The development of a Soccer-specific test:

Reproducibility and comparison with a treadmill test

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ABSTRACT

Introduction

Aerobic fitness is recognised as one of the principal fitness components in soccer (Helgerud et al, 2000). Thus, it is important to monitor the aerobic fitness of professional soccer players throughout the soccer season and throughout injury rehabilitation. Sub-maximal blood lactate assessment in soccer players has been shown to be a sensitive indicator of change in aerobic fitness over a specified time-period, and can also prove useful for monitoring aerobic fitness of professional soccer players undergoing a period of injury rehabilitation, when $\dot{V}O_2$ max assessment may be inappropriate.

Soccer, being a high-intensity, intermittent team sport is multi-directional in nature. However, traditionally most sub-maximal blood lactate assessments have been conducted on a treadmill, being only uni-directional in nature. Muscle fibres that are recruited during soccer-specific movements such as turning and decelerating may not be recruited to the same degree during treadmill running. Therefore, some specific peripheral aerobic fitness adaptations that arise from soccer-specific activities may not be fully detected by sub-maximal blood lactate assessment on a treadmill. To improve the specificity of sub-maximal blood lactate assessment of soccer players, a Soccer-specific Endurance Lactate Test (SELT), incorporating multi-directional movements was devised. If this soccer-specific test is to be of value in the monitoring of changes in training status, it must be shown to be reproducible. It is also important to establish if the SELT provides different information from a 'traditional' blood lactate test on a treadmill. This could provide some validation for using the SELT in the assessment of the endurance capabilities of soccer players in preference to a currently used test such as an incremental treadmill test.

Aims

The first aim of this study was to assess the reproducibility of a number of variables obtained from the SELT - lactate threshold (v-T_{lac}), 4 mmol.L^{-1} marker (v-4mM), and Oxygen consumption ($\dot{V}O_2$), heart-rate (HR) and Ratings of Perceived Exertion (RPE) at both v-T_{lac} and v-4mM.

The second aim of this study was to compare the physiological responses (Blood lactate, $\dot{V}O_2$, HR and RPE) of the SELT to continuous exercise performed on a treadmill at a similar exercise intensity for a comparable period of time.

Methods

Study 1

Twenty-three physically active males (mean ± sd) {21.9 ± 3 years; 182.6 ± 6 cm; 77.7 ± 9 kg} participated in two SELT tests with 3-10 days between tests. SELT incorporates running forwards and backwards, turning, moving sideways, and stop/start movements performed in a regular pattern on a 20m running track. Test speed is dictated by pre-determined audio bleeps on a CD and floor markings on the running track, as in the Multi-stage shuttle test. Whole blood lactate concentration (BLa) (Analox Instruments, UK), HR (Polar Accurex, Finland) and RPE (Borg 6-20 scale) were taken at the end of each test stage. Subjects performed two identical incremental tests with 5 min stages and a 30 s rest between each stage. The first stage test velocity was 7 km.h^{-1}, with test velocity increasing by 0.75 km.h^{-1} per stage. All subjects exercised to at least a BLa of 4 mmol.L^{-1}. In 10 out of the 23 subjects $\dot{V}O_2$ was monitored continuously using a portable oxygen analyser (Kosmed K4b2 – COSMED, Rome, Italy).

The limits of agreement (LoA) approach presented by Bland and Altman, and Deming Regression were used to assess the level of agreement and reproducibility of *v-T_{lac}* and *v-4mM*, $\dot{V}O_2$, HR and RPE at *v-T_{lac}* and *v-4mM*. Paired t-tests were used to detect any possible bias for Blood lactate, $\dot{V}O_2$, HR and RPE at the end of each completed level of the SELT between tests 1 and 2.

Study 2

Ten physically active males (mean ± sd) {20.8 ± 2years; 180.9 ± 5 cm; 77.6 ± 9kg;} participated in one SELT test and one treadmill test with 3-10 days between tests. The SELT was performed as in study 1. The treadmill test was designed with the intent to mimic the SELT minus the 'specific' movements (backwards/sideways running). The treadmill incorporates 5 min stages of continuous running and a 30 s rest between each stage. The first stage test velocity was 7 km.h^{-1}, with test velocity increasing by 0.75 km.h^{-1} per stage. Whole blood lactate concentration, HR and RPE were taken at the end of each test stage. $\dot{V}O_2$ was monitored continuously.

To compare the differences in blood lactate, $\dot{V}O_2$, HR and RPE at the end of each level between the SELT and the treadmill test a two-way analysis of variance (ANOVA) was used. This method was also used to compare difference between *v-T_{lac}* and *v-4mM*, and $\dot{V}O_2$, HR and RPE at *v-T_{lac}* and *v-4mM* for the two tests.

Results

Study 1

Bland and Altman Limits of Agreement (LoA) indicate that an improvement of 4.62 km.hr^{-1} in *v-T_{lac}* and 1.6 km.hr^{-1} in *v-4mM* is necessary to be considered outside day to day variability. For the other variables a change of 13.86 ml.kg^{-1}.min^{-1} in $\dot{V}O_2$/kg at *v-T_{lac}*, 10.62 ml.kg^{-1}.min^{-1} in $\dot{V}O_2$/kg at *v-4mM*, 67.95 beats.min^{-1} in Heart Rate at *v-T_{lac}*, 20.66 beats.min^{-1} in HR at *v-4mM*, *11.55 units in* RPE at *v-T_{lac}* and *4.4* units in RPE at *v-4mM* are needed in order to be interpreted as a change in training status. Large LoA, particularly in the variables associated with *v-T_{lac}*, may be due to a number of reasons such as the method of lactate threshold determination, low subject number or the physiological status of subjects. There was no evidence of a significant mean bias in any of the measures except *v-4mM*. *v-4mM* was on average, 0.31 km.h^{-1} higher in Test 2 compared with Test 1.

There was a significant mean bias across some of the levels between SELT test 1 and SELT test 2 for blood lactate and HR suggesting higher scores in test 1. There was no significant difference found across all levels between SELT test 1 and SELT test 2 for $\dot{V}O_2$/kg and RPE.

Study 2

Graphical analysis suggests that the treadmill tests is more taxing physiologically in the early levels and the SELT elicits a greater physiological cost in the later levels, with the crossover occurring between levels 6 and 7. The lack of significance of some of these results is most likely a function of low sample size, particularly in the later levels, and may limit conclusions made.

There was no convincing evidence of a mean SELT to treadmill difference for $v\text{-}T_{lac}$, $v\text{-}4mM$ or any of the associated variables.

Conclusions

The SELT has good reproducibility for the 4mM marker and associated variables, which is a promising result. However the reproducibility of $v\text{-}T_{lac}$ and associated variables is poor and LoA indicate that an unacceptably large change in scores is necessary before the change can be attributed to a difference in training status. These findings cast doubt on the sensitivity of this method of determining the lactate threshold in this population. The fact that a mean bias has been detected for a number of variables suggests that a study such as this may benefit from a more extensive familiarisation period.

Comparing the differences in blood lactate, $\dot{V}O_2$, HR and RPE at the end of each level between the SELT and the treadmill indicated that the SELT elicits a greater physiological cost than the treadmill test in the later levels when subjects are required to move at a faster pace. However analysis of the difference $v\text{-}T_{lac}$, 4mM and associated variables indicated no significant difference between tests. As the findings have been somewhat inconclusive further study may be beneficial.

The SELT offers sports scientists and rehabilitation staff a means of measuring the physiological status of soccer players by application of a soccer-specific lactate test.

INTRODUCTION

Soccer is the world's most popular sport (Reilly, 1996), with well managed championships and international competitions and great financial interest in many countries. The basic rules of the game were formulated in 1848 in England and, after modifications in 1863, have remained substantially unchanged thereafter. The international governing body, FIFA was founded in 1904 and the first FIFA World cup was held in Uruguay in 1930. Its world-wide popularity is most notable at a spectator level with huge television audiences for the major competitions – it was estimated that the 1998 FIFA World cup attracted approximately 40 billion television viewers (Shepard, 1999). The popularity of the game is further reflected in the millions who participate in soccer, at not only professional, but at all levels of play. It was estimated in 1984 that there was approximately 60 million licensed players and another 60 million unlicensed players, who participate in local soccer leagues throughout the world (Ekblom, 1986). This widespread popularity has ensured that soccer has now become a worldwide multi-million pound industry. Elite professional soccer players now have earnings of tens of thousands of pounds per week and the world's top soccer clubs are willing to pay millions of pounds to secure their services. Clubs in the top leagues in the world receive millions of pounds from television revenue, and even more if they qualify for the elite European competitions.

At a professional level particularly, there are many physiological stresses associated with competitive play that call for high levels of physical fitness. Despite the universal nature of the sport and its formal history dating back over a hundred years, there are still many uncertainties concerning the physiological requirements and optimum training and conditioning methods. One reason for this is that historically, sports physiologists have not been warmly welcomed by football practitioners, sceptical of the role of the physiologist

and the influence of science on the game. Also there are various methodological difficulties for sports scientists who wish to investigate such an open and varied sport. Nevertheless, due to its world-wide popularity and great financial interest, the scientific study of soccer is increasing.

Research, which has been carried out particularly over the last decade, is shedding increasing light on the physiological requirements of soccer and an impressive body of knowledge has accumulated about the scientific aspects of the game. The foundation for performance in soccer is represented by an array of attributes including various skills and tactical sense (Helgerud et al, 2001). Soccer requires physical and technical attributes as well as a high level of concentration and perceptual skills. However, when teams roughly equal in ability meet, the one with the higher overall fitness level is likely to have the advantage as the "fitter" team will be more able to cope with a fast pace of play over the course of a whole game. Considering the great financial pressures and rewards associated with success at a professional level both to players and clubs it would seem important to achieve an optimal fitness level throughout the competitive season.

The physiological demands of soccer are more complex than in many individual sports. The exercise is intermittent and players perform many different multi-directional movements – the intensity can alternate at any time, ranging from standing still to maximal sprinting. Players should have a well-developed ability to exercise with a high power output (anaerobic), whilst also being able to work for a long duration in a widely fluctuating tempo (intermittent aerobic endurance). This separates soccer from sports that exhibit a more continuous exercise profile, such as endurance running.

There is a large variability in the physiological demands imposed on soccer players during a game. The activity of an individual during a match is influenced by several factors such as physical fitness, tactics, positional role of the player, importance of the game, environmental conditions and quality of the opposition.

Aerobic fitness is recognised as one of the principal fitness components in soccer (Bangsbo, 1994). A recent study by Helgerud et al (2001) has shown a direct cause and effect relationship between improving endurance capacity and improving soccer match-play performance. Furthermore, decrements in performance caused by fatigue during a game have been demonstrated by reports of reduced distances, intensities of sprints, and increased injuries and goals as a game progresses (Bangsbo, 1994; Ekblom, 1998; Smaros, 1980; Thomas and Reilly, 1976). This highlights the importance of the achieving an optimal endurance capacity in soccer players. Thus, it is important to monitor the aerobic fitness of professional soccer players throughout the soccer season and throughout injury rehabilitation.

Pate and Kriska (1984) identified the three main determinants of aerobic endurance as – Maximal aerobic power ($\dot{V}O_2$ max), anaerobic threshold (as identified by the blood lactate response to exercise), and running economy.

Peak oxygen consumption ($\dot{V}O_2$ max) has become accepted as the criterion measure of cardiovascular fitness and is widely believed to be a strong correlate of endurance performance capability (Weltman, 1995). Running economy, usually measured on a laboratory treadmill as the relative oxygen cost ($ml.kg^{-1}.min^{-1}$) for a given sub-maximal velocity has also been shown to be an important determinant of endurance performance

(Berg, 2003). Sub-maximal blood lactate assessment in soccer players has been shown to be a sensitive indicator of change in aerobic fitness over a specified time-period (Bangsbo, 1994), and can also prove useful for monitoring aerobic fitness of professional soccer players undergoing a period of injury rehabilitation, when $\dot{V}O_2$ max assessment may be inappropriate (Grant and McMillan, 2001). In fact many researchers have suggested that blood lactate parameters are better indicators of endurance performance (Allen et al, 1985; Farrell et al, 1979; Fohrenbach et al, 1987; Helgerud, 1994; Ivy et al, 1981; LaFontaine et al, 1981; Weltman, 1995), are more sensitive to changes in training status (Gollnick et al, 1986; Sjodin et al, 1982; Weltman 1995), and provide better indices of exercise intensity by which to provide guidelines for training (Fohrenbach et al, 1987; Sjodin et al, 1982; Weltman, 1995) than the traditional 'gold standard' $\dot{V}O_2$ max.

Traditionally most sub-maximal blood lactate assessments have been conducted on a treadmill, which is uni-directional in nature. This is in contrast to the high-intensity, intermittent and multi-directional nature of soccer (Bangsbo, 1994). Muscle fibres that are recruited during soccer-specific movements such as turning and decelerating may not be recruited to the same degree during treadmill running. Therefore, some specific peripheral aerobic fitness adaptations that arise from soccer-specific activities may not be fully detected by sub-maximal blood lactate assessment on a treadmill.

To increase the specificity of sub-maximal blood lactate assessment of soccer players, a **Soccer-specific Endurance Lactate Test (SELT)**, incorporating intermittent, multi-directional 'soccer-specific' movements was devised. In theory this test should be better equipped to provide the coach and sports scientist with a more accurate an valid way of assessing a soccer player's training status and some aspects of performance capabilities.

Many field tests are routinely used by coaches and sports scientists to evaluate the physiological and performance related elements of soccer. Data derived from such tests provide the coach with valuable feedback for inter-individual comparisons and for intra-individual evaluations over time. To allow such temporal comparisons to be drawn, and resultant inferences implied with confidence, a quantification of the test reproducibility must first be made. Therefore if the SELT is to be of value in the monitoring of changes in training status, it must be shown to be reproducible. If it is not, it will be unable to detect meaningful changes in status. For example, if an athlete's lactate threshold velocity increases by 1.0 km h^{-1}, it is important to establish if this is a meaningful change, or if it could be attributed to day-to-day fluctuations in the lactate response. Highly variable results have little meaning and would therefore have no use in this context.

It is also important to establish if the SELT provides different information from a traditional blood lactate test. This could provide some validation for using the SELT for the assessment of the endurance capabilities of soccer players in preference to a currently used test such as an incremental treadmill test.

The first aim of this study was to quantify the reproducibility of a number of variables obtained from the SELT – lactate threshold (*v-T_{lac}*), 4 mmol.L^{-1} marker (*v-4mM*), and Oxygen consumption ($\dot{V}O_2$), Heart-rate (HR), and Ratings of Perceived Exertion (RPE) at both *v-T_{lac}*, v-4*mM and* at the end of each completed level of the SELT.

The second aim of this study was to compare the physiological responses (Blood lactate, *HR and RPE)* of the SELT to continuous exercise performed on a treadmill at similar exercise intensity for a comparable period of time. This comparison should ascertain whether or not the SELT provides different information than a traditional treadmill lactate test.

THE PHYSIOLOGICAL DEMANDS OF SOCCER

Soccer performance is determined by a player's technical, tactical, physiological and psychological/social characteristics (Bangsbo, 1994). These elements are closely linked to each other e.g. the technical quality of a player may not be utilised if the player's tactical knowledge is low. The physiological demands of soccer are more complex than in many individual sports. In soccer, the players perform many different multi-directional movements – the exercise intensity can alternate at any time, ranging from standing still to maximal sprinting. Under optimal conditions these demands are closely related to the player's physical capacity, which can be divided into the following categories: a) the ability to perform prolonged intermittent exercise (endurance); b) the ability to exercise at high intensity; c) the ability to sprint, d) the ability to develop a high power output (force) in single match situations such as kicking, jumping and tackling (Bangsbo, 1994).

There is a large variability in the physiological demands imposed on soccer players during a game. The activity of an individual during a match is influenced by several factors other than physical attributes, such as the positional role of the player, the importance of the game, environmental conditions and the quality of the opposition. Various aspects of soccer specific physiology are examined in this chapter, with particular reference to aerobic fitness.

MOTION ANALYSIS

In order to gain an impression of the physiological load imposed on players during soccer, observations have to be made during competitive match-play. Motion analysis of soccer players can provide data about the physiological demands of soccer in general. There are a number of different ways in which to study the motion characteristics of soccer. Activities may be classified according to mode, intensity, duration, distance and frequency. In this way an overall picture of the physiological demands can be gathered as a whole.

DISTANCE COVERED

Reilly and Thomas (1976) stated that the total distance covered in a game provides information about the physiological load associated with soccer match-play. Several studies have determined the individual distance covered during a game, which can be used as an indicator of the total work performed (based on the theory that the energy cost of running is related to mechanical work output and is largely independent of the running speed).

One of the first to analyse soccer in such a way was Walter Winterbottom, manager of the English national team and the FA Director of coaching from 1946 to 1962. He studied professional soccer players during match-play by tracking their movements on a scale plan of the pitch, and he estimated that the players covered a distance of 3361m (cited in Bangsbo, 1994). Wade (1962) reported a total distance ranging from 1600-5486m for professional players, and the ranges for walking-jogging and speed running were 1372-3657 and 229-1829m, respectively. Since then several methods have been have been used in order to determine the distance covered during a soccer match. Methods of monitoring movements of players during competition have included tape-recorded commentaries,

video-recordings, film analysis, synchronised trigonometric techniques, and computer-aided video analysis (Reilly 1996) (Table 1)

Source	Players	Distance covered (km)	Method
Winterbottom (1952)	Prof. Players (England)	3.3	Hand Notation
Wade (1962)	Prof. Players (England)	1.6-5.5	Undisclosed
Saltin (1973)	Non-Elite	11.5	Cine-Film
Knowles and Brookes (1974)	Prof. Players (England)	4.8	Hand Not.
Reilly and Thomas (1976)	Prof. Players (England)	8.7	Tape-Rec.
Withers et al (1982)	First Team Players (Australia)	11.5	Videotape
Ekblom (1986)	1st-4th Division (Sweden)	10	Hand Not.
Van Gool et al (1988)	University players (Belgium)	10.3	Cine-Film
Ohashi et al (1988)	Elite players	9.8	Trigonometry

Table 1. Distance covered (km) during a soccer game according to different researchers (adapted from Reilly, 1994 and Bangsbo, 1994)

On the basis of the following studies on Australian (Withers et al, 1982), Belgian (Van Gool, 1988), Canadian (Mayhew and Wenger, 1985), Danish (Bangsbo et al, 1991, Bangsbo and Lindquist, 1992), English League (Reilly and Thomas, 1976), Japanese (Ohashi et al, 1988) and Swedish (Saltin, 1973) players it is generally accepted that, on average, soccer players cover a distance of 8 -12 km during the course of a match.

WORK RATE

The overall distance covered in a game is an unreliable measure of work rate due to the frequent changes in activities. Reilly and Thomas (1976) found that English First division players had about 1000 changes in playing activities during a match with each activity being of mean duration of 5-6s. Bangsbo (1991) found the corresponding values for Danish elite players were 1179 changes and 4.5s respectively. These discrete bouts of action incorporate frequent changes of pace and direction as well as type of activity and involvement with the ball. In the same study by Reilly and Thomas it was found that players had short rest periods of around 3s on average every 2 min, with sprints averaging

about 15m in distance, and occurring approximately every 90s. Although these data were derived over 25 years ago, Reilly (1994) states that observations made on World Cup players performing in the English League in 1990 indicate that these profiles from the 1970's are still representative of top-level club soccer. Reilly (1996) found that overall distance covered by outfield players during a match consists of 24% walking, 36% jogging, 20% cruising sub-maximally, 11% sprinting, 7% moving backwards and 2% moving in possession of the ball. Masked within these broad categories are sideways and diagonal movements (Figure 1).

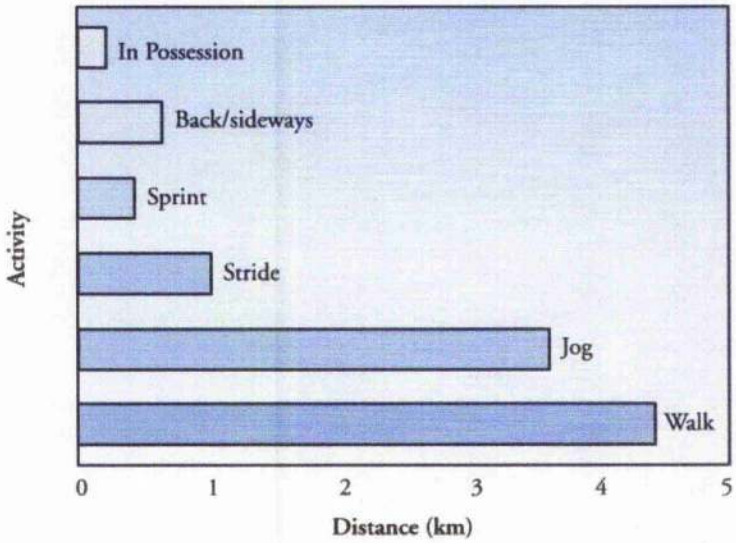


Figure 1. Mean distances covered (km) during a soccer match by an international striker playing in an English league match. Adapted from Reilly (1996)

The categories of cruising and sprinting can be combined to represent high intensity activity in soccer. Reilly (1996) found a ratio of low intensity to high intensity exercise to be 2.2 to 1 in terms of distance covered. In terms of time, this ratio is about 7 to1, denoting the predominantly aerobic outlay of energy i.e. principally sub-maximal stress on the aerobic energy system. The total distance covered by top class players with the ball is less

than 2%. Although the most decisive and memorable moments occur in possession of the ball, this small percentage highlights the importance of a high level of 'off the ball' fitness.

FACTORS AFFECTING WORK RATES

The work rate is influenced to a large extent by the positional role of the player. Midfield players who have to act as links between defence and attack cover the greatest distances. This has been noted in English (Reilly and Thomas, 1976), Swedish (Ekblom, 1986) and Danish (Bansgbo et al, 1991) elite football. Ekblom (1986) found that the greater overall distance covered by the Danish midfield players compared to other positions was due to more running at low speeds, denoting an aerobic type of activity profile for the midfield player in particular. Studies of English league players show that strikers and midfield players cover more distance sprinting than defenders. Fullbacks show the greatest variability in distance covered, while centre-backs generally cover the greatest distances moving backwards (Reilly, 1994). Although work-rate profiles are relatively consistent from match to match, Bangsbo (1994) states that it is the high-intensity component that is the most constant feature.

Goalkeepers cover a distance of around 4 km during a match. Their work-rate profile emphasises short duration anaerobic efforts when they are called into play. Therefore, a high aerobic fitness level is not regarded of being of prime importance for the goalkeeper (this study is devoted to the aerobic fitness / physiological demands of **outfield** soccer players).

The style of play may influence the work-rates of players. Some teams may be very direct in their approach to a game whereas some may be more patient and methodological, some

teams may emphasise defence whereas some may focus on attack. The style of play can also be influenced by opposition and significance of game, for example if a team is playing another which they feel is superior offensively, one tactic would be to be very defensively organised. Score-line can also influence play where a team which is in the lead may change tactics from attack minded to defensive in order to 'protect a lead'.

FATIGUE

Fatigue has been defined as a decline in performance due to the necessity to continue performance (Reilly, 1996). This inability to maintain a given workload is manifest in soccer as deterioration in work-rate towards the end of a game. Studies that have compared work-rates between first and second halves of matches have provided evidence of the occurrence of fatigue (Bangsbo et al 1991, Reilly and Thomas 1976, Van Gool et al 1988).

Professional soccer players should ideally be able to maintain a high level of intensity throughout a whole game, however Belgian university players were found to cover less distance in the second half than in the first half (Van Gool et al, 1988). Bangsbo et al. (1991) reported that the distance covered in the first half was 5% greater than in the second. Reilly and Thomas (1976) noted an inverse relation between aerobic fitness and decrement in work rate. Tumilty (1993) and Reilly (1994a) suggest that the aerobically fit player may be spared this decrement in work-rate. Although difficult to quantify it is also highly likely that fatigue not only influences work rate but may also cause a decrement in technical skills and, concentration and perceptual skills. Therefore it seems that a high aerobic fitness level is would be of particular advantage to soccer players and most evident in the later parts of a match.

THE PHYSIOLOGICAL DEMANDS OF MATCH-PLAY

In addition to analysing the motion characteristics of soccer, more specific physiological parameters such as measurements of oxygen uptake and heart-rate can be collected to provide an indication of the physiological load imposed on soccer players during competitive match-play. As mentioned soccer is a complex sport, more so than most individual sports. Therefore, the demands of the game will be specific to the sport and similarly complex in nature. Soccer match play requires not only physiological attributes, but mental ones as well, however this chapter will focus on the physiological demands of match play. Soccer players perform many different activities during match-play, with the intensity alternating at any time. The intermittent nature of the game demands that players should have a well-developed ability to exercise with a high power output (anaerobic), whilst also being able to work for a long duration in a widely fluctuating tempo (intermittent aerobic endurance).

Generally it is impractical to make physiological measurements on players during serious competitions. It is unrealistic to encumber players with monitoring devices, even the portable gas analysers for oxygen analysis or to interrupt the game for invasive measurements such as blood sampling. Research strategies employed to analyse the effects of soccer match-play have varied from the use of practice games and friendly matches where a range of physiological measurements were allowed.

AEROBIC ENERGY PRODUCTION DURING SOCCER MATCH-PLAY

There have been several attempts to determine the contribution of aerobic metabolism during soccer by measuring oxygen uptake ($\dot{V}O_2$) during match-play, and values of 1-2 $l.min^{-1}$ have been obtained (Covell et al, 1965; Ogushi et al, 1993; Yamaoka, 1965). These may not be representative of $\dot{V}O_2$ during match-play, since the collecting procedure (Douglas bag) interferes with normal play and only minor parts of the match have been analysed. More recently, Kawakami and colleagues (1992) minimised this problem by using a light-weight portable telemetry system (K2) to measure $\dot{V}O_2$ during various soccer related activities. The $\dot{V}O_2$ values were between 2 and 4 $l.min^{-1}$ for small-sided games (1 v 1 and 3 v 3), with the highest $\dot{V}O_2$ recorded from dribbling drills (4 $l.min^{-1}$).

Heart rate (HR) is another index of the physiological strain incurred by the soccer player during match-play. HR monitoring is relatively unobtrusive as it can be monitored continuously during a match by radio telemetry. For this reason HR might represent a more exact picture of the contribution of the aerobic energy system in soccer. The subject wears chest electrodes attached to a lightweight radio transmitter, the signal being picked up by a receiver on the sidelines. Alternatively, short-range telemetry may be used, the receiver being worn like a watch on the wrist of the player: the signal is retained in the memory of the receiver and played back for analysis after the game. It should be noted that, in some circumstances, the value of HR as a means to measure physiological strain may be limited, as it does not take into account changes in stroke volume and therefore cardiac output.

While HR may be used, there may be limitations in the interpretation of results. HR and oxygen uptake ($\dot{V}O_2$) are linearly related throughout a large proportion of the HR range (Astrand and Rodahl, 1986). Oxygen uptake can be estimated indirectly from the HR-$\dot{V}O_2$

relation determined in the sports laboratory. However, HR does not always reflect the actual $\dot{V}O_2$. HR may be elevated beyond the normal HR- $\dot{V}O_2$ relationship because of static contractions, emotional, and thermal stress (Astrand and Rodahl, 1986). Overestimation of $\dot{V}O_2$ due to these factors is probably minor in soccer, because of the high exercise intensity and the dominant use of large muscle groups (Bangsbo, 1994). A consideration when using the HR- $\dot{V}O_2$ relationship is the validity of using the relationship when it is determined from continuous sub-maximal exercise (usually running on a treadmill) and applying this relationship to estimate $\dot{V}O_2$ for soccer's intermittent exercise pattern. Research by Bansgbo (1994) suggests that the relationship obtained from sub-maximal treadmill running is valid for intermittent exercise (alternating low and high speeds on a treadmill for 10 and 15s respectively) and probably for soccer as well.

When the HR determinations are related to $\dot{V}O_2$ using the HR- $\dot{V}O_2$ relationship described, mean values of 70 – 80% of $\dot{V}O_2$ max for soccer match-play have been estimated (Bangsbo 1994, Ekblom 1986, Reilly and Thomas 1976).

Because of the relatively short recovery periods in soccer the HR stays at an elevated level and fluctuations during play are not very large. This is reflected in observations made during simulated competitions and friendly matches. Seliger (1968b) reported the mean HR during a competitive match for Czech players to be 165 beats per minute (bpm), or 80% of maximal HR, while Reilly (1986) found the average HR to be 157 bpm for English League players participating in friendly games. It is worth noting that positional role of the players monitored can influence the HR response. Van Gool (1987; cited by Bangsbo, 1994) observed that the mean HR for defenders was 155 bpm, while midfield and forward players exhibited higher average HR's (170 bpm). In competitive matches, Rhode and

Espersen (1988) found that the HR for Danish players participating in 1st Division games was below 73% of HR-max for 11% of the total playing time, between 73% and 92% of HR-max for 63% of the total playing time, and greater than 92% HR-max for 26% of the total playing time. In another Danish study, Bangsbo (1992b), when monitoring six professional players, found that the mean HR was 164 bpm during the first half, with a subsequent reduction of about 10 bpm during the second half. In a more recent study Strudwick and Reilly (1999) monitored seventeen professional youth players of an English Premier League team using short-range radio telemetry during competitive match-play and training. The mean HR from competition was found to be 175 bpm. Distribution of the mean percentage of HR-max is shown in Table 2. It is of interest that the results of this study show how significantly more intense soccer match-play was compared to that of training.

