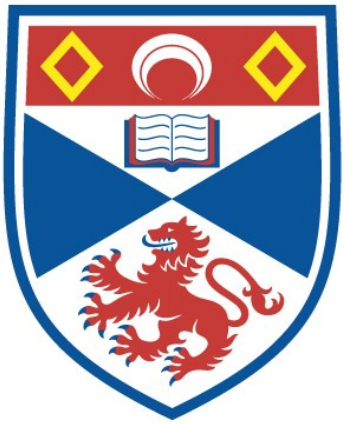
DEVELOPMENT OF PROCEDURES FOR ASSESSING THE EFFECT OF STROKE RATE ON PHYSIOLOGICAL VARIABLES DURING ERGOMETER ROWING

J.J. Forsyth

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews



1995

Development of Procedures for Assessing the Effect of Stroke Rate on Physiological Variables during Ergometer Rowing

Name: J. J. Forsyth
Degree: M.Phil.
Date: 31st March 1995

Abstract

To determine the effect of stroke rate on lactate concentration, oxygen consumption and heart rate during ergometer rowing, pilot investigations were necessary to clarify methodological procedures.

To examine the validity of using blood taken from the toe for the assessment of plasma lactate concentration, values were compared with those taken from the fingertip and earlobe. Subjects (n=9) exercised at work intensities corresponding to 76.4±6.1% and 91.4±4.7% of estimated heart rate maximum for 4 minutes. No significant differences (p>0.05) were found between any of the sites at either work intensity. The toe has the advantage that repeated blood samples may be removed without interrupting the rowing action.

A test to establish maximum oxygen consumption ($\dot{V}O_2max$) was developed for the Concept II rowing ergometer and examined for validity and reliability in 31 rowers. Re-test data for $\dot{V}O_2max$ proved reliable (r=0.86), although not all of the criteria for ascertaining whether a $\dot{V}O_2max$ value had been achieved, were satisfied. This was due to differences in response to maximal exercise among individuals. A final respiratory exchange ratio (RER) of 1.10 rather than 1.15 was recommended as a criterion for establishing $\dot{V}O_2max$ for club level rowers.

To determine the highest level of work that can be sustained during rowing exercise without an increase in plasma lactate concentration, 30 subjects exercised for 10 minutes at work intensities corresponding to 75%, 85% and 95% $\dot{V}O_2max$. From the results, it was hypothesised that subjects could work for 7 minutes at 80% $\dot{V}O_2max$ without significant differences occurring in plasma lactate concentration taken in the last minute of exercise of successive tests. These values were confirmed with a further study on 11 subjects.

A method of directly measuring mechanical variables from the ergometer was initiated. It was hypothesised that the data collected from this and preceding studies could be used for further investigation into the effect of stroke rate on both physiological and mechanical variables.

Declarations

(i) I, Jacky J Forsyth, hereby certify that this thesis, which is approximately 38, 000 words in length, has been written by me, that is the record of work carried out by me and that is has not been submitted in any previous application for a higher degree.

date 30.3.95 signature of candidate .....

(ii) I was admitted as a research student in September, 1992 and as a candidate for the degree of M.Phil. in September, 1992; the higher study for which this is a record was carried out in the University of St. Andrews between September 1992 and March 1995.

date 30.3.95 signature of candidate .....

(iii) I hereby certify that the candidate has fulfilled the conditions of the Resolution and Regulations appropriate for the degree of M.Phil. in the University of St. Andrews and that the candidate is qualified to submit this thesis in application for that degree.

date 30th March 1995 signature of supervisor .....

A Unrestricted

In submitting this thesis to the University of St. Andrews I understand that I am giving permission for it to be made available for use in accordance with the regulations of the University Library for the time being in force, subject to any copyright vested in the work not being affected thereby. I also understand that the title and abstract will be published, and that a copy of the work may be made and supplied to any bona fide library or research worker.

date 30.3.95 signature of candidate .....

Acknowledgements

I would like to thank all the rowers who participated as subjects both in the informal pilot investigations and in main studies. I am extremely grateful to them for the time they gave up for me, for their energy, and for the enthusiasm they showed towards my work.

I would also like to thank Ellis Jaffray, Murray Coutts and Dr Peter Jupp, who helped me gain knowledge in areas in which I was initially lacking, and to John Pearson (Architect and Design Consultant) for the last minute preparation of drawings.

I would like to thank the Department of Physical Education, since the opportunity to do this research was only possible by being employed on a part-time basis in the department.

Finally, I extend my utmost thanks to friends, family and colleagues (especially to Karen), who as well as giving me helpful comments on this thesis, have put up with me for the past two and a half years.

CONTENTS

CHAPTER 1

Introduction 1

1.1 Overview 2

1.2 Problem Statements and Hypotheses 4

CHAPTER 2

Review of literature 5

2.1 Introduction 6

2.2 The Physiology of Rowing 6

2.3 Blood Lactate Concentration 8

2.3.1 Background 8

2.3.2 "AT" definitions and methodology 8

2.3.3 Blood lactate concentration and endurance performance 10

2.4 Blood Lactate Concentration and Rowing 11

2.5 Laboratory Measurement of Physiological Variables in Rowing 14

2.5.1 Lactate 14

2.5.2 $\dot{V}O_2max$ 16

2.5.3 The rowing ergometer 18

2.6 Biomechanical Aspects of Rowing 19

2.6.1 The rowing technique 19

2.6.2 Components of velocity 21

a) Force 21

b) Stroke length 22

i) Rigging 22

ii) Oarsperson 22

c) Stroke rate 23

d) Drag 24

2.7 Laboratory Measurement of Mechanical Variables in Rowing 25

2.7.1 Ergometer measurements 25

2.8 The Effect of Mechanical Changes on Physiological Variables 26

2.9 The Effect of Stroke Rate on Oxygen Consumption and Lactate 26

2.10 Summary and Research Implications 28

CHAPTER 3

A comparison of plasma lactate concentration collected from the toe, ear and fingertip following simulated rowing exercise 29

3.1 Introduction 30

3.2 Methodology 30

3.2.1 Subjects 30
3.2.2 Equipment 31
3.2.3 Procedures 31
3.2.4 Blood sampling 32
3.2.5 Statistical Analysis 33
3.3 Results 33
3.4 Discussion 35

CHAPTER 4

Development of a $\dot{V}O_2$max test using the Concept II rowing ergometer 37
4.1 Introduction 38
4.2 Methodology 39
4.2.1 Subjects 39
4.2.2 Protocol - rationale and justification of design 39
4.2.3 Procedures 40
4.2.4 Reliability test 42
4.2.5 Statistical procedures 43
4.4 Results 43
4.4.1 $\dot{V}O_2$max data 43
4.4.2 Re-test data 45
4.5 Discussion 46
4.5.1 Verification of $\dot{V}O_2$max 46
4.5.2 Reliability data 47
4.5.3 Additional findings 48
4.5.5 Summary and recommendations 50

CHAPTER 5

Determination of the highest level of work that can be sustained during prolonged rowing exercise, without an increase in plasma lactate concentration 52
5.1 Introduction 53
5.2 Methodology 54
5.2.1 Subjects 54
5.2.2 Procedures 55
5.2.3 Statistical analysis 56
5.3 Results 56
5.4 Discussion 60
5.4.1 Ten minute tests 60

5.4.2 Seven minute 80% $\dot{V}O_2$max tests 62
5.4.3 Seven minute 80% $\dot{V}O_2$max tests: results and discussion 63

CHAPTER 6

Direct measurements of force, stroke rate and stroke length from the Concept II rowing ergometer using computerised instrumentation 68

6.1 Introduction 69
6.2 Instrumentation 70
6.2.1 Force 70
6.2.2 Stroke length 70
6.3 Discussion and Research Implications 72

CHAPTER 7

Summary and concluding remarks 74

REFERENCES 78

APPENDICES 96

Appendix 1 Four minute test 97
Appendix 2 Test protocols from BOMC and National Sports Medicine Institute 99
Appendix 3 Pilot work on $\dot{V}O_2$max 102
Appendix 4 Design of computerised instrumentation and software 109
A4.1 Software programme 110
Appendix 5 ANOVA tables 116
A5.1 ANOVA Tables for Chapter 3 117
A5.2 Chapter 5 Tables for Resting values 119
A5.3 Chapter 5 ANOVA Tables: 2-way Analysis on $\dot{V}O_2$ 121
A5.4 Chapter 5 ANOVA Tables: 1-way Analysis on $\dot{V}O_2$ 123
A5.5 ANOVA Tables for 7 Minute Tests at 80% $\dot{V}O_2$max 126
Appendix 6 Additional materials 131
A6.1 Information for Subjects 132
A6.2 Pre-test Questionnaires and Consent Forms 135
A6.3 Sample Data Recording Forms 138
Appendix 7 Correspondence regarding $\dot{V}O_2$max test 143
Appendix 8 Method of lactate estimation in blood 148

LIST OF TABLES

Table 2.1 Adaptation of FISA guidelines for the prescription of training intensities 13
3.1 Physical characteristics of subjects 31
3.2 Summary of performance data at the two estimated work intensities 33
3.3 Mean lactate values ($mmol \cdot l^{-1}$) found in plasma 34
4.1 Mean, standard deviation and range of maximum values 44
4.2 Reliability results for 11 subjects (10 males, 1 female). 45
5.1 Resting plasma lactate concentration and heart rate values for all subjects (n=30). 57
5.2 ANOVA 2-way analysis of variance for plasma lactate concentration at 75% $\dot{V}O_2max$ 57
5.3 ANOVA 2-way analysis of variance for plasma lactate concentration at 85% $\dot{V}O_2max$ 58
5.4 Mean values for plasma lactate concentration, oxygen consumption, heart rate and cumulative distance rowed taken during the last minute of successive 7 minute tests at 80% $\dot{V}O_2max$. 63
A1.1 Example of intensity prediction table 98
A5.1.1 to A5.5.9 ANOVA tables 117-130

LIST OF FIGURES

Figure 2.1 Method of detecting the IAT 10
2.2 Hypothetical graph showing boat velocity and position of rower 20
2.3 Effect of adjusting span or outboard on rowing arc 23
4.1 Criteria taken from the BASS Position Statement on the Physiological Assessment of the Elite Competitor 38
4.2 Continuous incremental test for establishing $\dot{V}O_2max$ 41
4.3 Revised protocol 50
5.1 Mean values of oxygen consumption at the 3 work intensities 59
5.1.1 At 75% $\dot{V}O_2max$ 61
5.1.2 At 85% $\dot{V}O_2max$ 61
5.1.3 At 95% $\dot{V}O_2max$ 62
6.1 Force strain gauge 71
6.2 Rotary position sensor attached via sprocket to ergometer 71

6.3 Lay-out of all instrumentation 71
A3.1 Protocol A 103
A3.2 Protocol D 104
A3.3 Heart rate response of female subject to protocol A 105
A3.4 Heart rate response of female subject to protocol B 105
A3.5 Heart rate response of male subject to protocol C 106
A3.6 Heart rate response of female subject to protocol D 107
A3.7 Heart rate response of female subject to protocol E 107
A3.8 Heart rate response of male subject to protocol E 108
A4.1 Interface block system diagram. 113
A4.2 Strain gauge amplifier. 114
A4.3 Stroke movement detector. 115
A5.1.1 Normal probability plot 118
A6.1 Blood sampling from the toe whilst rowing 142

Abbreviations

AT	Anaerobic threshold
BASES	British Association of Sports and Exercise Sciences
BASS	British Association of Sports Sciences
BOMC	British Olympic Medical Centre
EDTA	ethylenediaminetetra-acetic acid
GPT	Glutamate-pyruvate transaminase
IAT	Individual anaerobic threshold
LDH	L-Lactate dehydrogenase
LT	Lactate threshold
NAD	Nicotinamide-adenine dinucleotide
OBLA	Onset of blood lactate accumulation
OPLA	Onset of plasma lactate accumulation
RER	Respiratory exchange ratio
VT	Ventilatory threshold
$\dot{V}O_2max$	Maximum oxygen consumption

CHAPTER 1

Introduction

1.1 Overview

In rowing, successful performance is determined by several factors that concern both the rower and the equipment. The rower can enhance performance by optimising levels of anxiety and motivation (Raglin et al., 1990), working on technique (Schwanitz, 1991), and by improving his or her endurance capacity, strength and power (Bloomfield and Roberts, 1972; Hagerman et al., 1972; Larsson and Forsberg, 1980). Performance is also influenced by the type of boat and the blades used, both of which can be adjusted (referred to as rigging) to cater for anthropometrical and physiological variances of the rower (Herberger et al., 1990). An understanding of boat mechanics and rigging is important for examining, for instance, how power is applied to the water by the blade, and for determining the optimum stroke rate and stroke length to suit the individual (Hollmann, 1988; Millward, 1987; Roth, 1991; Sanderson and Martindale, 1986). It is not known which of these many factors has the biggest influence on performance nor how they are interrelated, but in terms of physiology, it seems that aerobic or endurance capacity of the rower is of paramount importance judging on the amount of research that has been conducted within this area. A 2000 m competitive rowing race, which can last between 5.5 to 8 minutes depending on the boat type, has been found to be fuelled largely by aerobic processes (Droghetti et al., 1991). Rowing has therefore been described as one of the most physiologically demanding endurance sports there is (Spinks, 1986).

Maximal oxygen uptake ($\dot{V}O_2max$) has long been considered as the best single criterion measurement of endurance capacity (Robinson et al., 1937; Sutton, 1992). In rowing, $\dot{V}O_2max$ has consequently been used as a means of assessing performance and even as a tool for selection (Hagerman and Howie, 1971). Several studies have suggested that measuring blood lactate concentration during constant exercise, in particular the highest work intensity at which lactate does not increase beyond the initial transient, may be a more valid indicator of an individual's endurance capacity (Davis, 1985; Farrell et al., 1979). The occurrence of this marked increase in lactate during prolonged exercise has been given several names and definitions, including the anaerobic threshold, onset of blood lactate accumulation and the lactate threshold. Whichever term or method is used to describe the phenomenon, the belief is that exercising above this work intensity will result in a deterioration of performance due to fatigue (Stegmann et al., 1981). For this reason, blood lactate concentration values have been used to establish training and competition exercise intensities. An additional advantage of measuring lactate concentration over $\dot{V}O_2max$, is that changes in blood lactate continue to occur as a result of training even when $\dot{V}O_2max$ has reached a plateau (Jacobs, 1986).

In the rowing race, it is important for the performer to sustain a high intensity of exercise without an excessive amount of lactate accumulating in the blood. Consequently, information concerning blood lactate concentration is considered to be beneficial to the rower. However, there has been far less research on lactate measurements carried out in rowing than there has been in other more popular sports such as running and cycling. Hence, certain methodological and logistical considerations remain unresolved, such as how blood lactate can be sampled in a continuous rowing test without disruption to the rowing stroke. It is also not known how variables such as stroke rate affect the behaviour of lactate. In cycling, for instance, researchers have found that there are pedal frequencies for certain workloads that are more efficient in terms of oxygen cost and the amount of lactate accumulating in the blood (Buchanan and Weltman, 1985; Hagberg et al., 1981, Hughes et al., 1982; Löllgen et al., 1980). Likewise in swimming, Wakayoshi et al., (1995) have related stroke rate with oxygen consumption to establish a rate that effectively could be used to improve performance. If there are optimal pedal rates in cycling and there is an optimum stroke rate in swimming, the same might be true for rowing. Stroke rate, as well as force, power and stroke length, is one of the mechanical components essential for boat progression, since increasing stroke rate will increase boat speed (di Prampero, 1986; Fukunaga et al., 1986). However, if an increase in stroke rate is found to be related to an exponential increase in lactate concentration or to an increase in oxygen consumption, there might be an upper limit or optimal stroke rate in terms of physiological performance.

To improve performance, therefore, rowers need to increase their endurance capacity, which will allow them to row at the highest possible work intensity without an excessive amount of lactate accumulating in the blood. To do this the rower may need to select a certain stroke rate so that undue increases in lactate are avoided. Measurements of blood lactate concentration are therefore essential for assessing performance and for examining the effect of stroke rate variation.

1.2 Problem Statements and Hypotheses

The main purpose of this study is to develop procedures to examine the effect of stroke rate on the physiological variables of blood lactate concentration, oxygen consumption and heart rate, as well as on the mechanical variables of stroke length, force and power.

It is hypothesised that changes in stroke rate will influence how and when force is applied during the stroke, the length of stroke, and will also affect physiological responses. Before this hypothesis can be tested, a series of investigations need to be carried out, the objectives of which are:

i) to compare plasma lactate concentration taken from the toe with that from the earlobe and fingertip. The objective of this is to enable the toe to be used as a sampling site during a continuous test protocol, since taking blood from the toe will not interfere with the rowing action. It is hypothesised that plasma lactate concentration taken from the toe will not differ significantly with that from the earlobe or fingertip;

ii) to develop a $\dot{V}O_2max$ test suitable for the Concept II rowing ergometer that is valid and reliable according to the guidelines set by the British Association of Sports Sciences (Hale et al., 1988). This will allow a relative percentage of $\dot{V}O_2max$ to be ascertained;

iii) to determine the minimum amount of time required for lactate to reach a steady state concentration when subjects are exercising at the highest work intensity that can be sustained without excessive increases in lactate. It is hypothesised that if subjects exercise at this intensity for this amount of time, values for plasma lactate concentration, oxygen consumption and heart rate taken during the last minute of exercise will not differ significantly on repeat tests;

iv) to develop instrumentation for accurate measurement of mechanical variables from the Concept II rowing ergometer. It is hypothesised that this instrumentation will be able to detect changes in force, stroke length and power with changes in stroke rate.

