cdot min^{-1}$), and heart rate (HR) ($beats \cdot min^{-1}$).**

## 4.5 Discussion

Assessments of the reliability statistics for adolescent runners male and female in both test and retest indicated that height, weight and peak $\dot{V}O_2$ were in rare conformity with available previous studies (Armstrong et al., 1990; Boreham et al., Slaughter et al. 1990) except for percent body fat and peak $\dot{V}O_2$ (McVeigh et al. 1995). A significant difference was detected in the present study between sexes and between both tests in relation to the above parameters. However, there were no significant differences in peak HR between boys and girls or between tests. This suggests that both sexes drive themselves to a comparable physiological end point on both tests regardless of individual inconsistency in both tests. The majority of participants (88%) were able to attain maximal heart rates (greater than 95% age predicted formula) all the way through both treadmill test performances.

Heart rates at fixed blood lactate 2.0 and 2.5 mM were less stable with some variability in the performance for both sexes and not significant only in boys with intraclass correlation coefficient of variability for (HR @ 2.0 mM was ICC= 0.39 $P \geq 0.05$). However, higher levels of reliability were detected in relation to peak heart rates in both tests and sexes despite that individual variation. There was no relationship between participant's level of performance during test and retest. Since all participants in this study were well trained and seem to be more familiar to the hard work out or physical performance, in agreement with (Hickey et al., 1992; Hopkins, 2000) this may have motivated them to perform well in both tests and thus limited any potential learning effect (Coldwells et al. 1994).

Regardless of the consequence of reliability at what time tests may be applied to evaluate alterations in performance, there is a lack of studies using well-trained adolescent athletes. The nonexistence of reliability studies concerning adolescent runners averts judgment of the preceding adolescent runners. However, the reliability data from these studies are in wide-ranging conformity with the assessments accounted by the previous researchers investigating the reliability of anaerobic assessments (McVeigh et al., 1995; Atkinson et al., 1995; Schabort et al., 1998; Tong et al., 2001).

There was a reduction in heart rates (Tables 4.3 and 4.4) at test 2 compared to test 1. This occurred in relation to HR @ LT and HR @ 2.5 mM with significant differences at

($p0 \leq 0.05$ and $p0 \leq 0.01$) respectively for boys and girls corresponding to LT and at ($p0 \leq 0.05$) in girls only for HR @ 2.5 mM. These results are similar to those reported by Heitkamp et al. (1991). Thus HR was not very stable between the two tests. Also, significant differences were observed in relation to HR @ LT between sexes at ($p0 \leq 0.05$). Although, Heitkamp et al., (1991) suggested that HR reduction between tests maybe due to learning effect of treadmill running and a subsequent reduction in oxygen cost. Therefore, a lesser demand for oxygen may lead to a reduction in HR. Grant et al., (2002) estimated limits of agreement of -11.6 to -7.1 beats·min$^{-1}$ for moderately fit group and -22.4 to -15.4 beats·min$^{-1}$ for the unfit group respectively, these values indicate that HR was not stable between the two tests. Limits of agreement in Grant et al.'s study were lower than those recorded for both tests and for boys and girls in this study (Table 4.5).

Tests and variability data for assessing the level of reliability (Table 4.5) indicated that, the reliability of both tests in the present study were similar to those presented by others (Weltman et al. 1990., Harman et al. 1990., Naughton et al. 1992., Tong et al. 2001), but for different sports, age groups and different test protocols. Naughton et al. (1992) investigated the variability of Wingate performance in young boys with range of age from 6-12 years. They observed a tendency of mean power output reduction throughout the above age era when estimated the coefficient of variation of 9% in children for the test retest in peak power output. Consequently, the reliability of test retest for adolescent runners in the present study may improve with increasing age and maturation. Also, high correlation coefficients of r=0.95 for HR at LT and r=0.96 for HR at 4.0 mM, were reported by (Weltman et al. 1990) in adult endurance runners. These findings are comparable to our findings in the present study except for HR @ 2.0 mM (Table 4.5).

Regardless the imperative of variability some of the available reliability data are in frequent conformity with the values accounted by investigators assessing the reliability of sport specific such as anaerobic tests (Schabort et al., 1998; 1999; Tong et al., 2001). It was indicated that reliability of performance is reliant on length of the test, for example, short period high intensity performance is subject to additional variation and is affected by aspects such as motivation and lack of pacing (Hickey et al. 1992).

## 4.6 Conclusion

The results of this study show that the assessment of running velocity and $\dot{V}O_2$ in boys and heart rates in both girls and boys were as expected and corresponded to the blood lactate parameters. Therefore, this suggests that these data are valid measures of endurance performance in adolescent runners. In this study the reproducibility of the above parameters were satisfactory when compared with other studies in different sports and age groups. Finally whilst there are some inherent problems with some measures used in this study (heart rate for example), blood lactate measures taken during endurance performance in trained boys and girls are reproducible and can thus be used as valid measures in further studies.

# Chapter Five

# Selected physiological predictor variables and endurance running performance in trained adolescent athletes

## 5.0 Selected physiological predictor variables and endurance running performance in trained adolescent athletes

### 5.1 Introduction

This study was designed to examine the selected physiological predictor variables that are most strongly associated with endurance running performance in endurance trained, adolescents. It is acknowledged that the highest power output that can be maintained over a set distance, or over time, will determine the relative success of an endurance athlete (Billat, 1996). However, a number of physiological determinants of endurance performance including running economy, a variety of blood lactate variables, maximum oxygen uptake ($\dot{V}O_2$ max), speed at $\dot{V}O_2$ max ($v\dot{V}O_2$ max), and the fractional utilization of $\dot{V}O_2$ max have all previously been identified in the adult population (Farrell et al., 1979; Powers et al., 1984; Snell and Mitchell, 1984; Tanaka and Matsuura, 1984; Yoshida et al., 1987; Fay et al., 1989; Billat and Koralsztein, 1996). It has been known for many years that a high $\dot{V}O_2$ max is a valuable means to evaluate the cardiorespiratory function and to perform a high level of aerobic endurance activity (Taylor et al., 1955). The $\dot{V}O_2$ max is the most widely accepted single measure of physical fitness in the adult population (Shephard, 1968). Longitudinal research has suggested that between 14 and 21 years of age, superior running performance may be associated with high absolute, rather than body mass relative, peak $\dot{V}O_2$[2]; i.e. $L \cdot min^{-1}$ not $mL \cdot kg^{-1} \cdot min^{-1}$ (Murase et al., 1981). In another study, ventilatory threshold (VT) was related to 3000 m time trial performance in prepubertal boys (Unnithan et al., 1995) although the authors concluded that peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) appeared to be the single most important factor associated with success at 3000 m. Within a group of eight 'elite' cross-country runners, anaerobic capacity and running economy were closely related to best career mile (BCM) run time, whereas peak $\dot{V}O_2$ was not (Mayers and Gutin, 1979). However, the inter-subject variability for the period between the measurement of BCM and peak $\dot{V}O_2$ may have affected the results. Moreover, mile run time, which was measured at the same time as peak $\dot{V}O_2$, was significantly correlated with peak $\dot{V}O_2$ ($r = -0.88$). In contrast, Coyle et al., (1988) indicated that there were no significant

[2] Peak $\dot{V}O_2$ is preferred to $\dot{V}O_2$ max when referring to children's studies because young people often fail to demonstrate a plateau in oxygen uptake during an incremental exercise test.

improvements in endurance performance related to increases in $\dot{V}O_2$ max following exercise training.

The measurement of the blood lactate response to exercise is increasingly regarded as the most acceptable criterion of endurance capacity, and is widely used to assess and train athletes and non-athletes in different sports (Maffulli et al., 1991a; Maffulli et al., 1991b; Weltman et al., 1992; Wakayoshi et al., 1993; Jones and Carter, 2000; Naughton et al., 2000). Studies related to endurance performance in children have used a variety of different events, race distances, and sports, but few have assessed the blood lactate response (e.g. Mayers and Gutin, 1979; Murase et al., 1981; Rowland, 1985; Rowland et al., 1987; 1988; Unnithan et al., 1995). Indeed, there appear to be no studies of adolescents who compete in middle distance running events. This may prove to be an interesting group to focus on because of the likely contribution from both aerobic and anaerobic energy sources in these events. Moreover, these events feature prominently in most athletic club and school sports programmes. Running speed at the blood lactate threshold (LT) in untrained adolescent boys has been used as a predictor variable of performance (Tanaka, 1986). However, the detection of the LT during incremental exercise using different suggested models has been identified previously as problematic (Morton, 1989; Yeh et al, 1983). Therefore, fixed blood lactate concentrations have been used in an effort to avoid some of the subjectivity related to the identification of a threshold (e.g. Weltman et al., 1990; Tolfrey and Armstrong, 1995). It has been suggested that in mature populations the measurement of blood lactate concentration [$BLa^-$], when used in conjunction with $\dot{V}O_2$ max or running speed, may provide the best method to predict and monitor endurance running performance (e.g. Nichols et al., 1997). This is especially relevant when attempting to differentiate performance within a homogenous trained group of athletes. Whether blood lactate can be similarly used to predict running performance in endurance adolescents trained has yet to be fully elucidated. In adults, increases in blood lactate concentration in response to sub-maximal exercise have been described in a variety of different ways using an assortment of terminology. This may have lead to some confusion in deciphering the main practical uses of blood lactate for monitoring and predicting endurance performance. Disparity in research findings involving children and adolescents may have resulted from differences in procedures and the lactate variable employed. It is clear, however, that considerable differences in the blood lactate response to exercise do exist between children and

adults (Tolfrey and Armstrong, 1995). Therefore, it would be prudent to assess the way in which lactate measurements taken during exercise might be employed to predict and monitor endurance performance in adolescent children. The focus in this study will be on the relationship between the selected physiological predictor variables and endurance running performance times in trained adolescent athletes.

## 5.2 Methods

### 5.2.1 Participants

Forty sub-elite, endurance trained, adolescent children, 23 boys and 17 girls volunteered to participate in this study. They were the 800 m and 1500 m finalist from the 1999 Cheshire and Staffordshire County Athletics Championships. The running performance times were used as the field-based performance measure in this study. The participants were tested within four weeks of the Championships. Approval for the study procedures was obtained from the Manchester Metropolitan University Research Ethics Committee. All participants and at least one of their parents received a written explanation of the nature of the study and general health was assessed using a pre-test questionnaire. Both the participant and at least one parent completed an informed consent form prior to any active participation in the study.

### 5.2.2 Anthropometric Measures

Stature was measured to the nearest 0.1 cm. (Seca stadiometer 208) and body mass to the nearest 0.1 kg (Seca beam balance 710). Participants were dressed in T-shirt and shorts without shoes. All participants' ages were calculated from their date of birth to the test date to the nearest tenth of a year. Descriptive characteristics of the participants are summarised in Table 5.1.

### 5.2.3 Body composition

Please see chapter 3 for more details.

**Table 5.1 Physical and performance characteristics**

| Variables | Boys (n = 23) | Girls (n = 17) |
|---|---|---|
| Age (years) | 16.1 ± 0.6 | 16.0 ± 0.8 |
| Stature (cm) | 174.6 ± 4.6 | 163.0 ± 4.9** |
| Body mass (kg) | 61.4 ± 5.6 | 50.7 ± 4.4** |
| Body fat (%) | 10.6 ± 3.1 | 17.0 ± 2.9** |
| 800 m time (min:s) | 2:10.4 ± 0:08 | 2:25.8 ± 0:08** |
| 1500 m time (min:s) | 4:33.9 ± 0:22 | 5:12.8 ± 0:22** |

All values are means ± SD; ** Significant difference between boys and girls ($P<0.01$).
800 m event – n = 18 boys, n = 14 girls; 1500 m event – n = 16 boys, n = 13 girls.

### 5.2.4 Anaerobic Power: Wingate anaerobic test (WAnT), vertical jump, and flexibility

Peak power (W) was assessed using a 30 s Wingate anaerobic power test (WAnT). The participants performed two trials interspersed by an active recovery period of 30 minutes. Capillary blood samples were taken prior to the start, directly at the end of the first trial, and three minutes later. These procedures were repeated for the second WAnT trial. The anaerobic test was completed within a week of the treadmill test. The best trial was recorded for both the boys and girls. A standard vertical jump test was measured using an electronic vertical jump mat. Each participant performed three trials and the best trial was recorded to the nearest 0.1 cm. Flexibility was assessed from a basic sit and reach position and the best trial out of three was recorded to the nearest 1.0 cm.

### 5.2.5 Treadmill (TM) protocol and test procedures

Each participant completed a two-phase treadmill (Powerjog EG30) test following habituation and familiarisation to treadmill walking and running. Phase one was a discontinuous incremental running test (Figure 3.1) with increments in running speed of 1 $km \cdot h^{-1}$ at the beginning of each stage. The incremental test consisted of six to eight 3-min stages following a 5 min warm-up of walking and running up to 7 $km \cdot h^{-1}$. The speed at the beginning of the actual test (9-11 $km \cdot h^{-1}$) was determined according to each subject's running performance time. Each stage was separated by a one-minute rest period for finger-tip capillary blood sampling. Following a 10-min active recovery

period, phase two was completed. This phase involved running at a fixed speed with the treadmill gradient being increased by 1% each min (Figure 3.1 chapter 3).

A resting fingertip, capillary blood sample was taken to determine the whole blood lactate concentration prior to the start of the test. Whole blood samples were also taken during the test at the end of each stage (Figure 3.1). The fingertip was wiped with a mediswab saturated with 70% v/v Isopropyl Alcohol and dried with a tissue. The blood samples were collected in heparinised capillary tubes after discarding the first drop of blood. The blood was analysed immediately in duplicate for whole blood lactate concentration using an automatic analyzer (YSI 1500 Sport; Yellow Springs, USA). The analyzer was calibrated with a known standard of 5 $mmol \cdot L^{-1}$ prior to testing and after every 20 samples.

Running speeds corresponding to 2.0, 2.5, and 4.0 $mmol \cdot L^{-1}$ fixed whole blood lactate concentrations [$BLa^-$] (v2.0, v2.5, and v4.0) and the lactate threshold (vLT) were calculated via linear interpolation (Figure 3.2). The lactate threshold was defined as the first sustained increase in blood lactate concentration above the baseline value, the level of precision was to the nearest 1 $km \cdot h^{-1}$ for the LT and to the nearest 0.1 $km \cdot h^{-1}$ for the fixed [$BLa^-$].