% HR-max	Match % of time	Training % of time
>90%	30.8 ± 22.9	3.3 ± 4.8
>80-90%	49.3 ± 14.5	14.9 ± 4.6
>70-80%	16.7 ± 9.0	21.0 ± 4.7
>60-70%	3.2 ± 4.2	23.4 ± 3.8
>50-60%	0	23.5 ± 5.9
>50%	0	14.3 ± 10.8

Table 2. Distribution of the mean % HR-max during soccer training and competitive match-play (Strudwick and Reilly, 1999)

ANAEROBIC POWER

It is difficult to quantify the contribution made from the anaerobic energy sources during soccer match-play because the exercise intensity varies frequently. Although the importance of high intensity efforts cannot be over-emphasised, contributing heavily to the most decisive parts of a game, the energy production from this system appears to account

for only a minor part of the total energy cost of match-play. For elite Danish players, Bansgbo et al (1991) reported the total duration of high-intensity exercise during soccer match-play to be approximately 7 mins. This included about 19 sprints with an average duration of 2-3s. The sprints a soccer player makes during match-play are mostly 10-25m in length, or 3-5 s in duration (Apor, 1988), therefore it is assumed that the ATP-CP system is the anaerobic energy system of most importance for soccer. However, it has been demonstrated that the breakdown of intra-muscular phosphagen stores [creatine phosphate (CP) and ATP] **and** anaerobic glycolysis supplies approximately equal amounts of energy production during 6s of all-out exercise (Boobis, 1987), supporting the claim of Jacobs et al (1983) that anaerobic glycolysis begins almost immediately after the commencement of high intensity exercise.

To determine whether the energy supplied from anaerobic glycolysis is of significance during soccer match-play, several researchers have collected blood lactate samples during matches. Results from these studies have varied from values as low as 2 $mmol.l^{-1}$ (Tumilty et al, 1988) to 12 $mmol.l^{-1}$ (Ekblom, 1986). Most studies cite values in the 4-8 $mmol.l^{-1}$ range, which suggests that anaerobic glycolysis has a meaningful role (Bansgbo et al, 1991; Bangsbo, 1994; Gerisch et al, 1988; Rhode and Espersen, 1988; Smaros, 1980; Smith et al, 1993). Contrasts in the results are probably due to the varying standards of soccer in the different studies, the importance of the match, the time-point of, and the blood media sampled (venous, capillary, whole blood, plasma lactate). Gerisch et al (1988) found that defensive tactics employed also affect the lactate response. Higher mean blood lactate levels were observed when teams used "man-to-man marking" compared to "zonal-coverage". The main reason for the contrast in results between studies may be due to the actual time of sampling. It has been demonstrated that blood lactate measurements are related to the incidence of high-intensity activities for the 5-minute duration immediately

before sampling occurs (Bangsbo et al, 1991). Bansgbo (1994), when sampling plasma lactate at various times during a competitive match, found that there was a significantly lower blood lactate concentration in the second half than when compared to the first. Observations of other studies (Bansgbo et al 1991, Ekblom 1986; Gerisch et al, 1988; Rhode and Espersen 1988; Smaros 1980) reported that the higher the level of play, the higher the lactate levels found. Division 1 players were found to show blood lactate levels of 8-10 mmol.l^{-1} decreasing to around 4 mmol.l^{-1} for Division 4 players (Figure 3). These results led Ekblom to conclude that as the playing standard increases, so may the contribution of anaerobic glycolysis. Ekblom (1986) noted, "It seems that the main difference between players of different quality is not the distance covered during the game but the percentage of overall fast-speed distance during the game and the absolute values of maximal speed play during the game".

Despite its relatively small contribution to the total energy turnover, anaerobic energy production is of vital importance as it supplies the soccer player with a high rate of energy provision during sustained intense periods of match-play. Intense anaerobic exercise is performed during the most decisive, interesting, and potential match-winning situations. Apor (1988) suggests that soccer players do not need an exceptional anaerobic capacity, but should have a high anaerobic power, while Tumilty (1988) concluded that the contribution of anaerobic glycolysis remains unclear, but is probably of significant importance to elite soccer players.

Division	Half-time	Full-time
1st Division	**9.5** (6.9 – 14.3)	**7.2** (4.5 – 10.8)
2nd Division	**8.0** (5.1 – 11.5)	**6.6** (3.1 – 11.0)
3rd Division	**5.5** (3.0 – 12.6)	**4.2** (3.2 – 8.0)
4th Division	**4.0** (1.9 – 6.3)	**3.9** (1.0 – 8.5)

Table 3. Blood Lactate concentrations (mmol. l^{-1}) for 1st – 4th Division Swedish players (halftime/fulltime) (from Ekblom, 1986)

GAME RELATED ACTIVITIES

Reilly (1979), and Van Gool et al (1988) both, using similar methods, estimated that outfield players exercise on average close to 75% of $\dot{V}O_2$max. Marathon runners tend to race at about 75% $\dot{V}O_2$max so this could give some indication of the aggregate intensity of competitive soccer. However the soccer player does not cover as much ground in a game as a marathon runner would in 90 min and so the energy expenditure in soccer is likely to be grossly underestimated if based solely on distance covered. The intermittent nature of activity means that a player frequently has to rely on anaerobic mechanisms for brief busts of intense action which accentuate the metabolic load above that required for continuous sub-maximal "marathon–like" exercise. The activity during the course of play includes abrupt accelerations and decelerations, changes of direction and angled runs and the many aspects of direct involvement in play.

Some attempts have been made to quantify the additional physiological demands of game specific activities over and above the physiological costs of running. Bangsbo (1994) indirectly evaluated the importance of these activities by comparing the physiological response during match-play and treadmill running. A competitive match was analysed in detail, HR was monitored continuously and blood samples were taken after each of four 5 minute periods for lactate analysis. A week later the same players carried out a treadmill test, consisting of, again, four exercise periods. This involved a warm up, and intermittent running until the HR was similar to that of the start of the observations during the match. Then subjects carried out a similar pattern of running as observed during the match. During the treadmill runs, the mean HR during each of the 5 min periods was found to be between 15 and 25 beats min^{-1} lower than that recorded during the match. Furthermore, the lactate

concentrations were significantly lower during treadmill exercise. The elevated HR ands lactate concentrations may be explained by the intermittent nature of exercise during soccer.

The fact that the intense intermittent exercise seems to be more energy demanding than the corresponding continuous exercise is supported by the observation of higher blood lactate concentrations during the former. Bangsbo (1994) found that the blood lactate concentration of 9.3 mmol.l^{-1} at treadmill speeds alternating between 8 km h^{-1} (for 10s) and 22 km h^{-1} (for 15s) was higher than the value (7.7 mmol.l^{-1}) obtained during continuous running at the same mean running speed (16.4 km/h^{-1}).

Skills of the game also impose physiological demands additional to the metabolic cost of running. Reilly and Ball (1984) demonstrated the increased energy cost as well as perceived exertion of dribbling a soccer ball using a rebound box on a treadmill. In the same study the lactate inflection point was calculated to occur at 10.7 km h^{-1} for dribbling but not until 11.7 km h^{-1} in normal running.

As mentioned, there are other game related activities that require unorthodox movements. Reilly and Thomas (1976) found that English players covered a distance of about 1400m running sideways and backwards equating to 16% of the of the total playing time. The percentage is highest in defenders who may, for example, have to "back up" quickly under high kicks from the oppositions half or move sideways in jockeying for position prior to tackling (Table 4).

Reference	Players	Position	Walk	Side/ back	Jog	Stride	Sprint
Reilly &	English division	Defence					
Thomas	1 team	Full back	27.8	8.1	35.2	19.2	9.5
(1976)		Centre back	22.9	8.4	37.5	20.6	10.7
		Midfield	20.7	5.2	41.2	22.0	10.8
		Attack	27.5	5.9	33.0	20.9	12.7
Withers et al	Australian	Defence					
(1982)	National League	Full back	23.7	8.9	45.0	14.5	7.9
	team	Centre back	30.3	15.3	37.9	12.5	3.9
		Midfield	21.9	7.8	49.9	15.1	5.3
		Attack	29.8	10.1	44.4	10.0	5.8

Table 4. Distance covered in each movement mode as a percentage of the total distance
Table adapted from Tumulty (1993)

The changes in energy demand and muscle recruitment from this type of activity have not been well studied or understood. Reilly and Bowen (1984) examined the physiological cost of these unorthodox movements by recruiting nine soccer players to run on a treadmill at speeds of 5, 7, and 9 km h^{-1}, running forwards, running backwards and running sideways. The study showed that oxygen consumption was significantly higher for sideways and backwards movement than for forwards running at the same speed. The difference increased disproportionately with velocity of movement. Running backwards and running sideways did not differ in terms of energy expenditure or rating of perceived exertion (Table 5). Clearly an improvement in muscular economy and muscular efficiency in running backwards and sideways would be of benefit to the soccer player.

Speed (km/h)	Forwards	Backwards	Sideways
	Energy	expended	
5	37.0±2.6	44.8±6.1	46.6±3.2
7	42.3±1.7	53.4±3.5	56.3±6.1
9	50.6±4.9	71.4±7.0	71.0±7.5
	Perceived	exertion	
5	6.7±0.1	8.6±2.0	8.7±2.0
7	8.0±1.4	11.2±2.9	11.3±3.2
9	10.2±2.1	14.0±2.0	13.8±2.5

Table 5. mean (±s.d) for energy expended (Kj/min) and ratings of exertion at three speeds and three directional modes of motion (n=9).
Source: Reilly and Bowen 1984.

Hughes (1973) also highlighted an important point when considering the energy expended in a soccer match, observing that "players are frequently having to use energy to overcome inertia". This would mean that energy cost may be frequently underestimated - speeds reached during a short sprint may not be that high, however a great deal of physiological effort may have been exerted. For this reason consideration should be given not only to the energy cost of distance covered or speed of movement but to a number of other factors including the type of movement, the "stop/start" nature of the activities, and the muscle actions involved.

AGILITY

Agility refers to the capability to change the direction of the body abruptly (Reilly, 1996). The ability to turn quickly, dodge and side-step calls for good motor co-ordination and is reflected in a standardised agility run test. Raven et al (1976) found that the Illinois Agility Run test distinguished soccer players as a group from the normal population better than any field test used for strength, power and flexibility. This is understandable, since soccer players have to be capable of dodging and weaving past opponents.

PHYSIOLOGICAL PROFILES OF ELITE PLAYERS

As well as examining motion characteristics and direct physiological measurements during soccer match-play, the physical capacity of **elite** players may give an indication of the physiological demands of soccer since it is to be expected that these have adapted to the requirements of the game. It should be noted that success can be achieved despite rather low fitness if a player has a well developed tactical sense or high technical standard, therefore individual physical capacity at elite level does not always reflect the physical demands in top league games. Nevertheless, a certain fitness level may be expected of all top-class players. Besides having a well developed ability to exercise with a high power output, a soccer player should have a good endurance capability.

MUSCLE FIBRE CHARACTERISTICS OF ELITE SOCCER PLAYERS

Muscle performance characteristics of athletes in many respects are determined by their distribution of fibre types. Soccer demands an ability to sustain physical effort, albeit discontinuous, over 90 minutes, some of which is a high intensity. As the activity profile is compatible with both fast and slow twitch muscle characteristics, a balanced combination of muscle fibre types would be expected in top players. The muscle fibre characteristics in the vastus lateralis of elite Swedish players was found to be about 60% FT, suggesting that the fibre types of elite soccer players are closer to that of a sprinter than an endurance athlete (Bansgbo, 1994). However, a large range of FT fibre percentage was found in the squad (40.8 - 79.1%). On the other hand, a smaller number of FTb fibres were found for the elite players compared to that of the non-elite players. Andersen et al (1993) [cited by Bangsbo, (1994)] revealed that in elite soccer players, a large component of the FTb fibres also had FTa myosin heavy chain expression. Bansgbo concludes that the muscles of the

elite soccer player can be characterised as having few FTb fibres, an observation found also in endurance athletes. Smaros (1980) reported an average muscle fibre type distribution of 53% ST and 47% FT in the vastus lateralis muscles of Finnish soccer players. Importantly, the same study by Smaros details that analysis of muscle biopsies taken at the end of matches showed that reduction in muscular glycogen stores occurred mainly in the ST fibres, reflecting the aerobic demand for this muscle in particular.

When sampling for oxidative enzymes of the gastrocnemius muscle, Bansgbo and Mizuno (1988) found that the occurrence of ST, FTa and FTb fibres in four elite Danish soccer players was 55.9% (range 48-63.6), 39.8 (33-46.5) and 4.4 (3.0-5.5) respectively. The concentrations of mitochondrial enzyme 3-hydroacyl coenzyme A (HAD) found was similar to that of cross-country skiers, and values for citrate synthase were found to be between that reported in the literature for middle-distance runners and non-athletes. Muscle fibre capilliarity of elite soccer players has been found to be higher than that of untrained individuals, but not as high as that found in elite endurance athletes (Bansgbo, 1994)

It is difficult to draw conclusions on the relative importance of the aerobic/anaerobic energy systems from the findings on the skeletal muscle characteristics of soccer players. Different muscles studied, the sample number, positional role of the players studied and training status of the players when sampled must be taken into consideration, but it is likely that in top level soccer, both aerobic and anaerobic fitness components are of importance.

AEROBIC FITNESS

Since the aerobic system is the main source of energy provision during soccer match-play (Bangsbo, 1994), it would be reasonable to expect high levels of aerobic fitness to have been reported in physiological profile studies of elite soccer players.

Maximal aerobic power ($\dot{V}O_2$max / Peak $\dot{V}O_2$)

The upper limit of the body's ability to consume oxygen is indicated by the maximum oxygen uptake or $\dot{V}O_2$max. The $\dot{V}O_2$max represents an integrated physiological function with contributions from the lungs, heart, blood and active muscles. The average values of $\dot{V}O_2$max for top level soccer players tend to be high, supporting the belief that high levels of aerobic fitness are important in soccer and there is a large contribution from aerobic power to playing the game. Mean $\dot{V}O_2$max of elite soccer players is normally reported between 55 and 65 ml.kg^{-1}.min^{-1} (Astrand and Rodahl, 1986; Davis et al, 1992; Nowacki et al, 1988; Rhodes et al, 1986; Thomas and Reilly, 1979; White et al, 1988; Williams et al, 1973, Withers et al, 1977), the higher values being found when players are at peak fitness. These high, but unremarkable values are similar to those found in other team sports, are higher than values reported for amateur soccer players (Ekblom, 1986), but are substantially lower than elite endurance performers where values close to 90 ml.kg^{-1}.min^{-1} have been found (Wisloff et al, 1998). Nowacki et al (1988) when reviewing 26 studies of $\dot{V}O_2$max assessment on German soccer players, reported that over half of the studies were conducted using a cycle ergometer, which would underestimate the $\dot{V}O_2$max of the players. Nowacki and colleagues found the highest average $\dot{V}O_2$max value reported from treadmill running to be 69.2 ml.kg^{-1}.min^{-1}. Treadmill testing of 17 members of the 1978 German National Squad revealed a mean $\dot{V}O_2$max value of 62 ml.kg^{-1}.min^{-1}.

It would seem reasonable to assume that when two teams equal in skill meet, the one with the superior aerobic fitness would have the edge, being able to play at the game at a faster pace throughout. Apor (1988) provided data on Hungarian players which showed a high rank-order correlation between mean $\dot{V}O_2$max of the team and the finishing position in the Hungarian First Division Championship (Table 6).

	$\dot{V}O_2$max ($ml.kg^{-1}.min^{-1}$)	League Position
Ujpesta Dozsa	66.6	1st
FTC	64.3	2nd
Vasas SC	63.3	3rd
Honved SE	58.1	5th

Table 6. The relationship between mean $\dot{V}O_2$max and finishing position in the elite Hungarian league (from Apor, 1988)

These findings have been supported by Wisloff et al (1988), who demonstrated a significant difference in $\dot{V}O_2$max between the top team and a lower placed team in the Norwegian elite division.

There is some evidence that $\dot{V}O_2$max also varies with positional role. Reilly (1976) (cited in Reilly 1996) demonstrated that midfielders have significantly higher $\dot{V}O_2$max values than those in other positions. The central defenders had significantly lower relative values than the other outfield players while the full-backs and strikers had values that were intermediate.

The observation of a high correlation between aerobic power ($\dot{V}O_2$max) and distance covered per game supports the adoption of training regimes that raise the aerobic fitness of soccer players to high levels (Reilly and Thomas, 1976; Smaros, 1980). Smaros (1980) found that, in addition to the strong correlation with the total distance covered in the game

(r=0.89), $\dot{V}O_2$max also influenced the number of sprints attempted during a match. This is not surprising as players with a high $\dot{V}O_2$max have a faster recovery from intense exercise, due to factors such as the pump capacity of the heart delivering blood to the active muscles, and have greater stores of muscle glycogen (Astrand and Rodahl 1986, Bangsbo and Mizuno 1988, Ekblom 1986). Soccer players with high endurance capacities would be expected to spare glycogen during moderate intensity exercise due to an increased utilisation of free fatty acids (FFA's). This glycogen-sparing effect would help to reduce a possible decrement in work-rate during the second half, as the fatigue that soccer players experience in the second-half of match-play may be due to glycogen depletion (Jacobs et al, 1982). Aerobic fitness training may enhance recovery, which is dependent on oxidative processes, between repeated short duration bouts of high intensity exercise (Balsom1994).

The "anaerobic threshold"

Whilst the $\dot{V}O_2$max indicates the maximal ability to consume oxygen in strenuous exercise, it is not possible to sustain exercise for a very long time at an intensity that elicits $\dot{V}O_2$max. The upper level at which exercise can be sustained for a prolonged period is thought to be indicated by the 'anaerobic threshold'(as identified by the blood lactate response to exercise)(Reilly 1994b). A wealth of research indicates that while a high $\dot{V}O_2$max is a prerequisite for elite level performance, the anaerobic threshold is a better predictor of endurance exercise capability (Conconi et al 1982, Costill et al 1973, Davies and Thompson 1979, Duggan and Tebbutt 1990, Fohrebach et al 1987, Ixwoka et al 1988, Lafontaine et al 1981, Powers et al 1983, Sjodin and Jacobs 1981, Tanaka and Matsura 1984, Tanaka et al 1986, Weltman 1995, Yoshida et al 1987, Yoshida et al 1993). This is perhaps not surprising as most endurance sports are run at sub-maximal intensities.

There has been much debate over the use of the term "anaerobic threshold", mostly due to the existing controversy over the cause of the blood lactate response to exercise. Researchers commonly express the "anaerobic threshold" as the work-rate corresponding to a blood lactate concentration of 4 mmol.l^{-1} [also sometimes expressed as the onset of blood lactate accumulation (OBLA) (Weltman 1995)] determined from invasive incremental tests. Wasserman (1984) defined the anaerobic threshold as the "level of exercise $\dot{V}O_2$ above which the aerobic energy production is supplemented by anaerobic mechanisms" and that this is an accurate determinant of the point during exercise where blood lactate increases nonlinearly above resting levels. This can be determined invasively or by incremental tests, or non-invasively by associated changes in respiratory gas exchange (Wasserman et al, 1973) The mean anaerobic threshold has been measured non-invasively by the aforementioned method at 77% of $\dot{V}O_2$max in English League 1st Division players (White et al, 1988), a value close to a work intensity associated with marathon running. Rahkila and Luthanen (1991), in tests on 31 elite Finish soccer players, found that the anaerobic threshold (determined as the inflection point in the blood lactate response from incremental exercise) represented 83.9% $\dot{V}O_2$max. Using a fixed blood lactate concentration (FBLC) of 3 mmol.l^{-1}, Bangsbo and Lindquist (1992) reported that this FBLC corresponded to about 80% of $\dot{V}O_2$max for both continuous and interval testing on a treadmill. The intermittent nature of soccer means that frequently players operate at above this intensity although the average fractional utilisation of $\dot{V}O_2$max is deemed to be 70-80% $\dot{V}O_2$max (Reilly, 1996).

SUMMARY

Due to its acyclical nature and intensity, soccer is classified as a high-intensity intermittent team sport (Bangsbo, 1994). During competitive soccer match-play, elite players cover a distance of about 10 km (Balsom, 1991, Bansgbo et al 1991) at an average intensity close to the "anaerobic threshold", being 80-90% of HR-max, or 70-80% of $\dot{V}O_2$max (Reilly, 1994a; Van Gool, 1988). It is estimated that aerobic metabolism provides 90% of the energy cost during soccer match-play (Bangsbo, 1994). In order to be successful, professional soccer players require a high aerobic fitness level as well as the game skills to create match-winning situations, and to sustain runs for defending or attacking purposes.

Although the majority of the time spent exercising during soccer match-play is of a sub-maximal intensity, match-play has some periods of high intensity that result in the accumulation of blood lactate. It is important that the soccer player has the appropriate anaerobic fitness to participate to the best of his ability in these intense periods of match-play and also has the aerobic fitness for quick recovery and elimination of muscle/blood lactate. Bangsbo (1994) states that a player's physical capacity can be divided into the following categories: a) the ability to perform prolonged intermittent exercise (endurance); b) the ability to exercise at high intensity; c) the ability to sprint; and d) the ability to develop a high power output in single match situations.

From the discussion of the several studies applied to soccer science in this chapter, most of the studies indicate the importance of aerobic fitness in soccer. It is reasonable to expect that the attainment of a high aerobic fitness level and subsequent maintenance of a high aerobic fitness level throughout the competitive season is beneficial to the professional soccer player (Apor 1988, Wisloff et al 1998).

Although this chapter has mainly focused on aerobic aspects of soccer performance, the importance of the anaerobic energy system, especially in top-level soccer players should not be underestimated. There is a requirement to execute unorthodox movements which are specific to soccer and may further tax the energy systems. Top-level soccer players are also required to train specifically for other important aspects of soccer, e.g. technical skills, tactical awareness, strength, speed and power throughout the soccer season.

THE BLOOD LACTATE RESPONSE TO EXERCISE

Traditionally, maximal oxygen uptake ($\dot{V}O_2$max) has been viewed as the "gold standard" measurement of aerobic fitness. However, $\dot{V}O_2$max assessment has a number of limitations (Weltman, 1995). It has been suggested that the blood lactate response to incremental sub-maximal exercise may be a better marker of endurance performance and a more sensitive indicator of changes in training status than $\dot{V}O_2$max. One reason for this may be that $\dot{V}O_2$max is limited by central circulation, dependent on cardiovascular factors such as cardiac output and stroke volume, and because the blood lactate response to exercise appears to be limited by peripheral adaptations at specific skeletal muscles, such as muscle fibre type and number of mitochondria (Sjodin et al 1982, Weltman et al 1992, Weltman 1995,). Also $\dot{V}O_2$max may be symptom limited in some causes such as with athletes in rehabilitation.

Blood lactate accumulation during incremental exercise is a measure commonly used to evaluate the effects of training, to test athletes, set training intensities and to predict performance (Bourdon 2000). Typically this is done through the determination of defection points or transition thresholds on the blood lactate versus workload curve. Although the concept of blood lactate transition thresholds has been developing for 60 years there is still much controversy both about the explanation of these phenomena and about the methods that should be employed to identify them.

The popularity of the use of blood lactate related thresholds as performance indicators has increased dramatically over the past 10-15 years with many exercise science laboratories

around the world now routinely measuring various blood lactate transition thresholds as an integral component of the physiological assessment of endurance athletes.

Bourdon (2000) identified the following reasons for this increased popularity:

- The predictive and evaluative power associated with the lactate response to exercise.
- The development of automated lactate analysers that offer ease of sampling and improved accuracy.
- The reliability of such measures under standardised conditions.
- Increased levels of coach education and understanding of such modern training methodologies.

While lactate testing has proven useful for evaluating endurance performance, prescribing exercise intensities, monitoring training adaptations, and subsequently enhancing performance, there are many different approaches to test methodologies, data analysis and interpretation. This chapter presents an overview of the major concepts relating to the blood lactate response to exercise as they relate to endurance performance. It also reviews the theory and mechanisms of the blood lactate response and demonstrates to the reader why sub-maximal blood lactate assessment may a useful tool for the assessment of aerobic fitness in professional soccer players.

REASONS FOR BLOOD LACTATE TESTING

Measurement of the blood lactate response to exercise in conjunction with HR, oxygen consumption ($\dot{V}O_2$), and workload is often a part of the routine physiological assessment of the high performance athlete. There are three main reasons for the use of blood lactate measurements:

- They are sensitive indicators of training adaptation.
- They correlate with endurance performance.
- They may indicate optimal training stimulus.

Numerous studies give strong support to the evaluative and predictive power of the blood lactate response to exercise, suggesting that it can serve well as a monitoring test for endurance performers.

Indicator of training adaptation. In the past endurance training studies commonly used changes in $\dot{V}O_2$max to indicate alterations in the capacity to performance endurance exercise (Daniels et al. 1978). However, in recent years, research has suggested that the blood lactate response is a more sensitive indicator of change in training status compared with $\dot{V}O_2$max (Sjodin et al, 1982). In particular, blood lactate transition thresholds have been shown to be more sensitive indicators of training adaptations (Gollnick et al. 1986; Sjodin et al, 1982, Tanaka et al 1983, 1986). This is especially true of highly trained athletes who may show little or no change in $\dot{V}O_2$max but significant changes in endurance performance (Daniels et al 1978, Foster et al 1982). Furthermore, numerous studies have demonstrated that blood lactate-related thresholds can increase with training beyond the point where $\dot{V}O_2$max fails to increase (Davis et al 1979, MacRae et al 1992, Sjodin et al 1982, Weltman et al 1992, Weltman 1995).

Correlation with performance. Blood lactate is highly related to performance in various types of endurance activities. Many researchers, studying different lactate variables (e.g. Lactate threshold, Anaerobic threshold, FBLC, MSS, OBLA) and different sporting pursuits, have in fact suggested that these parameters are better indicators of endurance performance than the traditional "gold standard" $\dot{V}O_2$max (Allen et al 1985; Farrell et al 1979; Fohrenbach et al 1987; Ivy et al 1981; LaFontaine et al 1981; Weltman et al 1987; Weltman 1995). Also Allen et al (1985), Farrell et al (1979), Hagberg and Coyle (1983), Kumagai et al (1982), Lehmann et al (1983) and Williams and Nute (1983) all found blood lactate variables to be more highly correlated to running performance than $\dot{V}O_2$max.

Optimal training stimulus. Prescription of endurance exercise training on the basis of relative exercise intensity (% $\dot{V}O_2$max) has been shown to result in markedly different metabolic and perceptual responses between subjects (Katch et al 1978, Simon et al 1983). Accumulated data suggest that the various blood lactate-related thresholds may provide the best indices of exercise intensity to provide guidelines for training intensity (Fohrenbach et al 1987, Mader 1991, Sjodin et al 1982, Weltman et al 1992, Weltman 1995). This is of particular interest to coaches, since these parameters can potentially provide them with a means to optimise training intensity and help prevent overreaching and over-training. This has been demonstrated in a study by Sjodin et al (1982) which suggested that the running velocity at the 'anaerobic threshold' represents an important component of a balanced training programme. Data for this study suggested that adding a 20 min run at 'anaerobic threshold' intensity improved velocity at the 'anaerobic threshold' although $\dot{V}O_2$max did not change. Similar findings have been reported by Acevedo and Goldfard (1989) and Keith et al (1992)

THEORY AND MECHANISMS OF BLOOD LACTATE ACCUMULATION

Lactate formation

Glycolysis is the term given to the breakdown of glucose into pyruvate, and high intensity, short duration exercise is fuelled predominantly via this anaerobic pathway. Glycolysis involves pyruvate being reduced by lactate dehydrogenase (LDH) to form lactic acid (McArdle and Katch, 1994). Once formed in the muscle, lactic acid rapidly dissociates to form a proton (H^+) and a lactate anion (Lac^-). The dissociation is buffered predominantly by the bicarbonate system – the lactate anion forms a salt with either Na^+ or K^+, while the proton joins with bicarbonate to form carbonic acid:

$$\text{Lactic acid} + \text{sodium bicarbonate} \rightarrow \text{sodium lactate} + \text{carbonic acid } (H_2CO_3)$$

The carbonic acid produced is then converted into CO_2 and H_2O by the enzyme carbonic anhydrase:

$$H_2CO_3 \leftrightarrow CO_2 + H_2O$$

This conversion occurs both intra-cellularly and also when the H_2CO_3 enters the muscle vasculature (Brooks, 1985a). It has been contended that the terms 'lactic acid' and 'lactate' can be used interchangeably, due to the almost instantaneous dissociation of lactic acid to lactate (Brooks, 1991).

Once lactate is produced, it has two main effects (Spurway, 1992). Firstly, it can be carried in the bloodstream (blood lactate) to sites where it is further oxidized or resynthesised back to glucose (Brooks, 1985a, 1991; Spurway, 1992). Secondly, the lactate anion and proton may accumulate in the source fibres (intra-muscular lactate) where the liberated protons strongly contribute to the fatigue process. Levels of intra-muscular H^+ arising from lactic acid dissociation may lower the intra-muscular environment pH to a value of 6.4 or lower,

causes inhibition of glycolytic enzymes, with phosphofructokinase (PFK) in particular being affected (Spurway, 1992). The increased acidity of the intramuscular environment also affects the mechanics of force generation, as troponin C's affinity to bind to Ca^{2+} is affected (Brooks, 1985a).

Blood lactate accumulation

During low levels of incremental exercise there is a minimal increase, no change, or sometimes a decrease in blood lactate concentration (Figure 2). However, as the intensity of the exercise increases, a work-rate is reached above which the blood lactate response to increasing exercise intensity is curvi-linear (Weltman, 1995). Several potential mechanisms that cause this response have been suggested. The amount of lactate present in the blood at any given time is related to both the **production** rate of lactic acid and the rate of blood lactate **clearance**.