CHAPTER 2

Review of literature

2.1 Introduction

This chapter will provide a general review of the rowing research that has taken place to date. The relative merits of using $\dot{V}O_2max$ and blood lactate concentration to assess endurance capacity will be discussed and rowing studies using these measurements will be reviewed. Areas of weakness in the methodological assessment of $\dot{V}O_2max$ and blood lactate concentration during rowing ergometry will be highlighted. The importance of stroke rate and how it could affect performance as well as consideration of other mechanical variables such as force and stroke length will be examined. The areas thought to require further investigation will then be addressed.

2.2 The Physiology of Rowing

The first attempt to describe the physiology of rowing was by Liljestrand and Lindhard in 1920 involving an ordinary rowing boat. This was followed with work by Henderson and Haggard (1925) who examined energy expenditure when rowing in a crew racing boat. Later in 1968 various physiological tests were carried out on two rowers who had won gold medals at the Olympic Games that year (Nowacki et al., 1969). From the results of these studies and others that followed (Hagerman and Howie, 1971; Hagerman et al., 1972; Jackson and Secher, 1976), it became clear that rowing required an extremely high aerobic capacity of the oarsperson. A measurement of maximum oxygen consumption was, at the time, considered to be a valid indicator of aerobic capacity. Most of the research in rowing during this time, therefore attempted to ascertain a value for $\dot{V}O_2max$ among elite rowers, and to use this as a prerequisite of successful performance. From reviews of the research by Secher (1983 and 1993), and by Spinks (1986) the $\dot{V}O_2max$ of a heavyweight oarsman competing at national and international level, was regularly found to be above 6.0 $l \cdot min^{-1}$ with an average of 6.4 to 6.6 $l \cdot min^{-1}$. For lightweight men (under a weight of 72 kg) a $\dot{V}O_2max$ of 5.1±0.7 $l \cdot min^{-1}$ has been reported, and for women of all weight categories a value of 4.1±0.4 $l \cdot min^{-1}$ (Hagerman et al., 1979).

These high absolute values found among elite rowers have been correlated with performance. Hagerman et al. (1972) found significantly higher values of $\dot{V}O_2max$ in Olympic as opposed to non-Olympic team members. Secher et al. (1982) reported that $\dot{V}O_2max$ related to 2000 m performance and placing in the European Championships (r=0.87) and that a time difference of 6 seconds at the finishing line was equivalent to a 0.54 $l \cdot min^{-1}$ difference in $\dot{V}O_2max$. These conclusions however were reached with only 10 crews being involved. Furthermore, the results may have been influenced by body weight, since the

winning crews also contained the heavier individuals, with body weight correlating significantly with final placing (r=0.74). When $\dot{V}O_2max$ was expressed per kilogram of body weight, the relationship to final placing was weak (r=0.38). The idea behind this information, however, was given great value by the coach, and became the basis of selection processes world-wide (Hagerman, 1984; Hagerman and Howie, 1971; Wright et al., 1976).

Before discussing the merits and drawbacks of using $\dot{V}O_2max$ to assess and delimit performance, a more detailed examination will be given as to why aerobic capacity is so important in rowing. Internationally rowers compete over a distance of 2000 m. For heavyweight males racing in a single scull, this takes on average 7.5 minutes (Osbourne, 1995). For the same category of men, but in a crew boat with 8 members plus cox, the race lasts approximately 5.5 minutes, and for lightweight women (less than 59 kg) competing in single sculls, the same distance can take 8.5 minutes (Osbourne, 1995). It is therefore to be expected that energy contributions in a 2000 m race will vary according to the type of boat and to the category of the performer. Attempts made to measure energy contribution will only give an estimate of an average race performance. With this in mind, 70% to 85% of energy sources have been found to derive from aerobic glycolysis (Droghetti et al., 1991; Hagerman, et al., 1978; Peltonen and Rusko, 1993; Secher, 1993), 14% from the lactic acid system and 8% from the phosphagen system (Hagerman, 1984, Spinks, 1986). The contribution of aerobic metabolism is therefore considerable and might even be greater with different race conditions. The first 30 to 40 seconds of a typical race for a crew boat usually involves a sprint with stroke rate between 40 and 44 strokes per minute. This is followed by a high intensity steady state type of exercise with a stroke rate of around 36 to 42 strokes per minute, which continues until the final sprint for the finish when the intensity is again increased (Steinacker, 1993). The middle steady state section of the race accounts for this relatively high aerobic contribution, and explains the importance of having a high endurance capacity.

$\dot{V}O_2max$ has long been considered an objective measure of endurance capacity, since the maximum amount of oxygen a person can consume depends on the ability of the heart and lungs to distribute and deliver oxygenated blood around the body and on the ability of the muscle to extract and utilise oxygen (Robinson et al., 1937; Sutton, 1992). However, measuring blood lactate concentration or the point or threshold where an abrupt increase in lactate occurs, has been found to give a better indication of an individual's endurance capacity. In terms of rowing, blood lactate concentration measurements have also become popular (Doherty, 1992; Hagerman and Hagerman, 1990; Hartmann et al., 1990; Womack et al., 1989), since

the rower has to be able to sustain the majority of the race at the highest possible work intensity without an excessive amount of lactate accumulating in the blood, which could lead to fatigue. Since there is a relatively small amount of research in rowing concerning measurements of blood lactate concentration, the general literature on lactate in other sports will be consulted first.

2.3 Blood Lactate Concentration

2.3.1 Background

Changes in blood lactate concentration with exercise were observed as early as 1905 by Douglas and Haldane. Later in 1930 Owles expanded on earlier research, stating that exercise was able to continue for long periods of time without undue fatigue, but only up to a 'critical level' of intensity, beyond which blood lactate increased significantly and performance deteriorated. This critical level was found to vary according to the exercise mode, the individual and with changes in training, but was not found to be directly related to an oxygen debt. It was not until the 1960s that this critical level became associated with and labelled the "anaerobic threshold" (Wasserman and McIlroy, 1964), and defined as

> "The level of work or oxygen consumption just below that at which metabolic acidosis and the associated changes in gaseous exchange occur."
>
> Wasserman et al. 1973.

The anaerobic threshold (AT) was found to coincide with changes in blood lactate concentration and could be used to estimate the onset of anaerobic metabolism, which was related to a deterioration in endurance performance. This concept has since been the target of much controversy and debate. The main concerns have been over the methods of interpretation and detection (Brooks, 1985), mechanisms of its occurrence (Walsh and Banister, 1988) and acceptable nomenclature (Davis, 1985).

2.3.2 "AT" definitions and methodology

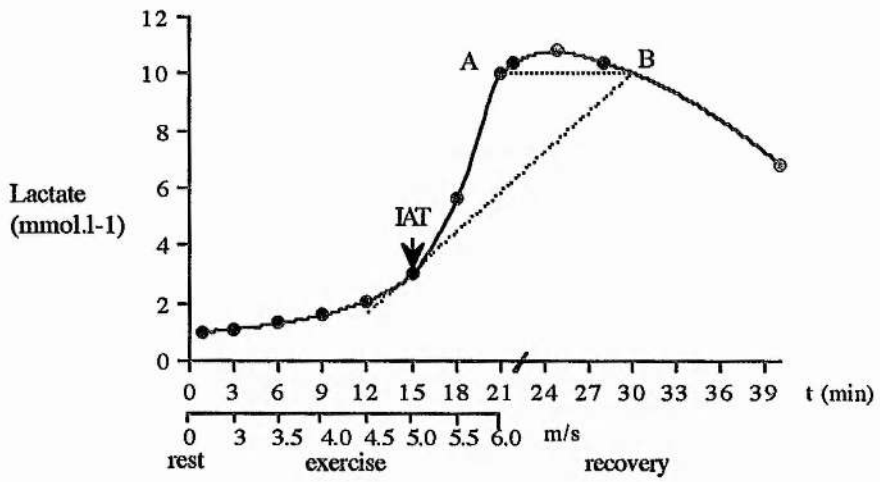
The change in blood lactate concentration was initially determined by examining changes in gaseous exchange variables, since these were thought to occur at approximately the same time. An increase in ventilatory equivalent ($\dot{V}E/\dot{V}O_2$) for oxygen without a corresponding increase in ventilatory equivalent for carbon dioxide ($\dot{V}E/\dot{V}CO_2$) came to be used as a practical, acceptable and non invasive

method of determining the observed increase in blood lactate concentration (Caiozzo et al., 1982; Davis et al., 1976; Powers et al., 1983; Wasserman et al., 1973). Other ventilatory parameters have similarly been used, including non-linear increases in minute ventilation (Davis et al., 1976), respiratory exchange ratio (Wasserman et al., 1973), and excretion of carbon dioxide (Beaver et al., 1986; Langill and Rhodes, 1992). The term "ventilatory threshold" (VT) has been used to describe these methods. However, the ventilatory threshold often occurs before the point associated with an increase in lactate concentration (Neary et al., 1985; Yeh et al., 1983), with differences also resulting from training (Gaesser and Poole, 1986). It has therefore been suggested that changes in ventilatory variables and blood lactate concentration are due to different underlying mechanisms and are indicative of different phenomena (Farrell and Ivy, 1987; Lout and Rhodes, 1993; Walsh and Banister, 1988; Weltman, 1989). They are now usually viewed separately when determining exercise intensities or endurance capacity. The term anaerobic threshold should, therefore, no longer be used to refer to both changes in blood lactate concentration and ventilatory variables, since these do not occur simultaneously.

Mainly for ease of identification, the work intensity at a fixed lactate concentration of 4 $mmol \cdot l^{-1}$ is taken as the upper limit beyond which an abrupt increase in lactate occurs (Heck et al., 1985; Kindermann et al., 1979; Mader et al., 1976). The onset of blood lactate accumulation or OBLA (Sjödin and Jacobs, 1981) is also determined by a fixed blood lactate concentration of 4 $mmol \cdot l^{-1}$. However, not all subjects reach a lactate concentration steady state at 4 $mmol \cdot l^{-1}$. Stegmann et al. (1981) introduced the term the individual anaerobic threshold (IAT), since they found that individuals differed in their lactate response to exercise. The IAT is determined from changes in blood lactate both during and after an incremental exercise test (Figure 2.1), and represents the maximal workload where production and elimination of lactate are in equilibrium. Work intensities above the IAT would therefore lead to progressively increasing lactate values.

Other names used to refer to the AT include onset of plasma lactate accumulation (OPLA) used by Farrell et al. (1979), maximal steady state (LaFontaine et al., 1981), the lactate threshold (Hagberg, 1984), and lactate turnpoint (Davis et al., 1983). The names usually imply that different protocols and methods for detecting the threshold have been employed.

Figure 2.1 Method of detecting the IAT from lactate kinetics during and after incremental graded exercise on a treadmill, adapted from Coen et al. (1991).



The letter 'A' denotes discontinuation of exercise, and 'B' the time when lactate concentration in post-exercise is the same as the value at 'A'. The arrow points to the exercise intensity equivalent to the IAT.

2.3.3 Blood lactate concentration and endurance performance

Whichever method used and whatever the cause of the increase in lactate and the fatigue with which it is associated, the measurement of blood lactate concentration has been found to give a more valid assessment of endurance performance than $\dot{V}O_2max$. Farrell et al. (1979), for instance, found that a running velocity corresponding to OPLA correlated more highly ($r \geq 0.91$) with running performance than did $\dot{V}O_2max$ ($r \geq 0.83$). Running performance was determined from times achieved in road races at distances between 3.2 km and 42.2 km. Sjödin and Jacobs (1981) reported that OBLA correlated to the performance of 18 male runners competing in the Stockholm Marathon. The velocity associated with marathon performance was found to be equivalent to 87.2% of the velocity associated with OBLA.

Blood lactate concentration values have also been useful for establishing training intensities and measuring adaptations to training. Sjödin et al. (1982) found that middle and long-distance runners who were able to train closest to the running speed which elicited a lactate concentration of 4 $mmol \cdot l^{-1}$, demonstrated a greater

"training response" after 14 weeks of endurance training than those who had higher or lower lactate concentrations during training. Keith et al. (1992) measured adaptations of 2 different types of training using the IAT. One group worked at a steady state exercise intensity that was equivalent to the IAT, for a period of 30 minutes up to 4 times per week. The other group exercised for the same amount of time, but did interval work at 30% above and 30% below the IAT. The work intensity and oxygen consumption at the IAT increased significantly and progressively during the 8 weeks of training for both groups. Intermittent and continuous work associated with the IAT were considered equally as beneficial for inducing an aerobic training effect.

Lactate measurements have been reported to be more sensitive to changes in fitness than $\dot{V}O_2max$ especially among very fit athletes when $\dot{V}O_2max$ has reached its limit. Biathletes and Nordic skiers were tested on a treadmill before and after 5 weeks of endurance training (Dunbar, 1991). It was found that $\dot{V}O_2max$ stayed the same, in spite of the running speed at a fixed blood lactate concentration of 2.5 $mmol \cdot l^{-1}$ increasing significantly from 4.66 $m \cdot s^{-1}$ to 5.09 $m \cdot s^{-1}$. Poor correlations have also been observed between $\dot{V}O_2max$ and endurance performance when individuals with similar $\dot{V}O_2max$ values were compared (McLellan and Cheung, 1992).

$\dot{V}O_2max$ is reported to be more closely related to central factors such as stroke volume, while skeletal muscle metabolic factors such as respiratory enzyme activity relate more to submaximum exercise capacity (Weltman, 1989). This may explain why blood lactate measurements give a better indication of endurance performance and adaptation to training, than $\dot{V}O_2max$. Training at the intensity equivalent to an increase in blood lactate concentration induces peripheral changes such as increases in capillary density and in the amount of slow twitch muscle fibre (Tesch et al., 1981). These changes result in the athlete being able to work at a higher intensity of exercise without excessive amounts of lactate accumulating in the blood.

2.4 Blood Lactate Concentration and Rowing

The Fédération Internationale des Sociétés d'Aviron (FISA) initiated an annual training programme for competitive oarsmen and women, which is used by the national squad in this country. The training is divided into two main parts: the preparation period (usually from October to March) and the competitive period (April to September). The levels of intensity and the physiological parameters that are related to them are presented in Table 2.1. Emphasis is on utilisation (levels 4

and 5) aimed at developing aerobic conditioning. In the preparation period 54% of training should therefore be at an intensity corresponding to a lactate concentration of less than 2.0 mmol·l^{-1}. Training at level 3 (anaerobic threshold) equivalent to a lactate concentration of 4 mmol·l^{-1} is given much less emphasis. However, more recent findings suggest that training at this level can improve rowing performance. Warrington et al. (1992), for instance, tested 14 females from the 1992 British Olympic squad using a step incremental test on the rowing ergometer, and found an increase in power output of 4.71 watts at the 4 mmol·l^{-1} fixed threshold level following a season of winter training. Vermulst et al. (1991) found that the power output at the 4 mmol·l^{-1} level was positively correlated to the volume of training (measured in minutes and kilometres rowed) among elite female rowers. However fixing blood lactate concentrations to produce a specific training effect is not recommended for all athletes as previously mentioned (Stegmann et al., 1981). In work by Stegmann and Kindermann (1982), 9 male and 10 female rowers were required to cycle at an intensity equivalent to the fixed 4 mmol·l^{-1} threshold. Five of the rowers were unable to complete the 50 minute continuous test at this work intensity, stopping after only 14 to 16 minutes. End values of lactate for these 5 subjects were found to be high (mean 9.6±1.2 mmol·l^{-1}). This method of obtaining a work intensity corresponding to a fixed lactate concentration of 4 mmol·l^{-1} is therefore not suitable for all subjects due to a non-steady state lactate concentration.

Extensive monitoring of lactate during both ergometer rowing and when rowing on the water has not been carried out, with little evidence produced to support the guidelines set by FISA. In the research, changes in blood lactate concentration are mainly estimated using gaseous exchange variables during incremental exercise on a rowing ergometer (Bunc et al., 1987; Fukunaga et al., 1986; Mickelson and Hagerman, 1982). Other reports examine lactate concentration after maximal exercise (Hollings et al., 1989; Steinacker et al., 1986; Womack et al., 1989). These measurements, although not related to submaximum work, can be useful for assessing performance. Jensen et al. (1991), for instance, found that a high lactate concentration after an "all-out" 6 minute rowing test was related to a drop in power (r=0.71). However, lactate was not analysed at any time during the test. The reason for this, and for the lack of research on lactates might be due to the logistical problems associated with taking blood samples while the rower is in action. Methods used to measure lactate will be discussed in the following section.

Table 2.1 Adapted from FISA guidelines for the prescription of training intensities and from Fritsch, 1985.