### 5.2.6 Determination of sub-maximal and peak $\dot{V}O_2$

Heart rate (HR) was recorded using short-range radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland) whilst rating of perceived exertion (RPE) was recorded at the end of each stage using the Borg scale (Borg, 1982). During phase one of the test, expired air was collected into Douglas bags during the last min of each exercise stage. These measurements were also taken for consecutive 1 min stages at the end of phase two of the test to determine peak $\dot{V}O_2$. The concentration of oxygen and carbon dioxide in the expired air samples was determined using a paramagnetic oxygen analyser (Servomex, Sussex, UK) and an infrared carbon dioxide analyser (Servomex, Sussex, UK). Expired air volumes were measured using a dry gas meter (Harvard Apparatus, Kent, UK) and corrected to standard temperature and pressure (dry). Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), expired minute ventilation, and respiratory exchange ratio (RER) were calculated for each Douglas bag. The analyser was calibrated with standard gases of known concentration before each test session. The

running speed that corresponded to peak $\dot{V}O_2$ ($v\dot{V}O_2$ peak) was estimated by linear interpolation of the sub-maximal running speeds and $\dot{V}O_2$ values collected during phase one of the test (Daniels et al., 1984; Billat et al., 1994b; Jones and Carter, 2000). The level of precision for $v\dot{V}O_2$ peak was to the nearest 0.1 $km \cdot h^{-1}$ for each athlete.

### 5.2.7 Data analyses

The data were stored and analysed using the Statistical Package for the Social Sciences (SPSS for Windows Version 9.0). Descriptive statistics were calculated for the 23 boys and 17 girls. Two-tailed, independent Student's t-tests were used to compare physical, performance, physiological, and blood lactate differences between the boys and the girls. Whereas multiple regressions would be the preferred method of analyses the numbers of subjects included in the study made this approach untenable. Therefore the bivariate relationship between these lactate variables and the performance times were calculated using Pearson's product moment correlation coefficients. The relationship between some other selected physical and physiological variables and the performance times were similarly determined. These variables included chronological age, peak $\dot{V}O_2$, $v\dot{V}O_2$ peak, running economy ($\dot{V}O_2$ in $mL \cdot kg^{-1} \cdot min^{-1}$ at 12 $km \cdot h^{-1}$), peak and mean WAnT power, vertical jump height, and flexibility. Statistical significance was set at $P \leq 0.05$.

## 5.3 Results

On average, the boys were taller, heavier, leaner and better performers in the both the 800m and 1500 m events than the girls (Table 5.1, $P<0.01$). The boys who competed in the 800m event had greater aerobic and anaerobic peak and mean power than the girls who competed over the same distance (Table 5.1). The $v\dot{V}O_2$ peak was also significantly faster for the boys than the girls. There were no significant differences between boys and girls for running economy ($\dot{V}O_2$ at 12 $km \cdot h^{-1}$) or flexibility. Apart from the difference in vertical jump test performance, these between sex differences were also apparent when comparing the boys and girls who compete in the 1500m event ($P<0.01$).

Peak $\dot{V}O_2$, percent peak $\dot{V}O_2$, and running speed at all three fixed [$BLa^-$] were different when comparing the boys and girls by 800m and 1500m event (Table 5.2). For peak $\dot{V}O_2$ and running speed, the values for the boys were higher than the girls', whereas the percent $\dot{V}O_2$ values at fixed blood lactate were lower.

For the boys, v$\dot{V}O_2$ peak and running economy ($\dot{V}O_2$ at 12 $km \cdot h^{-1}$), percent peak $\dot{V}O_2$, at each [$BLa^-$], and v$\dot{V}O_{2peak}$ were the only predictor variables significantly associated with their run times in the 800m event (Tables 5.2 and 5.3). The latter variable demonstrated a moderate, negative relationship, whereas the other relationships were all positive. The inter-independent variable correlations between RE, 2.0% $\dot{V}O_2$, 2.5% $\dot{V}O_2$, 4.0% $\dot{V}O_2$, and v$\dot{V}O_2$, were all significant with absolute coefficients ranging from r= 0.40 to 0.76 ($P<0.05$). Running economy, chronological age, and the running speed at each [$BLa^-$] for girls were significantly correlated with the 800-m run times (Tables 5.2 and 5.3). The former variable demonstrated a weak, positive association whereas the other relationships were all negative. When the chronological age was partialled out for the girls, no significant relationships remained between the physiological variables and 800-m performance. None of the other listed variables were significantly associated with the 800-m performance times for either boys or girls. The inter-independent variable correlations between age, RE, v2.0, v2.5, and v4.0 were all significant with absolute ranging from r= 0.59 to 0.72 ($P<0.05$). Although the running speeds at the three fixed [$BLa^-$] were the strongest predictors for the boys' 1,500-m run times ($P<0.05$), they were only weak to moderate, negative relationships. In addition, peak $\dot{V}O_2$ and v$\dot{V}O_2$peak had weak, negative associations with the 1,500-m performance times. The correlations between v2.0, v2.5, v4.0, peak $\dot{V}O_2$, and v$\dot{V}O_2$ peak were all significant with absolute coefficients ranging from r = 0.52 to 0.77 ($P<0.05$).

Chronological age had a moderate, negative relationship with the 1,500-m performance time for the girls (r = -0.77, $P<0.01$). Peak $\dot{V}O_2$, v$\dot{V}O_2$ peak, and mean WAnT power also had significant negative relationships with this race time. The $\dot{V}O_2$ ($P<0.05$) and running speeds ($P<0.01$) corresponding to the fixed [$BLa^-$] were all negatively associated with the 1,500-m performance times for the girls. When chronological age was partialled out for the girls, most of the zero order correlation coefficients were reduced in magnitude and some no longer quite reached the 0.05 alpha level (Tables 4

and 5). However, the overall trend was largely unaffected. The inter-predictor correlations between v2.0, v2.5, v4.0, $\dot{V}O_2$2.0, $\dot{V}O_2$2.5, $\dot{V}O_2$4.0, peak $\dot{V}O_2$, and v$\dot{V}O_2$ peak were all significant with absolute coefficients ranging from r = 0.51 to 0.93 ($P<0.05$).

For the girls, chronological age and absolute mean WAnT power were the strongest predictor variables for their 800m run times (Table 5.2) with v2.5 also contributing to the variance. Only v2.5 and v4.0 were different when comparing the blood lactate characteristics between the boys and girls who compete in the 800m event (Table 5.3). For the 1500m, between sex differences were identified at all of the fixed lactate reference values and the vLT.

The three fixed blood lactate variables were the only predictors significantly related to the boys' 1500m run times. They were also significantly associated with the girls' 1500m times. The vLT was the strongest predictor variable at this longer distance in girls with chronological age, v$\dot{V}O_2$peak, and absolute mean WAnT power also contributing to the variance in 1500m run times for the girls. If independent variables that were described in the methods section do not appear in (Table 5.2), they were not significantly associated with the performance times for either event.

**Table 5.2 Physiological characteristics by sex and running event**

| Variable | 800m event | | 1500m event | |
|---|---|---|---|---|
| | Boys (n = 18) | Girls (n = 14) | Boys (n = 16) | Girls (n = 13) |
| Age (years) | 16.0 ± 0.6 | 16.0 ± 0.8 | 16.2 ± 0.5 | 16.0 ± 0.8 |
| Peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 65.2 ± 4.0 | 56.6 ± 4.9** | 65.5 ± 4.0 | 56.9 ± 4.8** |
| $\dot{V}O_2$ @12 $km \cdot h^{-1}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 41.3 ± 2.5 | 41.5 ± 3.1 | 41.2 ± 2.6 | 42.1 ± 3.1 |
| v$\dot{V}O_2$ peak ($km \cdot h^{-1}$) | 19.0 ± 1.4 | 17.1 ± 1.3** | 19.2 ± 1.3 | 17.1 ± 1.3** |
| Peak WAnT power (W) | 644 ± 89 | 473 ± 59** | 637 ± 97 | 461 ± 54** |
| Peak WAnT power ($W \cdot kg^{-1}$) | 10.5 ± 1.1 | 9.3 ± 0.7** | 10.5 ± 1.2 | 9.2 ± 0.7** |
| Mean WAnT power (W) | 537 ± 68 | 402 ± 47** | 529 ± 72 | 398 ± 48** |
| Mean WAnT power ($W \cdot kg^{-1}$) | 8.8 ± 0.7 | 7.9 ± 0.7** | 8.8 ± 0.7 | 7.9 ± 0.7** |
| Vertical jump (cm) | 37.8 ± 4.9 | 33.0 ± 3.7** | 36.5 ± 3.5 | 33.7 ± 4.2 |
| Flexibility (cm) | 5.7 ± 8.7 | 7.0 ± 11.2 | 4.7 ± 8.8 | 9.9 ± 10.0 |

** Significant within event difference between boys and girls ($P<0.01$).

**Table 5.3 Blood lactate characteristics by sex and running event**

| Variable | 800m event | | 1500m event |
|---|---|---|---|
| | Boys (n = 18) | Girls (n = 14) | Boys (n = 16) |
| Resting [$BLa^-$] ($mmol \cdot L^{-1}$) | 1.0 ± 0.3 | 0.9 ± 0.3 | 1.0 ± 0.3 |
| Post-peak $\dot{V}O_2$ [$BLa^-$] ($mmol \cdot L^{-1}$) | 7.0 ± 1.7 | 6.6 ± 1.2 | 7.0 ± 1.7 |
| v2.0 ($km \cdot h^{-1}$) | 14.8 ± 1.8 | 13.7 ± 1.2 | 15.1 ± 1.7 |
| v2.5 ($km \cdot h^{-1}$) | 15.6 ± 1.6 | 14.1 ± 1.2* | 15.7 ± 1.7 |
| v4.0 ($km \cdot h^{-1}$) | 17.1 ± 1.3 | 15.8 ± 1.1** | 17.2 ± 1.4 |
| vLT ($km \cdot h^{-1}$) | 13.1 ± 0.6 | 12.8 ± 0.7 | 13.2 ± 0.7 |

v2.0, v2.5, and v4.0 – running speed at 2.0, 2.5, and 4.0 $mmol \cdot L^{-1}$ fixed whole blood lactate concentrations; vLT – running speed at lactate threshold.

* Significant within event difference between boys and girls ($P<0.05$).

** Significant within event difference between boys and girls ($P<0.01$).

**Table 5.4 Correlations for boys and girls between physiological variables and running performance time**

| Predictor variables | 800 m event (s) | | 1500 m event (s) | |
|---|---|---|---|---|
| | Boys (n=18) | Girls (n=14) | Boys (n=16) | Girls (n=13) |
| Age (years) | ns | -0.76** | ns | -0.77** |
| Peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | ns | ns | ns | ns |
| v $\dot{V}O_2$ peak ($km \cdot h^{-1}$) | -0.62** | ns | ns | -0.74** |
| $\dot{V}O_2$ @ 12 $km \cdot h^{-1}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | -0.62** | ns | ns | ns |
| v2.0 ($km \cdot h^{-1}$) | ns | ns | -0.53* | -0.79** |
| v2.5 ($km \cdot h^{-1}$) | ns | -0.57* | -0.53* | -0.79** |
| v4.0 ($km \cdot h^{-1}$) | ns | ns | -0.50* | -0.80** |
| vLT ($km \cdot h^{-1}$) | ns | ns | ns | -0.87** |
| Mean WAnT power (W) | ns | -0.73** | ns | -0.72** |

ns - not significant ($P > 0.05$)

* Significant bivariate correlation with 800 m and 1500 m race time (*P<0.05*)

** Significant bivariate correlation with 800 m and 1500 m race time (*P<0.01*)

Given age was such a strong factor when considering the girls' results, partial correlations were calculated for the significant predictor variables described above with age held constant. Following this adjustment, v2.5 and mean WAnT power were no longer significantly related to the 800m run times. For the 1500m event, v $\dot{V}O_2$ peak, v4.0, and vLT were the only remaining variables that were significantly related to the run times once variations in age had been accounted for (r = -0.61, -0.60, and -0.67 respectively, $P<0.05$).

## 5.4 Discussion

The peak $\dot{V}O_2$, v$\dot{V}O_2$peak, and race times reported for both the boys and girls show that they were all endurance trained and competing at a sub-elite level. The peak $\dot{V}O_2$ values are also similar to those reported previously for other trained adolescent athletes including elite age-group triathletes (Bunc et al., 1996; Fernhall et al., 1996; Unnithan et al., 1996). On average the boys completed both race distances faster than the girls, which is consistent with the findings of sex-related differences in endurance running performance in adults (Pate et al., 1992). Both Fernhall et al. (1996) and Cunningham (1990) suggested that the between sex differences in performance were probably due to the 23% and 13% higher peak $\dot{V}O_2$ values for the boys in their respective studies. Given the boys in the current study had peak $\dot{V}O_2$ values that were on average 13% higher than the girls, it would be reasonable to suggest that this may have been a contributory factor. However, it should be recognised that the performance events in this study are both shorter than those in the earlier studies with which they are being compared. Moreover, peak $\dot{V}O_2$ was not a significant predictor variable in the current study which may suggest that other factors would have to be used to explain the performance differences between the boys and girls.

The finding that chronological age for the girls was significantly associated with running performance times in both the 800 m and 1500 m events is in agreement with another study conducted with high-school, female cross-country runners (Fernhall et al., 1996). Moreover, the present findings concerning age have been supported by other studies of children in different age groups (Armstrong et al., 1991; Baxter-Jones et al., 1993). Several recent studies have indicated that both the aerobic and the anaerobic energy systems contribute significantly to the total energy yield during middle distance running events (Spencer et al., 1996; Hill, 1999; Spencer and Gastin, 2001). Although these studies were conducted with University aged 800 m and 1500 m athletes; the absolute WAnT power data for the girls in the current study may at least partially support this theory. However, given the body mass relative WAnT power measurements ($W \cdot kg^{-1}$) were not significantly related to the performance measures for the girls, it would appear that differences in size across the age span accounted for the relationship between the absolute mean power and performance times.