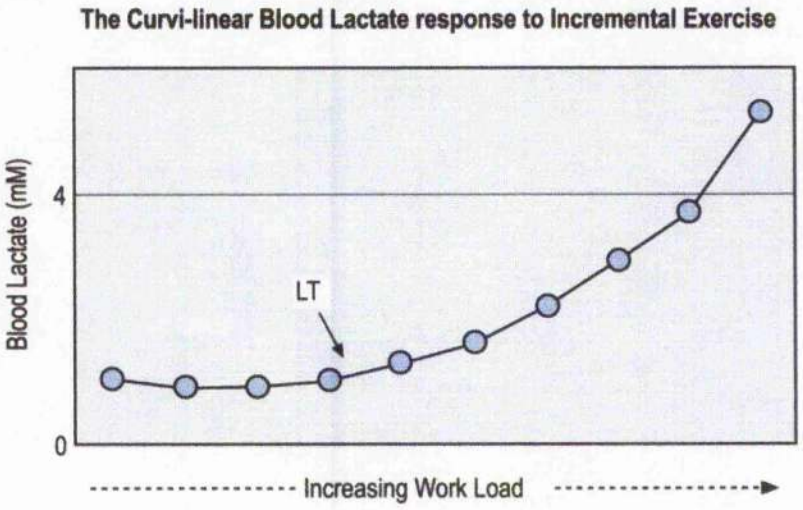


Figure 2 - The Blood Lactate Response to Exercise. With increasing work-rate, baseline blood lactate values typically begin to increase in a curvi-linear fashion after reaching a specific work-load, traditionally referred to as the "lactate threshold".

MECHANISMS OF LACTATE ACID METABOLISM DURING EXERCISE

Oxygen availability.

Muscle oxygen availability has been linked with lactate production for almost a century. Historically, rising blood lactate acid levels have been considered an indication of increased anaerobic metabolism within the contracting muscles due to low levels of oxygen in the individual muscle cells. In 1923, Hill and Lupton determined that hypoxia increased lactate production when studying isolated muscles in vitro. Hogan et al (1983) have shown that breathing hypoxic gas (FIO_2 = 0.17) increases $[Lac]^b$ and breathing hyperoxic gas (FIO_2 = 0.60) reduces $[Lac]^b$ in comparison to the $[Lac]^b$ elicited by breathing room air during incremental exercise. Wasserman (1984) cites these results as evidence that hyperoxic gas mixtures increase oxygen delivery to the muscles thereby alleviating muscle hypoxia and reducing lactic acid production, while Brooks (1985b) argues that hyperoxia may lower $[Lac]^b$ due to an increased perfusion of organs capable of lactate clearance. While muscular hypoxia can stimulate increased lactate production at the onset of exercise and during maximal exercise, evidence now exists that muscle lactate production during sub-maximal exercise need not imply the existence of tissue hypoxia. For example, Connett et al (1984) when using auto-perfused preparations of canine gracilis (red muscle) contracting in situ confirmed muscle lactate production in the absence of hypoxia.

Accelerated Glycolysis - Catecholaminergic stimulation.

Researchers have reported that blood catecholamines demonstrate a curvi-linear increase during progressive exercise, and this response has been speculated to be a possible cause of the curvi-linear blood lactate response to exercise (Jansson et al 1986, Jevoza et al 1985, Lehmann et al 1981, Lehmann et al 1986, Mazzeo and Marshall 1989, Mazzeo et al 1994,

Peronnet et al 1981, Podolin et al 1991,). Mazzeo and Marshall (1989) reported simultaneous threshold increases in plasma epinephrine and blood lactate concentration at identical workloads (r = 0.97), and hypothesised that increased epinephrine levels stimulate muscle glycogenolysis therefore increasing muscle lactate production. This increase in glycolysis increases the rate of NADH production (Stryer, 1988). Failure of the shuttle system to keep up with the rate of NADH production by glycolysis would result in pyruvic acid accepting come "unshuttled" hydrogen ions, and the formation of lactate could occur independent of whether the muscle cell had sufficient oxygen for aerobic ATP production.

Motor unit recruitment.

Some researchers have suggested that the increase in $[Lac]^b$ seen during incremental exercise is due to the progressive recruitment of motor units with greater glycolytic capacity, and report that the recruitment of FT fibres and LT are closely associated (Costill et al 1973, Jones and Ehrsam 1982, Vollestad et al 1984, Vollestad et al 1985). Nagata and co-workers (1981) demonstrated a strong correlation between integrated electromyography (iEMG) and LT (r = 0.92), and suggested that the increased iEMG found was due to the recruitment of FT fibres and increased firing of motor units already recruited. The physiological and metabolic characteristics of FT fibres relative to ST fibres supports the notion of the influence of FT fibre recruitment on blood lactate production. The LDH found in FT fibres has a greater affinity for reducing pyruvate, promoting the formation of lactate (Skinner and McLellan, 1980). In contrast, ST fibres contain an LDH form that promotes the conversion of lactate to pyruvate. Therefore, lactate acid formation might occur in FT fibres due to the type of LDH present. Early in an incremental exercise test it is likely that slow twitch fibres are first called into action, this may explain the dip in blood lactate concentration often exhibited at the beginning of tests. However as the exercise

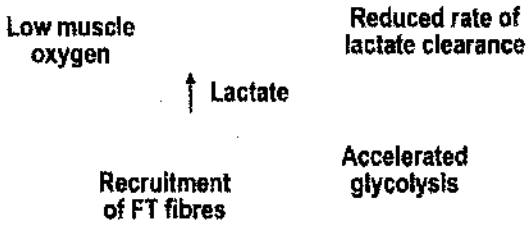
intensity increases, the amount of muscular force developed must be increased and this is supplied by recruiting more and more fast fibres. Therefore, the involvement of more FT fibres may result in increased lactate production. Davis (1985a) however, argues that FT motor unit recruitment may occur in response to muscle lactate production.

Mechanisms of Lactate Clearance

Traditionally it was accepted that the liver was the major site of lactate removal from the blood during exercise, but it is now clear that the liver is not the only site of lactate clearance, being found to not even be a major site of lactate clearance due mainly to the fact that at high exercise intensities blood flow is redistributed away from tissues involved in lactate removal and directed towards the working muscle and skin (Brooks, 1985a). Skeletal muscle and cardiac muscle are now accepted to be the major sites of blood lactate clearance, using lactate as a substrate (Stainsby and Brooks, 1990).

The mechanisms of lactate efflux are complex, and do not always involve simultaneous efflux of H^+. Studies have shown that H^+ efflux from contracting musculature greatly exceeds that of Lac^-. Research by Brooks (1986) has stressed the importance of mechanisms of lactate clearance in the determination of blood lactate accumulation and argues that lactate is an important gluconeogenic pre-cursor during exercise. Skeletal muscle is probably the most prominant site of lactate removal, being able to extract lactate from the blood for gluconeogenesis even when it exhibits a net lactate release (Stanley et al 1986). Lactate produced in neighbouring muscle fibres may be metabolised in less active neighbouring muscle fibres (Chirtell et al, 1984).

To summarise, controversy exists over the mechanism to explain the rise in blood lactate during incremental exercise. It is possible that a number of explanations might account for this phenomena (Figure 3).



Potential causes of increased lacate concentration during incremental exercise

Figure 3.

Jones (1994) concluded that the following mechanisms are the most important for the generation of the blood lactate response to incremental exercise –

- transient increases in blood lactate concentration at the onset of exercise by mass action
- recruitment of FT fibres at higher exercise intensities
- increased lactate production in all fibre types by catecholaminergic stimulation of muscle glycogenolysis at high exercise intensities
- further increased lactate production beyond LT due to recruitment of FT fibres, and development of anoxic loci in muscle when close to maximal work loads

THE INTERPRETATION OF THE BLOOD LACTATE RESPONSE TO EXERCISE: CONCEPTS AND CONTROVERSIES

Although the blood lactate response to exercise is used widely to analyse performance, and control and monitor training many factors in addition to training adaptations can affect the blood lactate response. Therefor one needs to consider the following points when collecting, analysing and interpreting blood lactate measurements.

TERMINOLOGY

One problem in understanding and interpreting the available literature regarding the use of blood lactate for evaluating endurance performance is the variety of terms used to describe similar phenomena. These terms include lactate threshold (Weltman, 1995), maximal lactate steady state (MLSS) (Tegtbur, 1993), anaerobic threshold (Wasserman 1973), aerobic threshold (Kindermann et al (1979), aerobic-anaerobic threshold (Mader et al, 1976), individual anaerobic threshold (Keul et al, 1979), individual aerobic threshold (Stegmann and Kindermann, 1982), lactate breaking/inflection point (Weltman, 1995), and lactate minimum running speed (Romer et al, 1998)(Figure 4)

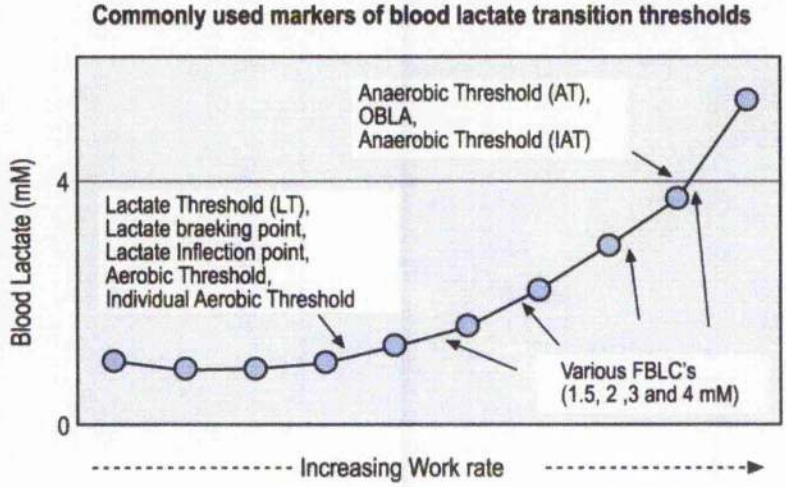


Figure 4 - Blood lactate marker terms used by researchers. Over the years, various researchers have used many different terms and definitions to describe the blood lactate response to exercise, causing confusion in a convoluted area of exercise science.

Furthermore, the lactate threshold has been defined by some researchers as the work-rate associated with a blood lactate inflection/breakpoint, while others have set the lactate threshold as a fixed blood lactate concentration (FBLC), e.g. 1 mmol.l^{-1} above baseline, or the work-rate/ corresponding to a FBLC of 2.5, 3, or more commonly 4 mmol.l^{-1} (Heck et al, 1985). To complicate matters further, some investigators have labelled the FBLC of 4 mmol.l^{-1} as the AT or onset of blood lactate accumulation (OBLA) (Sjodin and Jacobs, 1981).

Regardless of the controversies which surround the blood lactate response to exercise it is undoubted that it is of both scientific and practical importance. Among the many terms and definitions used for blood lactate transition thresholds, most can be categorised into one of the two broad classifications: (1) fixed blood lactate concentrations and (2) individualised lactate and anaerobic thresholds.

Fixed blood lactate concentrations. As a strategy for minimising the problems of biological noise associated with the detecting inflections in the blood lactate response curve, fixed blood lactate concentrations have been used. Fixed blood lactate concentrations are however strongly influenced by an athlete's nutritional and training state and care must be taken to control for such factors when testing and athlete (Bourdon 2000, Weltman 1995).

Individualised thresholds. Stegmann et al. (1981) reported that steady state blood lactate concentrations can vary greatly among individuals. On the basis of this fact they proposed the concept of individualised blood lactate threshold determinations. Numerous others have since proposed methods to determine individualised lactate thresholds (ADAPT

1995Coyle et al 1984) and anaerobic threshold intensities (ADAPT 1995, Cheng et al 1992, Stegmann et al 1981). Figure 5 shows seven commonly used employed methods to determine blood lactate transition thresholds.

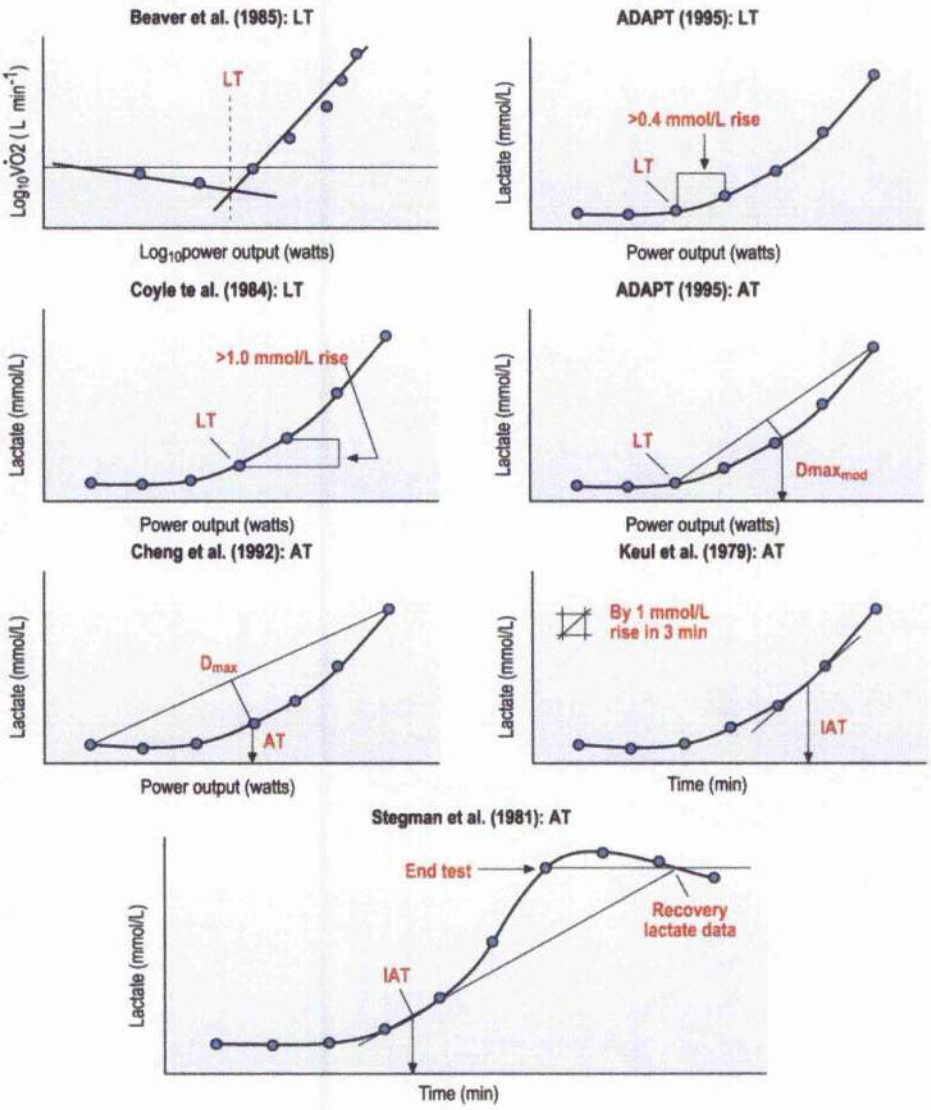


Figure 5. Seven commonly used methods for detection of blood lactate transitions.

Adapted from Bishop et al (1998)

TESING PROTOCOLS

Protocol-related factors such as sampling site, workload duration and continuous versus discontinuous exercise bouts can all effect the measurement of blood lactate response to incremental exercise. Therefore, one must consider such factors carefully when establishing a test protocol.

Blood Collection and analysis techniques

The blood media collected for analysis influences the blood lactate concentration measured (Foxdal et al, 1990, 1991). For example, Foxdal (1991) and his researchers reported that measuring lactate in the plasma, venous blood, and capillary blood in the same subjects during an incremental sub-maximal test resulted in the power output at the 4mmol.l^{-1} marker to be 180, 204, 216 Watts (W) for venous plasma, capillary blood, and venous blood respectively. Once the blood has been sampled it is also important to standardise treatment procedures such as the way in which it is analysed, for example, different automated analysers use different assaying techniques to determine blood lactate concentration.

Workload and rest duration

Another factor that affects the blood lactate exercise response curve is the workload duration. Some researchers have used continuous incremental protocols (Sjodin and Jacobs, 1981; Tanaka, 1983; Weltman et al, 1990) whilst others have used discontinuous exercise bouts (Allen et al, 1985; Coyle et al 1983; Farell et al, 1979; Hagberg et al, 1982). Stage duration of incremental tests has been shown to influence the interpretation of the blood lactate response (Weltman, 1995). Numerous studies have demonstrated that the longer the stage duration, the lower the AT values (Foxdal et al, 1996; Freund et al, 1989; Heck et al, 1985; McLellan, 1987; Rusko et al, 1986; Yoshida, 1984). Most exercise

physiology laboratories generally use incremental intensity exercise tests with workload durations between 3-5 minutes (Bourdon 2000). These durations are considered adequate for measurements of $\dot{V}O_2$ and HR because these variables are in a steady state within these time frames for trained individuals. However Bourdon (2000) advised that exercise durations shorter than 5 minutes may overpredict the AT exercise intensity. A number of recent studies have indicated that exercise periods of at least 5-7 minutes may be required to attain steady state blood lactate concentrations and therefore attain accurate determination of LT/AT (Foxdal et al 1996, Foxdal et al 1994, Heck et al 1985, Kindermann 1982, LaFontain et al 1981, Oyono-Enguelle et al 1990, Rieu et al 1989, Stegmann and).

The inter-stage rest interval duration can also affect the determination of blood lactate transition thresholds. With longer breaks blood lactate thresholds tend to move to higher work intensities (Foster et al 1995, Heck et al 1985). Therefor any intervals between work stages should be kept as brief as possible, with 1min being viewed as a possible maximum (Bourdon 2000).

Also, with many of the methods of determining individual thresholds, mathematical manipulations are performed to best fit the data curve and generate the blood lactate transition thresholds (ADAPT 1995, Cheng et al 1992, Foster et al 1995, Stegmann et al 1981). Such manipulations require a minimum number of work-rates with 5 to 8 generally sufficient (Bourdon, 2000)

In summary, within Sport science laboratories, the decision regarding work-rate duration, intensity and rest periods is generally a matter of convenience and logistics (Foster et al

1995). However, evidence suggests that longer work stages (5min or greater) are definitely preferable over shorter stages, breaks between stages should be as short as possible (less than 1min), and that there should be at least five work stages with relatively small increases in intensity.

FACTORS AFFECTING THE BLOOD LACTATE RESPONSE TO EXERCISE

Investigators have identified several factors that can alter the blood lactate response to exercise These factors – muscle fibre type, substrate availability, and caffeine use – are related to the attributes of the subjects.

Muscle fibre type/metabolic profile

A number of studies have examined the relationship between blood lactate concentration and the metabolic profile of skeletal muscle. Ivy et al (1980) reported that the percentage of ST fibres of the vastus lateralis muscles of cyclists was significantly related to both absolute (r = 0.74) and relative (r = 0.70) LT. A strong relationship was also found between the muscle's respiratory capacity and LT, suggesting that the mitochondrial content of the muscle is an important determinant of LT. Ivy and researchers (1980) concluded that the ratio of ST to FT fibres may have a genetic influence upon LT, ultimately affecting the ability to improve LT. Komi (1981) found that OBLA was significantly related to the percentage of ST fibres in runners (r = 0.78), while Sjodin and Jacobs (1981) found that OBLA (4.0mM) was positively correlated to %ST fibres and %ST fibre area. Tesch et al (1981) also found that 92% of the variance in OBLA was explained by the %ST area and capillary density.

An important study by Aunola et al (1988) investigated the power of muscle metabolic profile and oxygen transport capacity on the measurement of the aerobic and anaerobic threshold. Aunola and co-workers constructed a factor type model to estimate to what extent the thresholds could be explained by muscle metabolic profile and oxygen transport capacity. A factor model using four factors ($\dot{V}O_2$max, sub-maximal endurance [measured by aerobic and anaerobic threshold], muscle metabolic profile, and oxygen transport capacity) was constructed. Sub-maximal endurance correlated strongly with $\dot{V}O_2$max (r = 0.92), but correlated even more strongly with muscle metabolic profile (r = 0.83) than with oxygen transport capacity (r = 0.41). Muscle metabolic profile was also found to correlate more strongly with sub-maximal endurance (r = 0.83) than with $\dot{V}O_2$max (r = 0.70). The authors concluded that the **aerobic and anaerobic thresholds are to be considered as better indicators of sub-maximal endurance than $\dot{V}O_2$max, due largely to the influence of muscle metabolic profile.**

During incremental exercise, motor unit recruitment is thought to progress from an initial recruitment of ST fibres to FT fibres, therefore it is apparent that athletes with high percentages of ST (and FTa) fibres should be able to attain greater absolute work rates before observation of LT. Weltman (1995) concluded that muscle metabolic characteristics are of major importance in determining the blood lactate response to exercise.

Substrate availability

Results from two studies by Yoshida (Yoshida, 1984; Yoshida, 1986) and a study by Ivy (Ivy et al, 1981) have shown that alterations in substrate availability can affect endurance performance. Increases in circulating levels of blood glucose and insulin have been shown to stimulate glycolysis and increase blood lactate concentration, whereas increased levels

of circulating free fatty acids during muscular exercise indicate increased reliance on lipid oxidation and decreased blood lactate accumulation. These findings have led several researchers to speculate that altering substrate availability might affect the blood lactate response to exercise.

Hughes et al (1982) compared LT and AT in subjects who were in glycogen depleted and normal glycogen states. The glycogen depleted state was found to cause a dissociation between LT and AT, with LT occurring at a greater work load and AT occurring at a lower work-load when compared to a normal glycogen state. Yoshida (1984) observed that a carbohydrate (CHO) rich diet, a low CHO diet, and a mixed diet (3-4 days on each diet) had no effect on LT. However, because the high CHO diet was associated with an increased $[Lac]^b$ at each sub-maximal exercise stage, the work load and $\dot{V}O_2$ at 4 $mmol.l^{-1}$ were significantly reduced after the high compared to the low CHO diet.

Caffeine use

Studies that have investigated the effect of caffeine ingestion on the blood lactate response to exercise have produced mixed results, with some studies reporting that caffeine ingestion before exercise increases $[Lac]^b$ (Bell et al 2001, Collomp et al 2002, Gaesser and Rich 1985, Sasaki et al 1987) while others state that caffeine has no effect (Greer et al 1998, Tarnopolsky et al 1989).

THE EFFECT OF AEROBIC FITNESS TRAINING ON THE BLOOD LACTATE RESPONSE TO EXERCISE

Aerobic fitness training results in numerous adaptations to the neuromuscular, metabolic, cardiovascular, respiratory and endocrine systems. These adaptations are manifested by a graphical shift in the blood lactate response curve. For example, a typical graphical change in the blood lactate response curve of an individual who had undertaken 6 weeks of endurance training is illustrated in Figure 6.

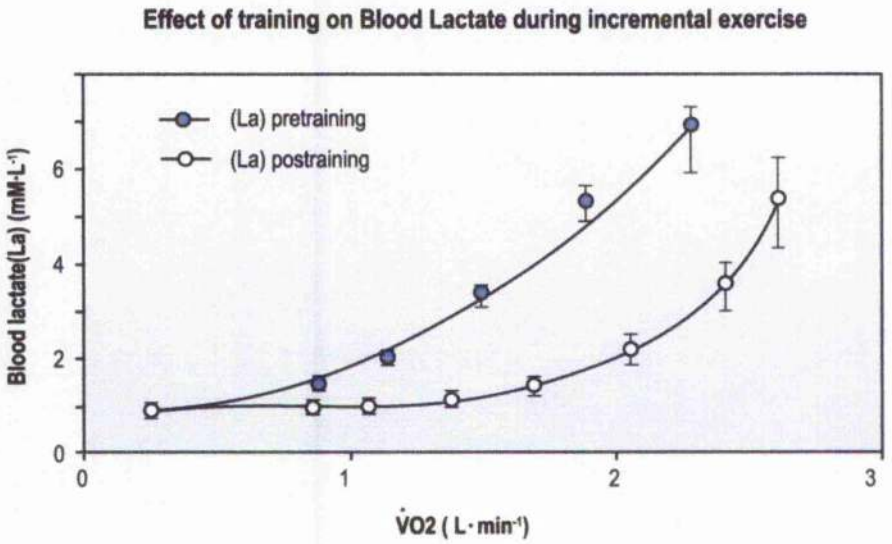


Figure 6- The effect of 6 weeks of endurance training on the blood lactate response to exercise [modified from Carter et al (1999)]. After endurance training, the blood lactate curve has shifted downwards and to the right.

Physiological adaptations to aerobic fitness training

It is widely reported in the literature that aerobic fitness training reduces blood lactate levels, and it has been suggested that training affects the blood lactate response to exercise by decreasing the rate of lactate production (caused by lowering of the rate of muscle glycogen utilisation, or by faster oxygen uptake kinetics that may increase initial O_2 availability) (Favier et al 1986, MacRae et al 1992), or increasing the rate of lactate

clearance from the exercising musculature (Donovan and Brooks 1983, Donovan and Pagliassotti 1990), or both (Bergman et al 1999, Stallknecht et al 1998).

Physiological adaptations to aerobic training that cause graphical shifts in the blood lactate response curve are now discussed.

Skeletal muscle adaptations

Successful aerobic fitness training results in numerous beneficial adaptations within skeletal muscle, including an increase in sodium-potassium pump concentration (Green et al, 1993) an increased lactate transport capacity (Pilegraard et al 1994, McCullagh et al 1996), and possibly an increased myoglobin concentration (Harms and Hickson, 1983). Endurance training markedly increases the oxidative capacity of skeletal muscle, due to an increase in size and number of mitochondria per unit area, and an increase in the concentration of specific enzymes belonging to the Krebs cycle, electron transport chain and malate-aspartate shuttle (Schantz et al 1986, Spina et al 1996, Suter et al 1995). These adaptations to aerobic training maintain cellular phosphorylation potential, improve the sensitivity of respiratory control and also increases the capacity for aerobic ATP resynthesis during exercise in both ST and FT muscle fibres. Higher concentrations of oxidative enzymes in ST muscle fibres might delay the point at which FT fibres are recruited during exercise (Moritani et al, 1993), while an increase in the oxidative potential of FT fibres may reduce their reliance on anaerobic glycolysis for ATP production (Gollnick and Saltin, 1982), therefore reducing lactate production. The greater capacity of the Krebs cycle to accept pyruvate following endurance training may be important in reducing the production of lactate by mass action at the onset of exercise and during high-intensity exercise (Graham and Saltin, 1989).

A strong relationship exists between the percentage of ST fibres and the LT (Aunola and Rusko 1992, Ivy et al 1980, Weston et al 1999). Aerobic training causes a selective hypertrophy of ST fibres, and can cause a shift in muscular enzymatic profile, e.g. FTb to FTa (Anderson and Henriksson 1977, Gaesser et al 1985) and perhaps FTa to ST (Simoneau et al, 1985; Sale et al, 1990) over a long period of endurance training.

Skeletal muscle capillarisation

Aerobic training increases the capillarity of skeletal muscle (Andersson and Henriksson, 1977; Ingjer, 1979) ultimately having the effect of increasing the maximal muscle blood flow capacity, and increasing the surface area available for the exchange of gases, substrates and metabolites between the muscle-blood barrier. This greater capillarity of aerobically trained muscle allows for a greater uptake of FFA's from the blood, and, along with an increased activity of enzymes involved in lipid metabolism, the capacity for mitochondrial B-oxidation is increased by aerobic training, lowering the rate of glycolysis and production of lactate of the exercising musculature.

Substrate utilisation

Changes in circulating levels of blood glucose and insulin have been shown to stimulate glycolysis and increase blood lactate concentration, whereas increased levels of circulating free fatty acids during muscular exercise indicate increased reliance on lipid oxidation and decreased blood lactate accumulation.

A high endurance level is expected to result in the sparing of glycogen during moderate intensity exercise due to an increased utilisation of free fatty acids (FFA's). This glycogen-

sparing effect would help to reduce a possible decrement in work-rate during the second half, as the fatigue that some athletes, such as soccer players, experience may be due to glycogen depletion (Jacobs et al 1982). With endurance training, lower levels of blood glucose and insulin and increased levels of free fatty acids during exercise cause an increased reliance on lipid oxidation and decreased blood lactate accumulation (Weltman 1995).

Hormonal response adaptations

The catecholamine response to exercise has been found to be significantly blunted by aerobic training after only a few training sessions (Green et al 1989, Mendenhall et al 1994). A lower secretion rate of epinephrine (a major effector of lactate production through modulation of muscle glycogenolysis) at the onset of exercise will result in a positive shift in the blood lactate response curve. The overall effect of aerobic training of reducing sympathetic nervous system activity will also contribute to changes seen in the blood lactate response curve.

Oxygen uptake kinetics

Some studies have evaluated the effects of endurance training on $\dot{V}O_2$ kinetics, and although the steady state $\dot{V}O_2$ for the same moderate intensity exercise has not been found to change following a period of endurance training (Davis et al 1979, Hagberg et al 1980), the primary exponential increase in $\dot{V}O_2$ at the onset of exercise may be accelerated. Faster $\dot{V}O_2$ kinetics at the onset of exercise which results in a faster attainment of the steady state oxygen uptake requisite may decrease the early increase in lactate production of the exercising muscles, causing a positive change in the blood lactate response curve.