Principal Physiological Effects of Training	*Energy Type Used*	*Percentage of Maximal Heart Rate*	*Lactic Acid Produced (mmol·l-1)*	*Example*	*Stroke Rate*	*Distance Covered (km)*	*Preparation Period (% of Total Amount of Work)*	*Competitive Period (% of Total Amount of Work)*
1. Anaerobic	Glycogen	95-100%	Above 6.0	6x500 m 10x30 strokes	34-44	Highly Variable	0%	1%
2. Transportation	Glycogen	90-95%	4.0-6.0	4x3 min	30-40	14-16	11%	12%
3. Anaerobic Threshold	Glycogen	85-90%	4.0	3x12-15 min 2x30 min	26-28	14-16	27%	4%
4. Utilisation 1	Essentially glycogen with fatty acids	75-85%	2.0-4.0	60-90 min continuous paddling	22-24	12-20	8%	50%
5. Utilisation 2	Essentially fatty acids with glycogen	65-75%	0-2.0	60-120 min continuous paddling	18-22	12-25	54%	33%

2.5 Laboratory Measurement of Physiological Variables in Rowing

2.5.1 Lactate

In the physiological testing of athletes it is common practice to use capillary blood for the assessment of lactate, rather than taking blood from the antecubital vein of the forearm or by determining muscle lactate through biopsy. Taking a small amount of capillary blood is less invasive and less time consuming, thus making it practical for experiments in the field (Williams et al., 1992). When taking blood while rowing, the sampling site ought not to interfere with the rowing action nor require a discontinuation of incremental and/or steady state exercise, since as Stegmann et al. (1981) state, interruptions of work may lead to a decrease in the lactate gradient between the blood and muscle, hence distorting the lactate profile. The guidelines presented by the British Association of Sports Sciences (BASS) for testing elite performers (Hale et al., 1988) also recommend a continuous load protocol in the determination of OBLA.

Capillary blood is usually taken from the earlobe (Kinderman et al., 1979; Robergs et al., 1990), or the fingertip (Foxdal et al., 1990; Johnson et al., 1991). Since the upper body is in constant motion whilst rowing, these two sites are inappropriate unless the exercise is stopped. Furthermore, if blood is taken from the fingertip between exercise bouts, the finger may continue to bleed each time the rower exerts pressure on the oar handle. In a racing shell, the rower's feet are attached to the boat by means of fixed training shoes or straps, so that the body can move backwards and forwards along a slide. This means that the feet are rendered relatively immobile. When rowing on an ergometer, the feet are similarly secured, making it possible and practical for the experimenter to remove repeated blood samples from the tip of the toe without obstructing performance.

Several studies on lactate testing have focused on differences between arterial and venous blood (El-Sayed et al., 1993; Johnson et al., 1991; Knowlton et al, 1990; Robergs et al., 1990; Williams, et al. 1992; Yoshida et al., 1982) and between plasma, whole and haemolysed blood (Forrest et al., 1990; Foxdal et al., 1990, 1991), but have not examined whether there are any differences in lactate values when taking capillary blood from different sampling sites. The only study to date is that by Smith and his co-workers (1991). They analysed arterialised capillary blood from the toe, the ear, and the thumb of 8 male subjects prior to and following a 5-stage, incremental, seated arm cranking test. The values of lactate accumulation at the toe compared to the other two sites were found to be significantly lower when exercising at higher work intensities (84 and 102 watts). These results are to be expected, since the legs were inactive and therefore had limited involvement in lactate production and removal. In contrast, rowing is a whole body action

involving the legs, the arms and the back. Smith's results, therefore, may have limited application to rowing.

The British Olympic Medical Centre has observed through standardised testing of national rowers, that blood samples taken from the fingertip reveal 'fractionally' higher values of lactate concentration than those taken from the earlobe (Doherty, 1992). Although this data have not been collected in controlled experimental conditions, it suggests that differences may occur depending on the sampling site. El-Sayed et al. (1993) suggest that such differences may affect the delineation of lactate variables, especially where training and performance prediction are concerned. It is therefore essential to establish whether different sites can be used inter-changeably before comparisons are made. This is why the possibility and validity of taking blood from the toe is included as one of the objectives in this study.

Another component of lactate testing, which may affect the results and which is also applicable to rowing, is the length of time at each work stage within a test to assess blood lactate concentration. A number of protocols of varying duration have been developed. For example Sjödin and Jacobs (1981) used a 4 minute test protocol to obtain OBLA and Coen et al. (1991) 3 minute incremental stages to establish the IAT. A possible reason the time at each work intensity is so short may be that the original protocol for determining the AT described by Wasserman et al. (1973) also used 3 minute incremental loads. However, this protocol was used to detect changes in ventilatory variables rather than in blood lactate concentration. Hagberg (1984) claims that a discontinuous exercise protocol using 10 minute steady state bouts, although time consuming, provides more valid data for measuring endurance performance than a continuous incremental protocol with 3 or 4 minute stages. This is because lactate concentration after only 3 to 4 minutes of exercise is not thought to be representative of the concentration after longer periods of work, since a steady state concentration has not been reached. In a more recent study, Foxdal et al. (1994) reported that the most accurate estimation of maximal endurance running velocity (defined as the highest running velocity that could be achieved without an accumulation of lactate) was found when a continuous test protocol with a running duration of 8 minutes was used. This was independent of training background of the subject. When taking a blood sample at 4 minutes, there was a 5-7% chance of making an over-estimation of endurance running velocity. This again was thought to be due to a non-steady state lactate concentration. Other studies support these findings with a lactate steady state concentration not occurring until after 10 minutes of constant work (Heck et al. 1985; Mader, 1991; Orok et al., 1989; Rieu et al., 1989).

The evidence, however, is not conclusive. For 15 trained runners, Weltman et al. (1990) compared a 3 minute incremental continuous running protocol with the 10 minute discontinuous test proposed by Hagberg. For the continuous protocol the initial velocity of the treadmill was 150 $m \cdot min^{-1}$. Velocity was then increased by 10 $m \cdot min^{-1}$ every 3 minutes. No differences between the 2 protocols were found in the velocity, oxygen consumption and heart rate at the lactate threshold, and at fixed blood lactate concentrations of 2 $mmol \cdot l^{-1}$, 2.5 $mmol \cdot l^{-1}$ and 4 $mmol \cdot l^{-1}$. They concluded that a continuous incremental test involving 3 minute stages is reliable and valid for measuring lactate concentrations. Dunbar et al. (1995) examined differences in lactate and heart rate values from 8 county standard middle and long-distance runners obtained during a 4 minute incremental running test with no more than 20 seconds allowed for blood collection, and a 6 and an 8 minute discontinuous test. Increments in the discontinuous tests were separated by 10 minute recovery periods. No differences ($p>0.05$) were found between mean heart rate and lactate values obtained with each protocol. It was recommended that 6 minute discontinuous running protocols could be used since data obtained would be the same as that obtained from an 8 minute protocol. Furthermore, if time was a constraint, the continuous 4 minute protocol was recommended as an acceptable alternative.

The results of these various studies seem to be conflicting. At one extreme there is the recommendation for a discontinuous 10 minute test, and at the other, a continuous test with 3 minute stages. Both types of test have been reported to produce values of blood lactate that are representative of a steady state concentration, and that can reliably be used to establish the work intensity corresponding to the point where lactate increases exponentially. Discrepancies in the findings may be due to differences in aerobic capacity of the subjects tested, although Foxdal et al., (1994) do not report any differences according to training status in their study. Findings might also be influenced by the exercise mode, as originally suggested in the early work by Owles (1930). Since the evidence is inconclusive and since studies have not involved the rowing ergometer, further investigation is required.

2.5.2 $\dot{V}O_2max$

The BASS Position Statement on the Physiological Assessment of the Elite Competitor (Hale et al., 1988) recommended that a protocol for determining $\dot{V}O_2max$, regardless of exercise mode, should be a continuous test lasting for a total of 9 to 15 minutes with 3 minute step increments. The test should have an initial

power output that would elicit 2 mmol·l^{-1} of blood lactate. For elite cyclists this roughly corresponds to a starting workload of 200 to 250 watts for men and 150 watts for women, with a 35 watt increment until exhaustion. With the awareness that fixing guidelines becomes increasingly difficult when using a wider variety of exercise modes, BASES (British Association of Sports and Exercise Sciences, formerly BASS) at a recent physiology workshop (MacLaren, 1994) have suggested that the protocol should be adjusted to suit both the athlete and the sport. It seems for instance that 3 minutes for each stage is often too long for the more elite athlete, as the body is able to adapt more quickly especially at lower workloads. MacDougall et al. (1992) recommended that step increments should be small enough to avoid undue increases in lactate and local muscle fatigue, yet the work time long enough and the increment large enough, so that the total time is not prolonged to the point where anxiety, boredom or physical discomfort force cessation in advance of achieving $\dot{V}O_2$max. When exercising on the rowing ergometer, the length of each work stage as well as the amount of watt increment needs further investigation, in order to establish an effective protocol which will ensure that a true $\dot{V}O_2$max is obtained. The test should also allow for differences in aerobic capacity.

Further to these recommendations, BASS present guidelines for establishing whether the $\dot{V}O_2$max value obtained is valid. These include a plateau in the oxygen uptake/exercise intensity relationship, an end respiratory exchange ratio of more than 1.15, a heart rate maximum of within 10 b·min^{-1} of age-related maximum, and a post-exercise blood lactate concentration of 8 mmol·l^{-1} or more.

A common maximum rowing test used mainly in Germany is the 6 minute "all-out" test. This, along with the 2,500 m test popular in this country are largely used for selection purposes rather than for establishing $\dot{V}O_2$max. However, the 6 minute all-out test has frequently been used to establish maximal variables (Mahler et al., 1984a; Steinacker et al., 1991), although the test does not comply with BASS recommendations. Mean maximum oxygen uptake achieved using an all-out test has been found to be lower than that achieved with a continuous incremental test (Tumilty et al., 1987). It is likely that a higher blood lactate concentration occurs earlier in the test leading to metabolic exhaustion, since there is no gradual increase in work intensity (Steinacker et al., 1984; Urhausen et al., 1987). The test, therefore, demands a high amount of motivation from the athlete and this, rather than physiological variables, may limit performance.

Mahler et al. (1991b) have used a one minute incremental continuous test on the Concept II rowing ergometer. The test is essentially for non-rowers, with an initial workload of 50 watts and a step increment of 25 watts each minute. The test was also designed to look at the effect of training on ventilatory responses and

entrainment of breathing, and not as a $\dot{V}O_2$max test *per se*. Koutedakis et al. (1993) have also used a one minute test protocol. For the warm-up, the work intensity is equivalent to a 500 m split time measured from the electronic performance monitor of the Concept II rowing ergometer of 2:20 min:s, and lasts 5 minutes. This starting level is used so that figures can be compared, but does not appear to take sex, age or expected rowing ability into account. After this stage, split times decrease by 5 seconds every minute until 1:50 min:s, and then decrease by 2 or 3 seconds down to 1:35 (min:s). The subjects continue until they are unable to maintain the required split time, after which a further 30 seconds is given for an all-out sprint. The main purpose of the test seems to be to obtain a peak$\dot{V}O_2$ due to the sprint finish. There are also no validity and reliability data reported for this test.

Other tests reported in the literature use the Gjessing rowing ergometer described in the following section, which although a popular ergometer used for laboratory measurements in the past, does not simulate rowing as effectively as ergometers such as the Concept II, which have been developed more recently. $\dot{V}O_2$max protocols designed for the Gjessing are not easily transferable to the Concept II since they rely on different methods to establish work intensity.

2.5.3 The rowing ergometer

The Gjessing rowing ergometer has the disadvantage that it operates on a fixed resistance (Mahler et al., 1987), which means that it requires a considerable amount of effort to move the flywheel at the catch (the start of the stroke, simulating the entry of the blade into the water, Figure 2.2). It is also considered difficult to row at normal race stroke rates for more than a few minutes without detriment to technique (Martindale and Robertson, 1984).

The Concept II is a variable wind-resistance braked ergometer, and is a more common ergometer used for laboratory testing in this country and in the USA. The Concept II works on the mechanical principle that the mean resistance of a rowing boat is directly proportional to its velocity to the power 1.95 (Celentano et al., 1974). The flywheel of the Concept II ergometer is designed to simulate this, and therefore should feel more akin to actual rowing (Lakomy, 1985). According to the experienced rower, the ergometer does provide a more realistic simulation of rowing than the Gjessing (Hahn et al., 1988; Steinacker et al., 1991). Performance on the Concept II ergometer has also been shown to relate well to performance on water in terms of oxygen consumption, lactate concentration, heart rate and work output (Chénier and Léger, 1991). However, work efficiency has been found to be higher in actual rowing (Martindale and Robertson, 1984). When comparing the Gjessing

with the Concept II, Hahn et al. (1988) found that more effort was required by the rower to obtain equivalent power outputs on the Gjessing as on the Concept II, energy being lost in the transmission of the system.

The Concept II is not without its faults. There are no means of scientifically calibrating the digital display or electronic performance monitor, since the manufacturer does not provide an explanation of how calculations are achieved (Hahn et al., 1988). Frictional differences may cause variation between machines, which makes them less than satisfactory for laboratory situations that require an exact knowledge of work output (Bassett et al., 1984). More information on measurements of mechanical variables from the Concept II will be given in section 2.7.1.

Ideally, evaluation of physiological characteristics of rowers should be performed on water, but logistical problems such as collecting blood samples and expired air without the rower having to stop, and changes in environmental conditions are difficult to minimise and control. It is also difficult to standardise and measure work intensity. Increases in speed are often met by increases in stroke rate alone rather than by a combination of stroke rate, force and power output. Testing in the boat therefore requires precise methodology, and technically perfect performance from the rower (Steinacker et al., 1991).

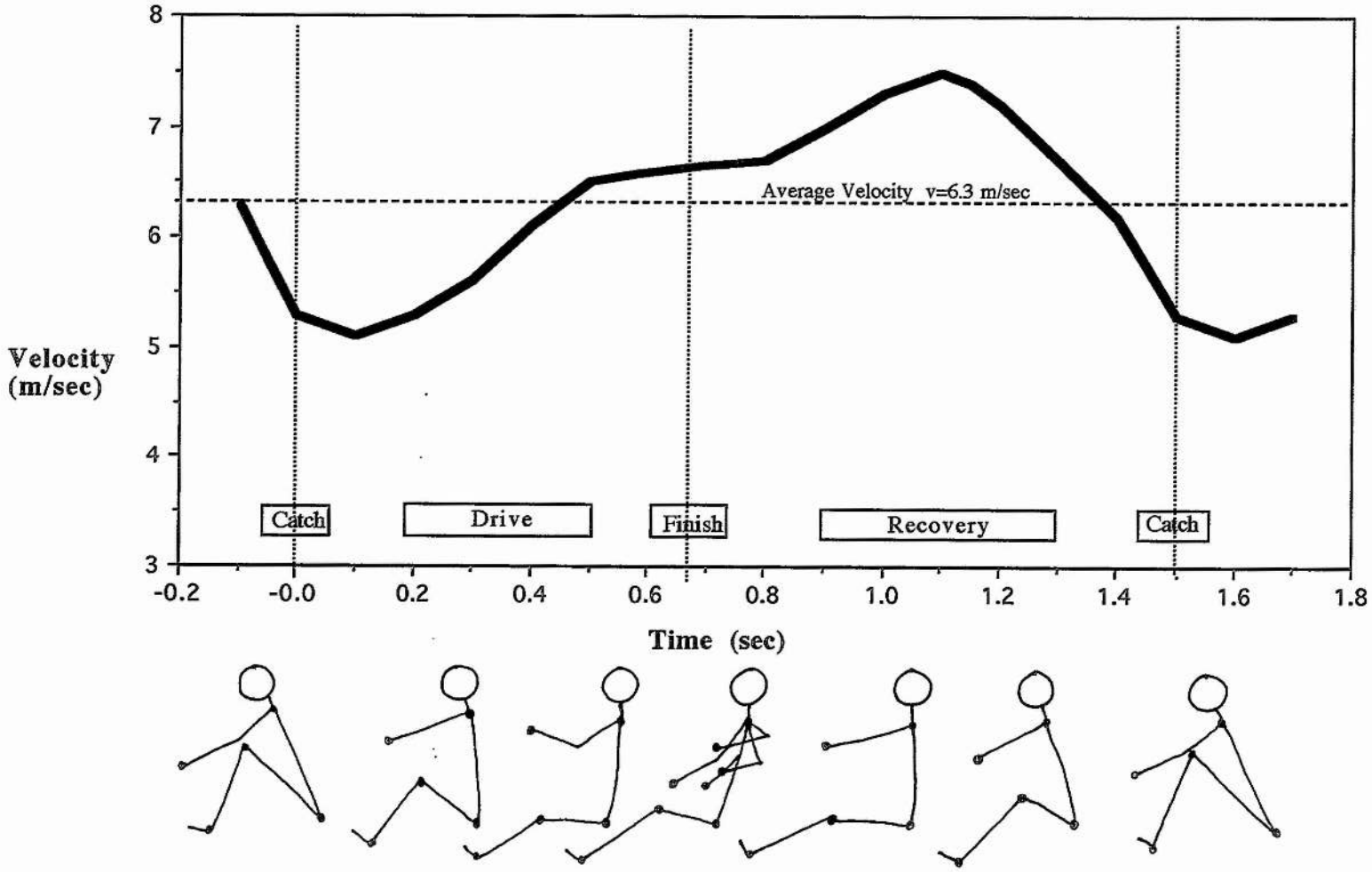
If an ergometer can simulate the rowing action sufficiently in terms of biomechanical and physiological variables, it should be considered as a suitable alternative for scientific testing (Martindale and Robertson, 1984). A more detailed examination of the mechanics of rowing and the physiological demands of the stroke will give some insight into the similarity of ergometer rowing and on-water rowing, and how testing on the ergometer can be used as an affective alternative.