It has been suggested that an improvement in endurance performance may be influenced, in part, by anaerobic mechanisms that change as a child ages (Rowland, 1989). This is further supported by the fact that both the mean and peak WAnT power values for the girls were significantly related to their age (not shown in previous Tables). Furthermore, using post-competition blood lactate concentrations as a marker of anaerobic metabolism (Rowland, 1990; Lacour et al., 1990), it has been estimated that 41% of the energy expended during an 800 m race came from the anaerobic energy system. The spread of data for age and performance times was not noticeably different between the boys and girls. Therefore, this is unlikely to have affected the correlation coefficients.

The results of this study demonstrated that peak $\dot{V}O_2$ was not significantly related to middle-distance running performance times. This is in contrast to a number of studies that have suggested that this measure is an important determinant of endurance running performance. For example, Butts (1982) studied a group of female, high-school cross country runners and indicated that peak $\dot{V}O_2$ and 3000 m running performance times were related ($r = -0.55$, $P<0.05$). Tanaka et al. (1984) investigated a group of young male runners, who competed over the 5000 m distance, across a period of nine months. The three separate tests that were conducted in this time revealed correlation coefficients between peak $\dot{V}O_2$ and the running performance times ranging from $r = -0.53$ to $-0.68$. Although studying a much younger age group, Unnithan et al. (1995) reported that peak $\dot{V}O_2$ was the single most important factor associated with success at 3000m in prepubertal boys. Mayers and Gutin (1979) reported that mile (1609m) run time was significantly correlated with peak $\dot{V}O_2$ ($r = -0.88$). More recently, Fernhall et al. (1996) found that peak $\dot{V}O_2$ was significantly related to 3 and 2 mile cross-country race times in boys and girls respectively. However, following a stepwise multiple regression analysis they concluded that it was not possible to separate the independent contribution of either peak $\dot{V}O_2$ or the $\dot{V}O_2$ at LT to the performance times. One of the obvious differences between most of these studies is the variation in race or performance distance under scrutiny. It is likely that aerobic metabolism plays a greater role in the events greater than 1500 m compared to the shorter 'middle distance' events in the current study. Therefore, it is not surprising that peak $\dot{V}O_2$ accounted for the greater proportion of the variance. The fact that the athletes in this study were

homogeneous when considering the peak $\dot{V}O_2$ values coupled to the relatively small sample sizes may have led to a reduction in the strength of the correlations shown in Table 5.4. It has been suggested that peak $\dot{V}O_2$ may not differentiate performance capability in groups of athletes with similar performance times (Conley and Krahenbuhl, 1980; Billat and Koralsztein, 1996; Jones and Doust, 1998).

The oxygen uptake required to run at a certain speed has been termed the running economy and can be reported in units of $mL \cdot kg^{-1} \cdot min^{-1}$ or $mL \cdot kg^{-1} \cdot km^{-1}$ (Jones and Doust, 1998). Running economy is important in long distance running events because it will determine the running speed that can be sustained for a given metabolic rate: that is, if two athletes with the same peak $\dot{V}O_2$ ran at 85 % of their $\dot{V}O_2$ max, the athlete with the better running economy would run at a faster speed. The running speed at peak $\dot{V}O_2$ ($v\dot{V}O_2$), a composite measure of peak $\dot{V}O_2$ and running economy, can be calculated by dividing peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) by running economy ($mL \cdot kg^{-1} \cdot km^{-1}$), and has been shown to be a powerful predictor of performance in adult runners (Morgan et al., 1989; Noakes et al., 1990; Jones and Doust, 1998). The relationship between $v\dot{V}O_2$ peak and the 800 m and 1500 m run times for the boys and girls respectively partially supports these studies. Cunningham (1990) also found a significant relationship between $v\dot{V}O_2$ peak and running performance in 22 female, high-school runners, mean age 15.9 years. Billat (1996) recently reported that $v\dot{V}O_2$ peak was closely related to 800 m running performance in adult runners, although this was not supported by Maffulli et al. (1991b) who studied 16, 12-16 year old middle distance athletes.

Studies by Grant et al. (1997) and Tanaka et al. (1984) both reported strong correlations between the $v\dot{V}O_2$ peak and longer race distances (3000 m and marathon respectively). The age range in the former study was considerably larger than in the current study that may have influenced the strength of the correlation (range 18 to 33 years). Moreover, it is difficult to know whether the age and possible maturity differences between 16 and 18 years of age would have affected the results in conjunction with the much longer performance distances. Unfortunately, it has only been possible to compare the results from the current study to mainly adult-based ones because of a distinct paucity of research with younger trained athletes.

Indeed, the author is unaware of any previous studies that have related v$\dot{V}O_2$ peak to performance in the transition period between adolescence and adulthood. Some research groups have hypothesised that the running speeds at certain lactate concentrations are better predictors of shorter endurance races when compared to longer distances (Farrell et al., 1979; Kumagai et al., 1982; Tanaka and Matsuura, 1984; Tanaka et al., 1984). Yoshida et al. (1990) indicated that blood lactate concentration is highly correlated with running performance for distances of 800 m, 1500 m and 3000 m in female's runners. In addition, it has been reported that the running speed associated with the onset of blood lactate accumulation (OBLA) at 4 mmol·L$^{-1}$ and the running speed at 12 km·h$^{-1}$ were both good predictors of running performance in non-athletes (Duggan and Tebbutt, 1990). The current data appear to support this when looking at the running speeds corresponding to the three fixed blood lactate concentrations and vLT for the girls who competed in the 1500 m event. When considering the 1500 m event, there is nothing to choose between any of the running speeds at the fixed lactate variables for both sexes (Table 5.4). Interestingly, most other studies that have examined the relationship between running performance and blood lactate appear to have focused on either heart rate or $\dot{V}O_2$ rather than running speed (Fernhall et al., 1996; Duncan and Howley, 1999). Given most athletes tend to base their training on lap split times; it is surprising that more studies have not elected to use a variable that may be directly related to the event itself.

## 5.5 Conclusion

In conclusion, the results from the current study tend to suggest that for the 'classic' middle distance event of 1500 m, running speeds corresponding to the fixed [BLa$^-$] may prove to be a useful measure in endurance trained boys and girls. Unlike previous studies, peak $\dot{V}O_2$ was not a significant physiological predictor of 1500 m performance in either boys or girls. For the girls, although the 1500 m performance appeared to be underpinned by both aerobic and anaerobic factors, once variations in age or size had been considered, none of the anaerobic measurements were significantly associated with performance. Whereas v$\dot{V}O_2$ peak and running economy may prove to be of some value when considering the 800 m for boys, the v2.5 was the only meaningful physiological predictor variable for the girls once differences in age and body size had

# Chapter Six
# Maximum lactate steady state (MLaSS) in trained adolescent runners

## 6.0 Maximum lactate steady state (MLaSS) in trained adolescent runners

### 6.1 Introduction

The data from the first study appear to suggest that the blood lactate response to exercise may be an important physiological variable to consider when attempting to provide support for adolescent, middle distance endurance runners. However, it is not clear which blood lactate variable may prove to be the most informative when studying young people. The primary finding from the first study was that a fixed blood lactate concentration [$BLa^-$] may provide a suitable starting point from which to investigate further.

Over the last twenty-five years, a number of research studies popularised the use of a single fixed [$BLa^-$] (4.0 $mmol \cdot L^{-1}$) to monitor and enhance endurance exercise training programmes with adults (Stegmann et al., 1981; Sjodin et al., 1982; Stegmann and Kindermann, 1982; Heck et al., 1985; Jacobs, 1986; Weltman, 1995 ). In children, the use of a single fixed [$BLa^-$] (2.5 $mmol \cdot L^{-1}$) seems to be the most appropriate criterion for assessing aerobic performance ( Williams and Armstrong, 1991). The rationale for this fixed [$BLa^-$] variable was that it was supposed to represent the maximum exercise intensity at which an equilibrium between blood lactate accumulation and elimination occurred (Kindermann et al., 1979; Heck et al., 1985). This physiological variable was said to represent the highest exercise intensity that could be supported by oxidative energy metabolism (Mader and Heck, 1986). That is, prolonged steady state exercise at this intensity should not lead to early fatigue as a result of lactic acidosis (Maffulli et al., 1991; MacRae et al., 1992).

It is now well recognised that to use a single blood lactate value to represent this equilibrium in all individuals is too simplistic, although it remains attractive from a practical standpoint (Weltman, 1995; Jones and Doust 1998). Consequently, the concept of a maximum lactate steady state (MLaSS) developed. Although some of the characteristics and definitions of this lactate variable may be quite similar to its predecessors, the way in which it is measured is usually different (e.g. Nagle et al., 1970; Urhausen et al., 1993; Beneke et al., 1996b). The MLaSS is defined as the highest steady state exercise intensity that can be sustained whilst maintaining an equilibrium between the processes of blood lactate accumulation and elimination (Heck et al., 1985.; Beneke and von Duvillard, 1996; Jones and Doust, 1998). Therefore, it does not

necessarily represent the same metabolic event within the muscle as some of the other commonly used blood lactate variables (Beneke et al., 1996b).

The major methodological difference is that it requires several separate longer duration exercise bouts (20 to 30 min) to be performed at a constant intensity (Beneke et al., 1996a; 1996b; Jones and Doust, 1998). Although it has been suggested that the MLaSS is an excellent tool to determine fitness levels, predict endurance performance, and to prescribe effective training programmes (Bacon and Kern, 1999), the number of studies that have directly determined this variable is quite low. Studies of the MLaSS with paediatric populations are rare and have presented equivocal results. In one of the earliest reported studies, Mocellin et al. (1990) indicated that MLaSS for 10-12 year old boys was 4.6 ± 1.3 mmol·L$^{-1}$. In stark contrast, MLaSS concentrations of only 2.3 ± 0.6 and 2.1 ± 0.5 mmol·L$^{-1}$ were reported for 13-14 year old girls and boys respectively (Williams and Armstrong, 1991).

More recently, Beneke et al. (1996a) suggested that MLaSS was independent of age from 11 to 20 years. However, the sample sizes at each age category were probably too small for this conclusion to be made unequivocally, and the MLaSS concentrations were reported from several constant workload tests on a cycle ergometer (4.2 ± 0.7 mmol·L$^{-1}$, range 2.8 to 5.5 mmol·L$^{-1}$). These between study differences may be partially ascribed to variations in protocol, blood assay techniques, and a variety of definitions of MLaSS (Beneke et al., 1996b). In their 1991 study, Williams and Armstrong compared the MLaSS with the fixed [BLa$^-$] of 2.5 and 4.0 mmol·L$^{-1}$. They concluded that a fixed value of 2.5 mmol·L$^{-1}$ may be the most appropriate criterion for assessing aerobic performance in children. However, this study was with untrained children, for whom performance data were not available.

All of the earlier MLaSS studies (Appendix 7.1 and 7.2) have been conducted with untrained children (Williams and Armstrong, 1991; Mocellin et al., 1990, 1991; Gildein et al., 1993; Billat et al., 1995; Beneke et al., 1996a; 1996b), one group of researchers used cycling rather than treadmill running (Beneke et al., 1996a; 1996b), and only two have included data from girls (Williams and Armstrong, 1991; Billat et a., 1995). If the MLaSS could be expressed as a running speed or a relative exercise intensity, it may prove to be useful as a training or monitoring tool for the athlete and coach Therefore,

rather than just attempting to identify the absolute [$BLa^-$] at which the MLaSS occurs, it may be prudent to compare the relative exercise intensity and running speed with other studies. The current study, therefore, had three main objectives, (1) to identify the exercise intensity that corresponds to the maximum lactate steady state (MLaSS) in adolescent, endurance trained runners, (2) to examine possible between sex differences, and (3) to compare the MLaSS with the fixed [$BLa^-$] of 2.0, 2.5 and 4.0 $mmol \cdot L^{-1}$.

## 6.2 Methods

### 6.2.1 Participants

Sixteen boys and nine girls volunteered to participate in the study. All participants were endurance trained, adolescent runners who had previously been tested in the laboratory. Data regarding their training characteristics were collected retrospectively from the athletic club coaches and the athletes. Although a retrospective data collection procedure has well acknowledged weaknesses, the data should be sufficient to allow us to describe the participants in our study as endurance trained. Moreover, their physical and physiological characteristics shown in Table 6.1 support this. In short, all of the participants had been active members of an athletic club for at least one year leading up to their involvement in the study. They were all competing regularly in mainly track-based events at club level or above (i.e. County and English Schools). The total weekly training mileage, per athlete, ranged from 27 to 54 miles. This was comprised of two or three track sessions that focused on interval and sprint-based work. The rest of the time was spent on continuous aerobic-type running on the road or cross-country. Approval for the study procedures was obtained from the Local Research Ethics Committee. All participants and at least one of their parents received a written explanation of the nature of the study and overall general health was assessed by a pre-test questionnaire. Both the participant and at least one of their parents completed an informed consent form prior to participation in any tests or measurements.

### 6.2.2 Anthropometry, body composition, and treadmill test

The procedures for anthropometry, body composition, and the incremental treadmill test protocol used to determine the blood lactate profile and peak $\dot{V}O_2$, described in (study 1 and 2), were replicated in the current study. In contrast to (study 1 and 2), an on-line computerised, expired air analysis system (Jaeger, Oxycon Alpha) was used rather than the Douglas bag method for all sub-maximal and peak $\dot{V}O_2$ measurements. Descriptive characteristics of the participants are presented in (Table 6.1). Running speeds corresponding to 2.0, 2.5, and 4.0 $mmol \cdot L^{-1}$ fixed whole blood lactate concentrations [$BLa^-$] (v2.0, v2.5, and v4.0) were calculated via linear interpolation (Figure 1). Three boys did not reach a [$BLa^-$] of 4.0 $mmol \cdot L^{-1}$ during the peak $\dot{V}O_2$ treadmill test. Therefore, the sample size was reduced from 16 to 13 for this variable in subsequent analyses.

**Table 6.1 Physical and physiological characteristics**

| Variables | Boys (n = 16) | | | Girls (n = 9) | | |
|---|---|---|---|---|---|---|
| Age (years) | 16.5 | ± | 0.8 | 16.7 | ± | 0.9 |
| Stature (cm) | 174.6 | ± | 6.9 | 164.2 | ± | 3.8** |
| Body mass (kg) | 61.1 | ± | 7.1 | 52.3 | ± | 3.4** |
| Body fat (%) | 8.0 | ± | 2.8 | 15.9 | ± | 3.1** |
| Peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 65.0 | ± | 3.2 | 58.0 | ± | 3.0** |

** Significant difference between boys and girls (*P<0.01*).

### 6.2.3 Determination of maximum lactate steady state (MLaSS)

The procedures for the determination of maximum lactate steady state (MLaSS) concentrations and treadmill test protocol in the current study were described in more details at chapter three (part 3.7 pp. 49-50).