PRACTICAL APPLICATION OF THE BLOOD LACTATE RESPONSE TO EXERCISE

Interpretation of training induced shifts in blood lactate response curves

Graphical overlays of the individual athlete test-retest blood lactate profiles, with a subjective assessment of any curve shifts, are the most commonly used methods of determining the extent of adaptation to aerobic fitness training (Bourdon, 2000). The most common changes in the blood lactate-intensity curve and their interpretations according to Bourdon (2000), Madsen and Lohberg (1987), Pyne (1989) and Weltman (1995) are as follows –

- A shift in the blood lactate response curve down and/or to the right is indicative of an increase in aerobic fitness of the subject, expressed by the subject's increased ability to exercise at a greater intensity for a given blood lactate level or to express lower blood lactate levels for the same intensity (Graphs A and B, Figure 8)

- A graphical shift upwards and/or to the left indicates deterioration in the aerobic fitness of the subject. This is expressed by the subject exercising at a lesser intensity for a given blood lactate level or expressing a higher blood lactate level for the same intensity (Graphs C and D, Figure 7)

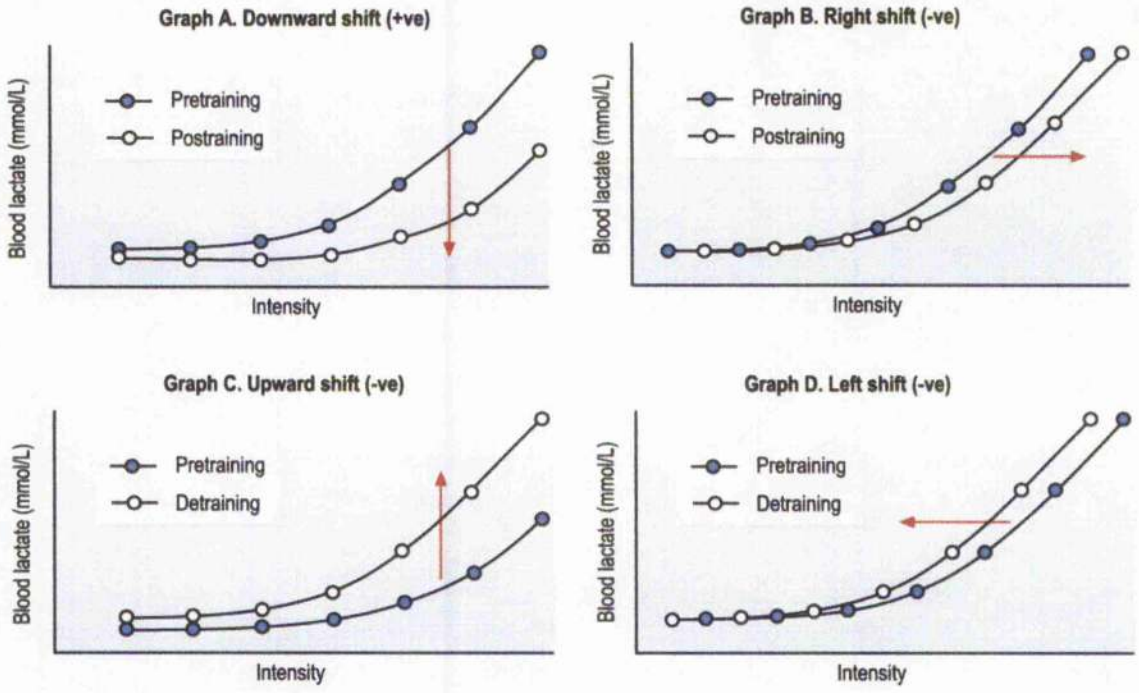


Figure 7 – Interpretation of blood lactate intensity curve shifts

(From Bourdon P (2000) Blood Lactate Transition Thresholds: Concepts and Controversies. In: Gore J C (ed) Physiological tests for elite athletes/Australian Sports Commission, pp 50-65. Human Kinetics)

BLOOD LACTATE ASSESSMENT OF SOCCER PLAYERS – PREVIOUS RESEARCH

It has been discussed that improved endurance performance as a result of aerobic training is associated with lowered blood lactate concentrations during sub-maximal continuous exercise and specific graphical shifts of the blood lactate response curve. This makes blood lactate measurements a potentially useful tool for evaluating aerobic fitness levels in soccer players, and un-surprisingly, such measures have been previously obtained by various researchers (Bangsbo and Lindquist 1992, Bangsbo 1994, Brady et al 1995, Dunbar 1999, Jensen and Larsson 1993, Nowacki et al 1988, White et al 1988).

THE PRACTICALITY OF BLOOD LACTATE ASSESSMENT IN SOCCER PLAYERS

There are a number of positive and negative aspects associated with using sub-maximal blood lactate assessment to assess the aerobic fitness levels of professional soccer players

PROS

- The results of previous studies (Bangsbo et al, 1994; Brady et al, 1995; Dunbar et al, 1999; Jensen and Larsson, 1993) indicate that sub-maximal blood lactate assessment of soccer players can be used as sensitive indicators of change in aerobic fitness over a specified time-period, therefore providing soccer coaches with useful information on the efficacy of their training regimes.

- Individual results from sub-maximal blood lactate assessment can be used for designing **individualised** training programmes to increase (or maintain) a player's aerobic fitness (Weltman, 1995).

- Sub-maximal blood lactate assessment serves as a good educational tool for educating soccer players (and coaches) on the importance of aerobic fitness in professional soccer. The time of assessment also proves to be a useful time for educating players on the merits of using a HR monitor.

- Results from sub-maximal blood lactate assessment can serve as a motivational tool for players to help them increase (or maintain) their aerobic fitness level.

- Regular sub-maximal blood lactate assessment can prove useful during the monitoring of soccer players undergoing a period of injury rehabilitation. This important application of sub-maximal blood lactate assessment in professional soccer. Knowledge of the player's vLT and vLac4 before injury provided some helpful information for the physiotherapists when deciding when it was appropriate for the player to resume full soccer training.

CONS

Although there are a lot of good reasons to advocate the use of sub-maximal blood lactate testing for the assessment of aerobic fitness in soccer players, there are also certain drawbacks –

- Soccer is a high-intensity, intermittent team sport (Bangsbo, 1994), and is multi-directional in nature. However, the blood lactate testing is usually conducted on a treadmill and is therefore only uni-directional. Therefore, some specific fitness adaptations that arise from soccer-specific activities may not be fully detected by sub-maximal blood lactate assessment. Muscle fibres that are recruited during soccer-specific movements such as turning and decelerating will not be recruited to the same magnitude during treadmill running. FT fibres recruited preferentially during intermittent, explosive bouts of exercise will probably not be recruited during the sub-maximal blood lactate assessment. Sub-maximal blood lactate assessment performed on a treadmill may not be specific enough for detecting aerobic fitness changes in FT muscle fibres that are routinely recruited during soccer match-play.

- Poor face validity - with sub-maximal blood lactate assessment being traditionally uni-directional, non-intermittent in nature, and generally carried out indoors on a treadmill (or

other exercise ergometer), the assessment of aerobic fitness by this method may be seen as alien and of little relevance to the professional soccer player.

- Sub-maximal blood lactate assessment is time consuming, with only one player being tested at a time (if only one Exercise Physiologist available). Therefore, assessment of a whole soccer squad requires a considerable amount of available time. The soccer coach may decide that time allocated for assessment purposes would be better spent on other aspects, such as technical training, or preparing for a forthcoming game.

- For the obtainment of "true" sub-maximal blood lactate assessment results, it is of vital importance that the test conditions are standardised as much as possible. It may prove difficult to schedule sub-maximal blood lactate testing of a soccer squad during the competitive season, with the players being assessed in a suitable physiological state.

- Due to the scientific nature of the testing, and also because of the previous lack of sports science support work in most soccer clubs (Bangsbo, 1994), some players (and coaches) may not fully understand the benefits of blood lactate assessment, and may be confused by the test results. Time is required to educate the players and coaches to facilitate their understanding of blood lactate assessment. It is important to educate the player's on the benefits of fitness assessment at an early an age as possible/relevant.

Development of the SELT
(Soccer-Specific Endurance Lactate Test)

Purpose of study

Only recently have investigators tried to replicate the demands of soccer using a combination of field and laboratory tests (Bangsbo, 1994; Drust, 2000; Nicholas, 2000; Reilly, 1996). The lack of soccer-specific protocols may be explained by the complex and unpredictable nature of the sport. An effective test should not only be based on the specific demands of the sport but also on sound physiological theory. The (Soccer-Specific Endurance Lactate Test) SELT was created with the purpose of combining the somewhat novel idea of a football specific test with the research proven blood lactate response to exercise and its sensitivity as an indicator of aerobic fitness.

A number of authors, if not all who have focused on soccer physiology, have emphasised the complex nature of the sport. Such unpredictability and its reliance on so many other factors (aerobic/anaerobic fitness, tactics, position, relevance of game etc.) is in clear contrast to the controlled conditions associated with experimental investigations or subject to the depth and accuracy of laboratory investigations. It should be noted that the purpose of the SELT is ***not*** to replicate a soccer match in the laboratory, such an attempt, given the nature of the sport, would appear futile. Rather, this test hopes to activate the energy systems, movements, and techniques common to soccer so that, combined with other tests and performance observations, it may provide a controlled reliable environment to measure an important aspect of soccer fitness. Fitness tests should address the performance capabilities of the muscle groups and muscle fibre types actually involved in the sport (Pyke, 2000). Also note that the author is aware of the importance of 'on the ball skill' and

its influence on the outcome of a match, however it would seem that this is better examined on the training ground rather than the laboratory. Given the fact that only 2% of distance covered in a match is with the ball (Reilly, 1996) the importance of 'off the ball fitness' cannot be overemphasised.

The SELT is based both on ***relevance*** and ***specificity*** as a soccer related test and ***practicality*** as a laboratory based protocol. An accurate measurement of all these factors is beyond the scope of this study, however it would seem reasonable, before further modifications are made, to assess the SELTs reproducibility. If this soccer specific test is to be of value in the monitoring in training status it must be shown to be reproducible.

Test details

The SELT is an incremental sub-maximal blood lactate test. It is performed on a 20 m indoor running track marked as shown in Figure 8.

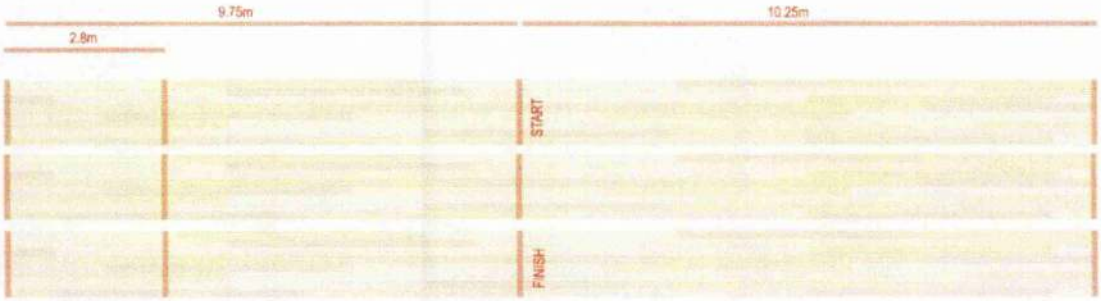


Figure 8. The SELT running track.

Mean running speed is dictated by pre-determined audio bleeps on a CD (Appendix 3), similar to the Multi-stage shuttle test (Leger et al, 1982). The test is split into levels each lasting 5 m. The first level has a mean speed of 7 km h^{-1}. Speed progresses by 0.75 km h^{-1}

with every level. All levels are separated by a 30 s interval. Each level is made up of a series of stages. Stages involve forward, backward/side-ways, and stop/start movements (Figure 9).

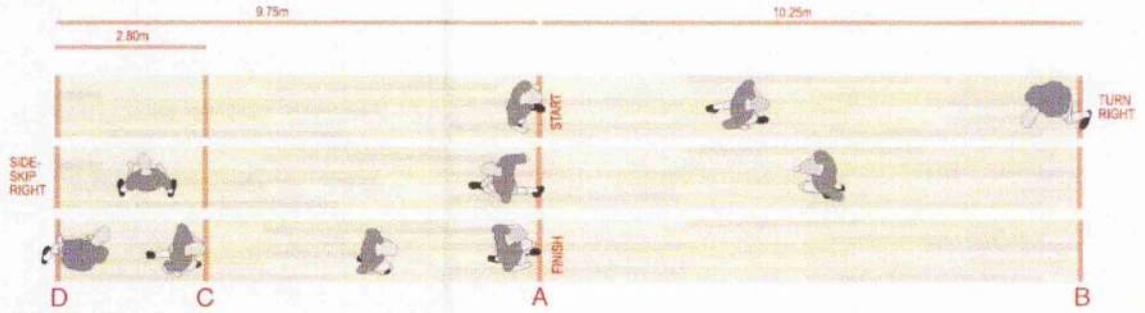


Figure 9. An example of one stage.

The subjects starts at the middle marker (point A). On the first 'beep' the subject commences running forwards to the marker at the end of the track (point B). On reaching this line the subject turns to his right and runs backwards in the opposite direction passing straight through the middle marker. The subject judges his running speed so that he passes over the middle marker on the second 'beep'. When the subject reaches the next marker (point C) he then turns to his right and side-skips to the end marker (point D). On reaching the end marker the subject changes direction to run back to the middle marker (A). Again the subject should time his speed of locomotion so that he reaches the middle marker on the third and final 'beep'. The final 'beep' also signal the beginning of the 5 second recovery period which follow every stage. In a single stage a subject therefore covers a total of 40m finishing at the same point as which he started. The "beep' at the end of the recovery period signals the start of the next stage (see figure 10).

Each stage is separated by a 5 s recovery period. The subject must complete 4 different type of stages (see figure 11). Running cues are placed at each end of the track to remind the subject which movement is necessary and when (Figure 12). *Note – Generally the*

running cues are only required by the subject during the familiarisation period, nevertheless they are present throughout the all testing. Once the subject has completed the 4, the subject commences the first stage again. The subject keeps rotating the stages until the 5 min are completed. Note that more stages are completed in 5 min with increasing levels due to the increased pace of running.

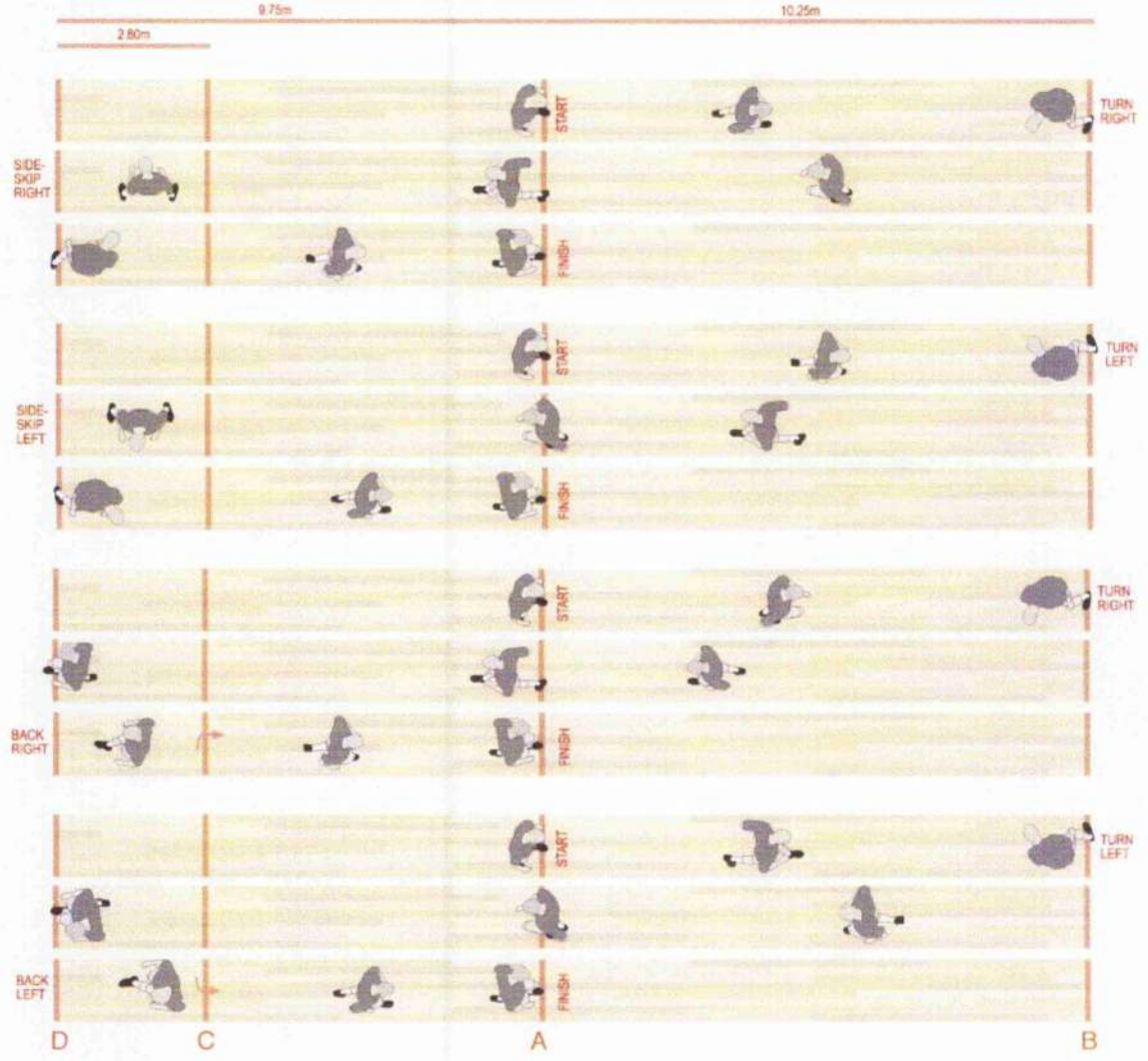


Figure 10. The four possible stages of the SELT.

There are 4 different stages in the SELT which are completed consecutively. The difference between the stages are the direction of the turn at point B (the subject either turns his left or right) and the direction and type of specific movement between point C and D (the subject either side-skips facing left or right from C to D, or runs backwards from D to C and turn right or left to run straight to the finish). See figure 11 for running cues.

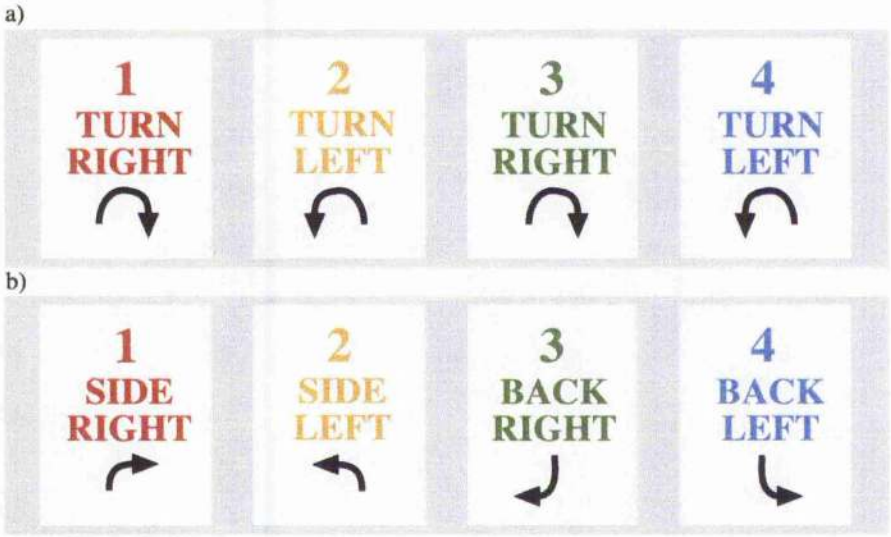


Figure 11. Running cues

Signs a and b are placed at the end of the track to help subjects remember the direction and nature of movements required. Sign a is located behind the marker labelled B (figure 10) in a visible position and sign b is positioned behind marker D. The signs are generally only a requirement during the familiarisation period as subjects become used to the test format, however for the purposes of the current study, cues were present throughout testing.

Measurements

Heart rate is taken immediately at the end of each level. Blood samples are taken and RPE is recorded in each of the 30 s intervals. The portable oxygen analyser monitored breathing continuously.

Considerations for test protocol

A number of factors had to be considered when creating the SELT. Ultimately decisions were made in attempt to find the difficult balance of a test which is both practical, specific, and scientifically sound. Given the fact that the SELT is a primarily a blood lactate test this was the most important factor take into account.

Level length – Bourdon (2000) advised that exercise durations shorter than 5 minutes may overpredict the AT exercise intensity. A number of recent studies have indicated that exercise periods of at least 5-7 minutes may be required to attain steady state blood lactate concentrations and therefor attain accurate determination of LT/AT (Foxdal et al, 1996; Foxdal et al, 1994; Heck et al 1985; laFontain et al, 1981; Oyono-Enguelle et al, 1990; Rieu et al, 1989; Stegmann and Kindermann, 1982).

Running speeds/increments – 7 km h^{-1} / 0.75 km h^{-1} - With many of the methods of determining individual thresholds, mathematical manipulations are performed to best fit the data curve and generate the blood lactate transition thresholds (ADAPT, 1995; Cheng et al, 1992; Foster et al, 1995; Stegmann et al, 1981). Such manipulations require a minimum number of work-rates with 5 to 8 work-rates generally sufficient (Bourdon, 2000). Weltman (1995) advised against only limited lactate measurements (as little as two

or three) stating that velocity associated with lactate thresholds/ markers could be drastically over or underestimated. Most investigators agree that the work intensity increments should be relatively small to allow more precise determination of the transition thresholds. Level increments also had to be considered from a practical standpoint. If smaller increments were used the total test length would be increased to a somewhat impractical length. Increments of 0.75 km h^{-1} were regarded to be suitable to allow for practical test length if a number of subjects are to be examined and also accuracy in determining lactate thresholds ad breakpoints.

Interval time – During approximately 24-32% (depending on level) of the SELT the subject is in "recovery". This is manifested in a 5 second break between every stage in every level. Mayhew and Wenger (1985) showed that approximately 49% of match *time* is spent standing/walking. To have the subject in recovery for almost half of the test would not be suitable as it would be probable that blood lactate levels fall.

Recovery time – 30seconds- The inter-stage rest interval duration can also affect the determination of blood lactate transition thresholds. With longer breaks blood lactate thresholds tend to move to higher work intensities (Heck et al 1985, Foster et al 1995). Therefor any intervals between work stages should be kept as brief as possible, with 1min being viewed as a possible maximum (Bourdon 2000).

Measurement of LT (v-T_{lac}) and 4 mmol L^{-1} marker (v -4mM) – Several blood lactate levels have been suggested as predictors of run performance. For example, the velocities associated LT (breakpoint) as well as lactate concentrations of 2.0, 2.5, and 3.0 mM have all been reported to correspond to marathon pace (depending on the level of the

competitive level of the runner). A blood lactate level of 4.0 mM has been more closely related to running performance of 10km or less (Weltman 1995).

Specific movements - The purpose of these movements (stop/start, acceleration/ deceleration, backwards/sideways)(figure 12) was an attempt to make the SELT a more soccer specific lactate test.

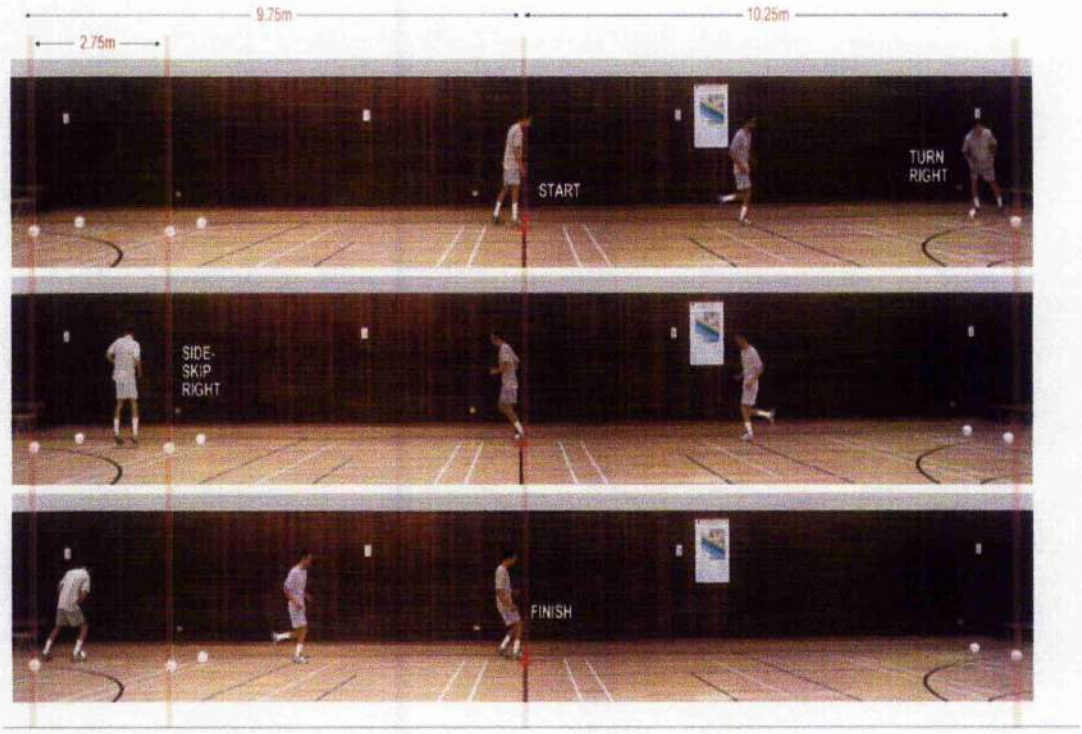


Figure 12. Subject performing the SELT

Backwards/sideways movements account for approximately 7% of the distance covered in the SELT. This percentage was felt to be appropriate as Reilly and Thomas (1976) found, for all players, that on average 7% of the distance covered during a game was sideways/backwards. This inclusion of these movements was also seen as appropriate as a

later study by Reilly and Bowen (1984) demonstrated a significantly higher energy cost for these movements as compared to running forwards.

Players taking part in the SELT, as mentioned are required to make "quick" turns right/left which require deceleration and acceleration in quick concession. The ability to execute these movements well is an obvious advantage when playing soccer. It would be expected that the successful soccer player would have both the technique and the tools, for example suitable muscle characteristics, to carry out these moves.

Core strength (abdominals, the hip, lumber spine, thoracic spine, and the cervical spine musculature) is a necessity for overall force production, stability, balance, lateral quickness, first step reaction and particularly rotational movements which are all desirable athletic qualities that are integral to the game of soccer. Blazevich (2000) stated that 'strength in the core regions enhances the ability to better utilise the musculature of the upper and lower body, reduces energy expenditure and ultimately improves running speed, efficiency, or both'. Therefore, successful performance of the SELT as well as soccer and most other athletic persuits, with the inclusion of twisting/turning, accelerating and decelerating movements, may require strength in the aforementioned musculature.

The possession of adequate muscle charateristics to be successful in both soccer and the SELT also applies to other regions of the body, particular the lower body. Accelerating/decelerating requires both strong eccentric and concentric muscle actions in the lower limb particularly the quadriceps and hamstring muscle groups. This is true also for the more unorthodox movements of soccer such as backwards and sideways running for example Keogh (1999) found that side-skipping places greater stress on the hip

adductors and abductors than does forward running. With lactate tests conducted on a treadmill for example with only forward running there would be no requirement for these specific muscle actions.

Traditionally most sub-maximal blood lactate assessments have been conducted on a treadmill, being uni-directional in nature. This is in contrast to the high-intensity, intermittent and multi-directional nature of soccer (Bangsbo 1994). Muscle fibres that are recruited during soccer-specific movements such as turning and decelerating may not be recruited to the same degree during treadmill running. Sport movement is tri-planar: movement occurs in the sagittal (left/right), frontal (front/back), and transverse (twisting/rotational movements) planes. So when we are training/testing performance it would seem advisable to incorporate movements which are tri-planar. To perform well in the SELT agility is required. Reilly (1996) has highlighted the importance of agility for soccer. Agility is the ability to maintain and control correct body position while quickly changing direction through a series of movements (Gambetta, 1998)(cited by Yap, 2000). The successful and economical execution of functional exercises such acceleration, deceleration, and stabilisation during multi-directional movement in all three planes is required in the SELT, unlike traditional uni-directional treadmill tests.

Hughes (1973) also highlighted an important point when considering the energy expended in a soccer match, observing that "players are frequently having to use energy to overcome inertia". This means that a for example even though fast speed of running may not be achieved a great deal of physiological effort may be exerted. The changes in direction and requirement to stop and start running from a standstill during the SELT takes this observation into account.

Biomechanical factors - Running economy has been associated with anthropometric, physiological and metabolic, biomechanical and technical factors (Bailey and Pate 1991). Improvements in exercise economy may result from improved muscle oxidative capacity and associated changes in motor unit recruitment patterns (Coyle et al, 1992), reduction in exercise ventilation and heart rate for the same exercise intensity (Franch et al, 1998), and improved technique (Williams and Cavanagh, 1987). Several studies have shown that, as an athlete fatigues during running, speed decreases, stride length shortens, and range of motion exhibited at the joint of the lower extremities is reduced (Elliot and Roberts, 1980; Elliot and Ackland, 1981; Sprague and Mann, 1983; Buckalew et al, 1985; Nummela et al, 1996).

Some biomechanical factors related to improved running economy which been identified by Anderson (1996) are as follows:

-slightly greater than average forward trunk lean

-arm motion that is not excessive

-fast rotation of shoulders in the transverse plane.

-low vertical oscillation of centre of body mass

-more acute than average knee angle during swing

-low peak ground reaction forces

-less range of motion than average but greater angular velocity of plantar flexion during the toe-off phase of running

To analyse the inter-dependence of running economy and bio-mechanics in relation to soccer and the SELT is beyond the scope of this study. However, athletes should have better running economy when carrying out actions such as that which they habitually train, therefore, since the SELT involves similar actions to that which is involved in soccer, it would be expected that successful execution of this test may require a somewhat 'football specific' running economy. This may be related to any, or a combination of any of the aforementioned factors such as running style or technique when side-skipping or turning for example.