2.6 Biomechanical Aspects of Rowing

2.6.1 The rowing technique

For convenience of explanation, the rowing stroke can be divided into four parts: the recovery, the catch, the propulsive or drive phase and the finish (Mahler et al., 1984b; Pannell, 1979). The stroke begins at the catch when the oar is placed into the water by a combination of deliberate action and a release of pressure on the oar handle. At this position the rower's knees and hips are flexed and the seat is at frontstops (at the bow position of the slide) as shown in Figure 2.2. The propulsive phase involves a leg drive, a simultaneous and continuous "opening" of the back, then a flexion or drawing in of the arms towards the lower chest. The blade is extracted from the water, which is achieved by striking the hands down, then away from the body in a circular motion. The blade should leave the water cleanly

Figure 2.2 Hypothetical graph showing velocity of boat and position of rower, adapted from Martin and Bernfield (1980) and Pannell (1979).



without throwing up water. This phase is called the finish. The body then rocks forwards rapidly before the knees are bent, so that momentum of the body swing rather than conscious effort carries the rower in a steady, controlled movement up the slide. During the first part of this recovery phase, the oar is feathered (parallel to the water). As the rower approaches front stops, the hands rise gradually and the blade is squared (perpendicular to the water) in preparation for the catch. The cycle is then repeated.

2.6.2 Components of velocity

Velocity can be defined as the distance the boat covers per unit of time, and can be measured either by determining a point on the boat and measuring its displacement in a forwards direction with the aid of film, or as is more customary, by the time required to complete a fixed distance such as 500 m. It is dependent on four main interrelated factors:

a) the application of force per stroke by the rower

b) the stroke length

c) the stroke rate

d) aero- and hydro-dynamic drag

(Martin and Bernfield, 1980; Millward, 1987; Schwanitz, 1991)

To gain velocity therefore, the aim is to generate a large force, over a long distance in as little time as possible (Nolte, 1991), without excessive amounts of drag.

Martin and Bernfield (1980) found minimum velocity of the boat to occur at 27% into the leg drive phase, and maximum velocity at the middle of the recovery (Figure 2.2). The greatest boat acceleration was obtained during the propulsive phase, and the least during recovery. They state that it is important to maintain a constant velocity, by reducing excessive amounts of acceleration and deceleration, as these increase the effects of inertia and drag.

a) Force

The various external and internal forces involved in the rowing action have been extensively analysed both through the application of basic mechanical principles, and by direct measurement (Affeld et al., 1993; Nolte, 1991; Sanderson and Martindale, 1986). These forces involve reactive forces of the oarlock and of the water, the force of air resistance, force of gravity and force of hydrostatic pressure. In addition, the distance the boat travels during one stroke will depend on when and how the rower applies his or her force throughout the stroke. When the blade enters the water, it will have the effect of stopping or checking the boat, since

it is opposing the direction of boat travel. To prevent exaggerating this negative force, the rower needs to achieve a very rapid entry into the water followed by immediate power generation (Herberger et al., 1990; Sanderson and Martindale, 1986). Furthermore, since maximum velocity occurs during recovery (Figure 2.2), a longer time in this phase is desirable. Although there exists no equation to date, relating boat speed to the movements and forces of the rower, stroke profiles have been computer analysed when rowing on the ergometer (Kinch et al., 1993), and lend support to this idea of using a fast catch and a steady, controlled recovery.

b) Stroke length

Stroke length is dependent on both the rigging and the rower.

i) Rigging

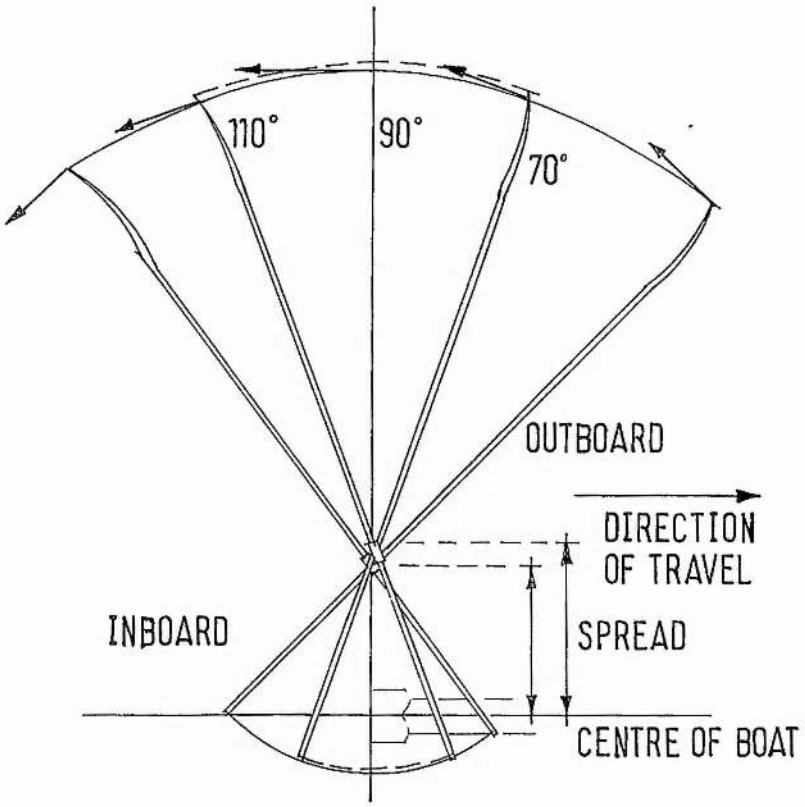
This refers to the adjustment of all moveable parts of the boat and oar. Increasing the outboard (distance from the pin to the end of the blade), or decreasing the spread (distance from the centre of the boat to the pin) will cause an increase in the length of the rowing arc (Figure 2.3). This should increase the velocity of the boat, since the force is applied over a greater percentage of time. However, by so doing, a larger force will be required by the rower on the handle, in order to maintain the same amount of force at the blade. The load will therefore feel greater, which may not be as suitable for smaller, lighter, less fit or less technically proficient rowers. In addition, more force may be applied that is not directly perpendicular to the direction of the boat travel, which may be wasteful. The efficient area of oar swing angle is usually cited as between 70 and 110 degrees (Herberger et al., 1990) as shown in Figure 2.3. The only advantage of going beyond this angle is that the hydrodynamic lift achieved at the most extreme forward position is thought by some to enhance boat progression (Nolte, 1991).

ii) Rower

Physiological and anthropometrical differences among individuals, such as length of limbs, height when seated, and flexibility, will alter the length of the arc irrespective of the rigging. Generally rigging is used to compensate for physiological differences, but on the rowing ergometer stroke length cannot be altered, which means that the oarsperson has total responsibility over the length of his or her stroke. Kinch et al. (1993) found variations in stroke length between individuals when on the rowing ergometer, but could not determine whether the differences occurred as a

result of body dimensions or due to differences in technique. These small differences found at the handle are magnified at the blade since stroke length at the blade is approximately 2.5 times that at the handle (Kinch et al., 1993).

Figure 2.3 Effect of adjusting span or outboard on the rowing arc.



Arrows on end of blades refer to the direction in which force is applied.

c) Stroke rate

Reducing the stroke rate should not increase the amount of time the oar spends in the water since, as explained earlier, a recovery to propulsive phase ratio of approximately 2:1 is always encouraged for efficiency (Herberger et al., 1990). In the course of a minute therefore, the blade should always be in the water for approximately 20 seconds, regardless of the stroke rate. In practice this is not always the case, as it is impossible for the rower to be this consistent. Often the stroke length is shortened as a means of increasing the rate, although it appears from

the results by Martindale and Robertson (1984) that a relationship between stroke rate and stroke length does not exist. Force does however appear to be related in some way to the stroke rate since both have been found to increase concurrently (Zatsiorsky and Yakunin, 1991).

If stroke length and the force applied via the oarhandle are kept constant and the effect of drag minimised, the boat speed is solely dependent on the stroke rate. Martin and Bernfield (1980) and Fukunaga et al. (1986) both report a significant relationship (r=0.66) between stroke rate (between a rating of 27 and 41 strokes per minute) and average velocity of a racing shell. This relationship is reported to be linear (di Prampero et al., 1971). It is therefore usually considered advantageous to increase the stroke frequency (di Prampero, 1986; Fukunaga et al., 1986), as long as it is within the limits set by the efficiency of muscular contraction estimated at approximately 40 strokes per minute (Celentano et al., 1974). However Sanderson and Martindale (1986) suggested that high strokes rates may reduce speed efficiency, since a large proportion of the stroke period will be spent decelerating the boat at the catch.

In the protocols that have been used to examine physiological variables on the rowing ergometer, stroke rates have been extremely varied and in many studies are not specified (Chénier and Léger, 1991; Jackson and Secher, 1976; Klusiewisz et al., 1992; Strømme, et al., 1977; McKenzie and Rhodes, 1982) presumably because stroke rate has been difficult to measure or because the measurement is not a relevant part of the study. As stroke rate seems to play an important part in boat progression, it is essential that this variable is taken into account.

d) Drag

Most of the drag or resistance in rowing is hydrodynamic rather than aerodynamic (Millward, 1987). Drag increases with velocity to the power of approximately two (Sanderson and Martindale, 1986; Nolte, 1991). This means that if velocity is doubled, the resistance will increase four fold. The size and shape of the hull of the boat and its depth of immersion have a considerable effect on drag. Turbulence also varies about the boat and with fluctuations in boat speed per stroke. To minimise drag, it is important to avoid excessive vertical movements of the boat, and limit acceleration and deceleration (Nolte, 1991). On the Concept II rowing ergometer, drag and changes in environmental conditions such as altitude and obstruction near the wheel, are taken into account in the design of the flywheel and hence result in changes in work intensity. However, manufacturers do not provide data on how this is achieved.

2.7 Laboratory Measurement of Mechanical Variables in Rowing

2.7.1 Ergometer measurements

All components of velocity can be varied and are measurable on the rowing ergometer. The Concept II incorporates an electronic performance monitor, which gives values of stroke rate, time, 500 m split time, power output, and an estimate of caloric expenditure. Power is established from the rate of deceleration of the flywheel and absolute speed. The force and speed of the oar handle are, however, not taken into consideration. When power has been measured directly by using a force strain gauge and a device to measure stroke length and stroke rate (Kinch et al., 1993; Lakomy, 1993), it has been found to differ from the output of the electronic performance monitor, especially at lower workloads. It is therefore more accurate to measure power output directly than to rely on the electronic performance monitor, especially as this cannot be calibrated (Hahn et al., 1988). Equally the 500 m split time is only an estimate of real boat speed, since other factors, such as a quick catch can increase velocity as previously stated. The study by Kinch et al., 1993 was designed to measure various components of the rowing stroke for use with the Concept II rowing ergometer, in order to gain a greater understanding of how velocity was achieved. Force was measured by a strain gauge, inserted between the chain and the handle. The movement and speed of the seat were recorded photoelectrically and flywheel speed was monitored by using the Hall effect transducer which is supplied with the Concept II. This latter feature allows the number of cog revolutions to be related to the distance the chain travels. All information was converted from analogue to digital to be displayed on computer. The software allowed the stroke to be graphically displayed during any 6 second work period in real time. Computer analysis of the first stroke in each six second block produced data on stroke rate, stroke length, peak force, both on the oar handle and on the foot stretcher, impulse, power, slide velocity and the duration of the different phases of the stroke cycle. By instrumenting the ergometer in this way, a more detailed analysis of the rowing stroke was possible. For instance, the study revealed that power and stroke rate increased significantly over the duration of a 1 minute incremental test, whereas no significant differences were observed in either stroke length or catch time. Faster split times were achieved by an increase in power and stroke rate. This study emphasises the importance of measuring mechanical variations directly, if there is a need to be more accurate about the components of velocity.

2.8 The Effect of Mechanical Changes on Physiological Variables

Changes in force, stroke length and stroke rate may have an influence on physiological variables, such as oxygen consumption and lactate concentration. If $\dot{V}O_2max$ and lactate measurements are used to assess rowing performance, consideration needs to be given to how these mechanical variables can be measured and controlled. Investigators usually examine rowing economy based on the relationship between oxygen uptake and rowing velocity. This relationship was found by Jackson and Secher (1976) to be linear when testing 2 rowers on water, becoming curvilinear above velocities of 160 $m \cdot min^{-1}$. A similar relationship has been found on the ergometer (Bassett et al., 1984). Hence a value for 500 m split time on the ergometer or velocity on the water are most commonly used to measure work intensity. However, the specific components of velocity, which include force, stroke length and stroke rate have not been individually examined for their influence on oxygen consumption. It is assumed that since force, stroke rate and stroke length all affect velocity, similar linear increases in oxygen consumption are expected when each component is independently increased.

2.9 The Effect of Stroke Rate on Oxygen Consumption and Lactate

The guidelines set by FISA specify stroke rates for improving aerobic capacity (Table 2.1). However, these suggestions appear largely to be based on empirical evidence. At the time of publication it was not known for certain how changes in stroke rate *per se* affected oxygen uptake or lactate concentration.

Before designing a protocol on the Gjessing rowing ergometer, Steinacker et al. (1984) looked at the influence of stroke rate on lactate behaviour. The relationship was found to be constant between 24 and 26 strokes per minute, but became curvilinear thereafter (up to 36 strokes per minute). In a study by Droghetti et al. (1991) a similar curvilinear relationship was found between oxygen uptake and stroke rate between 24 and 36 strokes per minute during 'no load' rowing (no additional weights or resistance added other than that caused by friction between moving parts) on the Gjessing rowing ergometer. These two studies suggest that increasing the stroke rate above optimum (approximately above 26 $str \cdot min^{-1}$) may be detrimental to performance, since the physiological demands on the rower become too great. There are also the obvious physical constraints to increasing stroke rate. At the upper limit, the speed of muscle shortening becomes so high as to lead to a decrease in the efficiency of contraction (Celentano et al., 1974). However, in spite of these findings it is still considered advantageous to increase stoke rate in order to increase boat velocity as mentioned in section 2.6.2, and rowers do tend to train

according to the FISA recommendations, even though there appears to be a lack of scientific information to support them. Furthermore, the study by Droghetti et al. (1991) also found that there was a large inter-individual variation in oxygen uptake at the different stroke rates. At 28 strokes per minute during no load rowing, oxygen consumption varied for individuals between 1.35 and 2.40 $l \cdot min^{-1}$, a 77% difference in movement economy. This suggests that there may be an optimal stroke rate for each individual.

Stroke rate may also have an effect on pulmonary function. At high workloads, increases in pulmonary ventilation are generally met by increases in breathing rate rather than by tidal volume (Szal and Schoene, 1989). However, breathing rate and stroke rate have been found to increase in concert, since rowers entrain or co-ordinate their breathing with the stroke (Mahler et al., 1991a; Steinacker et al., 1993). The suggestion therefore is that stroke rate could be altered to optimise pulmonary parameters (Rosiello et al., 1987; Steinacker et al., 1993). It has also been argued that the action of the stroke may impede pulmonary ventilation and venous return (Andrea et al., 1986; Cunningham et al., 1975; Jensen and Katch, 1991; Rosiello et al., 1987) due to the combined effect of expiration and compression of the chest and abdominal muscles, necessary to obtain maximum stroke length. Such changes brought about by the mechanical action of the stroke may influence oxygen consumption and the assessment of the ventilatory threshold (Carey et al., 1974).

Apart from these few studies there is little information on optimal or most economical stroke rates in terms of physiological performance, and yet the range of stroke rates possible is fairly large. During a race for instance, stroke rates can vary between 32 and 44 strokes per minute, depending on the stage of the race and the size and type of boat (Steinacker, 1993). The stroke frequency for an eight is higher than a coxed pair (2 people with one blade each), since the latter is relatively heavier and therefore requires greater effort exerted over a longer time period to overcome the larger amount of inertia. Further investigation into the influence of stroke rate on physiological variables may enable the establishment of a regression equation which relates oxygen consumption and lactate with stroke rate. This could be utilised as an effective index of evaluating performance and technical efficiency. More efficient rowers, for instance, might increase stroke length rather than increase stroke rate, if by so doing they are able to work at a higher intensity but with a lower oxygen consumption and net lactate concentration.

2.10 Summary and Research Implications

Although $\dot{V}O_2max$ has its uses as an assessment of aerobic capacity, measurement of blood lactate concentration has greater potential for the purposes of rowing. As well as providing specific information about an individual's overall endurance conditioning, measurements of blood lactate concentration are helpful for assessing the effectiveness and design of training programmes (Urhausen et al., 1986; Wolf and Roth, 1987). Some coaches have, however, rejected lactate testing owing to its complexity and impracticality (Korzeniowski, 1989), but more have acknowledged lactate testing as a means of improving performance (Jensen et al., 1990; Spinks, 1986) and as a predictor of competitive success (Wolf and Roth, 1987). If testing in rowing is to keep up with the advancements in sports science, it is important to resolve problems that might occur in lactate sampling methods, protocol design and ergometer measurements, hence making testing more viable and suitable for the rower. One of the ways that this can be achieved is by establishing the toe as a valid and reliable sampling site. The rower would therefore not need to stop for a lactate measurement to be obtained. Clarification in the design of the protocol also needs further consideration, since controversy exists over the length of test time required before lactate reaches a steady state concentration. A test for the assessment of $\dot{V}O_2max$ should also be developed, that would satisfy BASS recommendations. This would enable the point at which lactate increases exponentially to be expressed as a percentage of maximum oxygen consumption. In terms of the mechanical factors that are considered important for boat progression, investigation into the effect of stroke rate on oxygen consumption and lactate concentration may reveal information about an optimal stroke rate for training and performance purposes.