### 6.2.4 Data analyses

The data were stored and analysed using the Statistical Package for the Social Sciences (SPSS for Windows Version 9.0). Descriptive statistics (means ± SD) were calculated for the 16 boys and nine girls representing their physical and physiological characteristics (Table 6.1). Separate one-way repeated measures ANOVA were used to compare the baseline [$BLa^-$] at the start of each of the four constant speed runs for the boys and girls respectively. Independent, two-tailed Student's t-tests were used to compare physical, physiological, and blood lactate differences between the boys and the girls. Separate two-way mixed ANOVA were used to compare the running speed, % peak $\dot{V}O_2$, and % HR max at the MLaSS and the three fixed [$BLa^-$]. The [$BLa^-$] at the MLaSS was compared to the fixed [$BLa^-$] values using a one-sample Student's t-test with the fixed [$BLa^-$] as the designated population norms (i.e. 2.0, 2.5, and 4.0 $mmol \cdot L^{-1}$). Statistical significance was set at $P \leq 0.05$.

## 6.3 Results

The boys were taller, heavier, leaner and had a higher $\dot{V}O_2$ than the girls ($P<0.01$), while there was no difference in the age (Table 6.1). The comparison of baseline [$BLa^-$] revealed no within sex differences across the four treadmill runs although it is acknowledged that there was considerable inter-individual variability at baseline (Table 6.2, $P>0.05$).

**Table 6.2 Comparison of baseline whole blood lactate concentrations**

| | Whole blood lactate concentration ($mmol \cdot L^{-1}$) | | | |
|---|---|---|---|---|
| 20 min → | Run # 1 | Run # 2 | Run # 3 | Run # 4 |
| Boys | $1.10 \pm 0.32$ | $0.97 \pm 0.31$ | $0.99 \pm 0.18$ | $1.04 \pm 0.28$ |
| Girls | $0.95 \pm 0.25$ | $0.90 \pm 0.19$ | $0.88 \pm 0.23$ | $1.00 \pm 0.32$ |

No significant within sex differences ($P > 0.05$).

Only the running speed that corresponded to the MLaSS was different between the boys and girls (Table 6.3, $P<0.01$). On average, the boys had to run 1.4 $km \cdot h^{-1}$ faster than their female counterparts to elicit the MLaSS.

**Table 6.3 MLaSS data**

| MLaSS variables | Boys (n=16) | Girls (n=9) |
|---|---|---|
| [$BLa^-$] ($mmol \cdot L^{-1}$) | $2.7 \pm 1.3$ | $2.3 \pm 0.5$ |
| vMLaSS ($km \cdot h^{-1}$) | $15.7 \pm 1$ | $14.3 \pm 1$* |
| % peak $\dot{V}O_2$ @ MLaSS | $85 \pm 8$ | $85 \pm 2$ |
| % HR max @ MLaSS | $92 \pm 3$ | $94 \pm 3$ |

* Between sex difference ($P<0.01$)

The comparison between the running speeds, % peak $\dot{V}O_2$, and % HR max at the fixed [$BLa^-$] and the MLaSS are shown in Tables 6.4, 6.5 and 6.6 respectively. The one-sample Student's t-test revealed that for the boys, the [$BLa^-$] at MLaSS was significantly different to the fixed [$BLa^-$] of 2.0 and 4.0 $mmol \cdot L^{-1}$ (Table 6.3, $P< 0.05$). For the girls, only the fixed [$BLa^-$] of 4.0 $mmol \cdot L^{-1}$ was significantly different to the [$BLa^-$] at the MLaSS (Table 6.3, $P<0.05$).

The running speed at the MLaSS was not significantly different to that at either of the fixed [$BLa^-$] at 2.0 or 2.5 $mmol \cdot L^{-1}$. The v4.0 was faster than the speeds at all of the other lactate variables (Table 6.4, $P<0.01$).

**Table 6.4 Running speeds at the fixed [$BLa^-$] and MLaSS**

| Variables | Boys (n=16) | Girls (n=9) |
|---|---|---|
| vMLaSS ($km \cdot h^{-1}$) | 15.7 ± 0.9 | 14.3 ± 1.0 |
| v2.0 ($km \cdot h^{-1}$) | 15.6 ± 1.7 | 14.1 ± 0.5 |
| v2.5 ($km \cdot h^{-1}$)* | 16.4 ± 1.5 | 14.7 ± 0.5 |
| v4.0 ($km \cdot h^{-1}$)** | 17.9 ± 1.6 | 16.0 ± 0.7 |

* Significantly faster than v2.0 ($P<0.05$).
** Significantly faster than all other lactate variables ($P<0.01$).
For the boys n = 13 for 4.0 $mmol \cdot L^{-1}$

The % peak $\dot{V}O_2$ at the MLaSS was not significantly different to that at either of the fixed [$BLa^-$] at 2.0 or 2.5 $mmol \cdot L^{-1}$. The % peak $\dot{V}O_2$ was higher at 4.0 $mmol \cdot L^{-1}$ than at all of the other lactate variables (Table 6.5, $P<0.05$).

**Table 6.5 Percentage peak $\dot{V}O_2$ at the fixed [$BLa^-$] and MLaSS**

| Variables | Boys (n=16) | Girls (n=9) |
|---|---|---|
| % peak $\dot{V}O_2$ @ MLaSS | 84.6 ± 7.6 | 84.9 ± 2.3 |
| % peak $\dot{V}O_2$ @ 2.0 $mmol \cdot L^{-1}$ | 81.8 ± 6.8 | 83.3 ± 4.0 |
| % peak $\dot{V}O_2$ @ 2.5 $mmol \cdot L^{-1}$* | 85.9 ± 5.9 | 86.5 ± 4.2 |
| % peak $\dot{V}O_2$ @ 4.0 $mmol \cdot L^{-1}$** | 92.7 ± 4.8 | 91.9 ± 4.7 |

* Significantly higher than @ 2.0 $mmol \cdot L^{-1}$ ($P<0.05$).
** Significantly higher than all other lactate variables ($P<0.05$).
For the boys n = 13 for 4.0 $mmol \cdot L^{-1}$

The % HR max at the MLaSS was not different to that at the fixed [$BLa^-$] at 2.5 $mmol \cdot L^{-1}$. The % HR max at 2.0 $mmol \cdot L^{-1}$ was lower than all other lactate variables, whereas at 4.0 $mmol \cdot L^{-1}$ it was higher than all of the others (Table 6.6, $P<0.05$).

**Table 6.6 Percentage maximum heart rate at the fixed [$BLa^-$] and MLaSS**

| Variables | Boys (n=16) | Girls (n=9) |
|---|---|---|
| % HR max @ MLaSS | 92.2 ± 3.4 | 93.8 ± 3.0 |
| % HR max @ 2.0 mmol·$L^{-1}$* | 91.2 ± 3.8 | 90.9 ± 1.3 |
| % HR max @ 2.5 mmol·$L^{-1}$ | 93.4 ± 3.3 | 92.6 ± 1.2 |
| % HR max @ 4.0 mmol·$L^{-1}$* | 96.6 ± 3.7 | 96.9 ± 1.6 |

* Significantly different to all other lactate variables ($P<0.05$).
For the boys n = 13 for 4.0 mmol·$L^{-1}$

## 6.4 Discussion

The physical and physiological characteristics shown in Table 6.1 indicate that the young people who volunteered to take part in this study were endurance trained (Appendix 7.1 and 7.2) suggesting that this was a group of sub-elite, middle-distance performers. The main finding from this study was that the MLaSS in a group of endurance trained, adolescent athletes occurred at relatively high exercise intensity. Moreover, the running speed, % peak $\dot{V}O_2$, and % HR max at the fixed [$BLa^-$] of 2.5 mmol·$L^{-1}$ were not significantly different to those corresponding to the MLaSS. Although the boys in this study had superior levels of cardiorespiratory fitness (peak $\dot{V}O_2$) than their female counterparts, when the data were relativised to % peak $\dot{V}O_2$ and % HR max the MLaSS corresponded to the same exercise intensity. As far as we are aware, this is the first study that has identified the MLaSS in a group of both male and female, endurance trained, adolescent athletes.

The inter-individual variation in [$BLa^-$] at the MLaSS for the boys (range 1.2 to 5.0 mmol·$L^{-1}$) was double that seen in the girls (1.3 to 3.2 mmol·$L^{-1}$). It is not clear why the variation for the boys was larger than the girls'. However, this degree of variation supports the figures reported previously (Williams and Armstrong, 1991; Mocellin et al., 1990; Billat et al., 1995). The mean MLaSS [$BLa^-$] are similar to those reported for a group of untrained adolescent boys and girls (Williams and Armstrong, 1991), but are generally lower than those reported in most other studies of younger untrained children (Appendix 7.1). The most likely reasons for these differences lie within, (1) the definition of the MLaSS and, subsequently, the exercise mode and protocol underpinned by this definition, (2) the blood lactate assay technique employed (refer to Appendix 7.2), and (3) the activity or training status of the participants.

Beneke et al. (1996b) assessed the MLaSS in ten, active but untrained, adolescent boys using three different definitions that had been suggested previously within the literature. They concluded that test protocols lasting less than ten min do not take sufficient account of lactate kinetics resulting in an underestimation of the relative exercise intensity at which the MLaSS occurs. One of the primary recommendations was that constant workloads (speed) lasting at least 20 min were a prerequisite for the determination of a valid MLaSS in young people. Williams and Armstrong (1991) used a series of treadmill runs lasting only ten min with a group of 13-14 year boys and girls; they reported [$BLa^-$] that are considerably lower than any others reported for untrained children (Table 6.7). In contrast, the definition and exercise protocol for MLaSS adopted in the current study is very similar to one that has been suggested by Beneke et al. (1996b). Therefore, differences between the mean MLaSS [$BLa^-$] shown in Table 6.3 and those reported by Beneke et al. (1996b) are unlikely to be due to differences in protocol or definitions of MLaSS.

It has been suggested that the discontinuous nature of the constant speed runs used in the current study may alter the pattern of lactate production and elimination compared to a continuous protocol (Williams and Armstrong, 1991; Beneke at al., 1996b). The safety of the young athletes in the present study was of paramount importance, especially when considering the relatively fast running speeds. Hence, the use of a discontinuous protocol. Moreover, blood sampling during the cycle-Ergometry exercise adopted by Beneke et al. (1996a; 1996b) is probably easier than when participants are running fast on a motorised treadmill. More importantly, it has been shown that the running speed and heart rate at a variety of commonly used lactate reference values are not altered significantly when 30s breaks are used between exercise stages of 4 min duration for capillary blood sampling (Gullstrand et al., 1994). In an earlier study, Heck et al., (1985) reported that for every 30s that the exercise was interrupted, the running speed at a fixed [$BLa^-$] of 4.0 $mmol \cdot L^{-1}$ increased by 0.25 $km \cdot h^{-1}$. This increase was not statistically significant and it is less than the precision at which the MLaSS in the present study was determined.

If differences in the definition and treadmill protocol used to identify the MLaSS are not the likely cause of lower MLaSS [$BLa^-$] then one plausible reason appears to stem

from differences in blood lactate assay procedures. Williams and Armstrong (1991) used an identical technique to the one adopted in the present study and the [$BLa^-$] are very similar (Tables 6.7 and 6.8). In contrast, all of the other research groups have used an enzymatic assay procedure after first obtaining the blood sample from a hyperaemic earlobe. Enzymatic photometric assays of plasma lactate result in a systematic increase in lactate concentration relative to amperometric analyses of whole blood (Buono and Yeager, 1986; Foxdal et al., 1990; Beneke et al., 1996b). A proportion of this difference was probably offset by the use of finger-tip capillary as opposed to the earlobe which generally results in slightly higher [$BLa^-$] (Dassonville et al., 1998). Using the equation reported by Beneke et al., (1996b, pp. 34) to convert amperometric to photometric values, the [$BLa^-$] for the boys and girls in our study would be quite similar to those in the studies using this enzymatic assay (2.7 and 2.3 $\Rightarrow$ 4.2 and 3.6 $mmol \cdot L^{-1}$ respectively).

It is well known that endurance training results in a lower blood lactate accumulation at both absolute and relative workloads compared to the untrained state (Weltman, 1995). In adults, evidence of this physiological adaptation comes from numerous prospective intervention studies (Bergman et al., 1999; Carter et al., 1999; Jones and Carter, 2000; Londeree, 1997; Stallknecht et al., 1998). Given the adolescents in our study are endurance trained, the lower [$BLa^-$] at MLaSS might be expected compared to the active, but untrained children in all of the other studies shown in Table 6.7. Although the younger adolescents in the Williams and Armstrong study (1991) had comparable mean [$BLa^-$], the relative intensity at which this occurred was considerably lower than in the current study (77% vs. 85% peak $\dot{V}O_2$). To date, only one training study that has included lactate measurements with children appears to have been published (Rotstein et al., 1986). Following a nine week training programme, the running speed at the 'lactate inflection point' increased by 0.5 $km \cdot h^{-1}$, but the relative intensity at which it occurred decreased by 4.3 % peak $\dot{V}O_2$ (Rotstein et al., 1986). The authors suggested that this reduction in relative exercise intensity may reflect the 8% increase in peak $\dot{V}O_2$. Although it has been possible to give plausible reasons for inter-study differences in the absolute [$BLa^-$] at which the MLaSS occurs, a comparison of the relative exercise intensity or workload (running speed) that it corresponds to may be more meaningful. The % HR max at which the MLaSS occurs is almost identical to the values reported by

Williams and Armstrong (1991), and Beneke et al. (1996b). Billat et al., (1995) found values that were on average 8% lower (e.g. for boys 84% vs. 92%). As shown in Appendix 7.2, Billat et al., (1995) only used two, 15 min treadmill runs interspersed with a 40 min rest period to determine the MLaSS rather than the recommended four to five separate constant speed stages (Urhausen et al., 1993; Beneke et al., 1996b). The original version of this test (Billat et al., 1994a) was validated with endurance trained adults as opposed to active, 12 year old boys and girls. Therefore, this between study differences in % HR max may be ascribed to disparities in test protocol and definitions of the MLaSS. Whether the heart rate response can be used to reflect changes in the relationship between aerobic and anaerobic energy metabolism is open to debate (Beneke et al., 1996a).