Face Validity

Face validity, i.e. the appearance to the athlete that the test measures what it is supposed to measure, has been identified as an important aspect in the evaluation of test quality (Baechle and Earle, 2000). If a test has face validity, the athlete is more likely to respond to it positively (Anastasi A, 1982 – Cited in Baechle and Earle, 2000). Even though face validity is generally informal and non-quantitative, it is nevertheless desirable based on the assumption that anyone taking a test of physical ability wants to do well and is thus motivated by a test that appears to measure a relevant capability. With this in mind the SELT may exhibit high face validity as soccer players would be motivated to do well in a test that seems to be relevant to soccer performance with the accelerations/decelerations, and specific movements. However, a traditional uni-directional treadmill test may have poor face validity as a soccer player may see running on a treadmill as it as having little relevance to soccer performance and therefore have little motivation to perform.

Summary

In summary, the purpose of the SELT is as a Soccer-specific Endurance blood Lactate Test. The SELT is **not** an attempt to replicate the activity pattern of soccer match play. Any attempt to do this would seem futile because of the irregular nature of the game. Theoretically the SELT should call upon similar physiological energy systems, muscle actions, running manoeuvres, and technique (running style in turning/ running backwards etc) to that which is required in soccer.

Previous comparable research

It is difficult to compare the results of different studies dealing with the blood lactate response to exercise as the results and conclusions reported are dependent on several factors that affect the interpretation of the results of the study. These factors include exercise mode (running, cycling etc), duration of the sub-maximal bouts, length of training, training intensity, and the blood media sampled. Also, considering the present study is on the development of a new soccer specific lactate test, it is even more difficult to compare previous literature because the values obtained are very dependant on the procedures used.

A limited number of studies have attempted to replicate the activity patterns and work-rates of soccer match-play in the form of a laboratory based protocol (Nicholas et al, 2000; Drust, 2000; Bangsbo, 1994; Hoff et al, 2002; Wragg et al, 2000). Bangsbo was one of the first to recognise the possible usefulness of including soccer specific activities in the test protocol. Both Bangsbo (1994) and Wragg (2000) designed soccer specific field test of repeated sprint ability. Nicholas et al (1999) and Drust et al (2000) both designed exercise tests which were designed to stimulate the activity patterns and work rate characteristic of soccer match-play. Recently Hoff et al (2002) designed a soccer specific field test for maximal oxygen uptake ($\dot{V}O_2max$) which involved dribbling a ball and various other specific movements. Although the results from the study by Hoff et al cannot be compared to those in the previous study as they involve completely different protocols and measurement of different exercise variables in theory it is the most similar. Both tests involve taking a sound and proven physiological phenomena and applying it specifically to soccer. All the aforementioned tests may be of useful when assessing some aspects of performance or training status of soccer players, however unlike the present study they do not recognise the requirements of blood lactate testing. In order for valid comparisons to be

made between the present and previous studies specific similarities in both protocol and study aims must exist. At the current time the author knows of no such studies.

METHODS

Study 1 - Reproducibility of the SELT

SUBJECTS

Twenty-three male soccer players aged 21.9 $\pm$ 3 years, height 182.6 $\pm$ 6 cms, body mass 77.7 $\pm$ 9 kgs (mean $\pm$ sd) participated in this study. All the players were in good health and free of injury.

All subjects were physically active, and took part in at least two aerobic training sessions per week. All subjects played soccer at least once a week ranging from recreational to amateur level. Each subject completed a medical and physical activity questionnaire and was required to sign a consent form after being informed of the procedures and risks involved before each assessment. The study was approved by the University of Glasgow Interim Ethics Committee for Non-Clinical Research Involving Human Subjects. Testing was completed in the Kelvin Gallery, Bute Hall (both in the University of Glasgow) and in the Sports Performance Unit at Celtic Football Club. Although, due to availability, more than one testing venue was used, no one subject participated at more than one venue.

PRE-TESTING PROCEDURES

Subjects recruited for study were first informed of the full requirements of participation, and were made aware of the possible hazards and benefits of the exercise testing procedures. On arriving in the laboratory, each player was given an information sheet and a consent form (Appendix 1). All subjects completed and signed a medical questionnaire and activity diary (Appendix 2). The subjects were also asked to record diet the day before each lactate test and physical activity during the week before each lactate test. They were asked to maintain the same dietary intake and physical activity levels during the day

preceding testing. Subjects were asked to report to the testing venue in a rested state i.e. not to participate in training of any nature during the twenty-four hour period before each test and none or only very light training in the preceding 24 hr period. Subjects were also instructed and not to consume food or caffeine for 3 hrs before each test. These guidelines were given in the hope that the subjects would arrive for each assessment in comparable physiological states.

Subjects did not participate unless they were in full health. Subjects were informed that they could terminate an exercise task at any time.

Subjects wore lightweight running kit and the same running shoes on each testing session.

TESTING TIMES

All but 2 subjects completed the two required tests within 3 to 10 days of each other. To avoid possible effects of circadian rhythms all efforts were made to ensure that each subject was tested at approximately the same time of day ($\pm$ 1 hour) (McConnell, 1988; Reilly et al, 1984).

SUBJECT FAMILIARISATION AND WARM UP

All subjects took part in a short familiarisation session before the commencement of each test. Each subject was informed of the purpose of the test, the testing procedures, and what information was being collected.

Before the warm-up, subjects were familiarised with Borg's 6-20 category Rate of Perceived Exertion (RPE) scale. Instructions were based on those recommended by Borg (Borg, 1985). Subjects were asked to rate the total amount of exertion that they felt. They were asked to concentrate on the total feeling of exertion.

Before assessment, subjects were fitted with a Polar HR monitor (Polar Accurex Plus, Kempele, Finland) and the Portable Oxygen analyser (Kosmed K4b2 – COSMED s.r.l., Rome, Italy). The K4b2 portable metabolic system has been found to be an acceptable method for measuring oxygen uptake over a wide range of exercise intensities when compared with the criterion Douglas bag method which has been shown to be accurate and valid for estimating such measures (McLaughlin et al, 1999, 2001). This is supported by studies by Doyon et al (2001) and Parr et al (2001) who concluded that he K4b2 was valid and suitable for breath-by-breath measurements during field experiments.
Note: Due to equipment limitations not all subjects took part in breath-by-breath oxygen analysis. Ten of the twenty-three subject's taking part in the reproducibility carried out the test using the Cosmed Kb4 portable oxygen analyser.

Each subject performed a 5-minute warm-up on the first level of the test he was about to execute (an exercise intensity that is typically below a soccer player's vLT). The warm up was performed with the same procedures as the actual test including the physiological measures i.e. gas analysis, heart rate monitoring, RPE. This served to both specifically warm up the subject and to make the subject familiar with all the testing procedures. This was also useful as any problems the subject may have had were addressed at this time rather than interfere with the actual test. Note that blood was extracted from each subject's thumb during the pre and post warm-up on their first visit to the laboratory to familiarise them to the blood collection procedure.

Finally, subjects carried out static and ballistic stretching exercises for approximately 3-5 min, or until the subject felt that he was adequately prepared to commence the test.

TEST PROTOCOL

SELT : The SELT was performed as explained in the previous chapter. Briefly, this consisted of shuttle running on a 20 m track. The test is made up of 5 min levels separated by 30second intervals. Timing of running pace is provided by an audio CD (Appendix 3 explanation of audio CD). Staring speed was 7 $km.h^{-1}$, Running speed increases 0.75 $km.h^{-1}$ with each level.

Tests were terminated on volitional exhaustion, when it was obvious the subject would not be able to complete another level or by the subject's own request. HR was monitored during the last 30 s of each level and recorded immediately at the end of each level. Blood samples were withdrawn from the subjects thumb during the 30 s interval between each level by pin-prick. After successful attainment of the capillary blood sample (the procedure time taking approximately 10 - 15 seconds), the treadmill speed was increased by 0.75 km h^{-1}. Also at the start of the 30 s interval the subject was asked to point to the appropriate number on the RPE chart. When 25 s of the 30 s interval were over the subject was given a 5 s count down and then asked to commence exercise (With the SELT the 5 s count down is included in the audio CD). Breath by breath oxygen analysis was continuous throughout the test.

BLOOD LACTATE ANALYSIS

Blood samples were taken from the subject's thumb while the subject was stationary during the 30 s interval. The thumb was first cleaned with an alcohol Mediswab, and then a

small puncture in the skin was made using an Autoclix lancet. The first drop of blood after puncture was discarded to prevent sweat contaminating the collected blood sample. Approximately 20 – 25 µl of arterialised capillary blood was then collected in a capillary tube containing a fluoride/heparin/nitrite mixture. The blood samples were thoroughly mixed for 2 min and were then analysed for whole blood lactate concentration using an Analox GM7 Multi-assay rapid response analyser. The assay is a simple one step procedure that involves lactate reacting with oxygen to form pyruvate:

$$\text{L-Lactate} + O_2 \rightarrow \text{Pyruvate} + H_2O_2$$

The reaction is catalysed by the enzyme L-Lactate oxygen oxidoreductase (LOD) at pH 6.5. Buffered reagent is entrained into the reaction chamber of the analyser with the reaction being initiated by injection of the blood sample. The maximum rate of oxygen consumption measured by an electrical change across the membrane of the electrode is directly related to lactate concentration.

All blood samples were measured in duplicate. If the concentration of the two blood samples differed by no more than 0.2 $mmol.l^{-1}$, the average value was recorded. If the concentration of the two original blood samples differed by more than 0.2 $mmol.l^{-1}$, a third blood sample was analysed with the average of the two closest results taken.

Before all tests, and at regular intervals throughout each test, the Analox GM7 analyser was calibrated with an aqueous 5.0 $mmol.l^{-1}$ lactate standard supplied by the manufacturers.

GAS ANALYSIS

Respiratory determinations were made on a breath-by-breath basis by the K4 b2 portable metabolic system (COSMED s.r.l., Rome, Italy). Prior to gas analysis it was ensured that subjects had several minutes to acclimatise to the respiratory apparatus.

Gas calibration procedures. The K4 b2 system was calibrated according to the following procedures:

1 – *Room air calibration.* Room air calibration is performed by the system before every test and consists of a sampling room air. It updates the baseline of the CO_2 analyser and the gain of the O_2 analyser, in order to match the readings with the predicted atmospheric values (20.93% for O_2 and 5.00% for CO_2).

2 – *Reference gas calibration.* This was calibrated daily (as recommended by the manufacturer) and consisted of sampling a gas a gas with a known composition (i.e. 16.00% for O_2 and 5.00% for CO_2) from a calibration cylinder, ad updating the baseline and the gain (span) of the analysers in order to match the readings with the predicted values (i.e. 16.00% O_2 and 5.00% CO_2).

3 – *Delay calibration.* This was carried out daily before testing to measure accurately the time necessary for the gas sample to pass through the sampling line before being analysed.

4 – *Turbine calibration.* This was carried out weekly and consisted in measuring the volume of a 3 litre calibration syringe and in updating the gain of the flow-meter in order to match the predicted value.

Data Assimilation. Data can be either transmitted to a Windows-based PC by telemetry, or stored in memory and later downloaded directly to a PC. Once data was collected on the K4 b2 software it was edited (unrepresentative data in the breath-by-breath analysis was

deleted , for example that caused by coughs or sneezing). The respiratory exchange ratio (RER) is calculated automatically by the software. There is a function on the software which enables data to be transferred directly into Microsoft Excel for statistical analysis. Average Oxygen consumption and RER were calculated for the final minute of each test level completed (an example of a $\dot{V}O_2$ vs time graph is shown in Appendix 5)

AEROBIC FITNESS MARKER DETERMINATION

Each individual data set was analysed for two important aerobic fitness markers:

(1) the running velocity at the estimated lactate threshold (vLT) and,

(2) the running velocity at a fixed blood lactate concentration (FBLC) of 4 mmol.l^{-1} (vLac4).

vLT determination : Lactate threshold was identified in this study as the first significant elevation of blood lactate above resting levels (Kindermann et al. 1979). vLT was determined using a the ADAPT (1995) programme. This programme has been shown to have good precision for athletes tested at the South Australian Institute of Sport in endurance sports of running (Bourdon, 2000). When [Lac]^b is plotted against running velocity the inflection point of the lactate profile "curve" (corresponding to the lactate threshold) is identified by the computer programme.

vLac4 determination : The exact parameters in question, most notably running velocity at the 4 mmol.l^{-1} concentration was calculated by the ADAPT (1995) programme.

STATISTICAL ANALYSIS

Statistical analyses were performed using Minitab and 'Analyse it' for Microsoft Excel. The present study investigated the level of agreement and reproducibility of the speed, HR, RPE and $\dot{V}O_2$/kg at v-T_{lac} and vLac4 between 2 identical SELTs using Bland and Altman's limits of agreement (Bland and Altman, 1986; Pollock, 1992) and Deming Regression (Combleet and Gochman, 1979; Linnet, 1990; Strike, 1991). Bland and Altman plots, where the individual subject differences between the two readings (i.e. measure 1 – measure 2) for each method were plotted against the respective individual means, are provided. If the two measurements are comparable, the differences should be small, distributed around zero, and show no systematic variation with the mean of the measurement pairs. These plots allow examination of the direction and magnitude of the scatter around the zero line allowing an informal assessment of possible bias and are useful also in indicating whether the differences in test results depend on the magnitude of the mean (Atkinson and Nevill, 1998). In order to supplement the Bland-Altman plots with formal analysis, a 95% confidence interval for the mean difference was calculated. The measurements are deemed comparable therefore if the observations are distributed around zero, there is no systematic variation of the difference with the mean and the 95% confidence interval for the mean difference contains zero (i.e. suggesting no average difference in general). In each Bland-Altman plot, the lines of zero bias and estimated mean bias in addition to the limits of agreement are provided also. The estimated 95% Limits of Agreement provide a range that is likely to capture 95% of the differences between the two measurements. As these limits of agreements are estimates of the true 95% limits of agreement, interval estimates of the true 95% limits of agreement were calculated (Bland and Altman, 1986; Pollock, 1992).

In order to detect possible bias (constant and/or proportional), scatterplots with both the line of equality and line of best fit are provided to assess visually a departure of the line of best fit from the line of equality (which represents 'perfect' agreement). In order to formally test for a departure from the line of best fit and the line of equality, Deming regression (Cornbleet and Gochman, 1979; Linnet, 1990; Strike, 1991) was used to estimate the line of best fit as, unlike linear least squares regression, it allows for variation in both measurements. Interval estimates were calculated for the true constant term and slope allowing a formal comparison with the line of equality by testing whether the interval estimate for the constant term contains 0 and the interval estimate for the slope contains 1. Note that this approach is quite liberal as two separate tests (i.e. the intercept and slope) are performed rather than a simultaneous test of both parameters.

The intraclass correlation (ICC, sometimes called a retest correlation) were also used to analyse the agreement between SELT tests. The ICC gives a measure of agreement in a similar vein to the slope in a Deming regression. If a set of individuals each had the same unique score on a pair of tests the ICC would equal 1 and all the data points would fall on the line of equality. As a general rule the closer the ICC is to 1 the better the agreement. An ICC above 0.90 is considered to be high and to show a consistency of measurements across trials (Boddington et al, 2001).

Study 2 - Comparison of the SELT to a 'traditional treadmill test'

SUBJECTS

Ten male soccer players aged 20.8 ± 2 years, height 180.9 ± 5 cms, body mass 77.6 ± 9 kgs (mean ± sd) participated in this study. All the players were in good health and free of injury.

All subjects were physically active, and took part in at least two aerobic training sessions per week, all subjects played soccer at least once a week ranging from recreational to amateur level. Each subject completed a medical and physical activity questionnaire and were required to sign a consent form after being informed of the procedures and risks involved before each assessment. The study was approved by the University of Glasgow Interim Ethics Committee for Non-Clinical Research Involving Human Subjects. Testing was completed in the Sports Performance Unit at Celtic Football Club.

PRE-TESTING PROCEDURES

Subjects recruited for study were first informed of the full requirements of participation, and were made aware of the possible hazards and benefits of the exercise testing procedures. On arriving in the laboratory, each player was given an information sheet and a consent form (Appendix 1). All subjects completed and signed a medical questionnaire and activity diary (Appendix 2). The subjects were also asked to record diet the day before each lactate test and physical activity during the week before each lactate test. They were asked to maintain the same dietary intake and physical activity levels during the day preceding testing. Subjects were asked to report to the testing venue in a rested state i.e.

not to participate in training of any nature during the twenty-four hr period before each test and none or only very light training in the preceding 24 hr period. Subjects were also instructed and not to consume food or caffeine for 3 hrs before each test. These guidelines were given in the hope that the subjects would arrive for each assessment in comparable physiological states.

Subjects did not participate unless they were in full health. Subjects were informed that they could terminate an exercise task at any time.

Subjects wore lightweight running kit and the same running shoes on each testing session.

TESTING TIMES

All subjects completed the two required tests within 3 to 10 days of each other. To avoid possible effects of circadian rhythms all efforts were made to ensure that each subject was tested at approximately the same time of day (± 1 hour) (McConnell, 1988; Reilly et al 1984). As comparative experiments were being performed, conditions were applied in a random order so that out of the 10 subjects involved in this study, 5 completed the SELT test first and 5 completed the treadmill test first.

SUBJECT FAMILIARISATION AND WARM UP

All subjects took part in a short familiarisation session before the commencement of each test. To ensure subject confidence each subject was informed of the purpose of the test, the testing procedures, and what information was being collected.

Subjects were familiarised with Borg's 6-20 category Rate of Perceived Exertion (RPE) scale, and fitted with a Polar HR monitor (Polar Accurex Plus, Kempele, Finland) and the Portable Oxygen analyser (Kosmed K4b2 – COSMED s.r.l., Rome, Italy) (See previous section – Study 1).

Note: Due to equipment limitations not all subjects took part in breath-by-breath oxygen analysis. Nine of the ten subjects taking part in the treadmill comparison study carried out the test using the Cosmed Kb4 portable oxygen analyser.

Each subject performed a 5-min warm-up on the first level of the test he was about to execute (an exercise intensity that is typically below a soccer player's vLT). The wrm up was performed using the same protocol as the actual test including all physiological measures i.e. gas analysis, heart rate monitoring, RPE. This served to both specifically warm up the subject and to make the subject familiar with all the testing procedures. Note that blood was extracted from each subject's thumb during the pre and post warm-up on their first visit to the laboratory to familiarise them to the blood collection procedure.

For all exercise tests, particularly those carried out using the treadmill, subjects were informed that they were free to terminate the test if they felt dizzy or nauseous or at any other time of their choice. Subjects were taught hand signals which informed the

experimenters of the subjects desire to proceed or terminate exercise. Before the warm-up procedure the subject was instructed on the safety features of the treadmill. On cessation of the warm-up the subject rehearsed emergency termination of the test that involved the subject raising his legs away from the treadmill belt by supporting the body on the treadmill hand-rails and placing his feet each side of the treadmill belt. Experimenters were always on hand to support the subject in case of difficulty.

Treadmill incline – A number of authors have highlighted the possible differences which might exist between the energy demands of overground and treadmill locomotion (Daniels, 1985; Costill and Fox, 1969; Pugh, 1970, 1971; Maskud et al, 1971; Daniels et al, 1977; Hagerman et al, 1975). The first of these possible differences relates to the lack of air movement around a runner on a treadmill. The movement of air over a runner's body is known to air in heat loss and can reduce exercise heart rate (Riggs et al, 1982; Milliams and Kilgour, 1993). To compensate for this in the laboratory an electric fan was used to blow air over the runners head and upper torso. The second, and arguably more important difference between the energetics of treadmill and outdoor running, is the lack of air resistance in the laboratory situation which could reduce the energetic cost of treadmill running compared to outdoor running at any given velocity (Davies 1980). The treadmill in this study was set at an incline of 1% throughout the duration of the test. Jones and Doust (1996) found that this slight incline of the treadmill gradient accurately increases the energy cost in compensation for a lack of air resistance when running on a treadmill for speeds between 10.5 and 18 km h^{-1} for a duration of around 5 min.

Finally, subjects carried out static and ballistic stretching exercises for approximately 3-5 min, or until the subject felt that he was adequately prepared to commence the test.

TEST PROTOCOL

SELT: The SELT was performed as explained in the previous chapter.

Treadmill comparison : The treadmill test was intended to mimic the SELT ***minus*** the 'specific' movements i.e. turning, accelerating, decelerating, sideways running, backwards running. Therefor, the incremental treadmill test used in this study consisted of individual 5 min stages (starting speed was 7 km h^{-1}) with 0.75 km/h increase in treadmill speed with each stage until termination of the test. Each stage was separated by a 30 s interval between, where the subject 'straddled' the treadmill for 30 s as rehearsed in the familiarisation and then commenced exercise after the 30 s was completed (note – subjects were encouraged to be careful to pick up adequate speed and be sure of their footing before letting go of the treadmill had rails).

Tests were terminated on volitional exhaustion, when it was obvious the subject would not be able to complete another level or by the subject's own request. HR was monitored during the last 30 s of each level and recorded immediately at the end of each level. Blood samples were withdrawn from the subject's thumb during the 30 s interval between each level by pin-prick. After successful attainment of the capillary blood sample (the procedure time taking approximately (10 - 15 s), the treadmill speed was increased by 0.75 km h^{-1}. Also at the start of the 30 interval the subject was asked to point at the his RPE. When 25 of the 30 s interval was complete the subject was given a 5 s count down and then asked to commence exercise (With the SELT the 5 s count down is included in the audio CD, when running on the treadmill the count is given vocally be the experimenter. Breath by breath oxygen analysis was continuous throughout the test).

GAS ANALYSIS

For details see previous section (Study 1)

AEROBIC FITNESS MARKER DETERMINATION

For details see previous section (Study 1)

Note: In the study 2 (comparison of the SELT to a traditional treadmill test) not all subjects reached a blood lactate concentration of 4mmol. For this reason the 3mmol marker was also analysed. The ADAPT programme does not calculate this automatically therefore running velocity at 3mM was calculated manually by the experimenter (see Appendix 4)

STATISTICAL ANALYSIS

The present study investigated the difference between the speed, heart rate, RPE and oxygen consumption at v-T_{lac} and vLac4 between the SELT and the "traditional" treadmill test using a two-way analysis of variance (ANOVA). This method was also performed to compare differences in end of level data (lactate, HR, RPE, and $\dot{V}O_2$) between the SELT and the treadmill test. Statistical significance was set at $P<0.05$. Boxplots and interaction plots provide a visual presentation of the difference between the two tests for each variable at each exercise level and for each of the blood lactate markers and associated variables.

STUDY 1 - REPRODUCIBILITY STUDY

The aim of this study was to quantify the reproducibility of a number of variables obtained from the SELT – lactate threshold (v-T_{lac}), 4mmol.L^{-1} marker (v-4mM), and heart-rate (HR), and Ratings of Perceived Exertion (RPE) at both v-T_{lac}, v-4mM *and* at the end of each completed level of the SELT. 23 soccer players of various level took art in this study. In addition, 10 of the 23 subjects also took part in continuous breath-by-breath oxygen analysis.

Part A. Reproducibility measurements at blood lactate variables

The estimated mean bias, limits of agreement, intercept and slope of best fit (using Deming regression) for the pair of measurements taken for each variable using all 23 subjects are given in Table 7.

All Subjects (n=23)	Mean Bias (95% C.I.)	Limits of Agreement Lower (95% C.I.)	Upper (95% C.I.)	Intercept (95% C.I.)	Slope (95% C.I.)	ICC
v-T_{lac} (km.h^{-1})	0.24 (-0.27, 0.75)	-2.07 (-2.90, -1.25)	2.55 (1.73, 3.38)		1.60 (-9.81, 13.02)	0.06 (-0.34, 0.45)
v-4mM (km.h^{-1})	0.31 (0.12, 0.49)	-0.50 (-0.79, -0.20)	1.10 (0.81, 1.40)	1.87 (-0.20, 3.96)	0.85 (0.66, 1.05)	0.85 (0.67, 0.93)
VO_2 at *v-T_{lac}* (ml.kg^{-1}.min^{-1})	2.25 (-0.19, 5.23)	-4.91 (-8.92, -0.90)	9.95 (5.93, 13.97)	-26.60 (--84.51, 31.30)	1.94 (0.06, 3.81)	0.48 (-0.14, 0.84)
VO_2 at *v-4mM* (ml.kg^{-1}.min^{-1})	0.31 (-1.63, 2.25)	-5.00 (-7.88, -2.13)	5.62 (2.75, 8.49)	-13.81 (-31.84, 4.22)	1.36 (0.90, 1.81)	0.90 (0.66, 0.97)
HR at *v-T_{lac}* (beats.min^{-1})	-2.91 (-10.41, 4.58)	-36.89 (-48.99, -24.78)	31.06 (18.95, 43.17)	-132.57 (-623.39,358.25)	1.81 (-1.24, 4.86)	0.26 (-0.15, 0.60)
HR at *v-4mM* (beats.min^{-1})	-2.00 (-4.54, 0.54)	-12.33 (-16.38, -8.28)	8.33 (4.28, 12.38)	26.37 (-43.46, 96.21)	0.85 (0.47, 1.22)	0.73 (0.43, 0.89)
RPE at *v-T_{lac}*	0.43 (-0.85, 1.70)	-5.35 (-7.40, -3.29)	6.20 (4.14, 8.26)	t4.65 (10.26, 19.05)	-0.17 (-0.54, 0.18)	-0.20 (-0.56, 0.21)
RPE at *v-4mM*	0.47 (-0.07, 1.01)	-1.73 (-2.60, -0.87)	2.67 (1.81, 3.53)	2.00 (-5.43, 9.44)	0.90 (0.43, 1.38)	0.77 (0.33, 0.86)

***Table** 7. Estimated Mean Bias, Intercept and Slope of Line of Best Fit(using Deming Regression)for each Measure for 23 Subjects comparing SELT reproducibility.*

*Positive values indicate higher scores for test 2, negative values indicate higher scores for test 1. Red denotes findings which have been found to be significant.

v-T_{lac} . Figure 13A and B suggest that there is no systematic bias between test 1 and test 2. There is a very wide scatter of observations around the 45 degree line suggesting that there is a poor reproducibility. Table 7 shows that the mean bias of 0.24 km.h^{-1} is not significant. The ICC of 0.06 confirms the visual impression of figure 13A that there is poor reproducibility. Figure 13B and table7 show that the 95% CI limits of agreement are –2.07 to 2.55 km h^{-1} indicating poor reproducibility.

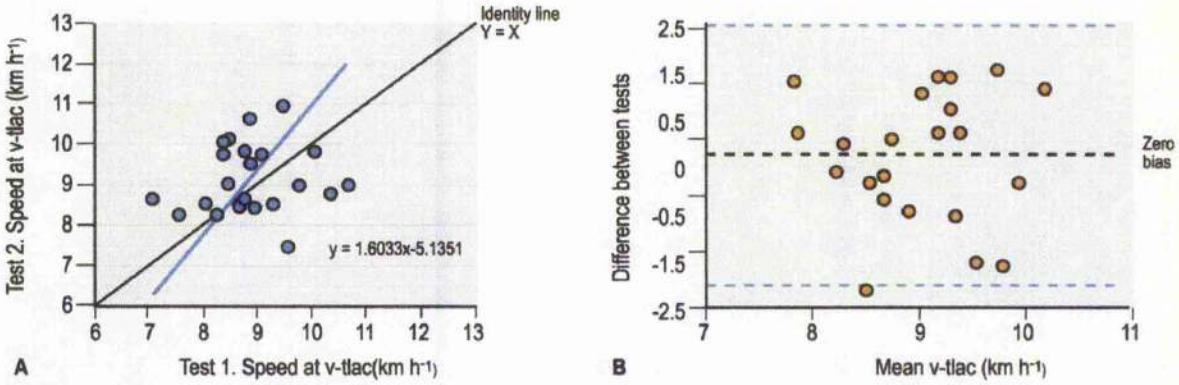


Figure 13 **A-** Scatterplot of **v-T_{lac}** (km h-1) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for **v-T_{lac}** (km h-1).

v-4mM. Visual observation of figure 14A and B suggest that there is a significant bias i.e. scores in test 2 are in general higher than in test 1. The spread of data around the 45 degree identity line looks much narrower than that of the v-T_{lac} in figure 13A. Table 7 confirms that there is a systematic bias with test 2 being on average 0.31 km.h^{-1} higher than test 1. The ICC of 0.85 indicates reasonably good reproducibility between the two tests. The 95% CI for limits of agreement, -0.50 to 1.10 km.h^{-1} are much narrower than the equivalent v-T_{lac} scores (figure 13B) and suggest fairly good reproducibility.

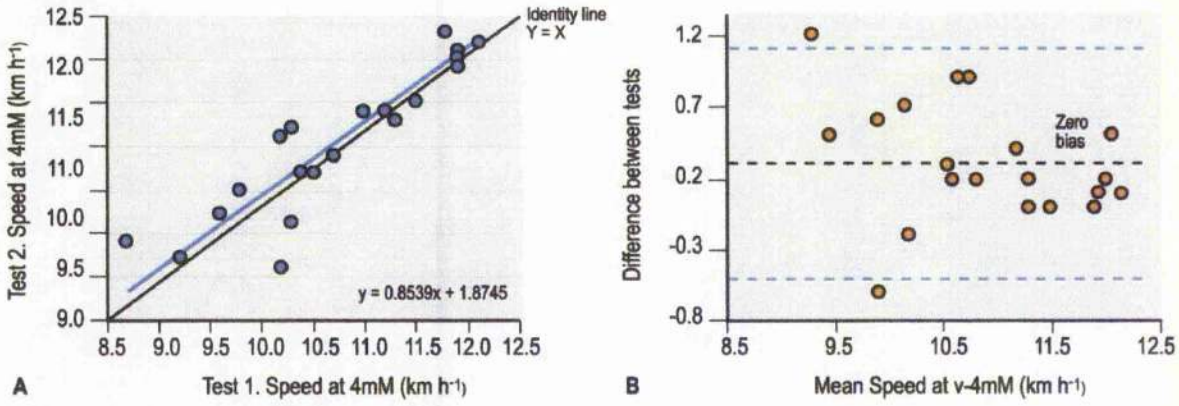


Figure 14 A - Scatterplot of **v-4mM** (km h-1) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for **v-4mM** (km h-1).