CHAPTER 3

A comparison of plasma lactate concentration collected from the toe, ear and fingertip following simulated rowing exercise

3.1 Introduction

The fingertip and the earlobe are the conventional locations for capillary blood sampling while subjects are exercising. In rowing these two sites are inappropriate since the rower has to stop for the sampling to take place. An interruption in steady state or incremental work can affect results when obtaining a work intensity equivalent to the point where lactate concentration increases abruptly or exponentially (El-Sayed et al., 1993; Stegmann et al., 1981). Since the feet are fixed into the boat or ergometer by shoes or straps, it is possible for the experimenter to remove repeated blood samples from the tip of the toe without affecting performance. Smith et al. (1991) found that lactate concentration in blood sampled from the toe was significantly lower than that taken from the earlobe following arm only exercise, and concluded that the lack of involvement of the lower body resulted in less lactate being produced in this region. Apart from this study, little work has been done on analysing differences in lactate concentration that might occur as a result of different sampling sites. Through standardised testing of rowers on the Concept II rowing ergometer, the British Olympic Medical Centre have observed differences between blood taken at the earlobe and fingertip, but have not used or analysed blood from the toe.

The purpose of this study is to compare plasma lactate concentration taken from the toe with that from the earlobe and fingertip following steady state rowing exercise equivalent to 60% and 90% of the individual's estimated heart rate maximum. These two percentages are chosen since it is assumed they represent the range of expected values that rowers are able to sustain for prolonged periods without excessive amounts of lactate accumulating in the blood (Koutedakis and Sharp, 1985; Zhou, 1990). From the results of this study it should be possible to establish whether the toe can be used as a valid sampling site for the estimation of plasma lactate concentration. It is hypothesised that values of lactate will not differ significantly between sites.

3.2 Methodology

3.2.1 Subjects

Nine subjects (4 males and 5 females), who gave their informed consent, volunteered to participate in the study. Four of the subjects were members of a university rowing club, and the remaining five were endurance athletes, who regularly used a rowing ergometer as a training mode. Physical characteristics are presented in Table 3.1.

Table 3.1 Physical characteristics of subjects.
Figures given are mean, standard deviation and range.

	FEMALES (n=5)	MALES (n=4)
Age (years)	28.0±9.2 (20-38)	23.3±3.8 (19-28)
Height (m)	1.64±0.05 (1.61-1.71)	1.83±0.05 (1.77-1.87)
Weight (kg)	69.4±10.6 (56.7-81.0)	81.9±6.5 (72.6-87.7)

3.2.2 Equipment

Exercise was performed on the Concept II rowing ergometer (Model B). The electronic performance monitor was used to obtain information about the stroke rate (str·min^{-1}), boat speed, expressed as the time taken to cover 500 m (min, s), and elapsed time (min, s). Although there is some dispute as to the accuracy of the displayed 500 m split time (Lakomy, 1993), figures are reported by the manufacturers to be reproducible. Since subjects were expected to differ in their lactate response to exercise (Stegmann et al., 1981), it was not intended to use individual values for direct comparison. The 500 m split time was therefore used merely as a guideline to elicit a certain heart rate response, rather than an accurate measurement of work intensity. All subjects were familiar with the Concept II having used this type of simulator extensively in training. Heart rate was measured by short-range telemetry (PE3000 Sport Tester).

3.2.3 Procedures

A four minute test developed by Lakomy and Lakomy (Concept II manual, Appendix 1) was used to establish individual exercise intensities. The test required the ergometer to be set with the vanes fully closed and on the larger of the two drive cogs. Subjects rowed on the ergometer for 4 minutes at a speed that they felt was comfortable, and were able to maintain. Further to these specific test requirements, the stroke rate was confined to within 24 and 28 strokes per minute, the subject receiving feedback of this from the electronic performance monitor. These stroke rates were selected because they represented a comfortable training range for most

rowers (Steinacker, 1993). The speed (500 m split time) and heart rate were recorded during the final minute of exercise. This information can be used to predict exercise intensities that elicit heart rates above 50% of the individual's estimated maximum heart rate (Table A1.1). After a short break subjects completed two separate 4 minute workloads, one at 60% of their estimated heart rate maximum, and the other at 90%, the order being randomly assigned. Adequate rest (denoted by heart rate recovery to within 10% of their original pre-exercise heart rate) was given between work bouts. During the final minute, heart rate, 500 m split time and mean stroke rate were recorded.

3.2.4 Blood sampling

Prior to the warm-up, an embrocation cream was applied to the earlobe, fingertip and toe to encourage superficial blood flow. The area of sampling was then prepared using non-alcoholic mediwipes, in accordance with BASS standards (Hale et al., 1988). Blood was taken simultaneously at each site by 3 experimenters immediately following the cessation of exercise, and the time taken to complete each sample was recorded. Capillary blood was collected using a heparinised capillary tube marked at 50 μl, and immediately placed into a standardised 4 μl preservative (fluoride/EDTA reagent) to prevent coagulation. The samples were centrifuged for 5 minutes and 20 μl of supernatant plasma was frozen for subsequent analysis. For the assay, a 10 μl sample of the plasma was diluted with a reagent solution containing sodium carbonate, NAD and L-glutamate. This was measured using a spectrophotometer at 340 nm zeroed against air. A standard enzyme mix containing LDH and GPT was then added and the change as a result of the reaction noted. This enzymatic method uses LDH as a catalyst for the production of pyruvate and NADH from lactate and NAD^+. The amount of NADH formed in the reaction has been found to be proportional to the concentration of lactate (Noll, 1974). Further information is given in Appendix 8.

This method of measuring lactate from plasma, although time consuming in its analysis and the amount of blood needed for the sample, is thought to give a better guide to the metabolic state of the muscle generating lactate. This is because diffusion of lactate into plasma is faster than diffusion into whole blood cells (Bishop et al., 1992; Forrest et al., 1990; Rodriquez et al., 1992). In several studies that used incremental test protocols, plasma lactate concentration values have been found to be significantly higher than values of lactate found in whole blood and lysed blood (Foxdal et al., 1991; Williams et al., 1992), especially at higher work intensities (Buono and Yeager, 1986; Harris and Dudley, 1989). In the BASS guidelines (Hale et al., 1988) it states that lactate concentrations can differ according to the method used for the assay, but no indication is given as to the extent of these

differences. If the same assay technique is used for repeat assessments, the difference should not be important, as long as values are not compared to other studies or extrapolated to field situations in order to set training intensities (Williams et al., 1992).

3.2.5 Statistical Analysis

A 3-way ANOVA was used to determine differences and to look at interaction effects between sampling sites, subjects and workloads. The level of significance was set at $p<0.05$. A Pearson product moment correlation coefficient *(r)* was used to look at the relationship between lactate values at different sites, and a normal scores plot was used to check the distribution of values.

3.3 Results

Performance data and plasma lactate values found at the three sites are given in Tables 3.2 and 3.3.

Table 3.2 Summary of performance data at the two estimated work intensities. *Figures given are mean and standard deviation.*

	FEMALES (n=5)	**MALES (n=4)**	**ALL SUBJECTS (n=9)**
WORK INTENSITY 1			
500 m Split Time (min:s)	2:48±0:10	2:08±0:05	N/A
Heart Rate ($b \cdot min^{-1}$)	164.6±8.7	154.4±3.6	160.1±8.5
Percentage of Estimated HR Max (%)	79.7±6.3	72.3±2.6	76.4±6.1
WORK INTENSITY 2			
500 m Split Time (min:s)	2:26±0:14	1:48±0:05	N/A
Heart Rate ($b \cdot min^{-1}$)	178.7±3.3	181.5±8.1	180.1±5.7
Percentage of Estimated HR Max (%)	90.8±3.0	93.2±6.5	91.9±4.7

It was intended that the first load should represent 60% of the individual's maximum heart rate. The methods outlined by Lakomy and Lakomy were designed to estimate a work intensity that would elicit a heart rate response equivalent to this 60% of heart rate maximum. Although these methods were adhered to, the actual heart rate response was higher than the estimated heart rate for all subjects. It is likely that the arousal level of the subjects was high, since they were apprehensive about the testing procedures and blood sampling, and wanted to perform well on the tests. The heart rate would therefore be slightly elevated. The test by Lakomy and Lakomy may not take the psychological state of the subject into account, since it is only designed for self-evaluation. Unlike the lower workload, the physiological demand of the higher workload seemed to out-weigh the psychological stimulation effect on the heart, and produced values that were closer to the estimated 90% of maximum heart rate.

The lactate response data for all subjects were pooled (Table 3.3), since no significant differences occurred when the lactate data were analysed separately for each sex.

Table 3.3 Mean lactate values ($mmol \cdot l^{-1}$) found in plasma sampled from capillary blood at the three different sites.

Work Intensity % HR max	**Site of Sample**	**Lactate $mmol \cdot l^{-1}$**	
		Mean	**SD**
76.4%	Finger	6.36	1.58
	Toe	5.81	1.11
	Ear	5.29	1.24
91.9%	Finger	8.81	2.30
	Toe	8.53	1.37
	Ear	8.41	2.35

SD = standard deviation

As can be seen in Table A5.1.1 (Appendix 5.1), no significant differences were found in the amount of lactate at the three different sampling sites at either work intensity, since the value for p was 0.085. Interaction analysis suggested that any small variations in lactate that were found at the different sites could be accounted for by differences between subjects rather than between sites.

The normal scores plot revealed a correlation of 0.98, greater than 0.96 for normality (Appendix 5.1, Figure A5.1.1). The Pearson product moment coefficient revealed significant correlations of lactate values between all sites, except for those between the ear and fingertip (r=0.64) at the first workload and between the toe and fingertip (r=0.46) at the second load. The highest correlation occurred between the toe and finger (r=0.79) at the lower workload. When comparing the values achieved at the same site but at different work intensities, all relationships were significantly different, and correlations were low.

The mean time taken (min.s) to collect 50 μl of blood from the fingertip, the toe and the earlobe was 2.25±1.15, 1.12±0.35, and 2.44±0.50 respectively. This gave a total mean time for all samples of 2.07±1.28 (mins.s). A 3-way analysis was also used on these values and showed significant differences between the times when comparing the three sites and the two work intensities (Appendix 5.1, Table A5.1.2).

3.4 Discussion

At both work intensities the mean amount of plasma lactate found at the toe, fingertip and earlobe were not significantly different. Although only 9 subjects were involved in the study, the normal scores plot indicates an even distribution of lactate responses, suggesting that the findings would be the same if larger numbers were tested. These results contradict the observations made at the British Olympic Medical Centre (Doherty, 1992) following rowing exercise, and of Smith et al.'s findings (1991) following arm cranking. Since the legs were inactive in Smith et al.'s study, it was proposed that less lactate was produced and more metabolised within this region, resulting in lower net amounts of blood lactate at the toe. Similar conclusions concerning lactate uptake by non-exercising muscle have been made by other researchers (Bassett et al., 1984; Davis et al., 1976; Karlsson and Jacobs, 1982; Rasmussen et al., 1991; Secher et al., 1977). In rowing, the muscles of the legs, back and arms are highly active (Mazzone, 1988), suggesting a more even distribution (from both production and utilisation) of plasma lactate concentration.

The time taken to complete the blood sample may have had an important influence on the results obtained, although by observing the data, no specific pattern emerges. Jensen (1989) tested 15 rowers on the Concept II rowing ergometer at an

intensity approximating the third and fourth minute of a six minute all out test, and found no significant differences ($p>0.05$) in plasma lactate sampled immediately following exercise and up to 5 minutes post-exercise. For this study, 5 minutes was therefore used as a maximum time limit for blood collection, the mean time (min.s) of collection for all samples being 2.07±1.28. At both work intensities, the time taken to complete the sample was lowest at the toe (a mean value of 1.12±0.35 min.s), and highest at the earlobe (a mean time of 2.44±1.50 min.s). These times may seem unusually long in comparison to other studies (Foxdal et al., 1991; Smith et al., 1991), but included the time taken for the subject to replace the oar handle, and for the investigator to prepare the subject and the site for sampling. A 50 μl sample was required for analysis rather than the normal 3 to 7 μl when using an automated analyser. Poor blood flow, especially at the earlobe in spite of this site being pre-warmed, and rapid blood clotting added to the delay in collecting the sample in some of the subjects. In both the toe and fingertip, blood flow improved after 30 seconds into the collection, as subjects relaxed.

Subjects were asked where most discomfort was felt. In all cases, the finger was the most sensitive, and the earlobe the least, independent of whoever was taking the sample.

The data suggest that the toe may be used as a valid site for assessing the amount of plasma lactate concentration, and values may be compared to other studies, where blood has been taken from the earlobe and the fingertip following submaximal rowing exercise. Furthermore, the relatively low standard deviation of lactate values taken from the toe compared with the other two sites suggests that there may be less measurement error when using the toe as a sampling site. The toe also took, on average, less time to make a blood collection and proved to be less sensitive for the subject than the fingertip. By using the toe as a sampling site, it should be possible to use a continuous protocol for the assessment of lactate during steady-state exercise or incremental load protocols without interfering with the rowing action.

CHAPTER 4

Development of a $\dot{V}O_2max$ test using the Concept II rowing ergometer

4.1 Introduction

In rowing there has been increased interest in using measurements of blood lactate concentration to assess endurance performance and to set training and competition exercise intensities (Doherty, 1992; Hagerman and Hagerman, 1990; Hartmann et al., 1990; Womack et al., 1989). Consequently most of the tests used on rowers in this country are designed for measuring lactate such as the discontinuous incremental test used at the British Olympic Medical Centre (BOMC) for testing squad rowers and the $\dot{V}O_2$max/lactate profile protocol used at the National Sports Medicine Institute (Appendix 2). These tests are discontinuous to allow for blood sampling and do not need to continue to exhaustion, since the lactate threshold determined by a curvilinear rise in the power/blood lactate relationship can be identified prior to this. The lactate threshold is also expressed as a work intensity or heart rate rather than a percentage of maximum. For these reasons, the protocols, if used to obtain a $\dot{V}O_2$max value, do not comply with the guidelines of the BASS Position Statement on the Physiological Assessment of the Elite Competitor (Hale et al., 1988).

In the literature $\dot{V}O_2$max tests that are incremental and continuous are designed for the Gjessing rowing ergometer (Brien and McKenzie, 1989; McKenzie and Rhodes, 1982; Steinacker et al., 1986). The Concept II rowing ergometer is, however, preferable since it provides a better simulation of actual rowing than the Gjessing (Hahn et al., 1988; Lakomy, 1985; Steinacker et al., 1991) and has been shown to relate well to performance on water (Chénier and Léger, 1991).

Figure 4.1 Criteria taken from the BASS Position Statement on the Physiological Assessment of the Elite Competitor (Hale et al., 1988).

> *Section 4.1.1* The following criteria should be considered in establishing maximum oxygen uptake in adults.
>
> 1. A plateau in the oxygen uptake/exercise intensity relationship. This has been defined as an increase in oxygen uptake of less that 2 $ml \cdot kg^{-1} \cdot min^{-1}$ or 5% with an increase in exercise intensity.
> 2. A final respiratory exchange value of 1.15 or above.
> 3. A final heart rate of within 10 $b \cdot min^{-1}$ of the age-related maximum.
> 4. A post exercise (4-5 min) blood lactate concentration of 8 $mmol \cdot l^{-1}$ or more.

The aim of this study is to develop a test to measure $\dot{V}O_2max$ on the Concept II rowing ergometer. The guidelines set by BASS (Hale et al., 1988) for testing the elite competitor will be followed, and the design and rationale of existing protocols will be examined, and if appropriate, adapted and modified. The results of the test will be checked for validity according to BASS recommendations, such that $\dot{V}O_2max$ is verified on consideration of the criteria presented in Figure 4.1. For reliability BASS recommend a test-retest correlation value of more than 0.85.

4.2 Methodology

4.2.1 Subjects

Letters were sent out to all rowing and boat clubs affiliated to the Scottish Amateur Rowing Association, requesting their help in obtaining subjects. The aim was to collect reliable data from rowers and scullers of a range of technical abilities, who trained at least three times per week, and who regularly used the Concept II rowing ergometer as part of their training. Altogether 31 subjects (24 males and 7 females) from 14 different rowing clubs throughout Scotland volunteered to participate in the study. Means and standard deviations of age, height and weight for male subjects were 27.0±6.1 years, 1.82±0.05 m and 78.6±8.4 kg respectively. For females corresponding values were 27.7±4.8 years, 1.67±0.06 m and 63.6±8.7 kg. Subjects ranged in their ability from novice to elite competitor. From results of a pre-test questionnaire, 26% of subjects described themselves as 'moderately fit', 58% as 'trained' and 16% as 'highly trained'. None of the subjects had relevant past medical histories or contra-indications to strenuous exercise.

4.2.2 Protocol - rationale and justification of design

To develop a $\dot{V}O_2max$ test a pilot investigation was carried out (Appendix 3). Five protocols of varying work stage duration and watt increment were examined using heart rate as a guideline to work intensity. With a one minute step protocol, subjects (5 male and 4 female university rowers who volunteered in the investigation) found it difficult to settle into a rhythm and heart rate did not stabilise at any point during the test. It is likely that this would produce a peak rather than a maximum value for $\dot{V}O_2$, since a plateau would not be achieved. With 3 minutes at each load subjects found it difficult to sustain higher workloads that they could otherwise sustain with just 1 or 2 minutes. It was therefore decided that a test protocol with 2 minutes at each work stage was more appropriate. Two minute incremental tests have been used by other researchers (Chénier and Léger, 1991;

Hagerman and Mansfield, 1984; Steinacker et al., 1984, 1985). However since these studies did not involve the use of the Concept II (Model B) they cannot be replicated for this study.