An explanation for the inter-study differences in the % peak $\dot{V}O_2$ at the MLaSS is not readily apparent. It is likely that study and participant characteristics highlighted above all contribute, in part, to explain some of the discrepancies and similarities. Given there is no real consistency within the methods and definitions employed to determine the MLaSS in young people, it should come as no real surprise that the % peak $\dot{V}O_2$ values range from 65% in the Billat et al. study (1995) to 92% for the 11.9 year old boys in Gildein's study (1993). Williams and Armstrong (1991) suggested that some differences may partly reflect the trained status of participants. If that were the case, a difference between the boys and girls in the current study, and those reported by Williams and Armstrong (1991), and Billat et al. (1995) might have been expected. Differences in cardiorespiratory fitness between the sexes were evident in all three studies; yet, once the MLaSS data were normalised to % HR max and % peak $\dot{V}O_2$, no between sex differences were found. The fact that Williams and Armstrong (1991) found that a mean % peak $\dot{V}O_2$ of 77% coincided with a mean % HR max of 94% and 92% for the boys and girls respectively is surprising. Given that HR should be dependent upon $\dot{V}O_2$, either a lower % HR max or a higher % peak $\dot{V}O_2$ mean value might have been expected in this study. These results may be a reflection of one of the shortest exercise stages used to determine the MLaSS. This would appear to suggest that the relative exercise intensity to which the MLaSS corresponds is independent of training status, but it is a reflection of methodological design as originally suggested by Beneke et al. (1996b).

Few studies have published absolute workloads at which the MLaSS occurs in young people; for example, running speed or cycling power output. This is somewhat surprising given this information may have the greatest practical value when considering young athletes, sports performance, and the associated training programme. Most of the data that are available are power output (W) values from cycling or rowing (Beneke et al., 1996a; 1996b; 2001). A small number of studies have reported the running speed at the MLaSS (vMLaSS). The vMLaSS for the girls compared to the boys in our study (girls' ~ 91.1% of boys' speed) is very similar to that published for untrained 12 year olds (Billat et al., 1995, girls' ~ 90.6% of boys' speed). The older and better trained athletes in the current study had to run almost twice as fast to attain the MLaSS compared with the younger children in the Billat et al. study (1995). A vMLaSS of approximately 11 $km \cdot h^{-1}$ (89 % of maximum running speed) was found for eleven prepubertal boys (Mocellin et al., 1991). This is, on average, 2.5 $km \cdot h^{-1}$ faster than the children of similar age in the Billat et al. study (1995). This is most likely to be a function of the test protocol, MLaSS definition, and differences in cardiorespiratory fitness or running ability. The mean peak $\dot{V}O_2$ for the German boys was 54 $mL \cdot kg^{-1} \cdot min^{-1}$ (Mocellin et al., 1991) whereas it was almost 10% lower for the French boys (Billat et al., 1995). These data appear to suggest that when the MLaSS is reported relative to running speed (vMLaSS), it may be sensitive to differences in aerobic power (peak $\dot{V}O_2$). Whether it is also able to differentiate between levels of performance in field based events such as athletic track competitions has yet to be shown with this age group. Hopefully, future studies will provide this important physiological-performance link. Although it has been tempting to report the vMLaSS results relative to the estimated running speed at peak $\dot{V}O_2$ ($v\dot{V}O_2$) (Billat et a., 1996), the incremental test protocol was not specifically designed for this purpose. Therefore, the reliability and validity of the $v\dot{V}O_2$ could not be assured.

Despite the volume of research that appeared to support a fixed [$BLa^-$] of 4.0 $mmol \cdot L^{-1}$ for monitoring endurance performance in adults, over a decade has passed since it was first suggested that a lower value in the region of 2.5 $mmol \cdot L^{-1}$ may be more appropriate when considering children and adolescents (Williams et al., 1990; Williams and Armstrong, 1991; Welsman and Armstrong, 1992; Tolfrey and Armstrong, 1995).

Although the present study used longer constant run stages to determine the MLaSS (20 vs. 10 min), the results are essentially the same as those published ten years ago from untrained adolescent boys and girls (Williams and Armstrong, 1991). That is, the mean [$BLa^-$], running speed, % peak $\dot{V}O_2$, and % HR max at the MLaSS were not significantly different to the fixed [$BLa^-$] of 2.5 $mmol \cdot L^{-1}$ for either the boys or girls. Although this appears to imply that a single incremental treadmill test with three min stage duration may be used in place of the more laborious, 20 min constant speed tests, a measure of caution should be exercised. Comparing group mean values at the different blood lactate variables does not necessarily give an accurate impression of the large degree of inter-individual variability associated with these physiological responses to exercise. For example, the mean difference between the % peak $\dot{V}O_2$ at the fixed [$BLa^-$] of 2.5 $mmol \cdot L^{-1}$ and the MLaSS was only -1.3 % and -1.6 % for the boys and girls respectively (see Table 5). However, the range of individual differences spanned -11.4 to 16.9% for the boys and -5.0 to 5.7% for the girls. Closer examination of the data also revealed that for the boys the smallest mean difference between the fixed [$BLa^-$] and the MLaSS occurred when comparing the 2.0 $mmol \cdot L^{-1}$ value, as opposed to 2.5 $mmol \cdot L^{-1}$, if % HR max and running speed were used to express the data. A similar finding was evident for the girls, but in this case it was the % peak $\dot{V}O_2$ and running speed at 2.0 $mmol \cdot L^{-1}$ that provided the nearest approximation to the MLaSS. Before it is possible to use a fixed [$BLa^-$] of 2.0 or 2.5 $mmol \cdot L^{-1}$ as a proxy measure in place of the MLaSS determined using long constant runs, a study needs to be conducted where a measure of cross-validation is determined. This study would need to include prolonged constant speed runs using the methods that resulted in the speed data reported in Table 6.4.

Although the number of studies focusing on the MLaSS in children and adolescents is slowly increasing (Appendix 7.1 7.2), it is important to note that the reliability of this variable has yet to be systematically studied in this population. The time that it takes to complete the measurements is likely to be a major obstacle in addressing this critical question, but this should not mean that it goes unchallenged. Moreover, although it has been suggested that the MLaSS may provide the 'gold standard' for endurance exercise capacity (Jones and Carter, 2000), and subsequent training regimes, until the reproducibility of the measure is established, its validity cannot be assured.

## 6.5 Conclusion

In conclusion, the running speed at the MLaSS may be used as a measure of cardiorespiratory fitness and it has potential as a marker of endurance performance, but this has yet to be confirmed with young people. The relative exercise intensity at which the MLaSS corresponds does not appear to be sensitive to differences in aerobic power (peak $\dot{V}O_2$) between young male and female middle distance athletes. The MLaSS corresponded to a relatively high exercise intensity in this group of endurance trained young athletes and large inter-individual variability in the [$BLa^-$] at the MLaSS was clearly evident. Finally, the running speed, % peak $\dot{V}O_2$, and % HR max at the MLaSS were not significantly different to the physiological response at a fixed [$BLa^-$] of 2.5 $mmol \cdot L^{-1}$ determined during a standard incremental treadmill test. Substantial inter-individual variability when comparing these two lactate variables may preclude the use of this method as a proxy measure until further cross-validation tests have been conducted using prolonged bouts of running.

# Chapter Seven
# Effect of the training programme and adolescent runners' performance

## 7.0 Effect of the training program and adolescent runners performance

### 7.1 Overview

Since the blood lactate response to endurance performance is the most preferred marker of continued endurance performance than $\dot{V}O_{2max,}$ it is imperative to appreciate the possessions of training on the different issues of the blood lactate to endurance performance. Numerous studies have accounted a discrepancy effect of training on the blood response to exercise compared to $\dot{V}O_{2max}$ (Oyono-Enguelle et al., 1990., Weltman et al., 1990; 1994). Practically all of these studies have shown that the intensity and $\dot{V}O_{2max}$ linked with a variety of blood lactate parameters progress to a large amount greater extent with training than does $\dot{V}O_{2max}$ (Coyle et al., 1988; 1991). Therefore, using sub-maximal blood lactate responses to exercise to plan, conduct, and evaluate an endurance training programme with young people.

### 7.2 Introduction

It is important to realize the necessity of numerous initial documentations of the cardiorespiratory capabilities and blood lactate response to endurance performance of children are required, with regard to the training adaptation in the physiological responses to exercise and the prepare training intensity to enhance these variables. Although it was indicated throughout many studies of submaximal energy expenditure that a spectrum of measurements through which submaximal performances by adolescents can be assessed including energy costs, cardiorespiratory responses and substrate and metabolic levels in the blood (Rowland and Boyajian, 1995; Turley, 1997; Naughton et al., 1997) but the endurance training responses are independent sex (Rowland and Boyajian, 1995). Therefore, more studies were required to investigate the effects of training programmes in boys and girls (Payne and Morrow, 1993). However, it was demonstrated that it is available to control the intensity of training with reference the basis of the individual anaerobic threshold (IAT) (Stegmann and Kindermann 1982; MacLellan and Jacobs, 1989; Coen et al., 1991). Also, MLSS responses were investigated in adolescent boys (15.4 $\pm$ 2.8 years of age), and the blood lactate responses corresponding to the intensity at which steady state could be maintained. The

authors concluded that was independent of age but may do to training status (Beneke et al. 1996).

Furthermore, the running speed at the maximum lactate steady state (vMLSS) is strongly correlated with endurance exercise performance in adults (Jones and Doust, 1998; Jones and Carter, 2000) and adolescents runners (Almarwaey et al., 2004) and measurement (or, at least, estimation) of the vMLSS is considered important in the physiological assessment of elite athletes (Jones and Carter, 2000). The vMLaSS demarcates the transition between 'heavy' and 'severe' sub-maximal exercise (Jones and Doust, 2001). In the 'heavy' domain (i.e. above the vLT but below the vMLaSS), both [$BLa^-$] and $\dot{V}O_2$ attain a delayed and elevated steady-state. However, in the 'severe' domain (i.e. above the vMLaSS, but below the $v\dot{V}O_2$ peak), both blood [lactate] and $\dot{V}O_2$ may rise inexorably with time until the exercise is terminated. The metabolic and perceptual responses to exercise will differ considerably between the heavy and severe domains and this explains the importance of the vMLaSS in fitness assessment, performance prediction, and training prescription. Continuous training at the existing vMLaSS for 20-30 minutes is often recommended as a method of improving the vMLaSS (Jones and Carter, 2000) and possibly endurance running performance, but there is virtually no empirical evidence to support this position.

Several studies have demonstrated that endurance training causes improvements in running economy, vLT, $\dot{V}O_2$ max and $v\dot{V}O_2$ max in adults (e.g. Carter et al., 1999; Jones, 1998). However, no studies currently exist whereby this has been explored with young people. The results of some studies which focused on critical power (Poole et al., 1990) or oxygen uptake kinetics (Carter et al., 2000) imply that endurance training increases the exercise intensity at which the MLaSS occurs. However, the effect of endurance training on the vMLaSS and endurance running performance has never been directly investigated in young people. Therefore, the aim of this proposed fourth study would be to use the vMLaSS to prescribe an endurance training programme for a group of adolescent male and female runners. A pre-post test, mixed research design would be used to study the effects of this intervention on the important variables identified in the first three studies.

## 7.3 METHODS

### 7.3.1 Participants

Sixty four adolescents children boys, 25 well endurance trained athletes (WTA), 25 normally endurance trained (non-athletes) and 14 untrained control group (normal healthy), volunteered to participate in this study. They were the 800-m, 1,500-m and 3000-m, finalists from the local athletic clubs and high schools at Makkah city in Kingdom of Saudi Arabia (K.S.A.). The twenty five of the athletes' and 21 of the 25 non-athletes boys competed in 800m of the finals. Also, the 14 untrained boys (control group) were asked to run only 800-m to include their performance time in the study during both pre and post tests. The post running performance time was established for all participants at the end of study but not in a competition. Therefore, their data were included in the analyses relating to previous race distances (Table.7.4). The running performance times were used as the field-based performance measure in this study. The participants were tested in the laboratory within four weeks of the Championships. Approval for the study procedures was obtained from the John Moores University Research Ethics Committee, and Umm Al-Qura University Research Ethics Committee (K.S.A).

All participants and at least one of their parents received a written explanation of the nature of the study and general health was assessed using a pre-test questionnaire. Both the participant and at least one parent completed an informed consent form prior to any active participation in the study.

### 7.3.2 Anthropometry, body composition, determination of sub-maximal and peak $\dot{V}O_2$ procedures

The procedures for anthropometry, body composition, and the incremental treadmill test protocol used to determine the blood lactate profile and peak $\dot{V}O_2$, described in studies 1-3 (above), were replicated in the current study. In contrast to study 2, an on-line computerised, expired air analysis system (Jaeger, Oxycon Alpha) was used rather than the Douglas bag method for all sub-maximal and peak $\dot{V}O_2$ measurements. Descriptive characteristics of the participants are presented in Table 7.1. Running speeds corresponding to 2.0, 2.5, and 4.0 $mmol \cdot L^{-1}$ fixed whole blood lactate concentrations [$BLa^-$] (v2.0, v2.5, and v4.0) were calculated via linear interpolation (Figure 3.1).

### 7.3.3 Treadmill (TM) protocol and test procedures

Each participant completed a two-phase treadmill (Powerjog EG30) test following familiarisation to treadmill walking and running. Phase one was a discontinuous incremental running test with increases in running speed of 1 $km \cdot h^{-1}$ at the beginning of each stage. The incremental test consisted of six to eight 3-min stages following a 5 min warm-up of walking and running up to 7 $km \cdot h^{-1}$. The treadmill gradient was set at 1% to simulate running outside (12). The speed at the beginning of the test for both well trained and normal trained (9-11 $km \cdot h^{-1}$) was determined according to each subject's running performance time, and from (8-9 $km \cdot h^{-1}$) for the control group. Each stage was separated by a 30 s rest period for fingertip capillary blood sampling. Following a 10-min active recovery period, phase two was completed. This phase involved running at a fixed speed with the treadmill gradient being increased by 1% each min until volitional exhaustion.