$\dot{V}O_2$ **at** ***v-T***$_{lac}$. Figure 15A and B suggest that there is no bias between test 1 and test 2. There is a very wide scatter of observations around the 45 degree line suggesting poor reproducibility. Table 7 shows that the mean bias of 2.25 $ml.kg^{-1}.min^{-1}$ is not significant. The ICC of 0.48 confirms the visual impression of figure 15A that there is poor reproducibility. Figure 15B and table1 show that the 95% CI limits of agreement are –4.91 to 9.95 $km.h^{-1}$indicating poor reproducibility. *Note that only 10 of the 23 subjects in this study took part in* $\dot{V}O_2$ *analysis.*

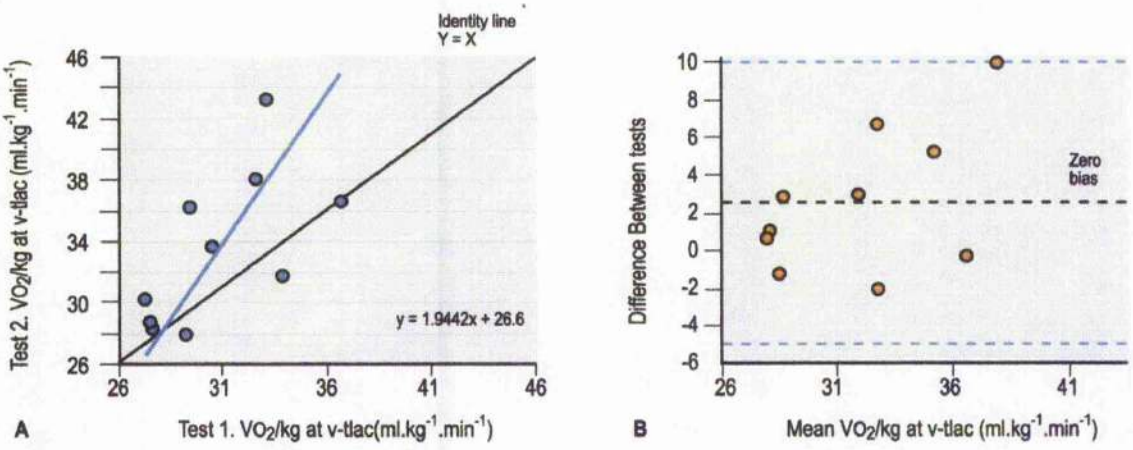


Figure 15.A - Scatterplot of $\dot{V}O_2$ **at** ***v-T***$_{lac}$ (km h-1) for SELT test 1 and 2 with line ofequality. **B**- Bland and Altman plot for $\mathbf{VO_2}$ **at** ***v-T***$_{lac}$. (km h-1).

$\dot{V}O_2$ **at *v-4mM*.** Visual observation of figure 16A and B suggest that there is no significant bias between tests 1 and 2 and this is confirmed in table 1 where the small bias of 0.31 is not significant. The spread of data around the 45 degree identity line in figure 16A looks quite narrow suggesting good reproducibility. The ICC supports this where a score of 0.90 indicates a high degree of consistency between the two tests. The 95% CI for limits of agreement are -5.00 to 5.62 $ml.kg^{-1}.min^{-1}$ which suggest fairly poor reproducibility however, again, it must be noted the small subject group which took part in $\dot{V}O_2$ analysis.

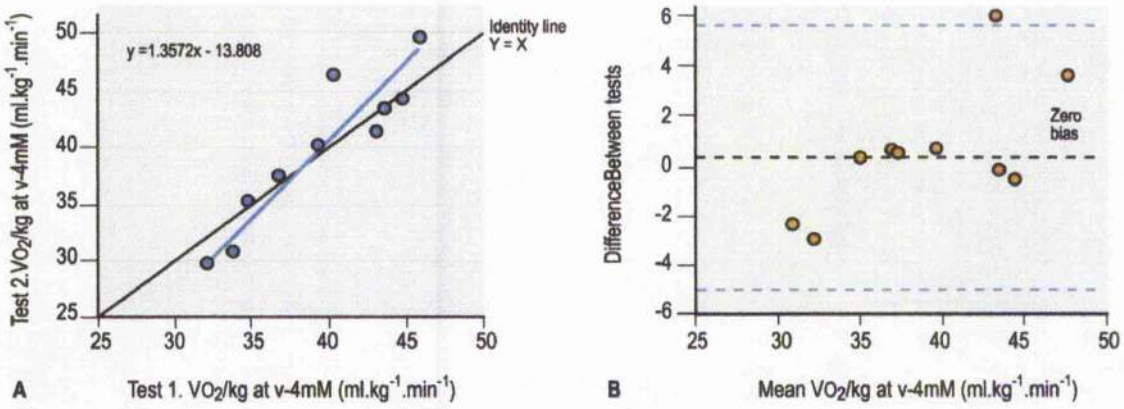


Figure 16.

A - Scatterplot of $\dot{V}O_2$ **at *v-4mM*** (km h^{-1}) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for $\dot{V}O_2$ **at *v-4mM*** (km h^{-1}).

HR at $v\text{-}T_{lac}$. Figure 17A and B suggest that there is no bias between test 1 and test 2. There is a very wide scatter of observations around the 45 degree line suggesting poor reproducibility. Table 7 shows that the mean bias of -2.91 beats.min^{-1} is not significant. The ICC of 0.26 confirms the visual impression of figure 17A that there is poor reproducibility. Figure 17B and table1 show that the 95% CI limits of agreement are –36.89 to 31.06 km.hr-1 indicating very poor reproducibility.

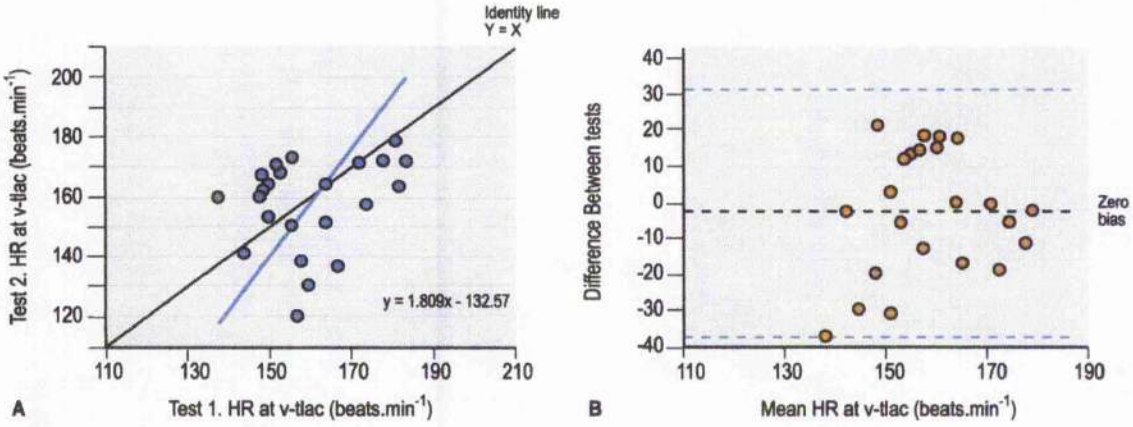


Figure 17.

A - Scatterplot of **HR at $v\text{-}T_{lac}$** (km h-1) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for **HR at $v\text{-}T_{lac}$** (km h-1).

HR at *v-4mM*. Visual observation of figure 18A and B suggest that there is no significant bias. The spread of data around the 45 degree identity line looks reasonably narrow suggesting possible reproducibility. The ICC of 0.73 supports this suggesting a possible consistency between tests. The 95% CI for limits of agreement, -12.33 to 8.33 beats.min^{-1} are much narrower than the equivalent v-T_{lac} scores (figure 17B) but still fairly wide suggesting, again, a fair but not good reproducibility.

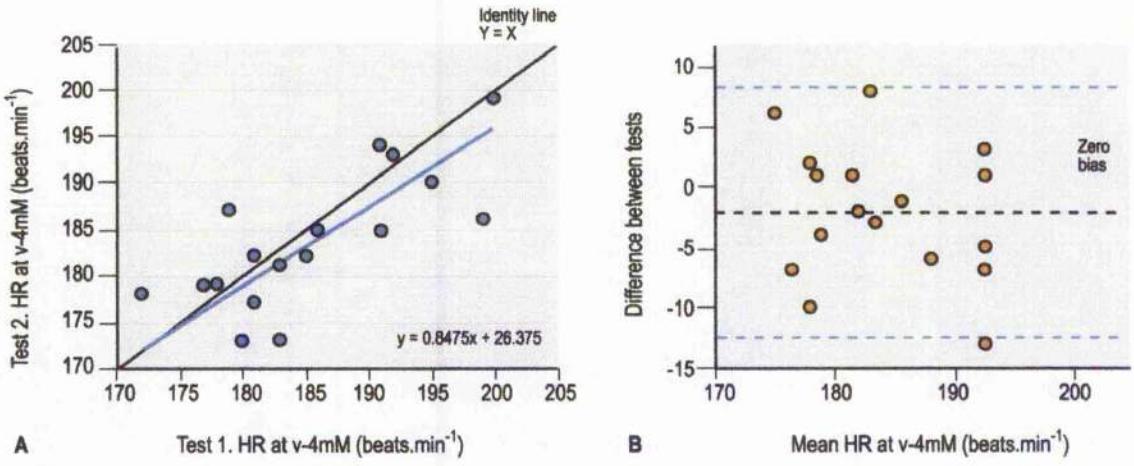


Figure 18.

A - Scatterplot of **HR at *v-4mM*** (km h-1) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for **HR at *v-4mM*** (km h-1).

RPE at $v\text{-}T_{lac}$. Figure 19A and B suggest that there is no bias between test 1 and test 2 however there is a very wide scatter of observations around the 45 degree line suggesting poor reproducibility. Table 7 shows that the small mean bias of 0.43 units is not significant. The ICC of 0.20 confirms the visual impression of figure 19A that there is poor reproducibility. Figure 7B and table1 show that the 95% CI limits of agreement are –5.35 to 6.20 units indicating poor reproducibility. According to table 7, for all variables except RPE at $v\text{-}T_{lac}$ there is a suggestion of reproducibility as the line of best fit is plausibly the line of equality in all cases.

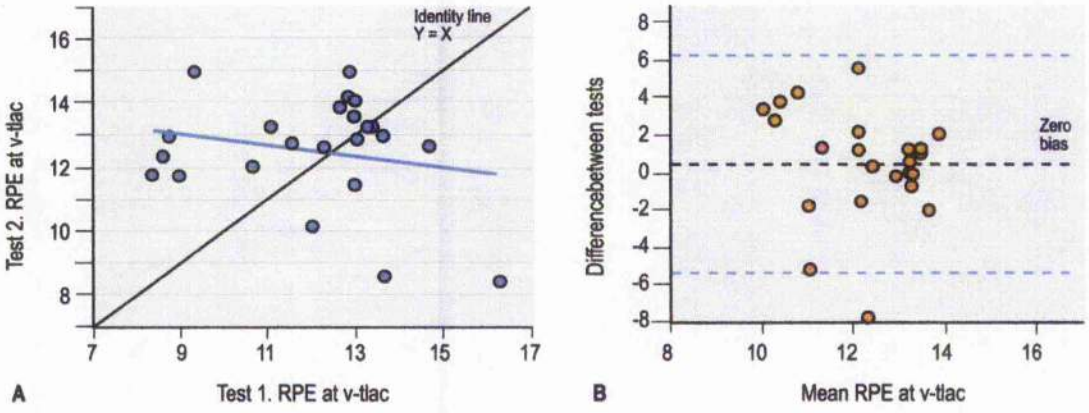


Figure 19.

A - Scatterplot of **RPE at $v\text{-}T_{lac}$** (km h-1) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for **RPE at $v\text{-}T_{lac}$** (km h-1).

RPE at *v-4mM*. Visual observation of figure 20A and B suggest that there is no significant bias. This is supported in table 7, which shows that a small bias of 0.47 is not significant. The spread of data around the 45 degree identity line is narrower than the equivalent for *v-*T_{lac} (figure 19A). Similarly the ICC of 0.77 also suggests more consistency than the equivalent *v-*T_{lac} score. The 95% CI for limits of agreement, -1.73 to 2.67 units are reasonably narrow suggesting possible reproducibility.

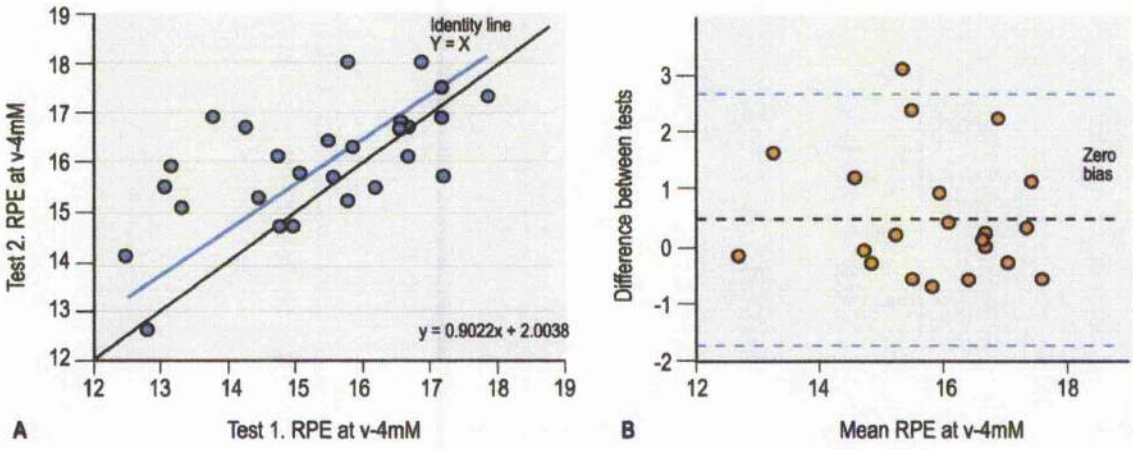


Figure 20.

A - Scatterplot of **RPE at *v-4mM*** (km h-1) for SELT test 1 and 2 with line of equality

B- Bland and Altman plot for **RPE at *v-4mM*** (km h-1).

Part B. Bias in end of level data.

The estimated mean bias using paired t-tests for the pair of measurements taken from each test for each variable are given in Table 8.

	Blood Lactate	**HR**	**RPE**	**V02**
	Mean Bias (95% C.I.)	**Mean Bias (95% C.I.)**	**Mean Bias (95% C.I.)**	**Mean Bias (95% C.I.)**
Level 1	0.06 (-0.13, 0.25)	5.87 (1.61, 10.13)	0.13 (-0.74, 0.10)	-0.78 (-2.44, 0.88)
Level 2	0.01 (-0.20, 0.22)	4.65 (-0.16, 8.14)	0.01(0.000) (-0.58, 0.58)	-0.57 (-2.80, 1.66)
Level 3	0.23 (-0.07, 0.53)	4.30 (0.63, 7.98)	-0.44 (-1.02, 0.15)	-0.61 (-2.68, 1.46)
Level 4	0.26 (0.03, 0.50)	6.87 (3.60, 10.14)	0.04 (-0.52, 0.60)	-0.05 (-1.65, 1.55)
Level 5	0.84 (0.50, 1.19)	6.04 (3.38, 8.70)	0.22 (-0.38, 0.81)	0.51 (-0.77, 1.79)
Level 6	0.67 (0.21, 1.13)	5.43 (2.01, 8.85)	0.43 (-0.16, 1.02)	-0.44 (-2.92, 2.04)
Level 7	0.93 (0.28, 1.58)	6.71 (3.44, 9.99)	0.43 (-0.20, 1.06)	-0.23 (-3.05, 2.59)
Level 8	0.92 (-0.05, 1.88)	3.00 (-0.135, 7.35)	0.67 (-0.60, 1.94)	-2.63 (-11.48, 6.23)

Table 8.

Red indicates significant results, in all of these cases mean bias is positive therefore indicating higher scores in test 1. No significant bias is suggested for RPE or $\dot{V}O_2$.

As shown in table 8 there is a significant mean bias for levels 4 to 7 for blood lactate. This bias is positive indicating higher scores in test 1. For HR there is a significant mean bias for levels 1, and 3 to 7. In both cases for blood lactate and Heart rate all significant results suggest that test 1 is harder.

There was no significant difference found across all levels between SELT test 1 and SELT test 2 for $\dot{V}O_2$/kg and RPE.

STUDY 2 – SELT/Treadmill test comparison STUDY

An additional aim of this study was to compare the physiological responses (Blood lactate, *HR, RPE and* $\dot{V}O_2$*)* of the SELT to continuous exercise performed on a treadmill at similar exercise intensity for a comparable period of time. This comparison should ascertain whether or not the SELT provides different information from a traditional treadmill lactate test.

Part A. Comparison of end of level data.

A repeated measures ANOVA was fitted in order to compare the effect of Test (i.e. Treadmill v SELT), Level (i.e. levels 1 to 8) and their possible interaction on the average response for lactate, heart rate, RPE and $\dot{V}O_2$/kg. The results for each of the response variables are as follows:

Lactate

Observation of figure 21 suggests that blood lactate for the treadmill test is on average higher than that of the SELT for levels 1 to 5. Figure 21 also suggests that for levels 7 and 8 blood lactate is higher for the SELT compared to the treadmill test. There appears to be little difference between tests for level 6.

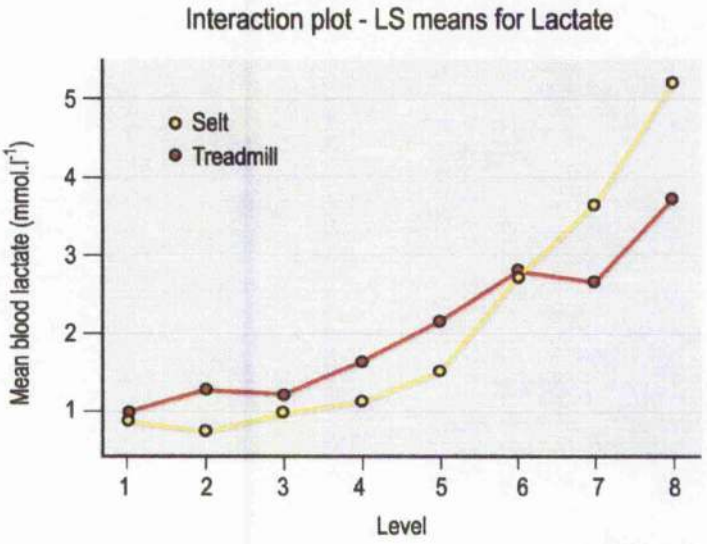


Figure 21. Interaction plot of the blood lactate mean values for both the treadmill test and the SELT. There appears to be lower blood lactate scores for the treadmill test compared to the SELT from levels 1-5. The opposite seems true after level 6. Observation of this plot suggests that there is a trend of lower lactate scores in early levels of the SELT compared with the treadmill, higher lower lactate scores in later levels of the SELT compared with the treadmill, with the crossover occurring around level 6.

Figure 22 also supports the observation that blood lactate scores are higher in the SELT compared to the treadmill test after level 6. Figure 22 clearly shows evidence of higher mean scores for levels 7, 8 and 9.

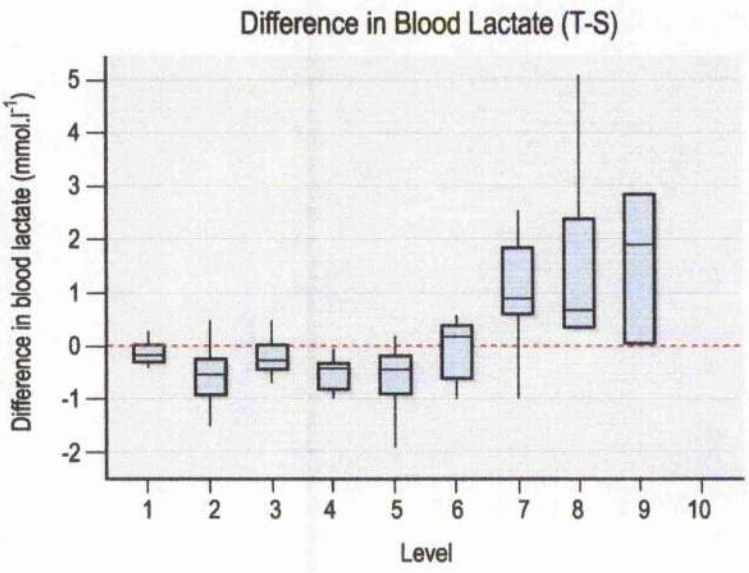


Figure 22. Boxplot of the difference between end of level blood lactate between the treadmill test and the SELT. It appears that blood lactate scores are lower for the SELT compared to the treadmill test in the early levels (1-5) but higher in the later levels (7-9).

The average lactate increased with increasing Level ($p < 0.001$) for both SELT and treadmill tests and there was a significant ($p=0.001$) interaction where the average lactate levels were significantly lower for the SELT test when compared to the treadmill test at levels 2, 4, 5 and significantly higher at level 7 (see Table 9). Lack of significance in some levels may be due to low sample size particularly in the later levels.

Lactate (n=10)	**Mean Difference (95% C.I.)**	**p-value**
Level 1	-0.13 (-0.29, 0.03)	0.104
Level 2*	-0.53 (-0.93, -0.14)	0.013
Level 3	-0.22 (-0.47, 0.03)	0.08
Level 4*	-0.50 (-0.72, -0.29)	0.001
Level 5*	-0.65 (-1.19, -0.11)	0.025
Level 6	-0.06 (-0.45, 0.34)	0.741
Level 7*	0.97 (0.08,1.87)	0.036
Level 8	1.45 (-0.49, 3.89)	0.112

Table 9. 95% C.I. of the mean difference between tests and the p-values for each level. Red denotes significant results.

$\dot{V}O_2$/kg

The interaction plot (figure 23) suggests that mean $\dot{V}O_2$ on the treadmill is higher until level 5 and then SELT mean $\dot{V}O_2$ is higher for levels 6 to 9. Figure 23 also suggest that the 'crossover' occurs between levels 5 and 6. These findings are supported by figure 24. Note that there are smaller sample sizes from level 8 onwards.

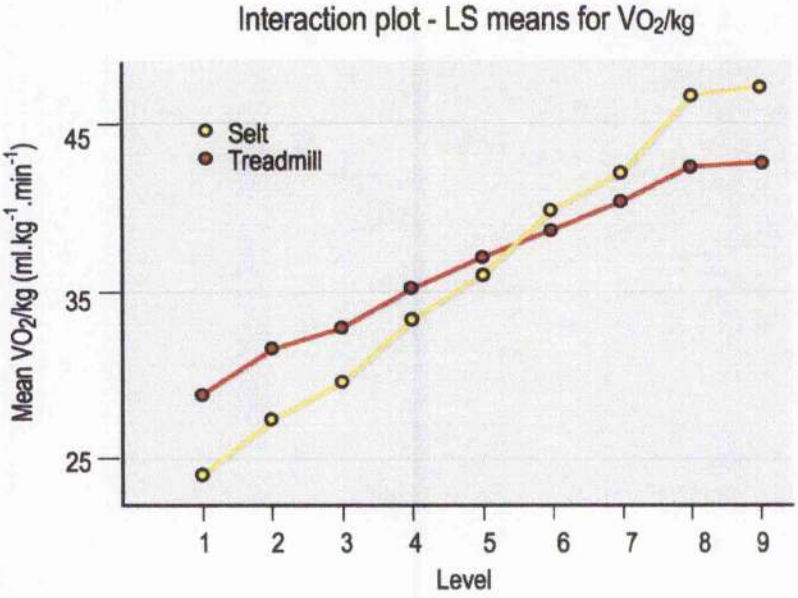


Figure 23. Interaction plot of the level means for both the treadmill test and the SELT.

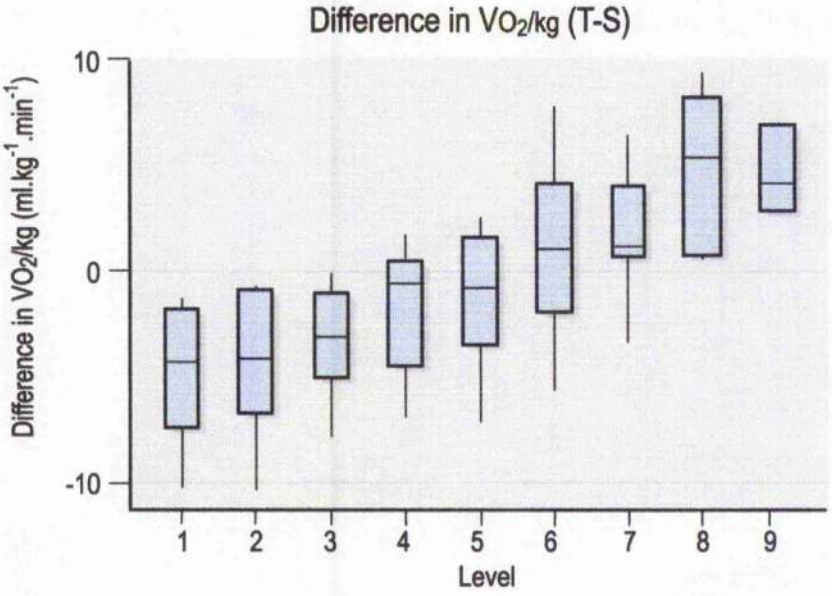


Figure 24. Boxplot of the difference between end of level blood $\dot{V}O_2$/kg between the treadmill test and the SELT. It appears that $\dot{V}O_2$/kg is lower for the SELT compared to the treadmill test in the early levels (1-5) but higher in the later levels (6-9).

The average $\dot{V}O_2$ increased with increasing level in both tests ($p < 0.001$) and there was a significant interaction where the mean $\dot{V}O_2$ was significantly lower for the SELT test when compared to the treadmill test at levels 1, 2 and 3. While there was no suggestion of a significant difference from level 4 onwards, mean differences in table 10 support those previous findings in figures 23 and 24. The treadmill test produces higher scores from level 1 to 5 (negative mean differences) and the SELT produces higher scores from level 6 to 9 (positive mean differences). Again the lack of significance is most likely a function of low sample size.

$\dot{V}O_2$ /kg (n=10)	Mean Difference (95% C.I.)	p-value
Level 1	4.79 (2.41, 7.17)	0.002
Level 2	4.27 (1.7, 6.84)	0.005
Level 3	3.256 (1.311, 5. 2)	0.005
Level 4	1.822 (-0.47, 4.12)	0.105
Level 5	1.02 (-1.45, 3.5)	0.369
Level 6	-1.22 (-4.35, 1.91)	0.394
Level 7	-1.76 (-4.58, 1.07)	0.179
Level 8	-4.58 (-9.37, 0.21)	0.057
Level 9	-4.6 (-9.8, 0.6)	0.063

Table 10. 95% C.I. of the mean difference between tests and the p-values for each level. Red denotes significance

Heart Rate

Figure 25 demonstrates how the balance of higher mean heart rate seems to shift from the treadmill in the early and middle levels and level off in the higher levels.

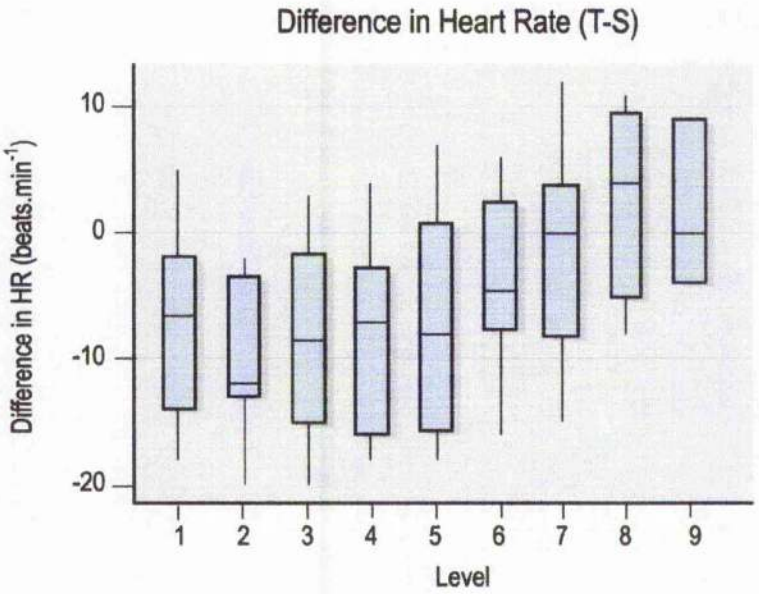


Figure 25. Boxplot of difference in Heart rate between the treadmill test and the SELT. Mean Heart rate seems to be lower for the SELT in levels 1-5, little difference is apparent for levels 6 and 7, and in level 8 and 9 mean heart rates are possibly higher for the SELT.