In addition the pilot investigation attempted to establish an appropriate watt increment. Heart rate responses indicated that if the increment in watts was too great or the initial work intensity too high, exhaustion occurred prematurely, suggesting that $\dot{V}O_2max$ may not be achieved. If the watt increments were too small the test took over 16 minutes before exhaustion was reached. It was decided to use a watt increment that was consistent throughout the test, and that was of appropriate size as to lead to exhaustion between 8 and 16 minutes.

The test protocol that was finally selected is presented in Figure 4.2. It is a continuous, incremental test with 2 minutes at each stage and requires the use of the electronic performance monitor of the Concept II as a guide to work intensity. There are two initial workloads to choose from ('a' or 'b'), depending on the athlete's level of conditioning. For the fitter rower this means that the test should not go on for longer than 16 minutes, since they will start at a higher workload. Conversely the less fit or less technically proficient subject should be able to complete at least 8 minutes of the test, since the initial workload should not be too difficult. The 500 m split times therefore provide a large enough range of workloads to cover differences in rowing ability and/or aerobic endurance capacity.

The 500 m split times are similar to the submaximal discontinuous incremental test used at the BOMC for testing male squad rowers, but have been extended to include two loads at lower work intensities to cater for the less fit athlete. For females the split times have been adapted from the BOMC test so that the same watt increment (mean for both tests 27.3±1.9 W) is used.

4.2.3 Procedures

Exercise tests were carried out over a period of 10 weeks, coinciding with the latter stages of the competitive season. Subjects were requested to avoid strenuous exercise and alcohol 24 hours prior to testing and to abstain from drinking caffeine, eating a large meal or taking medication 2 hours before the start of the test. Only one laboratory visit was necessary, apart from 11 subjects who returned for repeatability measures (section 4.2.4). Written consent was given after the subjects had been thoroughly informed of the testing procedures. Laboratory temperatures ranged between 18 °C and 22 °C and humidity between 38% and 47%.

Figure 4.2 Continuous incremental test for establishing $\dot{V}O_2max$.

Women

	500 m Time (min:s)	Power Output (watts)	Increment (watts)
a	2:34	96	-
b	2:21	123	27
	2:13	150	27
	2:07	177	27
	2:01	203	26
	1:55	230	27
	1:49	256	26
	1:46	283	27
	1:43	311	27

Men

	500 m Time (min:s)	Power Output (watts)	Increment (watts)
a	2:07	177	-
b	2:01	203	26
	1:55	230	27
	1:49	256	26
	1:46	283	27
	1:43	311	27
	1:40	338	27
	1:37	366	28
	1:34	400	34

A 3 minute warm-up at 'b' on the above protocol was used to establish the initial workload. If the heart rate taken in the last minute of exercise was above 65% of the theoretical heart rate maximum the subject started at stage 'a'. If it was less than this, the subject started at 'b'. This procedure was to satisfy the recommendation set by BASS to obtain an initial power output corresponding to 2 $mmol \cdot l^{-1}$ of blood lactate. To confirm this, a blood sample was taken prior to and during the last minute of the 3 minute warm-up, and subsequently analysed for plasma lactate concentration using the techniques described in section 3.2.4 (Noll, 1974). Theoretical heart rate maximum was taken as 211 - age, since maximum heart rate on the ergometer has been found to be slightly lower than 220 - age normally quoted for other modes of exercise (Lakomy and Lakomy, 1993).

Subjects resumed exercise after 5 minutes of rest, starting at 'a' or 'b' and increasing the intensity every 2 minutes until either they reached volitional

exhaustion, or they were unable to maintain the required 500 m split time. A stroke rate of between 24 and 32 strokes per minute was encouraged during both the warm-up and the $\dot{V}O_2$ max test, since this range was considered wide enough to cater for differences in rowing ability and style, yet restrictive enough to allow for comparability. Cumulative distance travelled, as displayed on the electronic performance monitor of the Concept II, was recorded each minute to verify that the required 500 m split time had been obtained. The gearing for the ergometer was fixed on the large cog with the fan closed. Although no verbal encouragement was given, subjects were fully aware of the demands of the test and the importance of continuing to volitional exhaustion.

Oxygen uptake and related respiratory variables were monitored continuously and displayed at the end of each minute using an on-line open-circuit gas analyser (COVOX MICROLAB). Calibration checks using zero, span and mixed gases were performed within 10 minutes of the start of the test and again on completion. Gas volumes were calibrated using a 3 litre syringe (HANS RUDOLF, 5530). Particular attention was paid to changes in oxygen consumption during the final work stages, and the maximum respiratory exchange ratio (RER). Heart rate was monitored using a PE3000 Sport Tester. A final blood sample was taken 4 to 5 minutes post exercise, in order to verify the fourth criterion from the BASS guidelines (Figure 4.1), that lactate should be 8 $mmol \cdot l^{-1}$ or more. Subjects remained seated during this time.

4.2.4 Reliability test

To obtain a test-retest correlation coefficient of more that 0.85, as recommended by BASS, 11 subjects were required to return to the laboratory. Volunteers (10 males and 1 female) were re-tested no later than 4 weeks after their initial test so that a change in conditioning level would be minimised. Mean age of male subjects was 28.2±5.01 years, height was 1.81±0.05 m, and weight 78.5±8.77 kg. Only one female returned (age 25 years, 0 months, 1.59 m, 50.1 kg). The same pre-test requirements of the subjects were enforced. Repeat tests were carried out at the same time of day apart from one subject who was unable to do this due to work commitments. Mean values of temperature and humidity were 20.2±2.3 °C and 44.9±7.2% respectively, and did not differ significantly from the first test ($p>0.05$). Exactly the same test procedures were followed as outlined above.

4.2.5 Statistical procedures

If the test passes all of the four criteria in Figure 4.1, BASS consider the $\dot{V}O_2max$ value for that subject to be valid. Each individual was therefore considered separately, although mean and standard deviation values were also calculated. An ANOVA 1-way analysis of variance was used to determine whether differences existed between male and female values. For measurements of plasma lactate 10 samples were used to examine the coefficient of variation *(v)* for the assay. Test-retest correlations were determined by a Pearson product moment correlation coefficient *(r)* and significant differences analysed by a repeated measures ANOVA test with subjects and trials as treatment factors. Statistical significance was accepted for $p<0.05$ for all tests.

4.4 Results

4.4.1 $\dot{V}O_2max$ data

All maximum values for male and female subjects are presented in Table 4.1. Values for males and females did not differ significantly ($p>0.05$) except for maximum oxygen uptake which was significantly higher for male subjects. All data, apart from $\dot{V}O_2max$, was therefore pooled and analysed together.

Seven subjects did not achieve a plateau in the oxygen uptake/exercise intensity relationship as defined by a less than 5% increase in oxygen uptake with an increase in exercise intensity. However the mean percentage increase was less than 5% (2.26±6.40%). The mean value increase in oxygen uptake with an increase in exercise was 1.19±3.17 $ml \cdot kg^{-1} \cdot min^{-1}$ although 9 subjects had an increase of more than 2 $ml \cdot kg^{-1} \cdot min^{-1}$.

Thirteen out of 31 subjects reached a final respiratory exchange ratio of 1.15 or above. The mean maximum value for all subjects was 1.12±0.07. One subject had a final heart rate that was 10 $b \cdot min^{-1}$ below his age related maximum taken as 211 - age. Seven subjects were 10 $b \cdot min^{-1}$ above their age related maximum. Five subjects did not have a post-exercise plasma concentration of 8 $mmol \cdot l^{-1}$ or more. The mean value for all subjects was 9.27±1.32 $mmol \cdot l^{-1}$.

The majority of subjects (n=22) failed on one or more of the criteria set by BASS. Of these, 13 subjects failed on 1 criterion only and 9 subjects did not meet 2 criteria. None of the subjects failed on 3 or more criteria.

Further to these specific criteria for verifying $\dot{V}O_2max$, BASS set other guidelines concerning the test protocol and procedures. For instance, it is recommended that the test should last between 9 and 15 minutes. In this study 5

subjects finished the test prior to 9 minutes, and 6 subjects exercised beyond 15 minutes. Mean time (min.s) for the test was 11.9±2.6 for all subjects.

Table 4.1 Mean, standard deviation and range of maximum values achieved by male and female subjects.

	MALES (n=24)	**FEMALES (n=7)**
$\dot{V}O_2$ ($l \cdot min^{-1}$)	4.53±0.49 (3.92-5.59)	2.77±0.53 (2.01-3.47)
($ml \cdot kg^{-1} \cdot min^{-1}$)	57.9±5.5 (49-71)	43.7±4.8 (35-49)
Heart Rate ($b \cdot min^{-1}$)	188.0±9.1 (168-205)	188.6±10.3 (176-206)
RER	1.12±0.07 (0.98-1.24)	1.10±0.06 (1.03-1.18)
Plasma Lactate ($mmol \cdot l^{-1}$)	9.47±1.30 (7.23-12.75)	8.62±1.28 (7.23-11.00)

BASS recommend that the work intensity in the warm-up should correspond to a value greater than or equal to 2 $mmol \cdot l^{-1}$ of lactate. Mean pre-test plasma lactate concentration ($mmol \cdot l^{-1}$) was 2.84±0.80 (range 1.83-5.51) and resting heart rate ($b \cdot min^{-1}$) was 74.5±13.8 (range 51-101). After the 3 minute warm-up, lactate was 3.81±0.80 (range 2.74-5.16) $mmol \cdot l^{-1}$ and heart rate was 144.1±16.8 (range 116-173) $b \cdot min^{-1}$. No subject had a value less than or equal to 2 $mmol \cdot l^{-1}$ of lactate after their initial warm-up. Only 3 subjects (all males) started at the higher workload 'b' owing to a high heart rate response for all other subjects during the last minute of the warm-up. Individual values of plasma lactate concentration for these 3 subjects were 4.52, 4.10 and 2.80 $mmol \cdot l^{-1}$.

Plasma lactate was analysed in duplicate for 10 individual samples. There was no significant difference in the results and the coefficient of variance *(v)* was 2.5%, less than the upper limit of 3% recommended by BASS.

4.4.2 Re-test data

When using a 2-way ANOVA with subjects and trials as treatment factors, no significant differences were found in any of the measured values (including absolute and relative $\dot{V}O_2$ max, end RER, maximum heart rate, post-exercise plasma lactate concentration, time to complete the test, and resting and warm-up heart rate and plasma lactate concentrations) in the re-test compared to the initial test.

Table 4.2 Reliability results for 11 subjects (10 males, 1 female). *Pearson rank correlation coefficient denoted by 'r'.*

	1st. Test	Re-test	*r*
$\dot{V}O_2$max ($l \cdot min^{-1}$)	4.40±0.85	4.39±0.87	.86
($ml \cdot kg^{-1} \cdot min^{-1}$)	56.8±5.9	55.6±5.5	.86
HR max ($b \cdot min^{-1}$)	189.0±9.4	187.6±11.3	.94
RER max	1.13±0.07	1.14±0.05	.54
Plasma Lactate ($mmol \cdot l^{-1}$)	9.58±1.15	9.21±1.43	.80
Time (min)	11.95±2.89	12.18±2.99	.95

Mean values of all maximum variables achieved in the re-test and in the initial test are given in Table 4.2 including Pearson rank correlation values.

Correlations, in the initial test compared to the re-test for pre-test heart rate and heart rate taken after the warm up, were low (r=0.74 and r=0.70 respectively).

Lactate measurements taken at rest, after the warm-up and post-exercise, also did not show high correlations (r=0.67, 0.47 and 0.41 respectively).

4.5 Discussion

4.5.1 Verification of $\dot{V}O_2max$

Only 9 of all 31 subjects tested (29%) satisfied all 4 criteria set by BASS to verify that $\dot{V}O_2max$ had been achieved. This can partly be explained by a low end RER (mean 1.12±0.07) with 18 subjects having a value less than 1.15. The equipment used to monitor gases might have been the cause, due to not allowing enough gas to flush through the system during calibration after re-connecting the inlet tubes to the gas cylinders. This, however, did not seem to influence any of the other respiratory values measured, and 13 subjects *did* have values in excess of 1.15. If the RER values are accurate, it might be that 1.15 is an unrealistic value for most subjects to achieve. When originally trying to establish effective treadmill protocols for $\dot{V}O_2max$ assessment, the value for RER was reported as being lower than 1.15. Kasch et al. (1976) for instance report a value of 1.09±0.03 for trained subjects tested during inclined treadmill running. The highest value for RER reported by Stamford (1975) when using a variety of test protocols and testing subjects of varying aerobic capacity, was 1.06±2.41 and the lowest was 1.03±7.28. An RER value greater than unity has therefore often been suggested as one of the criteria for $\dot{V}O_2max$ identification (Åstrand and Rodahl, 1986; Fox and Mathews, 1981; MacDougall et al., 1992). In rowing tests RER values have also been lower. Brikci et al. (1980) reported a mean RER of 1.12±0.13 following a continuous incremental $\dot{V}O_2max$ test performed in a rowing tank, and for an all-out 6 minute test, a mean of 0.98±0.27 was found. Only one subject out of a group of 7 rowers tested on both types of test had an RER value of 1.15. In examining seasonal variations in training among 13 oarsmen, Wright et al. (1976) reported respiratory exchange ratios of between 0.98 and 1.16. $\dot{V}O_2max$ was still accepted as valid for all subjects since either a plateau in oxygen consumption defined as a less than 2 $ml \cdot kg^{-1} \cdot min^{-1}$ increase with a further increment of treadmill slope had occurred, or subjects had high final heart rate and/or blood lactate values. This report suggests that individuals vary in response to exercise. Although some athletes might have a low RER value, other criteria for $\dot{V}O_2max$ verification are fulfilled.

A number of subjects (n=7) did not achieve a plateau for $\dot{V}O_2max$, identified by a less than 5% increase in oxygen consumption with an increase in workload. Of these 7 subjects, 6 failed to fully complete the final minute of work. Since the gas analysis system was set up to sample at the end of every 60 second period, the $\dot{V}O_2$

value given did not represent the volume of oxygen consumed for the entire minute, and therefore was lower than expected. Had the athlete been able to continue to the end of the minute, or if the gas analysis system had been set to estimate the value from a sampling of 30 seconds, an extra reading would have been available and a plateau may have been achieved.

Five subjects did not have a post-exercise lactate concentration that was equal to or greater than 8 $mmol \cdot l^{-1}$. Low maximum lactate values are known to occur in subjects who have been depleted of glycogen brought on by either training or a carbohydrate-poor diet (Hughes et al., 1982; Jacobs, 1981; Urhausen and Kindermann, 1992). Although subjects in this study were encouraged to maintain a regular diet and to avoid strenuous exercise before testing, the amount of glycogen available in the muscle may have been low, and although not known, might explain the occurrence of the low lactate concentration in these 5 subjects. Lower lactate values have also been observed in trained athletes as opposed to non-trained subjects even at maximum work intensities (Urhausen et al., 1993). This could explain why 3 of the 5 subjects had low post-exercise lactate concentration values, since these particular subjects were elite rowers who described themselves in the pre-test questionnaire as being highly trained.

The only subject who was 10 $b \cdot min^{-1}$ below their theoretical heart rate maximum was 17 years old. It might be that a value of 211 - age for estimated heart rate is too high for this particular subject.

Clearly not all of the criteria set by BASS may be realistic for all subjects. Some athletes do not exhibit high plasma lactate responses, for instance, in spite of achieving maximum values in other variables. At a BASES physiology workshop, the guidelines were discussed and it was accepted that there was rarely a situation where all criteria were met (MacLaren, 1994). In this study subjects mainly failed on the criteria concerning the RER value, which if the equipment is accurate, seems an unrealistically high ratio.

4.5.2 Reliability data

Of the 11 subjects who returned for the reliability measures, only 3 subjects fulfilled all of the BASS criteria. Subjects tended to fail on the same criteria as they did in their initial test. Two subjects, for instance, had low post-exercise blood lactate concentrations both following their initial test and in the re-test. Four subjects who had an RER value of less than 1.15 in the repeat test, also had low RER values in their initial tests. This again emphasises that subjects vary in how they respond physiologically to maximal exercise. A failure according to the BASS

criteria is therefore more likely to be a result of individual differences rather than a weakness in the design of the protocol.

All measured values taken in the initial test did not differ significantly from those taken in the repeat tests. Correlations for $\dot{V}O_2max$ values were also above a value of r=0.85 as recommended in the BASS guidelines. However, correlations for maximum RER (r=0.54), plasma lactate concentration (r=0.80), and resting and warm-up heart rates (r =0.74 and r=0.70 respectively) were lower than recommended. As already discussed the value for RER may not have been accurate owing to the method of gas analysis. The variance in plasma lactate concentration might again be explained by differences in pre-test substrate availability or prior training load. The resting heart rate was lower in the repeat test (69.7±12.9 b·min^{-1}) than the initial test (76.8±14.9 b·min^{-1}) for all but one subject. Likewise mean heart rate taken in the last minute of the 3 minute warm-up was lower for the re-test (143.3±14.9 b·min^{-1}) compared to the initial test (147.9±18.4 b·min^{-1}). This suggests that subjects were less anxious since they were familiar with test procedures. Familiarity did not seem to affect maximum values of heart rate (Table 4.2).

4.5.3 Additional findings

In addition to examining the test for validity and reliability, BASS also provide recommendations for the test protocol and procedures. It is recommended for instance, that the test should last between 9 and 15 minutes. For this test 8 to 16 minutes would be more appropriate, since the stages last 2 rather than 3 minutes. If such times are acceptable, then only 1 subject stopped the test before 8 minutes. This particular subject weighed 49.6 kg. Subjects who are very light in weight do not achieve favourable 500 m split time scores on the ergometer (Hagerman et al., 1979; Concept II inc., 1992). In rowing or sculling, weight can be compensated for, to some extent, by altering the rigging and/or weight of the boat (Nilson and Nolte, FISA manual; Sanderson and Martindale, 1986; Schwanitz, 1991). However, it is important to allow for differences in weight since rowing has a lightweight category. All other subjects completed the test within 8 to 16 minutes .