A resting fingertip, capillary blood sample was taken to determine the whole blood lactate concentration prior to the start of the test. Whole blood samples were also taken during the test at the end of each stage. The fingertip was wiped with a mediswab saturated with 70% v/v Isopropyl Alcohol and dried with a tissue. The blood samples were collected in heparinised capillary tubes after discarding the first drop of blood. The blood was analysed immediately in duplicate for whole blood lactate concentration using an automatic analyser (Miniphotometer plus LP 20: DR Lange for whole blood parameters, Medical Division, Berlin Germany). The analyser was calibrated with a known dissolve starting reagent standard prior to each individual test and after every 20 samples. Running speeds corresponding to 2.0, 2.5, and 4.0 $mmol \cdot L^{-1}$ fixed whole blood lactate concentrations [$BLa^-$] (v2.0, v2.5, and v4.0) were calculated via linear interpolation. The level of precision was to the nearest 0.1 $km \cdot h^{-1}$ for each fixed [$BLa^-$]. This procedure was repeated to determine the $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) ($\dot{V}O_2$2.0, $\dot{V}O_2$2.5, and $\dot{V}O_2$4.0 respectively) and % peak $\dot{V}O_2$ (2.0%$\dot{V}O_2$, 2.5%$\dot{V}O_2$, and 4.0%$\dot{V}O_2$ respectively) that corresponded to the fixed [$BLa^-$].

### 7.3.4 Determination of maximum lactate steady state (MLaSS)

During a single laboratory visit participants completed two separate constant speeds, 20 min treadmill runs. Each run was separated by a 30-45 min active recovery period.

During each 20 min run, fingertip capillary blood samples were taken at 5 min intervals, following an initial baseline sample for the determination of whole blood lactate concentration (i.e. 0, 5, 10, 15 and 20 min). For the safety of the athlete, the run was interrupted for 30s each time a blood sample was required. An interruption in the exercise of this duration does not affect the heart rate, running speed, or $\dot{V}O_2$ that correspond to a variety of blood lactate variables (Gullstrand et al., 1994).

This interruption was strictly standardised to reduce the variability within the data. Participants completed four 20 min constant speed runs in total. At least two days of rest, but no more than five days, separated the two constant run tests. Rating of perceived exertion (RPE), heart rate (HR) and expired air were also recorded at 5 min intervals. The initial running speed for the first 20 min run was determined from the participant's blood lactate profile from the aforementioned incremental treadmill test. The MLaSS was defined by analysing the [$BLa^-$] between the 10th and 20th min of each constant speed test. It was defined as the highest [$BLa^-$] that increased by no more 0.5 $mmol \cdot L^{-1}$ during the last 10 min (Figure 2, Chapter 3).

This increase in lactate per unit time is similar to that defined by numerous authors (e.g. Beneke and von Duvillard, 1996; Jones and Doust, 1998). The [$BLa^-$] at 20 min was accepted as the MLaSS concentration. The running speed, $\dot{V}O_2$, and HR that corresponded to the MLaSS were recorded and used in subsequent analyses the definition of MLaSS was used to determine the change in running speed across the four different constant speed runs.

### 7.3.5 Proposed statistical analyses

A mixed (group by time) factorial ANOVA will be used to evaluate the efficacy of the exercise training programme. Should there be any baseline differences between the control group and the two experimental groups, the baseline variable will be included as a covariate in an ANCOVA. Simple (main) effects or planned contrast will be used to complete the analyses in the event of a significant interaction. Changes in vMLaSS, running performance, peak $\dot{V}O_2$, LT, vLT, and fixed [$BLa^-$] will serve as the separate dependent variables in this study.

### 7.3.6 Brief overview of methods and training programme

Approximately 64 adolescents were recruited to the study from local schools and athletics clubs: the subject group will include 25 well trained athletes (WTA), 25 normally trained non athletes (NTA) and 14 untrained control group (UCONG). The participants will first perform an incremental exercise test for the determination of the LT and peak $\dot{V}O_2$ (refer to studies 1-3) Subsequently, the participants' vMLaSS will be determined from a series of constant speed treadmill runs of 20 min duration at a range of speeds between the vLT and the v$\dot{V}O_2$ peak. The 64 participants will be subdivided into three groups. These groups will be re-assessed for LT, peak $\dot{V}O_2$, and MLaSS after twelve weeks, whereas, during which time the control group (no training) will be asked to maintain their normal physical activities. The athletic participants in the two other groups will be pair-matched for vMLaSS and then will maintain their endurance training programme for twelve weeks. The 'base' training will be identical in these two groups, but one group will replace a 30-40 minute 'steady' run with a 20-30 minute training run at the existing individual vMLaSS on two days per week. As for the control group, the participants in the two training groups will be re-tested for LT, peak $\dot{V}O_2$, and MLaSS after twelve weeks. All participants will be issued with diaries to record their daily training, and the experimental groups will be issued with heart rate monitors to assist them in achieving the prescribed training intensities. All participants will record their activities and dietary intake in the days over which the initial tests are made and they will then replicate this over the days when they are re-tested following completion of the twelve week training programme.

These studies will provide unique data regarding the physiological responses to exercise in young people. There would appear to be a clear gap in the current knowledge regarding these important issues and the studies described above should advance the body of knowledge that is a necessary requirement of research.

### 7.3.7 Explanation of training programme

The training programme was conducted for three months directly after pre-test for both well trained and normal trained boys (only the experimental groups). All boys had to train on the treadmill for two separated days per week whereas they have no training day. The training programme included 2 to 3 sessions; each session was 10 to 15 min. Also, 10 to 15 min. of rest was given between working sessions. Each participant was

requested to run at a specific percentage according to their MLaSS heart rate and running velocity during the pre-test. The running session during the training programme was 10 to 15 min. and if the runner reached his percentage of HR then he will be asked to stop running and take enough rest (active rest). However, from our observations all participants did not reach to that before the 10 min. that was suggested for this programme during both first and second suggested RV. But for the third suggested RV some participants of the second group (normal trained) did during first and second weeks at the first or second session and some participants of the first group (well trained) at the third session of training programme and only during the same time. Each participant was sustained for one more week of the same intensity (RV) and (HR) of training before transferring him to the next suggested one.

### 7.3.8 Instructions of the programme

Fifty boys (25 well trained and 25 normal trained boys) completed a three months of exercise training programme (ETP) and (14 boys) acted as control group (UCONG) during the same time period three months later. The UCONG were told to do their normal daily life style during the period of the investigation for three months. All methods for this study which explained previously were repeated at the end of training programme time. Data reported in this study were from boys who volunteered for the study.

The duration of the training programme consist of a 12 wk. Each week has 2 sessions and each session consist 2 sets of at least 10 min of running. All boys maintained the first suggested % of HR beyond 10 min and before 15 min. Some subjects did not maintain the second and third suggested % of HR at 1$^{st}$ week. Each suggested % of HR takes 4wk long (Tables 7.1, 7.2, 7.9 and 7.10). If the subject maintained the suggested % of HR then move to the next one. Also, the suggested % of RV treated same way as above with different %.The % HR for the training programme according to the MLaSS during the pre-test for the three suggested sessions were 85, 90 and 95 respectively. The % RV for the training programme according to the MLaSS during the pre-test for the three suggested sessions were 95, 100 and 105 respectively.

The following are exactly what the participants did.

**Table 7.1 Training programme at % HR and RV for well trained group.**

| Training periods | Mode of training | Duration of each session | Frequency at each period per week | Range of intensity at %(HR) and (RV) for well trained | |
|---|---|---|---|---|---|
| | | | | HR | RV |
| First month | Treadmill running | 10-15 min. X 2-3 times | 2 sessions at each week | 154-162 | 12.4-15.2 |
| Second month | Treadmill running | 10 -15 min. X 2-3 times | 2 sessions at each week | 163-172 | 13-16 |
| Third month | Treadmill running | 10-15 min. X 2-3 times | 2 sessions at each week | 172-181 | 13.7-16.8 |

*The total number of the training sessions were 2400 (n=50 X 48).

**Table 7.2 Training programme at % HR and RV for normal trained groups.**

| Training periods | Mode of training | Duration of each session | Frequency at each period per week | Range of intensity at (HR) and (RV) for normal trained | |
|---|---|---|---|---|---|
| | | | | HR | RV |
| First month | Treadmill running | 10-15 min. X 2-3 times | 2 sessions at each week | 151-167 | 9.5-12.6 |
| Second month | Treadmill running | 10 -15 min. X 2-3 times | 2 sessions at each week | 167-176 | 11.6-13.3 |
| Third month | Treadmill running | 10-15 min. X 2-3 times | 2 sessions at each week | 176-186 | 12.8-14.7 |

*The total number of the training sessions were 2400 (n=50 X 48).

## 7.4 Results

The descriptive physical characteristics of the adolescents trained and untrained groups in this study are presented in Table 7.3. Despite the changes over time for body mass the untrained group was slightly heavier than both well trained and normal trained groups in both pre and post tests, and there were no significant differences between groups ($P \geq 0.05$). Also, it did not show any significant differences between groups in age and stature ($P \geq 0.05$) before and after training programme. However, there was only a significant difference in %BF over time between tests and between groups. The significant difference between tests was observed in the well trained group among pre and post tests at ($P \leq 0.05$). Although the reduction in %BF between groups was observed over time to be significantly different in pre and post tests among groups 1 and 3, 2 and 3, at ($P \leq 0.001$), and between groups 1 and 2 at ($P \leq 0.05$) respectively. Well trained and normal trained groups by training time interaction revealed that whilst %BF was reduced throughout the training times at different levels of significant, it did not change for the UCON as shown in Table 7.3. Mean (± SD) physiological parameters responses, before and after training programme are shown in Table 7.4.

**Table 7.3 Mean ± S. D., physical characteristics for WTG, NTG runner boys and UCON group before and after training programme.**

| Variables | Well trained (n=25) | | Normal trained (n=25) | | Untrained (n=14) | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post |
| Age (y) | 15.7 ±0.9 | 16.0 ±0.9 | 15.7 ±1.1 | 16.0 ±1.1 | 15.2 ±1.0 | 15.5 ±1.0 |
| Body mass (kg) | 52.6 ±10.1 | 52.4 ±9.3 | 53.7 ±8.7 | 52.8 ±8.1 | 54.5 ±3.7 | 54.9 ±3.5 |
| Stature (m) | 166 ±8.7 | 167.1 ±8.3 | 163.1 ±7.3 | 164.8 ±6.5 | 162.4 ±3.9 | 163.8 ±3.5 |
| Body fat (%)**† | 12.1 ±2.9 | 9.9 ±3.5*† | 14.7 ±4.4 | 12.6 ±5.0**† | 19.1* ±2.3 | 18.2 ±2.1** |

***Between tests difference ($P \leq 0.05$). **Between groups difference ($P \leq 0.01$). *† Significant main effect for group ($P \leq 0.05$). **† Significant main effect for training time ($P \leq 0.01$).**

Resting HR only was similar between groups during the pre tests ($P \geq 0.05$). Conversely, these similarities were significantly different following the involvement in the intervention time between well trained and normal trained groups during the post test ($P \leq 0.05$) and for UCON at ($P \leq 0.05$ and $P \leq 0.01$) from WTG and NTG respectively. Resting blood lactate did not show any differences among pre tests and groups, but there was significant difference between WTG and NTG ($P \leq 0.05$) and ($P \leq 0.01$) for UCON group. However, it was observed that the WTG seems to be more fit than the NTG and both groups seems to be more fit than UCON before training intervention and so, regardless of the highly improvement in the NTG as an outcome of the training programme. The parameters of LT, RV @ LT, HR @ LT, $\dot{V}O_2$ @ LT and peak $\dot{V}O_2$ @ LT in (Table 7.4), revealed a significant differences among all groups and tests at ($P \leq 0.05$ and $P \leq 0.01$) respectively. In addition, the groups by training time interactions for the pervious parameters were highly comparable to the above results in many different applied statistical procedures.

**Table 7.4 Physiological parameters responses for WTG, NTG runner boys and UCON group before and after training programme.**

| Variables | Well trained (n=25) | | Normal trained (n=25) | | Untrained (n=14) | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post |
| Resting HR (beats.min$^{-1}$)*† | 67.0 ±8.0* | 63.0 ± 7.0*† | 78.0 ±6.0* | 71.0 ± 5.0*† | 77.0 ± 4.0 | 77.0 ±3.0** |
| Resting BL (mmol.L$^{-1}$) | 2.04 ±0.42 | 1.80 ±0.4* | 2.06 ± 0.31 | 1.83 ±0.23* | 1.99 ±0.18 | 1.95 ±0.12 |
| LT (mmol.L$^{-1}$)*† | 2.93 ±0.55 | 2.72 ± 0.51 | 3.16 ±0.35 | 2.94 ± 0.33* | 2.95 ±0.18 | 2.92 ±0.2 |
| RV @ LT (km.h$^{-1}$)*† | 13.1 ±0.3 | 13.3 ± 0.5 | 11.8 ±0.6 | 12.2 ±5.0* | 10.9 ±0.2 | 11.1 ± 0.2* |
| HR @ LT (beats.min$^{-1}$) | 168 ±7.0 | 165 ±7.0* | 169 ±10.0 | 168 ±9.0* | 177 ± 7.0 | 178 ±6.0* |
| $\dot{V}O_2$ @ LT(mL·kg$^{-1}$·min$^{-1}$)*† | 46.2 ±2.8 | 46.6 ±2.6 | 39.9 ±3.3 | 41.0 ±3.0 | 34.0*† ±2.3 | 37.3 ± 3.3* |
| Peak $\dot{V}O_2$ (mL·kg$^{-1}$·min$^{-1}$)**† | 60.7 ±2.4 | 62.7 ±3.1 | 49.6 ±2.5* | 53.0*† ±2.6* | 45.1 ±2.6 | 47.0 ±2.8 |

***Between tests difference (P≤0.05). *† Between groups difference (P≤0.05), **Between groups difference (P≤0.01). **† Significant main effect for training time ($P \leq 0.01$).**

The assessment of baseline whole blood lactate concentrations before each of the constant-speed runs used to determine the maximal lactate steady state revealed no significant difference between groups in the pre test before the first 20 min run ($P \geq 0.05$). However, there were significant differences among tests at ($P \leq 0.05$) in pre and post tests for the WTG and the NTG, also, there were significant differences between WTG and NTG in post test at ($P \leq 0.05$) and between NTG and UCON at ($P \leq 0.01$) in post test during both first 20 min runs before and after training programme (Table 7.5). Although, significant differences were revealed from the second and third 20 min. runs at rest pre tests during the same times as before and WTG was significantly different in post test from NTG and UCON at ($P \leq 0.05$) and between NTG and UCON at ($P \leq 0.01$), and among tests for all groups at ($P \leq 0.05$).