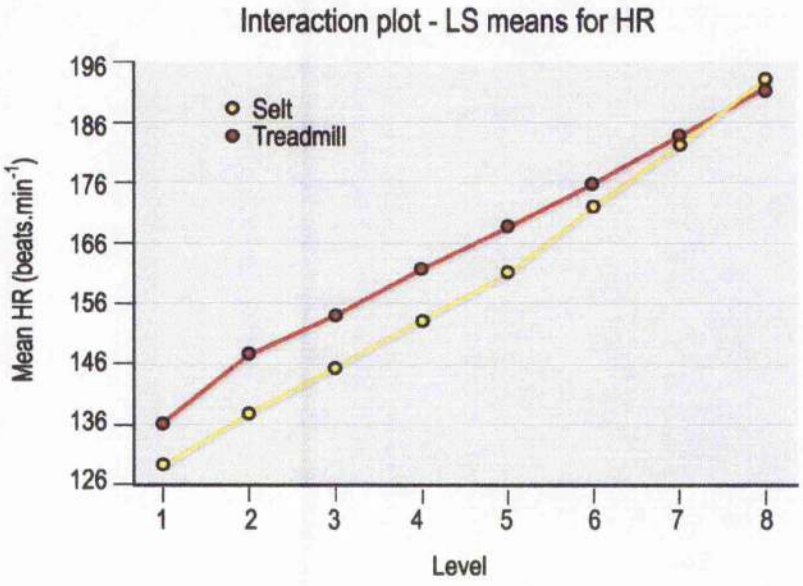


Figure 26. Interaction plot of the level means for both the treadmill test and the SELT for HR.

Heart rate increased on average with increasing Level for bother SELT and treadmill tests($p < 0.001$) and there was evidence of a significantly higher average heart rate for the treadmill compared to the SELT test ($p < 0.05$) for levels 1 to 5 (negative mean differences indicate higher scores in the treadmill test. This increase was not additive across Level as there was a significant Test by Level interaction (p=0.0.02). As the level increases the difference in mean HR between the two tests becomes smaller and there was no evidence of a difference in mean HR from level 6 onwards (Table 11).

HR (n=10)	Mean Difference (95% C.I.)	p-value
Level 1	-6.80 (-12.24, -1.36)	0.020
Level 2*	-9.80 (-13.98, -5.62)	0.001
Level 3	-8.60 (-14.12, -3.08)	0.006
Level 4	-8.50 (-13.82, -3.18)	0.006
Level 5	-7.30 (-13.94, -0.66)	0.035
Level 6	-3.70 (-8.83, 1.43)	0.137
Level 7	-1.38 (-8.54, 5.79)	0.664
Level 8	2.67 (-5.18, 10.51)	0.422

Table 11. 95% C.I. of the mean difference between tests and the p-values for each level. Red denotes significant results.

Although there is no significant difference in mean heart rate from level 6 onwards it is possible that there are higher heart rates for the SELT in the later levels (8 and possibly 9). The mean difference for level 8, although not significant, indicates higher scores for the SELT. The that a lack of significance may be due to smaller sample size in the higher levels.

RPE

Observation of figure 27 suggests that RPE for the treadmill test is on average slightly higher than that of the SELT for levels 1 to 6. Figure 27 also suggests that for level 8 RPE is higher for the SELT compared to the treadmill test. There appears to be no difference in RPE between tests for level 7.

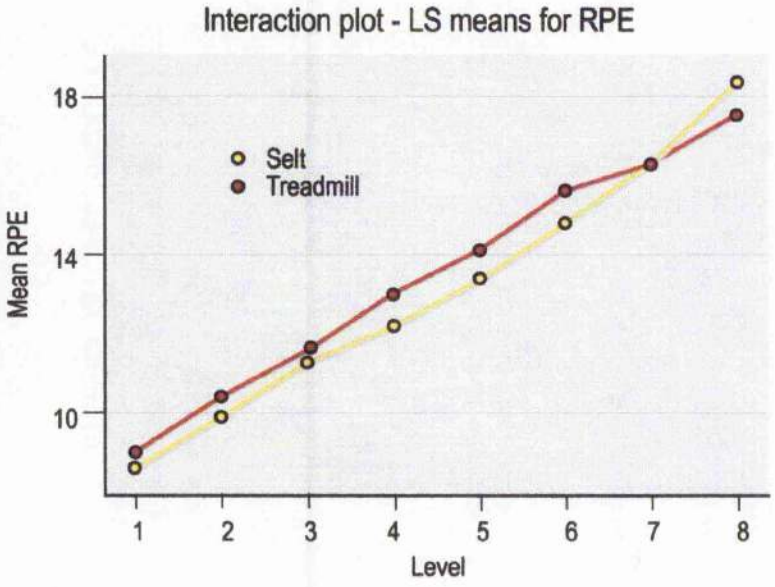


Figure 27. Interaction plot of the level means for both the treadmill test and the SELT for RPE.

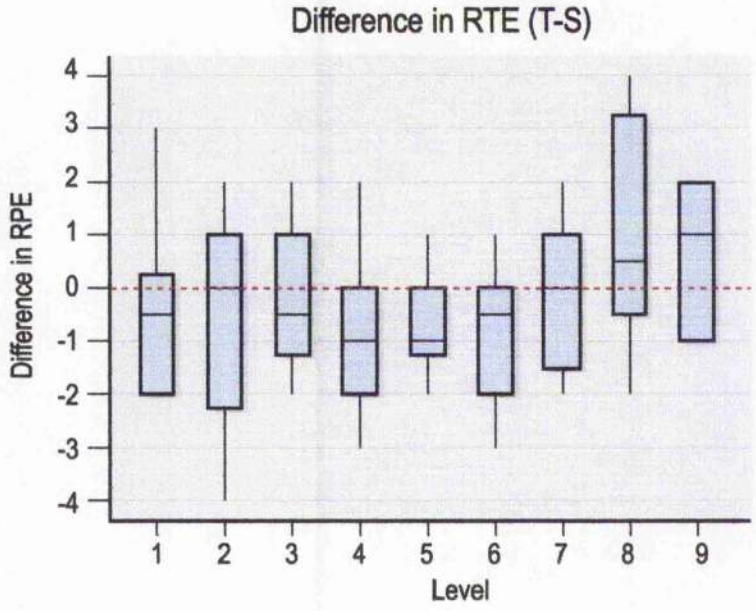


Figure 28. Boxplot of difference of RPE between the treadmill test and the SELT.

There was a significant increase in average RPE with increasing Level for both tests ($p < 0.001$). There was no test level interaction. There was no significant difference in the average RPE for the treadmill compared to the SELT test except for level 5, where the treadmill test was significantly higher than the SELT. Although results were not found to be significant, observation of the mean differences in table 12 suggest that the average RPE tended to be higher for the treadmill compared to the SELT test for levels 1 to 6 (negative mean difference) and lower for level 8 (positive mean difference). There appears to be no difference between tests for level 7. These observations support those taken from figures 27 and 28. It is probable that the lack of significant finding is due to the low subject number.

RPE (n=10)	Mean Difference (95% C.I.)	p-value
Level 1	-0.400 (-1.53, 0.73)	0.44
Level 2	-0.500 (-1.90, 0.90)	0.440
Level 3	-0.300 (-1.26, 0.66)	0.496
Level 4	-0.800 (-1.80, 0.20)	0.104
Level 5	-0.700 (-1.38, -0.02)	0.045
Level 6	-0.800 (-1.68, 0.08)	0.07
Level 7	0.000 (-1.18, 1.18)	0.999
Level 8	1.00 (-1.30, 3.30)	0.314

Table 12. 95% C.I. of the mean difference between tests and the p-values for each level. Red denotes significance

Part B. Comparison of blood lactate variables.

A paired t-test was used to compare the difference in the mean response for each variables of interest (Table 13).

	Mean difference (St. Dev) 95% C.I.	**P-value**
v-T_{lac}	0.100 (1.479) (-1.158, 0.958)	0.836
v-4mM	0.422 (0.612) (-0.893, 0.048)	0.072
v-3mM	- 0.250 (0.544) (-0.639, 0.139)	0.180
VO_2 at *v-T_{lac}*	3.42 (4.47) (-6.86, 0.01)	0.051
VO_2 at *v-4mM*	0.32 (4.69) (-5.50, 6.14)	0.886
HR at *v-T_{lac}*	5.89 (17.31) (-19.19, 7.42)	0.337
HR at *v-4mM*	3.33 (7.97) (-11.69, 5.03)	0.325
RPE at *v-T_{lac}*	0.51 (3.17) (-2.94, 1.92)	0.641
RPE at *v-4mM*	0.483 (1.772) (-2.344, 1.377)	0.534

Table 13.

Table 4 shows that there was a possible suggestion of evidence of a mean difference between the two test types (i.e. SELT v Treadmill) for $\dot{V}O_2$/kg v-Tlac (p=0.051 borderline significance) and for v- 4 mM (p=0.07 borderline significance). There was no convincing evidence of a mean SELT to Treadmill difference in the response variables for the other variables in question.

DISCUSSION

Study 1. Reproducibility study

A. Reproducibility of Blood lactate variables

Reproducibility of the v-T_{lac} and associated variables

The SELT shows poor reproducibility for all variables (velocity, heart rate, RPE and $\dot{V}O_2$/kg) associated with the lactate threshold. There is no bias detected between tests 1 and 2, however the ICC show little agreement between the scores and the LoA are so large that great differences in scores are needed to detect changes in training status. For example LoA indicate that a change greater than –2.07 to 2.55km h^{-1} in v-T_{lac} is necessary to be considered a change in training status. These figures cast doubt on the sensitivity to change of blood lactate testing in this population for this test. Assuming all external variables that may effect performance are minimised and errors associated with laboratory measures are small, the lack of reproducibility for these variables may be due to the following reasons:

Lactate threshold determination. For the purposes of this study, the lactate threshold was determined as the first significant elevation of blood lactate above resting levels (Kindermann et al. 1979). When blood lactate is plotted against running velocity the inflection point of the lactate profile "curve" (corresponding to the lactate threshold) is identified by the ADAPT computer programme. Although this programme has been shown to have good precision for athletes tested at the South Australian Institute of Sport in endurance sports of running (Bourdon, 2000) the use of statistical methods to determine such a phenomena has been criticised. While the use of statistical analysis has been supported, based on the exponential relationship between blood lactate and work intensity during incremental exercise, a number of papers have challenged the ability of such

procedures to detect the existence of the lactate threshold, and have suggested that the mathematical modelling of such complex biological systems may prove delusive (Morton, 1986; Morton, 1989; Morton, 1993). This method of blood lactate analysis may have inconsistencies therefore lactate determination may lack precision, consequently lactate threshold and any variable based on the lactate threshold may not be very reproducible. Consider the following hypothetical example of a subject who experiences large oscillations in blood lactate in the early levels (figure 29). The ADAPT package defines the lactate threshold as the first rise in blood lactate over 0.4mmol. l^{-1}. The dip in lactate of the early recordings may confound results causing a false lactate threshold to be recorded.

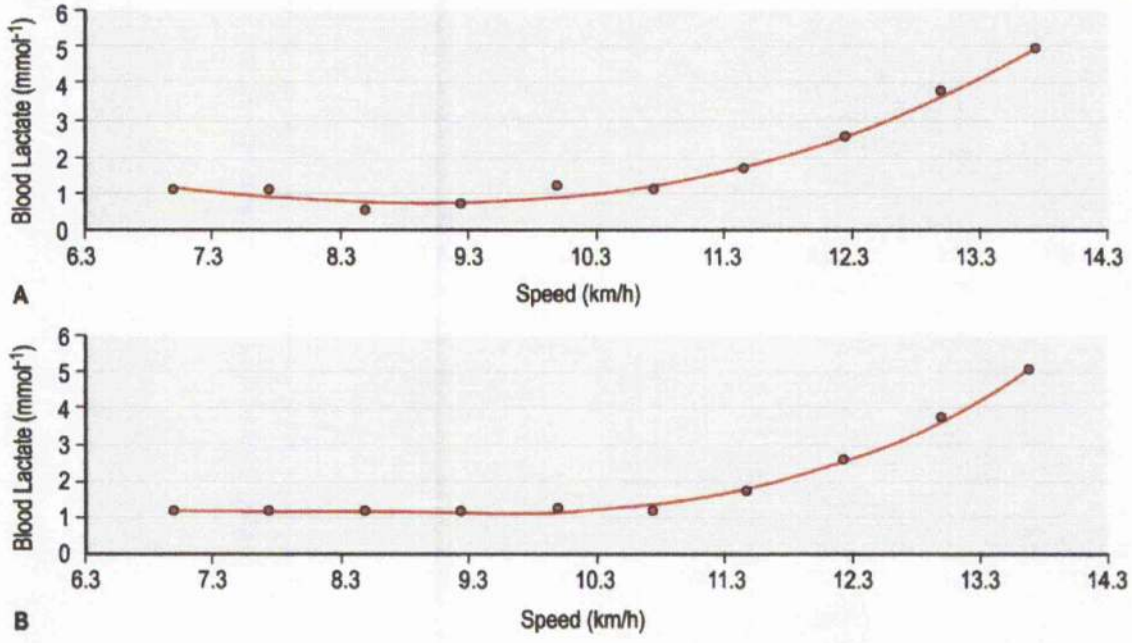


Figure 29. The ADAPT package reports the lactate threshold to occur at 8.6 km/h in A(top graph). Lactate threshold in graph B (bottom graph) occurs at 10.9 km/h. Graphs A and B are the same except for the second and third point which dip in graph A but stay constant in graph B. This demonstrates that relatively small oscillations in blood lactate in early levels may lead to markedly different results compared with a graph that does not have oscillations in the early stages.

Subject number. While the number of subjects used in this part of the study (23) was more than some other comparable reproducibility studies (Doyle and Martinez, 1998; Nicholas et al, 2000; Drust, 2000; Boddington et al, 2001; Hood, 2002; Krustrup et al, 2003) it was also less than some others (Wragg, 2000; Grant et al, 2002; Dabonneville, 2003; Garcin, 2003). There is no exact number of subject has been quoted as the 'ideal' or minimum required for a reproducibility study however, as a general rule it could be said that the more subjects the better. The LoA in this study may have been closer had a larger group of subject been used. It is a possibility that the use of more subjects could have resulted in more reproducible results.

The protocol specific nature of blood lactate. The blood lactate response to exercise has been shown to be highly protocol specific (Weltman, 1995). As this is the first case of experimental analysis on the SELT, it is possible that the protocol chosen for this may not be suitable to detect meaningful changes in the lactate threshold. However, although this is always a possibility it would be illogical to come to such a conclusion without further study.

The physical and nutritional status of players. It is possible that subjects in this study have reported for assessment in differing physical and nutritional states across testing sessions. Although all efforts were made to standardise all aspects of the testing procedures, it was possible that some subjects may have attended sessions in a glycogen depleted of fatigued state. Several researchers have shown that alterations in substrate availability might affect LT and/or AT (Hughes et al, 1982; Yoshida, 1984; Ivy et al, 1981).

Reproducibility of the *v*-4mM and associated variables

The SELT appears to have reasonable reproducibility in general for all variables (Velocity, HR, RPE, and $\dot{V}O_2$) associated with the blood lactate 4mM marker. There is a suggestion of a systematic bias for *v-4mM* as the interval estimate for the mean difference does not contain zero. As the mean difference for this variable is positive, this indicates better performance in test 2. This suggests that a possible improvement of performance is to be expected from test 1 to test 2. This could be due to the subjects experiencing a learning or training effect. Having performed the test once already, subjects may be more comfortable in the second test and able to focus better on physical effort rather than on procedure. It is possible that subjects may learn from carrying out the first test how to be more economical with specific movements and put this into practice with an improved technique in the second test leading to improved performance. This raises the question of whether familiarisation procedures were thorough enough in this study to limit such effects. Due to time constraints the test familiarisation had to be carried out on the say day as testing. Every effort was made to make sure each subject was comfortable with the SELT protocol, nevertheless, if time had allowed, it might have been beneficial to include a previous day of familiarisation to further limit possible training/learning effects. Note however if there was an improvement in running economy from test 1 to test 2 a decrease in $\dot{V}O_2$/kg might also be expected which has not been found.

Observation of the LoA for the 4mM variables suggests a reasonable reproducibility in general (-0.50 to 1.10 $km.h^{-1}$, -5.00 to –5.62 $ml.kg^{-1}.min^{-1}$, -12.33 to 8.33 $beats.min^{-1}$, -1.73 to 2.67 units for *v-4mM*, $\dot{V}O_2$/kg at *v-4mM*, HR at *v-4mM*, RPE at *v-4mM* consecutively). Most notably, even though a slight bias between tests 1 and 2 has been

detected, *v-4mM* appears to show good reproducibility. Reproducibility of $\dot{V}O_2$ at *v-4mM* and HR at *v-4mM* seems questionable as the LoA still look large. For example improvements of 10.62 ml/min/kg and 20.66 bpm would be required to be considered a change in training status. Possible reasons for this may be the smaller subject number for $\dot{V}O_2$ analysis (10) compared to other variables, and the possible influence of blood sampling on Heart rate.

The spread of the data around the lines of equality for *v-4mM* also raises a potentially meaningful finding. Figure 2 (results section) shows that as velocity at which 4mM is reached increases, the spread of data around the line of equality becomes narrower. This highlights the possibility that the SELT may become more reproducible the fitter the subjects. This finding corresponds with other studies which found that fitter individuals produce more reproducible results. Heitkamp et al (1991) assessed the reproducibility of the *v-4mM* in trained and untrained women. Trained women were found to produce considerably more reproducible results than untrained. Aunola and Rusko (1984) and Grant et al (2002) reported similar findings which supports the observations of the aforementioned and the present study.

Most notable from the results from this study is the fact that the LoA for all variables involving the *v-4mM* measurement are considerably narrower than those involving *v-*T_{la} (see table 14). This suggests better reproducibility of the measures at *v-4mM* than *v-*T_{la}.

	Lactate threshold (mmol)	4mM marker (mmol)
V (km.h^{-1})	4.62	1.6
VO_2/kg (ml.kg^{-1}.min^{-1})	14.86	10.62
HR (beats.min^{-1})	67.95	20.66
RPE	11.55	4.4

Table 14. Comparison of the LoA for Lactate threshold variables and 4mM marker variables. Note that the LoA for all variables based on the 4mM marker are narrower than those of the lactate threshold.

There could be a number of possible reasons for the reproducibility of the 4mM marker being better than that of the Lactate threshold. The possible reasons for the poor reproducibility of the variables associated with the lactate threshold have been discussed. One factor was the influence of the method of lactate determination i.e. the ADAPT computer programme determined the lactate threshold. Although the ADAPT package also automatically determined the 4mM markers results, this is achieved by a simple extrapolation process on the blood lactate – work intensity graph and is therefor not subject to the same criticism previously mentioned (Morton 1986, Morton 1989, Morton 1993). It s also possible that both the test and the test population are more sensitive to the 4mM marker than the lactate threshold. *Note that in the present study, although the reproducibility of v-4mM is considerably better than that of v-T_{lac}, a change of 1.6 km h^{-1} is still necessary to be considered a change in training status.*

The fact that the 4mM variables display better reproducibility than that of the v-T_{lac} possibly negates the earlier suggestion that diet may be a reason for poor v-T_{lac} reproducibility. It may be expected that the influence of nutrition would greater be greater on FBLC's than on the Lactate threshold (Bourdon, 2000).

It is difficult to compare previous research to the present study as, to the author's knowledge. There are no other studies similar in design. It is only possible to compare to other reproducibility studies which mostly involve treadmill running. However, care must be taken in comparison because, as this study involves the development of a new test involving test specific movements, there will be no previous studies using the same testing protocol.

In order to compare the results of previous studies similar statistical analysis must have been used. A number of studies have quoted the correlation coefficient as a measure of reproducibility however, it must be noted that the correlation coefficient is not an adequate measure of agreement in this context (Bland and Altman, 1986). The correlation coefficient tests for linear agreement (i.e. the slope of the line does not have to be 1) while in a study such as this the aim is to test for agreement (i.e. slope equals 1) so in theory there could be high correlation but poor agreement i.e. a systematic bias.

Grant et al (2002) used LoA to investigate the level of agreement and reproducibility of blood lactate, HR and RPE. Similar to the present study, Grant et al (2002) investigated the reproducibility of blood lactate measurements, HR and RPE at speeds corresponding to the lactate threshold and the fixed lactate concentration of 4mM. 36 subjects performed two identical incremental treadmill tests consisting of at least six four minute stages. Note that this subject number is number is greater, but not by much, as the subject number used in the present study. Blood lactate, heart rate and RPE were recorded at the end of each stage. The LoA for this study are shown in table 2. As can be seen from table 15 the SELT

test shows better/similar reproducibility than treadmill lactate assessment using similar stage duration / test velocity increment, especially for the 4 mmol.L^{-1} marker.

	SELT/SELT (n=23)	**Grant et al (2002) (n=36)**
v-T$_{lac}$ (km.h^{-1})	4.6	2.7
v-4mM (km.h^{-1})	1.6	2.61
HR at *v-T$_{lac}$* (beats.min^{-1})	67.9	31.6
HR at *v-4mM* (beats.min^{-1})	20.6	25.2
RPE at *v-T$_{lac}$*	11.6	6.1
RPE at *v-4mM*	4.4	5.6

Table 15. Comparison of the widths of the LoA for each variable for the present study and Grant et al (2002). *Comparing these to the LoA for the previous study suggests that the SELT test (even with the smaller sample size) may be more reproducible. Comparable 4 mmol.L^{-1} marker variables are highlighted in red.*

The fact that SELT demonstrates better reproducibility than the treadmill test is encouraging as one would normally expect the treadmill test to exhibit a higher degree of reproducibility as a test such as this is more traditionally associated with blood lactate assessment. In both the present study and that of Grant et al (2002) the LoA for all variables associated with v-T$_{lac}$ are very wide.

The intraclass correlation support the findings of the LoA in that the 4mM variables display better reproducibility than the lactate threshold variables which are poor. The ICC results also provide further support of consistency between measures of the 4mM variables across tests. The ICC of 0.85 and 0.90 suggest good reproducibility for *v-4mM* and VO_2 at

v-4mM. ICC for HR at *v-4mM* and RPE at *v-4mM* are not quite as good being 0.73 and 0.77 respectively. With higher subject numbers it could be expected that ICC scores would improve.

Boddington et al (2001) studied the Reliability of a 5-m multiple shuttle test. Although the test protocol in this study was dissimilar to that of the present study, similar to the present study the intra-class correlation (ICC) was used as a measure of the agreement of heart rate and RPE between successive trials of the same test. Due to different procedures carried out in the Boddington study a number of ICCs are quoted for each variable. Boddington et al found that he ICC for heart rate ranged from 0.65 to 0.91 and that for RPE from 0.85 to 0.91. It was concluded from the Boddington study that the test in question was a reliable measure of hear rate and RPE response and is sufficiently reliable to track changes in fitness over a season. Comparing the results from the study by Boddington to that of the present study supports the finding of good reproducibility for these variables from the SELT particularly *v-4mM* and $\dot{V}O_2$ at *v-4mM* (0.85 and 0.90 consecutively). Note that caution must be applied when comparing these two studies because of different test protocols and procedures.

Bias of level data

Analysis of the bias in the end level data was carried out to determine changes in variables at given levels. Theoretically this data should be uncorrupted by any potential problems associated with methods of assessing the blood lactate response to exercise. The aforementioned criticism associated with the determination of lactate variables should therefore not be an influencing factor when analysing the reproducibility of the end of level data. Statistical analysis of these data produced mixed results. Blood lactate was found to be significantly higher in test 1 for levels 4-7. Similarly Heart rate was found to be

significantly higher in test 1 for 6 out of 8 levels. A training or learning effect is a possible reason for the decrease in response for these two variables. Subjects may be more accustomed to the testing protocol, more comfortable with the blood sampling procedure, and may be more economical when performing the soccer specific movements in the second of the two trials. Each of the aforementioned factors may lead to a decrease both lactate and heart rate from test 1 to test 2. Note that apprehension would not be expected to an influencing factor on the later levels where exercise intensity is high. The paired t-tests carried out indicated that there was no significant mean bias for both RPE and $\dot{V}O_2$/kg between trials. General observation of the confidence intervals for both variables also indicated little difference between both tests. It is difficult to explain why RPE and $\dot{V}O_2$/kg did not show a similar response as Lactate and Heart rate. If a training/learning effect were apparent it would be expected that $\dot{V}O_2$/kg would decrease from test 1 to 2 due to improvements in running economy. No such improvements in running economy are suggested. It may be expected that heart rate would be most likely to be higher in test 1 due to subject apprehension concerning both test procedure and blood lactate sampling. This again raises the possibility that a more extensive familiarisation session be required particularly with blood sampling procedures. It is possible that blood lactate may have been affected by external factors such as diet, however as all efforts were made to keep these constant it is difficult to quantify the effect of such influences.

Study 2. Comparison of SELT to a 'traditional' treadmill test

The second aim of this study was to compare the physiological responses (Blood lactate, HR, RPE and $\dot{V}O_2$) of the SELT to that continuous exercise performed on a treadmill at similar exercise intensity for a comparable period of time. This comparison should ascertain whether or not the SELT provides different information than a traditional treadmill lactate test and could be used to assess the usefulness of the SELT as a soccer specific test.

Part A - Comparison of end of level data.

Results suggest that for all variables (Blood lactate, HR, RPE and $\dot{V}O_2$/kg) the treadmill test is physiologically more taxing until approximately level 5/6 and the SELT test is more taxing in the later levels, with a crossover occurring at approximately around levels 6 and 7. Although there is a lack of significance in some stages this may be attributed to low subject numbers, particularly in the later levels.

Blood lactate and $\dot{V}O_2$. Figures 7 and 9 (results section) suggests a similar response of lactate and $\dot{V}O_2$/kg for the two tests. The average lactate levels were significantly lower for the SELT test when compared to the treadmill test at levels 2, 4, 5 and significantly higher at level 7. Average $\dot{V}O_2$ was significantly lower for the SELT test when compared to the treadmill test at levels 1, 2 and 3. Although only the results from the aforementioned levels were found to be significant this is most likely due to the power of the statistics being reduced by low subject numbers in the later levels. This is most notable in the later levels when subject number is reduced further, for example for Vo2/kg all subjects completed at least 6 levels whereas only 5 completed 8 and only 3 completed 9. It would

therefore be advantages to carry out similar testing with fitter subjects so that all levels could be analysed to a similar power with a higher subject number.

Reason for the response to both tests and the relationship to each other

The treadmill test elicited a larger physiological strain than the SELT in the early levels (approximately levels 1-5). This is possibly due to the 5 s interval between stages in the SELT test. As in these early levels subjects are not required to run at a high speed the 5 s interval may aid recovery. Performing the specific movements (sideways/backwards running, turning, accelerating/decelerating) in the SELT at such a low pace may be less taxing than performing constant exercise on the treadmill.

The SELT test was physiologically more taxing than the treadmill test in the later levels. The possible reasons for this are as follows:

Running economy. It is impossible to quantify the exact speed of locomotion during the SELT. The turning, decelerating and accelerating means an almost constant change in running pace throughout the test. Subject's speed of locomotion is also dependant on other factors such as muscle strength and running style (Blazevich, 2000). For example a subject who has an efficient running style may take less time to turn, accelerate and decelerate and therefore is not required to reach as high speeds of running as a subject which has a less efficient style. Also with more economical technique when performing these movements less energy will be expended. Nevertheless, even accounting for theses factors it can be assumed that the average speed of locomotion while performing the SELT should be approximately that of the equivalent level in the treadmill test. The results from the comparison study between the SELT and the treadmill test suggest that, although it appears

easier in the early levels, the SELT is physiologically more taxing in the later stages. Where the specific movements do not appear to further increase the metabolic load over that of normal running in the early stages it is apparent that they do considerably in the later stages. Note that in the early levels the reason for the treadmill being more taxing may not be that the specific movements do not make any difference but the fact that subjects have a 5 second recovery period between each stage (see Appendix 3). As speed of locomotion increases the specific movements become physiologically more taxing to perform so much so that the SELT becomes more and more difficult than the treadmill test as speed increases. This could have been anticipated as it is to be expected that deceleration and acceleration becomes more physiologically taxing as speed increases. This is also in agreement with a study by Reilly and Bowen (1984) which found that there was an added physiological cost when performing backwards and sideways movements over that of forwards running. Furthermore, the same study also found that the extra cost of such unorthodox modes of running increased with speed of movement. Also twisting the body to turn and change direction, and running sideways and backwards at increasingly faster speeds may also continually increase the metabolic load over that which is expected for running continuously on the treadmill. It could therefore be postulated that, although average speed of locomotion is similar for each equivalent level between the SELT and the treadmill test, running economy (i.e. the average physiological load to perform a particular level) is considerably larger in the SELT compared to the treadmill test in later levels (demonstrated in figure 2B). It is also likely that where, as aforementioned, the intermittent 5 s intervals between SELT stages may aid recovery in the early levels, in the later levels it may add to the metabolic load because of the need to stop/start, decelerate from and accelerate to higher speeds. This is in agreement with the findings of Bangsbo (1994) who found that $\dot{V}O_2$ during intense intermittent exercise is significantly higher than during

continuous exercise at the same mean work rate. This can be demonstrated for the SELT/treadmill test comparison in figure 9 (results section). Although $\dot{V}O_2$ differences were not found to be significant in the later levels it may be expected that with a higher subject number the power of the calculations may be increased. It therefore may be expected that improvements in efficiency in performing the 'soccer specific' movements may aid performance of the SELT. Similarly Reilly and Bowen (1984) concluded from their study that improving muscular efficiency in unorthodox modes of movement (backwards and sideways running) would clearly benefit the soccer player.