BASS recommend that the initial workload should elicit a blood lactate concentration of no more than 2 mmol·l^{-1}. Only 3 subjects started at a workload equivalent to their warm-up load, since end warm-up heart rate for all other subjects was greater than 65% of their theoretical heart rate maximum. For these 3 subjects lactate was above the recommended 2 mmol·l^{-1} concentration level. However, this study measured lactate concentration from plasma rather than from whole blood.

Plasma has been found to give higher values for lactate concentration than whole or lysed blood, both at rest and during exercise (Foxdal et al., 1991: Williams et al., 1992). This would explain the higher than usual values of lactate concentration in this test. When comparing plasma lactate values taken in the last 3 minutes of the warm-up with resting values, means were not much higher (3.81±0.80 mmol·l^{-1} for the warm-up and 2.84±0.80 mmol·l^{-1} at rest) with a correlation of r=0.67. Although values were above the recommended 2 mmol·l^{-1}, this information suggests that the warm-up did not produce values of lactate concentration that had increased greatly from resting values.

The fact that the majority of subjects started on the lower of the two workloads suggests that an even lower work stage, for instance, 2:52 (69 W) for women and 2:13 (150 W) for men could be offered, especially if testing less fit or lightweight rowers. This would ensure that the initial workload would not be too high and would be more likely to elicit 2 mmol·l^{-1} of lactate. Furthermore using 65% of theoretical heart rate maximum only provides a guide to work intensity. A further two subjects would have started at workload 'b', if a true maximum heart rate value had been known prior to testing. The test also used 211 - age as a value of theoretical heart rate maximum. This study found that 215 - age was a more accurate estimate of actual heart rate maximum for the majority of subjects. With this in mind, 65% of maximum heart rate would extend the limit for deciding whether a subject started at stage 'a' or 'b'.

Subjects were asked what they thought about the test protocol. It was generally felt that the initial workload was adequate for warm-up purposes, and was not so demanding as to lead to fatigue prematurely. The range of values at the higher workload also seemed adequate even for the fittest and most elite athlete tested in this study, although an additional workload could be set, such as 1:40 (388 W) for women and 1:32 (416 W) for men. Mean maximum 500 m split time achieved in this test was 1:55 min:s for women and 1:41 min:s for men.

Some subjects expressed a preference for a longer warm-up with a greater time to stretch or prepare for the test. A gradual warm down at the end was also requested. The same amount of time in the warm-up and for rest was given to all subjects so that values could be compared, but consideration of a particular subject's needs is otherwise advisable.

Recording the cumulative distance covered offered a means of verifying the actual split time achieved. Subjects needed little encouragement to maintain the required split time accurately and stayed within a stroke rate of 24 and 32 strokes per minute at all times. In spite of the obvious discomfort in the blood sampling, removing blood from the toe did not appear to have an effect on performance while subjects were rowing.

4.5.5 Summary and recommendations

It is important to be aware that BASS merely set guidelines for exercise testing and variability is expected to occur between subjects for different reasons. Although not all subjects in this study satisfied all 4 criteria set by BASS, the mean values were sufficient to suggest that $\dot{V}O_2max$ could be achieved using this protocol for most rowers. The recommendation for an RER value of above 1.15 might be unrealistic, although in this instance a low value might be explained by an inadequacy in the use of the gas analyser. The test proved to be reliable, with no significant differences found in the re-testing of 11 subjects. With some adjustment, this proposed protocol should therefore be considered valid and reliable for testing male and female rowers with a range of abilities and fitness levels. Figure 4.3 shows a suggested revised protocol with modifications made in light of the discussion.

Figure 4.3 Revised protocol

Women

	500 m Time (min:s)	Power Output (watts)	Increment (watts)
a	2:52	69	-
b	2:34	96	27
c	2:21	123	27
	2:13	150	27
	2:07	177	27
	2:01	203	26
	1:55	230	27
	1:49	256	26
	1:46	283	27
	1:43	311	27
	(1:40)	(338)	(27)

Men

	500 m Time (min:s)	Power Output (watts)	Increment (watts)
a	2:13	150	-
b	2:07	177	27
c	2:01	203	26
	1:55	230	27
	1:49	256	26
	1:46	283	27
	1:43	311	27
	1:40	338	27
	1:37	366	28
	1:34	400	34
	(1:32)	(416)	(16)

Time should be spent on fully familiarising subjects with the test procedures to ensure that anxiety does not elevate resting and warm-up heart rates, which might affect the prediction of the initial work intensity. The theoretical heart rate maximum is calculated by 215 - age. All subjects warm up at level 'c' for 5 minutes. This level is chosen in order to estimate the initial work intensity. If heart rate taken within the last minute of the warm-up is above 75% of theoretical heart rate maximum, then subjects start at level 'a'. If it is between 65% and 75% then subjects start at 'b' and if below 65%, subjects start at 'c'. The initial load should also take into account how subjects rate themselves in terms of fitness and rowing ability. Lightweight rowers may also need to start at a lower work intensity. This greater range and flexibility should ensure that the initial work intensity corresponds to a lactate concentration of 2 $mmol \cdot l^{-1}$ or less.

Stages at higher intensity levels have been added (1:40 for women and 1:32 for men) for fitter, heavier or more experienced athletes. However, for males, the watt increment in these final stage varies. This is because a reduction by a fixed amount for the 500 m split time (1 second for instance) does not correspond to a fixed increment in watts, since the Concept II accounts for the effects of drag in estimating velocity.

A stroke rate of between 24 and 32 strokes per minute should be encouraged during the warm-up and actual test. Cumulative distance travelled, as displayed on the electronic performance monitor, should be recorded at the end of each minute to verify the 500 m split time. If analysing oxygen variables every 60 seconds then subjects should be encouraged to complete a full minute in order to obtain a final reading.

It is recommended that the greater the number of BASS criteria (Figure 4.1) achieved, the greater the chance the $\dot{V}O_2$ value for the particular subject is accurate. If none of the four criteria is achieved, then the $\dot{V}O_2$ value should be described as a peak rather than a maximum value. Less emphasis should be placed on obtaining a final respiratory exchange ratio value of 1.15 or above. A value that is greater than or equal to 1.10 is recommended for club level rowers.

CHAPTER 5

Determination of the highest level of work that can be sustained during prolonged rowing exercise, without an increase in plasma lactate concentration

5.1 Introduction

The aim of the ultimate study is to assess how changing stroke rate affects both physiological variables (namely oxygen consumption, heart rate and lactate), and mechanical variables (stroke length, force and power). Subjects will be required to complete a series of continuous work bouts at a fixed percentage of their maximum oxygen uptake. Stroke rate will vary between 24 and 32 strokes per minute, these being the most commonly reported training and race paces (Herberger et al., 1990; Jensen et al., 1990; Steinacker, 1993). Before undertaking this experiment, a preliminary investigation is necessary to determine values for 'X' and 'Y', where

X = the highest work intensity that can be sustained without an exponential or abrupt increase in lactate concentration, and

Y = the minimum amount of time required by subjects to reach this steady state lactate concentration when exercising at 'X'.

It is assumed that the intensity (X) will correspond to the upper limit of work that can be sustained for prolonged rowing exercise (McLellan and Cheung, 1992; Urhausen et al., 1993). Above this level blood lactate will accumulate at a faster rate than it can be metabolised, and fatigue will soon occur (Brooks, 1985; Heck et al., 1985; Karlsson and Jacobs, 1982; Stegmann et al., 1981; Stegmann and Kindermann, 1982; Wasserman et al., 1973). Although 'X' will differ depending on the aerobic capacity and lactate kinetics of the subject (Keul et al., 1979; Stegmann and Kindermann, 1982), it is the intention to find the minimum level applicable to all subjects tested (P>95%). If 'X' and 'Y' can be attained and all mechanical variables are kept constant, then values for lactate concentration, oxygen consumption and heart rate taken during the last minute of exercise should not differ significantly on repeat tests.

In rowing research the point where lactate begins to increase abruptly is most often obtained by examining changes in ventilatory variables, such as an exponential increase in ventilatory equivalent for oxygen without a corresponding increase in ventilatory equivalent for carbon dioxide (Fukunaga et al., 1986; Mahler et al., 1985). The point where this occurs (VT) is commonly expressed as a percentage of maximum oxygen consumption. Mickelson and Hagerman (1982) testing 25 heavy weight oarsmen of Olympic standard, found that VT occurred at 83.5±5.1% of $\dot{V}O_2$max. Mahler et al. (1984b) tested 8 members of a national rowing squad and found VT to occur between 78±5% and 89±4% of $\dot{V}O_2$max depending on the type of

training predominant at the time of testing. For female collegiate rowers Mahler et al. (1985) reported the intensity to be lower (between 69±3% and 80±2%) but again the level was dependent on current training. Although VT tends to occur before the lactate threshold or before an increase in blood lactate concentration (Neary et al., 1985; Yeh et al., 1983), it gives an indication of the value for 'X'. To accommodate the large standard deviations of the measures given above, a work intensity between 75% and 95% of $\dot{V}O_2$max would therefore appear to be the optimum range for most rowers independent of rowing ability and aerobic conditioning.

Often 3 or 4 minutes is considered an adequate amount of time for lactate concentration to reach steady state, and hence this time period is used for incremental tests when obtaining the work intensity equivalent to OBLA or IAT (Coen et al., 1991; Hale et al., 1988; Sjödin and Jacobs, 1981). However Hagberg (1984) claims that a steady-state lactate concentration is not reached until after 10 minutes of constant exercise. Orok et al. (1989) found that arterialised-venous lactate concentration during a 3 minute progressive exercise test was not representative of the concentration observed during prolonged exercise at the same work rate, especially when near the IAT. They found that lactate levels tended to rise initially, reach a plateau, then decrease, suggesting a delay in lactate uptake and utilisation by the muscle. Other studies support these findings with a blood lactate steady state concentration not occurring until after at least 6 minutes of constant exercise (Foxdal et al., 1994; Heck et al., 1985; Mader, 1991; Rieu et al., 1989).

The purpose of this study is to determine values for 'X' and 'Y'. It is assumed that 'X' will be somewhere between 75% and 95% of $\dot{V}O_2$max, and 'Y' between 4 and 10 minutes of constant work. When exercising at this level, it is hypothesised that values of oxygen consumption, lactate concentration and heart rate will not differ significantly in repeat tests on the same subject.

5.2 Methodology

5.2.1 Subjects

Subjects who took part in the $\dot{V}O_2$ max test (section 4.2.1) were also used for this study. Data for one subject were omitted since equipment failed during testing. Means and standard deviations of age, height and weight for male subjects (n=23) were 27.4±5.8 years, 1.82±0.05 m and 78.9±8.3 kg respectively, and for females (n=7) were 27.7±4.8 years, 1.67±0.06 m and 63.6±8.7 kg. Laboratory temperatures ranged between 18 °C and 22 °C and humidity between 39% and 48%.

5.2.2 Procedures

After completion of the $\dot{V}O_2$max test which was necessary to determine work intensities in the range of 75% to 95%$\dot{V}O_2$max, subjects rested for at least an hour. Following a $\dot{V}O_2$max test, Böning et al. (1984) and Keith et al. (1992) allowed a break of 75 minutes and Hagberg et al. (1981) 25 minutes before their subjects resumed exercise. It was therefore assumed that an hour recovery time was sufficient to allow lactate and heart rate levels to return to pre-test values.

The $\dot{V}O_2$ max test and the tests described here were carried out on the same day, so that subjects would not have the inconvenience of attending the laboratory on two separate occasions. It was assumed therefore, that the protocol for obtaining $\dot{V}O_2$ max produced data that was valid and reliable, although at the time of testing this had not been confirmed.

Subjects attempted to complete 3 sets of 10 minute steady state work bouts at 500 m split times corresponding to 75%, 85% and 95% of their predetermined $\dot{V}O_2$max value. The work intensities were randomly assigned for each subject. An option of stroke rates between 24 and 32 strokes per minute was given, although subjects were encouraged to maintain the same rating throughout each exercise period. The flywheel was set on the larger of the two drive cogs, and the vanes were fully closed. The total distance covered was measured and recorded from the electronic performance monitor of the Concept II, in order to verify that the required intensity (500 m split time) had been achieved. Subjects rested for 15 minutes between successive tests. This amount of time was used in the protocol by Weltman et al. (1990) when examining the validity of a 10 minute constant work protocol for measuring lactate concentration. Subjects remained seated throughout the rest periods.

Oxygen uptake and related physiological variables were sampled continuously and displayed at the end of each minute of exercise using an on-line open-circuit gas analyser (COVOX MICROLAB). Calibration checks were performed within 10 minutes of the start of the test and again on completion. Heart rate was sampled every 15 seconds using a PE3000 Sport Tester. Blood samples were taken pre-test and between 3 and 4, and 9 and 10 minutes of each exercise period. A further sample was taken during the last minute of each 15 minute rest period. This gave a total of 10 samples per subject. If subjects did not complete the full 10 minutes of exercise, a sample was taken as soon as possible after they had stopped. If subjects stopped during sampling, no additional sample was taken. Blood was sampled from the toe and subsequently analysed for lactate concentration from supernatant plasma in accordance with procedures described in section 3.2.4.

5.2.3 Statistical analysis

A 2-way ANOVA was used to examine differences between plasma lactate concentration sampled between 3 and 4 minutes of exercise with that sampled in the last minute of exercise. If the second value of lactate was significantly higher than the first, it was assumed that lactate had not reached a steady state concentration, either because 4 minutes was an inadequate amount of time, or because the intensity of work was too high resulting in an excessive increase in lactate. Individual differences in lactate concentration were also considered. If lactate concentration taken in the tenth minute had increased by 1 $mmol \cdot l^{-1}$ or more compared to that taken in the fourth minute, it was assumed that lactate concentration had not reached steady state for that individual. Urhausen et al. (1993) also used this criterion to determine that a maximum lactate steady state (max Lass) had been reached during prolonged cycling ergometry and treadmill running.

ANOVA analysis of variance tests were used to determine statistical differences in oxygen consumption using subjects, time and workload as treatment factors. Analysis of plasma lactate concentration and oxygen consumption were used together to determine values for 'X' and 'Y'.

All lactate and heart rate values taken pre-test and in the last minute of each 15 minute rest period were analysed using an ANOVA repeated measures test, in order to confirm that adequate time had been given for recovery. The level of significance was set at $p<0.05$ for all tests.

5.3 Results

After one hour of recovery, heart rate at rest differed significantly from resting heart rate taken prior to the $\dot{V}O_2max$ test, although plasma lactate concentrations sampled at the same time did not show significant differences (Table 5.1). None of the resting heart rate values taken in the last minute of each 15 minute recovery (post 75% to 95% $\dot{V}O_2max$) showed any significant differences (Table 5.1). However pre-test heart rate taken at the start of all 10 minute tests was significantly lower than all other resting heart rate values. Resting values of plasma lactate concentration taken during the final minute of the 15 minute rest interval were all significantly higher than those taken before the start of the 10 minute exercise bouts. Resting values also increased significantly according to the prior work intensity as can be seen in Table 5.1.

Table 5.1 Resting plasma lactate concentration and heart rate values for all subjects (n=30).

	Pre-$\dot{V}O_2$ max test	Pre-10 min tests		Last minute of 15 minute recovery following work intensities equivalent to: 75% $\dot{V}O_2$max	85% $\dot{V}O_2$max	95% $\dot{V}O_2$max	
Plasma Lactate Concentration (mmol.l^{-1})	2.84±0.81	3.38±1.14	NS	4.27±1.141	5.36±1.23	6.72±1.55	p=0.000
Heart Rate (b·min^{-1})	73.9±13.6	84.7±14.2	p=0.004	96.5±11.8	101.5±13.5	102.1±12.4	NS

NS = not significant (p>0.05). ANOVA tables are given in Appendix 5.2.

At a work intensity equivalent to 75% $\dot{V}O_2$max, plasma lactate concentration taken between 3 and 4 minutes of exercise did not differ significantly from that taken between 9 and 10 minutes (Table 5.2). Mean values for all subjects were 5.77±1.72 mmol·l^{-1} and 5.44±1.43 mmol·l^{-1} respectively. No subject had an increase in lactate concentration greater than 1 mmol·l^{-1}. At the exercise level corresponding to 85% $\dot{V}O_2$max the 2 values of lactate showed significant differences (Table 5.3). The mean value of lactate taken between 3 and 4 minutes was 5.47±1.76 mmol·l^{-1} and during the last minute was 6.63±1.50 mmol·l^{-1}. An increase of 1 mmol·l^{-1} or more was observed with 14 subjects. Three subjects stopped prior to the end of the test having high concentrations of lactate (up to 9.03 mmol·l^{-1} for one subject).

Table 5.2 ANOVA 2-way analysis of variance for plasma lactate concentration (mmol·l^{-1}) at 75% $\dot{V}O_2$max.

Source	DF	SS	MS	F	p
Subjects	29	124.11	4.28	5.85	0.00
Time of sample	1	1.60	1.60	2.19	0.15
Error	29	21.20	0.73		
Total	59	146.92			

Factors are subjects and time of sample (3 to 4 minutes and 9 to 10 minutes).