**Table 7.5 Comparison of baseline whole blood lactate concentrations for WTG, NTG runner boys and UCON group at rest before pre test and before post test after training programme.**

| 20 min Run | Whole blood lactate concentrations ($mmol \cdot L^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Well trained (n=25) | | Normal trained (n=25) | | Untrained (n=14) | |
| | Pre | Post | Pre | Post | Pre | Post |
| First Run*† | 2.00 ±0.46 | 1.81 ±0.32* | 2.13 ±0.25 | 1.79** ±0.22* | 2.08 ±0.19 | 2.05** ±0.15 |
| Second Run*† | 1.98 ±0.46 | 1.80 ±0.32* | 2.11 ±0.26 | 1.77** ±0.21* | 2.01 ±0.17 | 2.00** ±0.17* |
| Third Run*† | 1.99 ±0.46 | 1.77 ±0.31* | 2.05 ±0.26 | 1.75** ±0.22* | 2.01 ±0.16 | 1.99** ±0.15* |
| Fourth Run*† | 1.98 ±0.45 | 1.78* ±0.31* | 2.07 ±0.26 | 1.77* ±0.24* | 2.03 ±0.20 | 1.99 ±0.16* |

***Between groups difference ($P \leq 0.05$). **Between groups difference ($P \leq 0.01$).**
***† Between tests difference ($P \leq 0.05$).**

Finally in this table, the forth 20 min. run shows significant differences between tests and between groups in pre and post tests at ($P \leq 0.05$) for both WTG and NTG and different from UCON at ($P \leq 0.05$), it should be noted that UCON had similar levels of resting blood lactate throughout the period of study with no changes at all.

The blood lactate concentrations and the running velocity in (Table 7.6) were only the corresponded variables to the maximal lactate steady state and there were significant differences between WTG, NTG and UCON in blood lactate at post test ($P \leq 0.05$). The running velocity was significantly different at pre and post tests for both WTG and NTG at ($P \leq 0.05$) and between groups ($P \leq 0.05$, $P \leq 0.01$) respectively. The WTG had to run in the post test 0.9 $km.h^{-1}$ faster than NTG and 2.1 $km.h^{-1}$ than their UCON counterparts to elicit the $km.h^{-1}$ maximal lactate steady state. The percent of peak $\dot{V}O_2$ @ MLaSS and % HR max @ MLaSS were not significantly different to that at either of among tests or between groups (Table 7.6; $P \geq 0.05$).

**Table 7.6 Comparison of MLaSS variables for WTG, NTG runner boys and UCON group before and after training programme.**

| MLaSS Variables | Whole blood lactate concentrations ($mmol \cdot L^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Well trained (n=25) | | Normal trained (n=25) | | Untrained (n=14) | |
| | Pre | Post | Pre | Post | Pre | Post |
| [BLa] ($mmol \cdot L^{-1}$) | 5.04 ±0.94 | 5.09* ±0.74 | 4.6 ±0.79 | 4.9* ±0.85 | 3.97 ±0.26 | 4.16* ±0.36 |
| vMLaSS ($km.h^{-1}$) | 14.3* ±0.68*† | 15.1** ±0.66 | 12.3* ±0.75*† | 13.0** ±0.61 | 10.7 ±0.38 | 10.81 ±0.31 |
| % peak $\dot{V}O_2$ @ MLaSS | 89.8 ±2.9 | 88.2 ±4.8 | 91.9 ±3.5 | 88.9 ±2.9 | 89.7 ±4.0 | 88.46 ±3.29 |
| % HR max @ MLaSS | 94.5 ±2.7 | 94.2 ±2.3 | 94.2 ±1.8 | 94.7 ±1.7 | 95.18 ±1.94 | 94.2 ±1.3 |

***Between groups difference ($P \leq 0.05$). **Between groups difference ($P \leq 0.01$).**
****†Between tests difference ($P \leq 0.01$).**

Table 7.7 indicated that the percent peak $\dot{V}O_2$ at the fixed blood lactate was not significantly different to that of 2.0 and 2.5 $mmol \cdot L^{1}$ in relation to among tests for all groups, but there was only significant different between NTG and other groups in both pre and post tests ($P \leq 0.01$). The percent peak $\dot{V}O_2$ at 4.0 $mmol \cdot L^{-1}$ did not show any significant different to that at either among tests or between groups ($P \geq 0.05$).

Although, the percent HR max at 2.0 mmol·L$^{-1}$ shows significant difference between groups at ($P \leq 0.05$; $P \leq 0.01$) respectively, and between pre and post tests for UCON at ($P \leq 0.05$). Also, the percents HR max at 2.5 and 4.0 mmol·L$^{-1}$ obtained significant differences between groups at either pre or post tests ($P \leq 0.05$; $P \leq 0.01$) consequently. However, it should be noted that the lower percentage may be better for endurance performance.

**Table 7.7 Comparison of the percentage of physiological variables and fixed blood lactate concentrations for WTG, NTG and UCON group before and after training programme.**

| MLaSS Variables | Whole blood lactate concentrations (mmol·L$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Well trained (n=25) | | Normal trained (n=25) | | Untrained (n=14) | |
| | Pre | Post | Pre | Post | Pre | Post |
| %peak $\dot{V}O_2$ @ 2.0 mmol·L$^{1}$ | 63.3 ±6.4 | 62.04 ±10.3 | 71.0 ±7.0 | 70.0 ±5.5** | 63.4 ±7.2 | 63.1 ±4.2 |
| % peak $\dot{V}O_2$ @ 2.5 mmol·L$^{1}$ | 70.7 ±6.13 | 71.7 ±7.6 | 76.0 ±6.1 | 75.1 ±5.6** | 71.3 ±3.1 | 68.2 ±2.5 |
| % peak $\dot{V}O_2$ @ 4.0 mmol·L$^{-1}$ | 85.1 ±4.3 | 85.2 ±6.8 | 86.6 ±9.7 | 86.7 ±3.9 | 85.9 ±4.2 | 86.2 ±3.1 |
| % HR max @ 2.0 mmol·L$^{-1}$ | 77.0 ±5.5** | 76.6 ±5.6** | 80.7 ±4.8** | 81.5 ±4.0* | 76.5*† ±6.3 | 82.7*† ±3.0* |
| % HR max @ 2.5 mmol·L$^{-1}$ | 81.1 ±5.0* | 81.7** ±4.7 | 83.5 ±4.4* | 84.5** ±4.3 | 86.0 ±1.2* | 86.4** ±2.7 |
| % HR max @ 4.0 mmol·L$^{-1}$ | 91.2 ±3.4* | 91.7** ±4.0 | 92.0 ± 3.5* | 94.2** ±3.2 | 96.0 ±1.4* | 94.2** ±1.7 |

***Between groups difference (P ≤0.05). **Between groups difference (P ≤ 0.01).**
***†Between tests difference (P ≤0.01).**

The effects of suggested training times according to the % of HR and RV are shown in Table 7.8 and indicated that, there was no significant differences between well and normal trained boys at all suggested levels ($P \geq 0.05$).

**Table 7.8 Means (± SD) of training times according to % of HR and RV**

| Variables | Well Trained (n = 25) | | | Normal Trained (n = 25) | | |
|---|---|---|---|---|---|---|
| | Mean | | SD | Mean | | SD |
| Training time at 1st % levels | 23.2 | ± | 1.4 | 22.7 | ± | 0.9 |
| Training time at 2nd % levels | 20.9 | ± | 1.3 | 20.7 | ± | 1.2 |
| Training time at 3rd % levels | 19.0 | ± | 1.3 | 18.8 | ± | 1.4 |

However, Table 7.9 indicated that the effect of the suggested training times according to running velocity was observed and well trained boys were significantly different from normal trained boys at all levels of suggested RVs at ($P \leq 0.05$, and $P \leq 0.01$) respectively.

**Table 7.9 Means (± SD) of HR and RV according to training program**

| Variables | Well Trained (n = 25) | | | Normal Trained (n = 25) | | |
|---|---|---|---|---|---|---|
| | Mean | | SD | Mean | | SD |
| 1st level of HR zoon training | 159.0 | ± | 2.5 | 158.5 | ± | 2.8 |
| 1st level of RV* | 13.6* | ± | 0.6 | 11.7 | ± | 0.7 |
| 2nd level of HR zoon training | 168.3 | ± | 2.6 | 168.0 | ± | 3.0 |
| 2nd level of RV** | 14.3** | ± | 0.7 | 11.7 | ± | 0.7 |
| 3rd level of HR zoon training | 177.7 | ± | 2.7 | 177.2 | ± | 3.2 |
| 3rd level of RV** | 15.0** | ± | 0.7 | 13.0 | ± | 0.8 |

* Significant difference between well and normal trained boys (*P<0.05*).
** Significant difference between well and normal trained boys (*P<0.01*).

**Table 7.10 Means (± SD) of running performance times at both pre and post tests.**

| | Performance times in seconds | | | | | |
|---|---|---|---|---|---|---|
| | Well Trained | | | Normal Trained | | |
| Running distance | No | Mean | SD | No | Mean | SD |
| 800-m performance at pre test | 25 | 131.10 | ± 3.7 | 22 | 154.75 | ± 4.2** |
| 800-m performance at post test | 25 | 125.43* | ± 2.5 | 22 | 143.56* | ± 3.6** |
| 1500-m performance at pre test | 19 | 323.37 | ± 28.6 | 16 | 369.45 | ± 21.0** |
| 1500-m performance at post test | 19 | 283.39* | ± 20.8 | 16 | 323.10* | ± 17.3** |
| 3000-m performance at pre test | 20 | 657.83 | ± 19.8 | 15 | 724.17 | ± 15.0** |
| 3000-m performance at post test | 20 | 602.70* | ± 28.8 | 15 | 664.18* | ± 17.1** |

* Significant difference between pre and post performance times ($P<0.05$).
** Significant difference between well and normal trained boys ($P<0.01$).

## 7.5 Discussion

The foremost finding from this study was that the training programme significantly improved peak $\dot{V}O_2$ in groups of well and normal trained adolescent runners. The improvement in peak $\dot{V}O_2$ was significant in the normal trained group (NTG) but not significant for the well-trained group (WTG) after the intervention period. The relative increase in peak $\dot{V}O_2$ could be dependent upon the contents and design of the intervention training programme in particular the intensity, duration, frequency and mode of training that was carefully adjusted to meet the needs of the participant's baseline capability (Raven and Hagen, 1994). Whilst any increases in peak $\dot{V}O_2$ for the exercise training in children were affected by adjustments to the training programme over the intervention period this discussion emphasises changes in key physiological measures of aerobic and anaerobic performance.

The NTG obtained higher baseline values for %BF when compared to the WTG (Table 7.1) and performed comparatively low levels of running performance time (Table 7.1 to 7.3). It was indicated that a young population may not react positively to exercise training due to their ability and high levels of physical performance (Krahenbuhl et al., 1985; Sady, 1986). Therefore, children with lower levels of physical fitness need an appropriately prescribed training programme if improvements in performance are to be gained (Rowell, 1986; Shephard, 1992). With this in mind interval training a high level

of intensity closer to optimal predicted HR values has been suggested for young people according to those results observed in adults (Rowland and Green, 1989). Observations of training sessions and discussion with subjects suggest that the training programmes were enjoyable and developmentally appropriate.

One of the main physiological differences between the WTG and NTG children were related to differences in percent body fat which were significantly different between pre and post test the intervention training period. Thus, over this period both trained groups lost body fat in comparison to the NTG. These are likely to be a result of the increased energy expenditure of the training programmes. There is also some evidence that the relative reduction in adiposity was not matched by similar decreases in body mass. Thus suggesting that lean body mass increased. Increases in lean body mass may also contribute towards increases in aerobic performance as theses tissues provide greater demand on the aerobic system resulting in higher peak $\dot{V}O_2$ (Eriksson et. al. 1973).

Although, it was demonstrated in this thesis that MLaSS and vMLaSS in WTG group of adolescent runners occurred at relatively high exercise intensity when compared to the NTG and the UCON and these seem to be the most important considerations of improving running performance time in this case. Eriksson et al. (1973) indicated that high-intensity endurance training can significantly increase the PFK enzyme activity and the peak lactate responses throughout training period in young people and may improve the anaerobic glycolysis function with training. However, a 12% improvement in $\dot{V}O_2$ peak for adolescent girls following high-intensity endurance training programme of five weeks and 1hr a day has been reported (Eliakim et. al 1996).

Furthermore, the running velocity, % peak $\dot{V}O_2$, and % HR max at the fixed [$BLa^-$] of 2.0 and 2.5 $mmol \cdot L^{-1}$ were dissimilar to those corresponding to the MLaSS. Moreover, the WTG in this thesis had greater levels of cardiorespiratory fitness (peak $\dot{V}O_2$) than their NTG and UCON counterparts, when the data were normalised to % peak $\dot{V}O_2$ and % HR max the MLaSS corresponded to the same training exercise intensity. As far as we are aware, this is the first training study that has identified the MLaSS in groups of well trained adolescent middle distance athlete runners, compared to normally trained

athlete who were middle distance runners as well as an untrained adolescent control group.

The physical and physiological characteristics shown in (Table 7.3) demonstrate that the adolescent athlete runners who volunteered to take part in this study were similar to some endurance trained participants in other studies that have focused on the MLaSS (Tables A and B). Regrettably, it was not feasible to get hold of valid performance times for enough of the athletes in the previous studies to identify a potential association between the 800m and 1500m track events, and the MLaSS. On the other hand, if the performance times (Table 7.10) that were available are considered to be representative of the WTG and NTG athletes, they do suggest that this was a group of well trained, middle-distance runners.