Muscle fibre recruitment. Another factor which may be an important influence in the SELT having an increased physiological cost over that of the treadmill test in the later levels is muscle fibre recruitment. The fact that the SELT involves multidirectional, sideways and backwards running and the need to accelerate from and decelerate to a standing stop and accelerate and decelerate to change direction may separate the SELT from the continuous uni-directional treadmill test as far as muscle fibre recruitment is concerned. The need to twist the body to change direction or prepare for sideways running may involve muscles and activate muscle fibres which otherwise would not be used for treadmill running e.g. core musculature or those muscles that move the thigh, lower leg and foot laterally and medially. Similarly backwards and sideways running will further involve muscles that are not used to the same extent in treadmill running. Hip abduction and adduction is necessary for sideways running but not when performing the treadmill test. Similarly, it could be assumed that backwards running would require more use of the muscles such as the gastronemius, soleus, peroneus longus for plantar flexion of the foot for example than treadmill running. After performing both tests it was common for subjects to report more feelings of fatigue in the leg musculature after the SELT test

compared to treadmill test. The need to decelerate economically and effectively to, and accelerate from inertia and for the purposes of changing direction will require both more concentric and eccentric strength in the hip and leg musculature than treadmill running (Hughes, 1973). All the aforementioned differences between the tests will result in different muscle fibres being recruited which may be an important contributing factors to the SELT being 'harder' than the treadmill test in the later levels.

Part B – Comparison of measurements at blood lactate variables

There was no convincing evidence of a mean difference between the SELT and the treadmill test for v-T_{lac}, v-4mM or any of the associated variables. This may be a function of the low subject number however there are other possible reasons for this. Firstly, it has already been noted that the Treadmill test and SELT seem to 'cross over' each other in that the treadmill appears more difficult in the early stages and the SELT more difficult in the later (see Figure 2). It is possible that one or more of the variables measured may occur approximately where the two tests 'cross over'. Therefor results may not reflect the differences between the tests as the most apparent differences between the tests seem to occur in the early and later levels and less difference, physiologically, in the middle levels. This speculation is supported by figures 7 and 9 (Results section). Note that the crossover in both interaction plots occurs around levels 5 to 7, a point where the 4mM marker may be expected to most commonly occur. This effect may not be as expected with the lactate threshold variables as this is expected to commonly occur around level 4 where, according to same interaction plots, differences appear to be more marked. One reason for no significant mean difference being detected here could be the aforementioned criticism of the determination of the lactate threshold. This criticism has been supported by the poor reproducibility of this variable reported for this study.

Conclusion

The comparison between the SELT and the treadmill test demonstrates the significance of the 'soccer specific movements' which the SELT comprises. It appears that the specific movements have little effect over that of normal continuous running (represented by the treadmill test) in the early levels. In fact the intermittent 5 s intervals between every stage (see Appendix 3) appear to aid recovery and therefore makes the SELT less demanding than the equivalent in the treadmill test in the early levels. However, in the later levels where the speed of locomotion is increased it appears that the SELT becomes physiologically more taxing the treadmill test. This is most likely due to the need to perform the 'soccer specific movements' at a fast pace and could be a result of use of more muscles, the activation of more muscles fibres and different muscle fibres, and less economic running because of the more demanding movements. As the movements involved in the SELT are 'soccer specific' and the fact that it appears that performance of the SELT results in a different physiological response than continuous uni-directional treadmill running is a promising result. Note that the author recognises that no significant difference has been found between the two test according to the lactate threshold and 4mM marker variables. These results, according to the end of level data, suggest that the SELT may be of more use than a traditional style treadmill test for testing soccer players as it may be more specific to this population owing to its intermittent nature and the involvement of the 'soccer specific' movements.

Limitations of the study

Subject number

23 subjects took part in reproducibility study 1 and 10 in comparison study 2. This was due to difficulty in recruiting subjects and time constraints. It is likely that more conclusive results could be achieved with higher subject numbers. It is also possible a better reproducibility of the SELT may have resulted from the use of more subjects. Nevertheless the used of 23 subjects, as in the present study compares favourably with a number of published studies. Reproducibility studies by Krustrup et al, 2003; Doyle and Martinez, 1998; Nicholas et al, 2000; Boddington et al, 2001; Drust, 2000; and Hood, 2002 all used a smaller study group than that involved in the present study.

Test familiarisation

For many of the players involved in this study it was their first visit to an exercise laboratory, therefore anxiety might have effected results. Every effort was made to familiarise the subject during their warm-up prior to their first assessment, especially with the test protocol and the blood lactate sampling procedure. Results from this study suggest that a separate familiarisation session with all of the players before commencement of the study may have been useful however this was impossible due to time constraints. It is possible that a more extensive familiarisation may have produced more reproducible results in this study.

Determination of lactate inflection point and use of 4mM marker

As mentioned earlier in this section there has been criticism over using computer programmes involving mathematical modelling to determine the lactate threshold. There has also been criticism of the use of fixed blood lactate concentrations which have

highlighted the fact that they may not take into account inter-individual differences in blood lactate accumulation and the dependency of measured blood lactate on substrate availability. Nevertheless, studies carried out have validated the use of the method used to determine the lactate threshold in this study (Bourdon, 2000) and there has been an abundance of support of the use of the 4mM marker also (Heck et al, 1985; Weltman, 1995). It is possible that the use of different methods of blood lactate breakpoints and markers may have resulted from different conclusions being drawn from this study. However the author believed, based on previous studies, that the methods used were practical, suitable, and deemed to be valid analytical methods by the exercise science community.

Alternative methods of comparison

An important factor when comparing the SELT to a 'traditional treadmill test' was the selected protocol for the treadmill test. A number a methods could have been used for this comparison. To achieve a genuine comparison of the SELT and a treadmill test, the treadmill test protocol must be such that both a sound comparison can be made and any inferences on the differences can be valid. In the present study the equivalent pace on treadmill was calculated as the average speed of locomotion for each stage using the speed = distance/time equation. It was felt that it was more suitable to use levels of the same average running speed for an identical time for the treadmill test as the SELT. Therefore, theoretically the effect of the soccer-specific movements and stop/start nature of the SELT should be able to be compared to that of the continuous nature of the treadmill. To the author's knowledge there are no comparable studies to the present, however studies have compared intermittent to continuous exercise (Bangsbo, 1996). A number of different

protocols have been devised to compare the aforementioned including using the same mean exercise intensity, power output, or distance covered.

An important factor that must be considered when comparing these two tests is the lack of air resistance in the laboratory setting which could reduce the energetic cost of treadmill running compared to normal running for any given velocity (Davis, 1980). In order to compensate many researchers have used slight inclinations of the treadmill. A variety of gradients appear in the literature including 0.5% (Novak et al, 1984), 1.0% (Heck at al, 1985; Weltman et al, 1990; Jones and Doust, 1996) and 2.0% (Tegtbur et al, 1993; Rocker et al, 1994) while others made no reference to the matter and used a flat treadmill (Hale et al, 1988). The treadmill in this study was set at an incline of 1% throughout the duration of the test. Jones and Doust (1996) found that this slight incline of the treadmill gradient accurately increases the energy cost in compensation for a lack of air resistance when running on a treadmill for speeds between 10.5 and 18 km h^{-1} for a duration of around 5 minutes. The author recognises that a number of different methods could have been utilised which may produce differing results however it was felt the most appropriate protocol was applied.

To be sure an accurate inclination of 1% could be achieved the treadmill used in this study was checked by the manufacturer before testing commenced. However, once testing had been completed it was found that the treadmill surface had a slight 'bend' in it. Therefore it was found that while the back of the treadmill was set at 1% incline the front third was set at 1.5%. It is difficult to assess the effect which this may have had on results, however it is thought that any effect would be minimal.

The practical application of the SELT

Training and testing performance. Performing the SELT at specified time points during the soccer season as well as the off-season may be useful to monitor fitness. Further study is required to examine the relationship between SELT performance and soccer performance, however it is possible that the SELT may be more useful tool than for example a treadmill test for monitoring in 'soccer fitness' over an extended period of time. If a relationship can be established between the SELT and soccer performance the SELT could also be used as a training tool. It is possible that performing the SELT regularly, because of the 'soccer specific' nature of the test, could lead to improved fitness which may be translated into improved performance on the pitch. Regular performance of the SELT may improve a players ability to perform the unorthodox movements in which soccer requires such as sideways/backwards running, accelerating and decelerating, and changing direction quickly and efficiently particularly at both a high pace and in a fatigued state which are regularly needed in soccer match-play.

Exercise prescription

Poor performance in the SELT may highlight the need to improve 'soccer specific' running economy. It has been shown at higher speeds of locomotion that subjects have greater oxygen cost when performing the SELT than at a similar pace when running continuously on a treadmill (see Results section). It may be beneficial to prescribe exercises which have been shown to improve running economy to players who perform badly in the later levels of the SELT. Training can be used to improve economy in several ways. High intensity training has also been reported to be effective in eliciting improved running economy (Conley et al, 1984). Hoff and Helgerud (2002) have shown that maximal strength training results in improved running economy. Plyometric training, sprinting and explosive weight

training have also been shown to improve economy (Paavolainen et al, 1999). Running in itself may improve economy by reducing the cost of breathing (Franch et al, 1998), converting type II to type I fibres and tightening muscles of the hips, which may facilitate using more elastic energy in these muscle groups (Paavolainen et al, 1999). With this in mind it may be postulated that performance of the SELT may also improve running economy and possibly in a more soccer specific manor than the aforementioned factors. This however would require further study before and conclusions could be drawn.

Rehabilitation

Another potentially beneficial use for the SELT could be throughout the rehabilitation process. The rehabilitation progress of injured players is often difficult to assess. The balance of how much to push a player to progress and how much to hold back in order to avoid any reoccurrence of injury can be difficult to assess. In this context the SELT may be more useful than say a treadmill test to monitor fitness and the readiness of a player to be involved in match play.

Consider the following example. A player with ligament damage to the knee or ankle, or with a severe muscle strain. After the initial period of rehabilitation where function is regained, the SELT could act as a stepping stone between the low stimulation rehab on a treadmill and the rehab of uncompetitive match play. Rather than force the player into math-play and risk recurrence of injury or waste time with low stimulation exercise on a treadmill, the SELT could gradually test the ability of the player to accelerate, decelerate and perform unorthodox movements which are typical to soccer. Since the SELT is an incremental test of endurance performance stimulation can gradually be increased to either the effected muscle or ligament as well as to endurance capacity which can be monitored.

It can therefore be hypothesised that the SELT could be a more useful tool for rehabilitation purposes than a treadmill test as the SELT may more effectively monitor the ability of the physiological systems to perform in a soccer environment. Performance of the SELT may be a useful tool for assessing the ability and appropriateness of a return to match play for a previously injured player.

Recommendations for future research

Alterations to the current methodology

Although the subject number used in the reproducibility study compares favourably with a number of published studies, the use of a higher number a subjects may result in more compulsive results. The same can also be said for the SELT/treadmill test comparison study where a higher subject number may have resulted in more significant findings. Also in the reproducibility study there was some evidence of a possible training effect between tests 1 and 2. It may be useful if a similar study was to be carried out to include a more extensive familiarisation period, possibly another day previous to the first day of testing, if time allowed.

Modifications to current test protocol

Modifications to the current test protocol may be warranted. At the beginning of this study a number of SELT tests were created involving different level lengths, recovery periods and increments. Slight changes in the test protocol may produce either more or less favourable SELT results however it was felt that the current SELT was the most suitable and practical while still being scientifically sound.

Correlation with soccer performance

A number of studies have correlated exercise tests or physiological markers with soccer performance. A significant relationship between $\dot{V}O_2$max and both distance covered during a game (Bangsbo, 1994) and number of sprints attempted by a player (Smaros, 1980) has been demonstrated. Rank-order correlation between average $\dot{V}O_2$max and placing fro the first four teams in the Hungarian top soccer division was shown by Apor

(1988). These findings have been supported by Wisloff et al (1988), who demonstrated a significant difference in $\dot{V}O_2$max between the top team and a lower placed team in the Norwegian elite division. It would be beneficial to examine how performance of the SELT relates to soccer performance whether it is number of sprints, distance covered, league ranking or some other measure of soccer performance. It could be hypothesised that the SELT would be highly correlated with the aforementioned measures however this would need to be investigated.

Conclusions

Study 1 – Reproducibility

Part A - Reproducibility measurements at blood lactate variables

1 – The SELT test shows poor reproducibility in general for all variables (Velocity, HR, RPE and $\dot{V}O_2$) associated with the lactate threshold. LoA are so large that it appears to have limited value and would be unable to detect meaningful changes above day to day fluctuations. It should be noted that the sample (n=23) is relatively small which limits the strength of the predicted limits of agreement.

2 – The SELT appears to have reasonable to good reproducibility in general for all variables (Velocity, HR, RPE and $\dot{V}O_2$) associated with the blood lactate 4mM marker.

Part B - Reproducibility of end of level data.

1 – There was significant mean bias across some of the levels between SELT test 1 and SELT test 2 for lactate and HR suggesting higher scores in test 1

2 – There was no significant difference found across all levels between SELT test 1 and SELT test 2 for $\dot{V}O_2$/kg and RPE.

Study 2 – SELT/Treadmill comparison study

Part A - Comparison of end of level data.

It appears that for all variables (Lactate, HR, RPE and $\dot{V}O_2$/kg) the Treadmill is more taxing physiologically in the early levels and the SELT elicits a greater physiological cost in the later levels, with the crossover occurring between levels 6 and 7. Small subject numbers in the later stages may limit the conclusions made.

Part B - Reproducibility measurements at blood lactate variables

There was no convincing evidence of a SELT / Treadmill difference for any variable Only a borderline significance was found for $\dot{V}O_2$/kg v-Tlac and for v- 4 mM.

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APPENDIX 1 –

INFORMATION SHEET

You are invited to take part in this study which will evaluate a football specific exercise test. Fitness testing of footballers is carried out regularly by many top European clubs. A potential limitation of some tests is the lack of specificity of some of the tests. For example, it is difficult to simulate football movements on a treadmill. A new test has been developed which mimics many of the movements carried out by players during a game. The test can be carried out in a gymnasium or a field. This progressive test could prove to be useful in the evaluation of players. More information is needed on this test. It is important to compare the responses of the new football specific test with that of a traditional treadmill test. It is also important to determine the reproducibility of the football specific test.

The aims of the study are:

1) to compare the responses of a football specific test with a traditional incremental treadmill test.
2) To determine the reproducibility of the football specific test.

Testing will take place at the Kelvin Gallery, Laboratory 327, Celtic Park the and in the Stevenson Building.

Research Design

You will be either asked to undertake a football specific incremental test on two occasions or you will carry out a football specific incremental test on one occasion and an incremental blood lactate test on a treadmill. Tests will be at least two days apart. All tests will involve heart rate monitoring, blood collection for subsequent blood lactate analysis and determination of oxygen consumption. Comparison of a range of physiological responses will be made to assess the reproducibility of the football specific incremental test. A comparison of the responses between the football specific and treadmill tests will be made. .

Football Specific Incremental test

After a warm-up, you will be asked to carry out an incremental test. You will perform a number of movements on a 20 metre track. The movements include running forwards,

backwards and sideways, walking and turning. The speed of movement will be regulated using a bleep on an audiotape. You will start at around 8 kilometre per hour. This speed will remain constant for 5 minutes after which you will stop for 30 seconds during which a blood sample will be taken for subsequent blood lactate analysis. After the 30 seconds rest, the you will perform the next 5 minute stage at 0.75 kilometres .hour^{-1} faster than the previous stage followed by a 30 second rest. This procedure will continue until the blood lactate level is over 4 mM (a fairly high exercise intensity - you will be breathing quite hard) or you request that the test is stopped.

Treadmill incremental test

After a warm-up you will perform an incremental test on a treadmill. You will start at around 7 kilometres per hour . This speed will remain constant for 5 minutes after which you will stop for 30 seconds during which a blood sample will be taken for subsequent blood lactate analysis. After the 30 seconds rest, the you will perform the next 5 minute stage at 0.75 kilometres per hour faster than the previous stage followed by a 30 second rest. This procedure will continue until the blood lactate level is over 4 mM or you request that the test is stopped.

Please note that you can stop the tests at any time for any reason.

Heart Rate:

Heart rate will be monitored using a Polar heart rate monitor.

Capillary Blood Lactate Analysis :

Capillary blood will be taken by pinprick capillary sampling on a number of occasions during the tests and lactate levels assessed. A small puncture will be made in the skin of your thumb using a lancet. The resulting small amount of blood on the skin surface will be collected in a capillary tube for analysis of blood lactate concentration using an Analox analyser. The sampling technique may cause minor discomfort.

Oxygen Consumption:

Oxygen Consumption will be monitored using a K4 portable analyser. This apparatus is like a gas mask which is attached to a small rucksack via small tubes. Instruments in the rucksack measure the amount of oxygen consumed.

It is stressed that participation in the tests is completely voluntary. It is our intention to publish results of this study, but not in a way that individuals and their performances can be identified outwith the group. All information obtained both from the preliminary

medical questionnaire and from the study itself will be treated confidentially. You will be given your own test results. If you so wish, you will be informed of the study findings.

You will be free to leave the study at any time. The outcome of the study may not benefit you directly. You may feel uncomfortable during certain stages of the tests.

Individuals who do not have an exercise science background may find some of the above terminology difficult to understand. Please ask one of the experimenters to explain any aspect which is unclear.

Contact with Experimenters

If you are concerned about any of the procedures or any possible adverse side effects, please contact:

Dr Stan Grant
Institute of Biomedical and Life Sciences
West Medical Building
University of Glasgow
Glasgow G12 8QQ
Phone: 0141 330 6490
FAX: 0141 330 2923
e-mail: S.Grant@bio.gla.ac.uk

Consent Form

I .....

give my consent to the research procedures which are outlined above, the aim, procedures and possible consequences of which have been outlined to me

Signature----------Date----------

APPENDIX 2 –

PRE-TESTING MEDICAL QUESTIONAIRRE

UNIVERSITY OF GLASGOW
INSTITUTE OF BIOMEDICAL AND LIFE SCIENCES
SUBJECT QUESTIONNAIRE AND ASSENT FORM FOR HIGH INTENSITY EXERCISE TESTING

If you feel unwell on the day of a proposed test, or have been feeling poorly within the last two weeks, you are excluded from taking part in an exercise test. The considerations that follow apply to people who have been feeling well for the preceding two weeks.

NAME .....

SEX: M/F AGE: ..... (yr) HEIGHT: ..... (m) WEIGHT: ..... (kg)

Details of last medical examination (where appropriate):

Date: ..... Location:

.....

(*day/mo/yr*)

Exercise lifestyle:

What kind(s) of exercise do you regularly do (20 min or more per session), and how often?
(*Please circle the number of times per average week*):

Walking	1	2	3	4	5	
Running	1	2	3	4	5	
Cycling	1	2	3	4	5	
Swimming		1	2	3	4	5
Skiing		1	2	3	4	5
Rowing	1	2	3	4	5	
Gymnastics		1	2	3	4	5
Martial Arts		1	2	3	4	5
Tune Up	1	2	3	4	5	
Popmobility		1	2	3	4	5
Sweat Session		1	2	3	4	5
Weight Training		1	2	3	4	5

Field Athletics		1	2	3	4	5
Racket Sports		1	2	3	4	5
Rugby/soccer/hockey		1	2	3	4	5
Others*	1	2	3	4	5	

*(*Please specify*)

.....

How long have you been exercising at least twice/week for at least 20 min/session?

..... years

Smoking: (*Please tick one*) Never smoked ..... Not for > 6 months .....

Smoke < 10 per day ..... Smoke > 10 per day .....

Illnesses: **Have you ever had any of the following? (*Please circle NO or YES*)**

Anaemia	NO/YES	Asthma	NO/YES
Diabetes	NO/YES	Epilepsy	NO/YES
Heart Disease	NO/YES	High Blood Pressure	NO/YES
Other*	NO/YES		

*(*Please specify*)

.....

Symptoms:

Have you ever had any of the following symptoms to a significant degree ***at rest or during exercise***? That is, have you had to consult a physician relating to any of the following?

	Rest	*Exercise*
Breathlessness	NO/YES	NO/YES
Chest Pain	NO/YES	NO/YES
Dizzy Fits/Fainting	NO/YES	NO/YES
Heart Murmurs	NO/YES	NO/YES
Palpitations	NO/YES	NO/YES
Tightness in chest/jaw/arm	NO/YES	NO/YES
Other*	NO/YES	

*(*Please specify*)

.....

Muscle or joint injury:

Do you have/or have had any muscle or joint injury which could affect your safety in performing exercise ***(e.g. cycling or running)***, strength testing or strength training?

NO/YES*

*(*Please specify*)

.....

Medication:

Are you currently taking any medication? NO/YES*

*(*Please specify*)

.....

Family History of Sudden Death:

Is there a history of sudden death in people under 40 years in your family? NO/YES*

Can you think of any other reason why you should not take part in our tests?

(*Please specify*) .....

The following exclusion and inclusion criteria will apply to this study:

Exclusion Criteria

If you have any of the following, you will be excluded from the study:

(a) Asthma, diabetes, epilepsy, heart disease, a family history of sudden death at a young age, fainting bouts, high blood pressure, anaemia and muscle or joint injury.

(b) If you are taking any medication that may adversely affect your performance or health in this study, you will not be allowed to take part in the study.

(c) If you take recreational drugs, you will not be allowed to take part in the study.

(d) If you have ingested alcoholic drinks in the previous 48 hours, you will not be allowed to take part in the study.

Inclusion Criteria

(a) Male or female subject aged at least 18 years and ***normally no more than*** 35 years.

(b) In good health at the time of testing.

Signature .....Date .....

Physical Exam:

Body Weight: ..... Height: .....

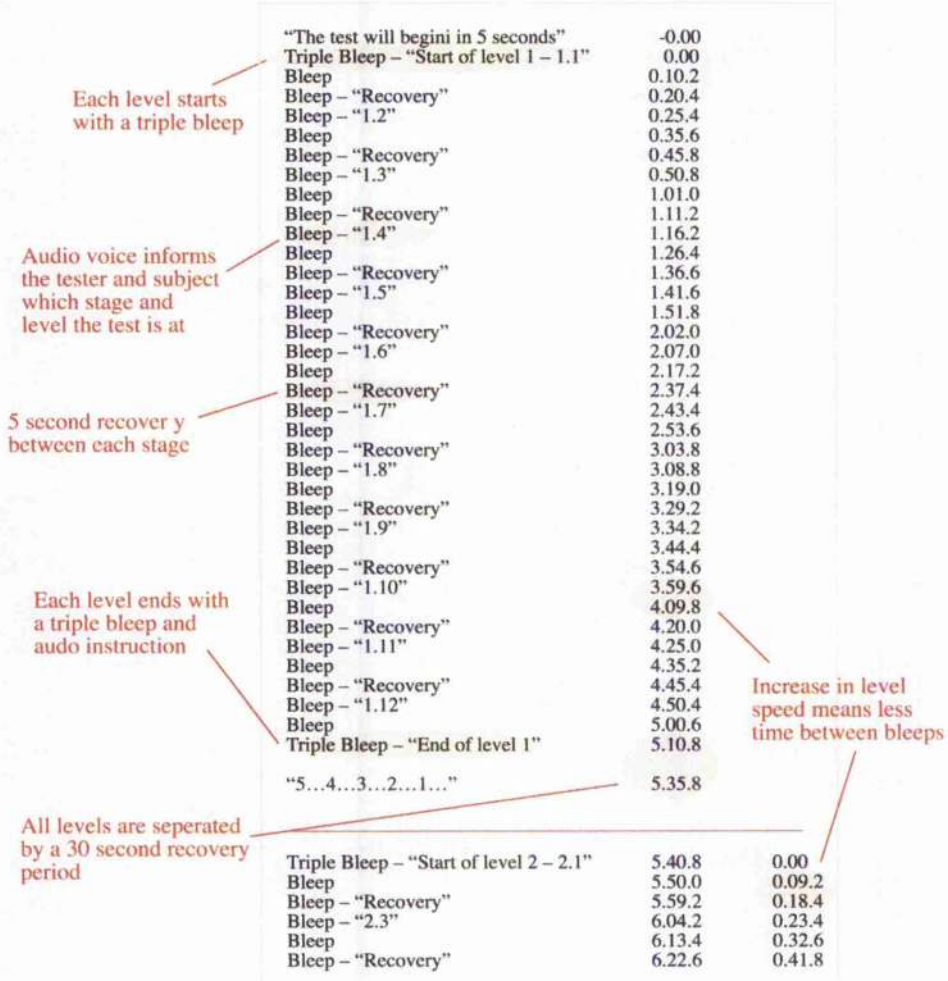
BP (Resting) .....

Screened by: ..... Date: .....

APPENDIX 3 -

EXPLAINATION OF SELT TEST CD

The Soccer-specific Endurance Lactate Test (SELT) is a multi-stage test where speed and timing of running is dictated by an audio CD. The audio CD involves a series of audio cues ('beeps') which dictate to the subject the speed of locomotion necessary, and vocal instructions which inform the subject when to stop/ start ad rest (and how long for). An example of a portion of the original script used when creating the CD is shown below. This shows level 1 in its entirety and a small portion of level 2 along with explanation of key points.



"The test will begini in 5 seconds"	-0.00	
Triple Bleep – "Start of level 1 – 1.1"	0.00	
Bleep	0.10.2	
Bleep – "Recovery"	0.20.4	
Bleep – "1.2"	0.25.4	
Bleep	0.35.6	
Bleep – "Recovery"	0.45.8	
Bleep – "1.3"	0.50.8	
Bleep	1.01.0	
Bleep – "Recovery"	1.11.2	
Bleep – "1.4"	1.16.2	
Bleep	1.26.4	
Bleep – "Recovery"	1.36.6	
Bleep – "1.5"	1.41.6	
Bleep	1.51.8	
Bleep – "Recovery"	2.02.0	
Bleep – "1.6"	2.07.0	
Bleep	2.17.2	
Bleep – "Recovery"	2.37.4	
Bleep – "1.7"	2.43.4	
Bleep	2.53.6	
Bleep – "Recovery"	3.03.8	
Bleep – "1.8"	3.08.8	
Bleep	3.19.0	
Bleep – "Recovery"	3.29.2	
Bleep – "1.9"	3.34.2	
Bleep	3.44.4	
Bleep – "Recovery"	3.54.6	
Bleep – "1.10"	3.59.6	
Bleep	4.09.8	
Bleep – "Recovery"	4.20.0	
Bleep – "1.11"	4.25.0	
Bleep	4.35.2	
Bleep – "Recovery"	4.45.4	
Bleep – "1.12"	4.50.4	
Bleep	5.00.6	
Triple Bleep – "End of level 1"	5.10.8	
"5…4…3…2…1…"	5.35.8	
Triple Bleep – "Start of level 2 – 2.1"	5.40.8	0.00
Bleep	5.50.0	0.09.2
Bleep – "Recovery"	5.59.2	0.18.4
Bleep – "2.3"	6.04.2	0.23.4
Bleep	6.13.4	0.32.6
Bleep – "Recovery"	6.22.6	0.41.8

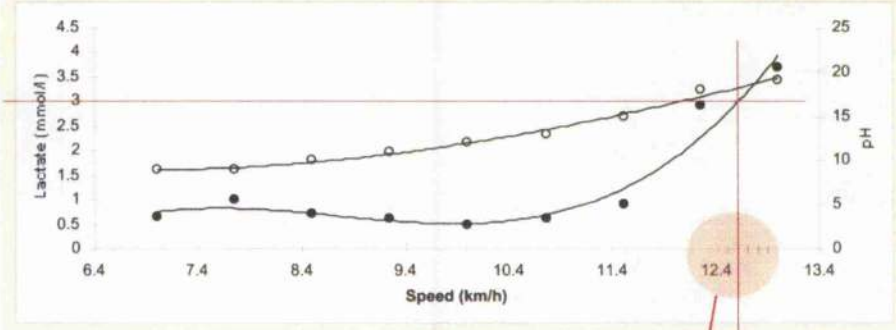
APPENDIX 4 –

MANUAL CALCULATION OF RUNNING VELOCITY AT 3 mM

In the study 2 (comparison of the SELT to a traditional treadmill test) not all subjects reached a blood lactate concentration of 4mmol. For this reason the 3mmol marker was also analysed. The ADAPT programme does not calculate this automatically therefore running velocity at 3 mM was calculated manually by the experimenter (see below).

subject2-selt(1) **Mass (kg): 83**

Max Values	[Lactate] (mmol/l)	Speed (km/h)	Speed/kg (km/h/kg)	VO2 (l/min)	VO2 (ml/kg/min)	HR (b/min)	R	RPE	SELT LEVEL
Lactate Threshold Results									
TEM method	1.24	11.5	0.14	3.18	38.3	160	0.941	15.240	7.0
Log-log	0.76	10.9	0.13	3.02	36.4	153	0.924	13.788	6.2
Berg Method	0.57	9.3	0.11	2.61	31.4	135	0.908	10.757	4.0
2 mM	2.00	12.1	0.15	3.33	40.1	166	0.967	16.754	7.8
4 mM	2.00	12.1	0.15	3.33	40.1	166	0.967	16.754	7.8
IAT									
SASI TEM	2.30	12.3	0.15	3.38	40.7	168	0.977	17.229	8.0
SASI log-log	1.93	12.0	0.15	3.32	40.0	166	0.965	16.634	7.7
Dmax	0.76	10.9	0.13	3.02	36.4	153	0.924	13.775	6.2
Dmax TEM	2.32	12.3	0.15	3.38	40.7	168	0.978	17.270	8.0
	1.86	12.0	0.14	3.31	39.9	165	0.963	16.522	7.7



Speed at 3mM was calculated by interpolating 2 lines for each axis, one horizontal at 3mM and one vertically where the horizontal meets the line of best fit. In this case the spees at 3mM as 12.6 kmh^{-1}.

APPENDIX 5 –

EXAMPLE OF $\dot{V}O_2$ RESPONSE TO THE SELT FOR ONE SUBJECT

Below is an example of the $\dot{V}O_2$ graphs which result from the breath by breath analysis of subjects performing the SELT.