The inter-individual discrepancy in [$BLa^-$] at the MLaSS for the WTG (range 3.5 to 5.0 $mmol \cdot L^{-1}$) was slightly higher than that seen in the NTG (3.4 to 4.7 $mmol \cdot L^{-1}$) and in the UCON (3.7 to 4.0 $mmol \cdot L^{-1}$). It must be clear that the disparity for the WTG was larger than the NTG and UCON and seems to be due to higher levels of intensity and running velocity that was applied for WTG corresponding to their counterparts in both NTG and UCON groups. However, this degree of discrepancy supports the figures reported previously (Williams and Armstrong, 1991; Mocellin et al., 1990; Billat et al., 1995). The mean MLaSS [$BLa^-$] were slightly higher than those reported for a group of untrained adolescent boys and girls (Williams and Armstrong, 1991; Almarwaey et al. 2004), and were also generally lower than those reported in most other studies of younger untrained children (Table 6.7). The majority of previous work was also limited by (1) the definition of the MLaSS and, subsequently, the exercise mode and protocol underpinned by this definition, (2) the blood lactate assay technique employed (refer to Table 6.8), and (3) the activity or training status of the participants.

MLaSS had been evaluated in 14 active but untrained adolescent boys using three different explanations previously reported within the literature (Beneke et al. 1996b). These studies indicated that test protocols conducted for less than ten minutes did not provide adequate explanation of lactate kinetics, resulting in an underestimation of the comparative exercise intensity at which the MLaSS takes place. One of the suggestions was that steady workloads (speed) for at least 20 minutes were a requirement for the

determination of reproducible MLaSS in this age population. On the other hand, a sequence of treadmill runs lasting only ten minutes was used with a group of 13-14 year old boys and girls (Williams and Armstrong, 1991). They reported [$BLa^-$] that was significantly lower than any other estimated for untrained children (Table 6.8). The explanation and exercise protocol for MLaSS assumed in the present study were very similar to one that has been suggested by Beneke et al. (1996b) and more recently similar to that demonstrated by Almarwaey et al. (2004). Consequently, discrepancies connecting the mean MLaSS [$BLa^-$] shown in Table 6.7 and those accounted by Beneke et al. (1996b) and by Almarwaey et al. (2004) are unlikely to be due to differences in protocol or explanations of MLaSS.

Gluconeogenesis may also change as a result of intense training in adolescents. Therefore it may be that the discontinuous nature of the steady speed runs used in the present study improved lactate fabrication and removal compared to a continuous protocol (Williams and Armstrong, 1991; Beneke at al., 1996b). However, the protection of the young participants in the present investigation was of dominant importance more than ever, particularly when thinking about the comparatively fast running velocities during tests and throughout the suggested intervention training programme. Whereas, the use of a discontinuous protocol along with blood sampling during the cycle-ergometry exercise demonstrated by Beneke et al. (1996a; 1996b) is perhaps easier than when young participants are running fast on a motorised treadmill.

Additionally, it has been observed that running velocity and heart rate at fixed blood lactate reference values are not changed significantly when 30 second breaks are used between exercise stages of 4 minute duration for capillary blood sampling (Gullstrand et al., 1994) and 5 minute duration (Almarwaey et al. 2004). In a previously and earlier investigation, Heck et al., (1985) demonstrated that on behalf of each 30 seconds that the exercise was discontinuous, the consecutively speed at a fixed [$BLa^-$] of 4.0 $mmol \cdot L^{-1}$ increased by 0.25 $km \cdot h^{-1}$. This increase was not statistically significant in the current study and was found to be less precise than that which the MLaSS in the present and previous study (Almarwaey et al. 2004).

A number of studies have suggested that the intervention programme should be matched to the performance capabilities of the athletes (Rowland, 1985; Sady, 1986;

Pate and Ward, 1990; Shephard, 1992; Morrow and Freedson, 1994). Therefore, the suggested intervention training programme in the present investigation applied adolescent specific training for improving performance. Rowland and Green (1989) reported that children may be trained at higher level of intensity to improve their fitness performance compared to adults. The current study applied to boys only in Saudi Arabia. However, a meta analysis by Payne and Morrow (1993) demonstrated that increases in aerobic capacity may be reduced with increased training status although this was not evident in this study.

However, studies that concentrate on MLaSS in young people and adolescents are few but increasing in number (appendix 7.1, 7.2). Because of the limited number of studies methodological issues need to be considered. In our work it was essential to understand that the reproducibility of the MLaSS predicted associated variables had nevertheless to be scientifically investigated in this age group population (Almarwaey et al. 2004). Results from our work (chapter 4) suggest that physiological measures were repeatable and thus the increases in performance as a result of the training programme are true.

## 7.6 Conclusion

In conclusion, the running speed at the MLaSS may be used as a measure of cardiorespiratory fitness and it has potential as a marker of endurance performance, but this has yet to be confirmed with young people. The relative exercise intensity at which the MLaSS corresponds appears to be sensitive to differences in aerobic power (peak $\dot{V}O_2$) between WTG and NTG middle distance athletes' runners. The MLaSS corresponded to relatively high exercise intensity in both groups of endurance well and normal trained young athletes. Also, large inter-individual variability in the [$BLa^-$] at the MLaSS was clearly evident. Finally, the running speed, % peak $\dot{V}O_2$, and % HR max at the MLaSS were significantly different to the physiological response at a fixed [$BLa^-$] of 2.5 and 4.0 $mmol \cdot L^{-1}$ determined during a standard incremental treadmill test after the intervention training programme. Considerable inter-individual variability when comparing these two lactate variables may exclude the use of this method as a substitute assessment in anticipation of additional cross-validation tests being conducted using prolonged sessions of endurance performance.

# Chapter Eight

# Synthesis of Findings

## 8.0 Synthesis of Findings

The aim of this section is to synthesise the findings and make suggestions for future work.

## 8.1 Synthesis

The main aims of this thesis were to assess the reliability of measures, assess physiological correlates of aerobic performance, and detect MLaSS and to quantify the effects of training on MLaSS in adolescent endurance runners.

The first study demonstrated that peak $\dot{V}O_2$ corresponded to fixed blood lactate reference values pre-determined running speeds, and that lactate threshold measures were reliable. Reliability for test and retest ranged between 0.6 to 0.97 and 0.8 to 0.98 for boys and girls respectively. The coefficient of variation for these measures ranged from 1.6 to 4.8% for boys and 1.5 to 4.0% for girls. These results support further use of peak $\dot{V}O_2$, fixed blood lactate at carefully controlled running speeds in young athletes in studies 2, 3 and 4.

Data from the second study found that peak $\dot{V}O_2$, v $\dot{V}O_2$ and the running speed at 2.5 mmol.L (v2.5), were significant independent variables of 1500-m performance in boy and girl endurance runners. In addition, the peak $\dot{V}O_2$, at 2.5 mmol.L was related to 1500-m time in the girls. The variance in 800 m and 1500 m performance times were not measured, but the performance times were used as the field-based performance measures throughout studies 2, 3 and 4.

The results from studies 1 and 2 verified further use of MLaSS, peak $\dot{V}O_2$, and v $\dot{V}O_2$ in endurance trained, adolescent runners. Furthermore the findings from these studies suggested that middle distance running potential and the effects of a training programme could be detected using these measures.

Having developed reliable and valid testing protocols in studies 1 and 2 the third study was designed to identify lactate break points during treadmill run performance. Data from this study indicated that, the running speed, % peak $\dot{V}O_2$, and % HR max at the fixed [$BLa^-$] of 4.0 $mmol \cdot L^{-1}$ was significantly higher and corresponded to a relatively high exercise intensity. It appeared that the running speed, % peak $\dot{V}O_2$, and % HR max at the MLaSS lay somewhere between the fixed [$BLa^-$] of 2.0 and 2.5 $mmol \cdot L^{-1}$. These results confirm earlier work that has suggested a fixed [$BLa^-$] of 2.5 $mmol \cdot L^{-1}$ may be used with young people to assess and monitor endurance running performance

in place of the more commonly used 4.0 $mmol \cdot L^{-1}$ that has received so much attention in adult-based studies. Also, an athlete's stage of maturation may have partial effect on both variables and running performance time especially at supra suggested training levels.

The fourth study was designed to investigate the effects of a training programme on variables those were both reliable and predictive of aerobic performance from studies 1, 2 and 3. Thus HR, LT and RV, HR, $\dot{V}O_2$ and peak $\dot{V}O_2$ at LT were used to quantify the effects of the training programme on aerobic performance in sub-elite Saudi Arabian male adolescent runners. The effect of running 27 to 45 kilometres combined with two or three extra treadmill running sessions per week for 3 months found that resting HR, LT and RV, HR, $\dot{V}O_2$ and peak $\dot{V}O_2$ at LT were significantly affected by endurance training.

## 8.2 Implications for adolescent research

Work undertaken in this thesis indicated that aerobic performance in adolescent boys and girls were related to a combination of physiological measures. Moreover, these findings also suggested that MLaSS thresholds were age specific and lower than those reported for adults. The effect of endurance training positively affected endurance performance by shifting the lactate curve to the right, although this was only demonstrated in boys. Whilst this work supports the plasticity and trainability of adolescent boys little is known of the effects of similar training on the endurance performance of adolescent girls. In this sense girls are an understudied group and further work is recommended with this population. Unfortunately there are limited longitudinal studies on changes in MLaSS between childhood and adulthood nor are there many studies on physiological performance across elite junior sports populations to further inform our work.

Whilst invasive measures and methodological limitations restrict a more detailed investigation of the fundamental mechanisms responsible for changes that affect endurance performance during adolescence, qualitative variations may take place in the muscle that stimulate improvements in performance through increases in oxidative phosphorylation, and concomitant changes in lactate production or increases in lactate clearance. Other anthropometric, endocrinological, body composition and biomechanical factors may affect endurance performance differences between boys and girls.

## 8.3 Implication for Coaching

Evidently the efficient assessment of aerobic and anaerobic performance throughout adolescence would allow coaches to formulate more scientifically derived training programmes. These programmes delivered by a coach with knowledge and experience would guarantee the runners the most favourable training stimulus throughout adolescence.

This is important, as the adolescence is an important phase where a runner's core performance and proficiency is developed. Findings from this study suggest that coaches should help young runners become aware of how factors such as frequency of training affect running velocity and ultimately performance. Furthermore, during the early development phase runners should be exposed to aerobic/anaerobic sets of different intensities and distances. Then from the age of 13 years for girls and 14 years for boys, runners should be progressively introduced to anaerobic sets using for example lactate tolerance, lactate production and sprint sets. Coaches should also encourage runners to experiment with pace during training and in competition in attempt to detect lactate acidosis during field settings. Where appropriate it may also be useful for coaches to use portable lactate monitoring instruments to assess blood lactate in conjunction with measures of heart rate and performance times during training in the field.

## 8.4 Limitations

Sample size in any investigation on specific populations of youngsters is problematic. Whist numbers of participants could have provided greater statistical power this body of work included relatively large numbers of participants compared with other studies in the literature. The lack of female participants in study 4 was a resulted of cultural influences in the Kingdom of Saudi Arabia, thus results from this study are limited to boys. Other factors that may affect the generalisability of results were limitations in accurately measuring maturation, participant's exact compliance to training programmes, a lack of run performance times for all runners as well as technological limitations in the measurement of lactate production and removal.

## 8.5 Conclusion

In conclusion, the results of this thesis support an age-related increase in endurance aerobic and anaerobic performance. Measurements taken and training programmes implemented were reliable, valid and practical. This thesis has indicated significant sex differences in endurance performance. However the statistical analysis indicated that differences in endurance performance exist between boys and girls. With increasing age, boys demonstrated an improved running velocity, cardiorespiratory function and blood lactate profile, although this work has not established whether differences are biochemical, hormonal or neural. The results suggested that in both sexes, factors other than age, body size and boy composition contribute towards endurance running performance. Moreover, these are likely to differ between boys and girls. Maturity may have a slight impact on adolescent endurance performance, and its effect cannot be completely ignored, as body size and body composition alter with age and are not fully independent of maturity. From a coaching viewpoint the findings of this thesis clearly reveal that from the age of 14-18 years runners should be introduced to high intensity training and that changes should also be made to the format of the adolescent middle distance running competition.

## 8.6 Recommendations for future research

As a result of the findings from the 4 studies undertaken in this thesis the following recommendations for future research can be made:

- To investigate the effect of maturity and interaction with training intensity on aerobic performance in adolescent athletes.
- To further investigate gender specific training in adolescent athletes.
- Use additional neuroendocrine measures to elucidate the mechanism and factors that affect endurance performance in adolescent athletes.

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# Appendices

**List of publications**

**Full Science Citation Index (SCI) rated publications**

- Almarwaey, O. A., Jones, A. M., and Tolfrey, K. (2003). Physiological correlates with endurance running performance in trained adolescents. *Medicine and Science in Sports and Exercise*, 35(3), 480-487.

- Almarwaey, O. A., Jones, A. M., and Tolfrey, K. (2004). Maximum lactate steady state (MLaSS) in trained adolescent runners. *Journal of Sports Sciences*, 22, 215-225.

**Published abstracts**

- Tolfrey, K., Almarwaey, O. A., Bracken, R., Alfrey, C., and Jones, A. M. (2001). The relationship between fixed blood lactate reference values and 1500 m running performance in endurance trained teenage boys and girls (Abstract). *Journal of Sports Sciences* 19(1), 64-65. Liverpool (BASES).

- Tolfrey, K., Almarwaey, O. A., Abbott, J., Satherley, H., and Jones, A. M. (2001). Maximum lactate steady state (MLaSS) in endurance trained, adolescent runners (Abstract). *Paediatric Exercise Science*, 13(3), 306-307. Belgium (PWP).

- Tolfrey, K., Almarwaey, O. A., Abbott, J., Satherley, H., and Jones, A. M. (2002). Maximum lactate steady in trained adolescent boys and girls (Abstract). *Medicine and Science in Sports and Exercise*, 34(5), S86.St. Lows, USA (ACSM).

- Tolfrey, K., Almarwaey, O. A., Abbott, J., Satherley, H., and Jones, A. M. (2003). Reliability of the blood lactate response during an incremental treadmill exercise test in adolescent athletes (Abstract). *Paediatric Exercise Science*, 15(1), 114. Michigan, USA (NASPEM).