Table 5.3 ANOVA 2-way analysis of variance for plasma lactate concentration ($mmol \cdot l^{-1}$) at 85% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
Subjects	29	129.66	4.47	5.13	0.00
Time of sample	1	20.20	20.20	23.19	0.00
Error	29	25.26	0.87		
Total	59	175.11			

Factors are subjects and time of sample (3 to 4 minutes and 9 to 10 minutes).

At 95% $\dot{V}O_2max$, only 5 subjects were able to complete the full 10 minutes. Mean time for all subjects on this test was 6.16±2.35 minutes. Lactate values for all subjects taken between 3 and 4 minutes of exercise compared to those taken either in the last minute of exercise or immediately after the subject had stopped were significantly different. Means were 6.38±1.92 $mmol \cdot l^{-1}$ and 8.31±1.25 $mmol \cdot l^{-1}$ respectively. Only 4 out of all 30 subjects had an increase in lactate concentration of 1 $mmol \cdot l^{-1}$ or less between the sample taken in the fourth minute and the final sample. Four out of the 5 subjects who were able to complete 10 minutes had a lactate concentration increase in excess of 1 $mmol \cdot l^{-1}$.

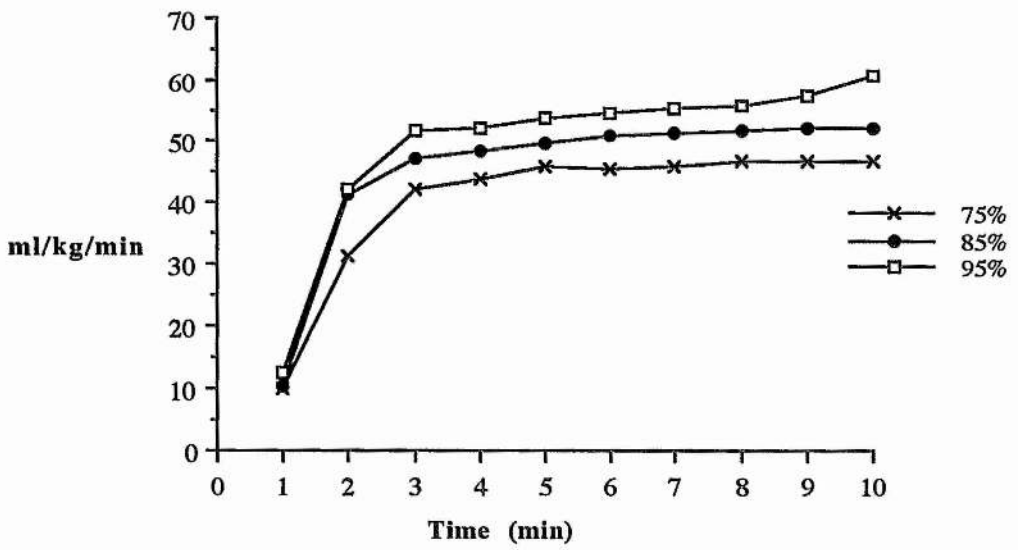
The 2-way ANOVA that examined differences in lactate concentration between individual subjects as well as between the fourth and tenth minute of exercise showed that subjects differed significantly in their lactate response to exercise at all work intensities (Tables 5.2 and 5.3). However, no significant differences were found in heart rates nor lactate concentration values between male and female subjects.

Only two samples of blood were used to determine whether lactate had reached a maximum steady state concentration. This identified those subjects who had a steady state lactate concentration by 4 minutes of exercise, but did not identify subjects who may have reached a steady state somewhere between 4 and 10 minutes. As oxygen consumption was analysed each minute, values were used to help determine 'X' and 'Y' more precisely. When exercising at intensities that are less than the intensity equivalent to the point where lactate increases exponentially, lactate concentration and oxygen consumption show similar trends (Myers et al., 1994). It was therefore assumed that when $\dot{V}O_2$ had reached steady state, lactate might also be near a steady state concentration.

A 3-way ANOVA test showed differences in oxygen consumption values between all three factors of subjects, time and workload. For greater precision, the

oxygen consumption values for the first 3 minutes were not used in subsequent analysis, since it was clear that these figures were very different from those achieved from 4 minutes onwards (Figure 5.1), as a relative steady state had not been reached. The work intensity was also split so that values at the 75% level and 85% level could be analysed independently. An ANOVA 2-way test design was then used, with subjects and time as factors for comparison (Appendix 5.3). The factor of time was analysed by both grouping data (for example all values between 7 and 10 minutes), and by analysing the data collected each minute separately. At the 75% $\dot{V}O_2max$ work intensity, values for oxygen uptake at 6 minutes showed significant differences with values obtained at 7, 8, 9 and 10 minutes analysed both separately and by grouping the data. At 7 minutes values were not significantly different (mean 45.9±6.7 $ml \cdot kg^{1} \cdot min^{-1}$) than those at and between 8 and 10 minutes (grouped mean 46.7±6.7 $ml \cdot kg^{-1} \cdot min^{-1}$). At the 85% level, the values for oxygen consumption at 6 minutes compared to 7 to 10 minutes were significantly different, but again when comparing 7 minutes (grouped mean 51.2±6.5 $ml \cdot kg^{-1} \cdot min^{-1}$) with 8 to 10 minutes (51.9±6.76 $ml \cdot kg^{-1} \cdot min^{-1}$) differences were not significant (Appendix 5.3).

Figure 5.1 Mean values of oxygen consumption at the 3 work intensities



5.4 Discussion

5.4.1 Ten minute tests

The work intensity equivalent to 75% $\dot{V}O_2$max was considered to be below 'X' for most subjects tested. In the last minute of the test lactate values had not increased significantly compared to those taken between 3 and 4 minutes. Individual values showed that for most subjects (n=17) plasma lactate concentration had declined suggesting that lactate removal might not have reached its upper limit after only 3 to 4 minutes of work. This finding supports the conclusion drawn by Orok et al. (1989). At the 85% $\dot{V}O_2$max work intensity, plasma lactate concentration was significantly higher during the last minute of the exercise compared to between 3 and 4 minutes. For 14 subjects the increase in lactate concentration was greater than 1 mmol·l^{-1}. This signifies a non-steady state lactate concentration at 4 minutes of exercise, lactate continuing to increase beyond this time. This also suggests that 85% $\dot{V}O_2$max is above 'X'. Data taken during the work intensity equivalent to 95% $\dot{V}O_2$max was not analysed as it was clear that lactate did not reach a steady state, but was increasing, leading to fatigue after 6 minutes for most subjects.

A steady state in oxygen consumption seemed to occur around 7 minutes when exercising at intensities corresponding to both 75% and 85% of $\dot{V}O_2$max. Figure 5.1 shows an initial increase in oxygen consumption at all work intensities until approximately 3 or 4 minutes into the test, after which values start to plateau. This is more apparent at the 75% $\dot{V}O_2$max workload (Fig. 5.1.1). By 7 minutes it seems that oxygen consumption has reached a steady state level with no further increases occurring at both the 75% and 85% loads (Figures 5.1.1 and 5.1.2). At the 95% $\dot{V}O_2$max load there is a continuous increase in mean oxygen consumption. However, at this load the mean values between 9 and 10 minutes are not representative of all subjects tested, since only 5 subjects were able to complete the full 10 minutes. As these subjects were able to sustain a workload that was close to their maximum, they would be expected to have a greater aerobic capacity and therefore higher values of $\dot{V}O_2$max (Hagerman et al., 1972). This could explain the apparent abrupt increase in oxygen consumption in the final minute of the test at 95% $\dot{V}O_2$max. Although no blood samples were collected to compare 7 minutes with 10 minutes of work, it was assumed that lactate had also reached a steady state concentration at the same time as the steady state in oxygen consumption.

Fig 5.1.1 Mean and standard deviation of oxygen consumption at 75% $\dot{V}O_2max$

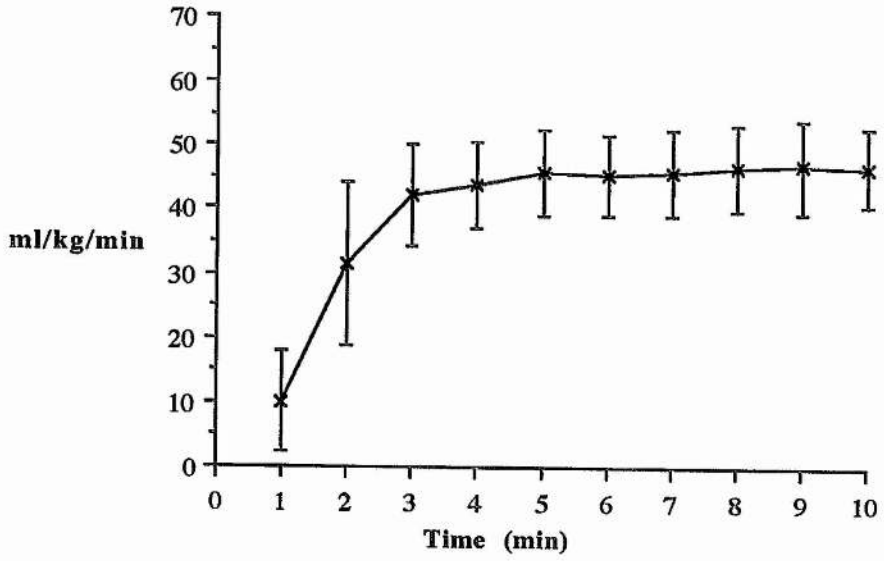


Fig 5.1.2 Mean and standard deviation of oxygen consumption at 85% $\dot{V}O_2max$

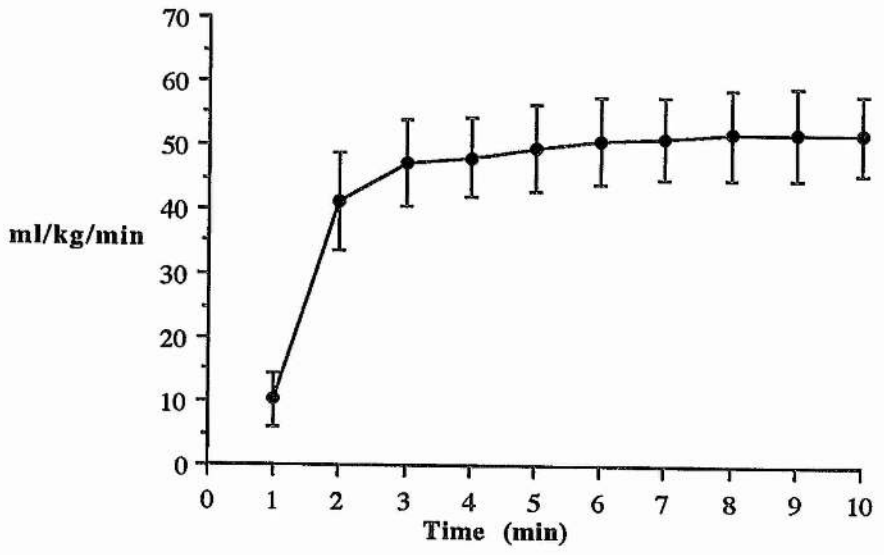
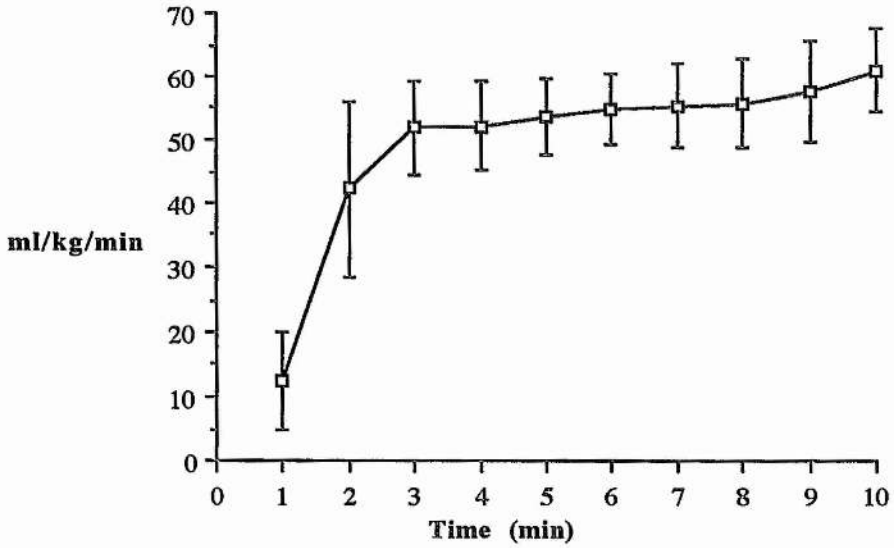


Fig 5.1.3 Mean and standard deviation of oxygen consumption at 95% $\dot{V}O_2max$



From this information it was estimated that the value for 'X' was between 75% and 85% $\dot{V}O_2max$ (80% was selected) and 'Y' at approximately 7 minutes. A further test was carried out in order to help verify these values.

5.4.2 Seven minute 80% $\dot{V}O_2max$ tests

Subjects who returned for the $\dot{V}O_2max$ reliability test (section 4.2.4) were also used for this test. Males (n=10) were aged 28.2±5.0 years, with height 1.81±0.05 m and weight 78.5±8.77 kg. The 1 female subject was 25.0 years, with height 1.59 m and weight 50.1 kg. Following a break of one hour, subjects exercised for 7 minutes at a work intensity corresponding to 80% of their predetermined $\dot{V}O_2max$ value. This was undertaken 3 times with a 15 minute rest period between successive tests. Stroke rate was further confined to between 26 and 28 strokes per minute in order to minimise variability. Blood samples were taken pre-test, in the last minute of each exercise period and in the last minute of the 15 minute rest. Ventilatory variables and heart rate were monitored as before. Laboratory temperatures ranged between 17 °C and 18 °C and humidity between 44% and 53%. All data collected during the last minute of each exercise period and at rest were analysed for statistical significance using a repeated measures ANOVA with trials and/or subjects as treatment factors.

Table 5.4 Mean values for plasma lactate concentration, oxygen consumption, heart rate and cumulative distance rowed taken during the last minute of successive 7 minute tests at 80% $\dot{V}O_2max$.

	TEST 1	TEST 2	TEST 3
Plasma Lactate ($mmol \cdot l^{-1}$)	5.26±1.16	4.87±0.85	5.37±0.89
$\dot{V}O_2$ ($l \cdot min^{-1}$)	3.57±0.69	3.70±0.74	3.88±0.77
Heart Rate ($b \cdot min^{-1}$)	166.2±11.6	170.9±11.5	173±11.5
Total Distance Rowed (m)	1806.2±128.6	1811.8±130.8	1815.2±129.8

5.4.3 Seven minute 80% $\dot{V}O_2max$ tests: results and discussion

All mean values of plasma lactate concentration, oxygen consumption and heart rate are presented in Table 5.4. Using a 2-way ANOVA with subjects and trials as treatment factors, values for oxygen consumption and heart rate taken during the last minute of exercise of the 3 trials showed significant differences (Appendix 5.5). Interaction analysis suggested that variations in these values were due to large differences occurring between subjects as opposed to between successive trials. However, using the same analysis, lactate values did not show any significant differences (Table A5.5.1) with a p value of 0.248. When a 1-way ANOVA was used with only trials as the treatment factor, there were no significant differences in any of the values taken during the last minute of successive trials (Appendix 5.5).

There were no significant differences in all resting values of lactate concentration and heart rate taken in the last minute of the 15 minute rest period. These values compared to the initial resting heart rate taken prior to the tests were also not significantly different (p=0.638 and p=0.360 respectively, Tables A5.5.8 and A5.5.9).

The work intensity was estimated by using 80% of predetermined $\dot{V}O_2max$. By the last minute of the 7 minute tests, the value of oxygen consumption was

slightly higher than this. For the first test oxygen consumption was equivalent to 82.9±3.0% $\dot{V}O_2$max, for the second test was 86.1±3.9% and for the final test was up to 90.1±5.6% $\dot{V}O_2$max. Heart rate taken during the last minute of exercise was 88.6±3.2%, 91.1±3.4% and 92.3±2.9% of heart rate maximum on the three consecutive trials.

Results of the 7 minute tests would seem to confirm that a lactate steady state concentration occurs after 7 minutes of exercise at an intensity equivalent to 80% $\dot{V}O_2$max, since there were no differences found in the lactate concentration values taken during the last minute of 3 successive tests ($p>0.05$). Values of oxygen consumption and heart rate taken at the same time were also not significantly different in successive tests, but only when statistical procedures did not specify individual differences between subjects.

The value of 80% $\dot{V}O_2$max for 'X' is within the intensity range found to be equivalent to the ventilatory threshold among highly trained rowers (Fukunaga et al., 1986; Mahler et al., 1984b; Mickelson and Hagerman, 1982). For females Mahler et al. (1985) found this intensity to be lower with ventilatory threshold occurring at 69±3% $\dot{V}O_2$max in the off-season. In this study a work intensity corresponding to 80% $\dot{V}O_2$max was also achievable by the one female, who was tested on the 7 minute trials and who described herself as 'trained'. Data from subjects in the 10 minute tests found no differences between female and male values. Mahler et al. (1985) suggested that the lower value found in their study was due to the shorter competition distance for women. Prior to 1986 women competed at a distance of only 1000 m compared to 2000 m which is the normal race distance for men and now also for women. Since anaerobic metabolism in a race of 1000 m has been estimated to represent as much as 45% of the total energy requirements (Hagerman et al., 1979) the aerobic capacity of women tested prior to 1985 is likely to have been less well developed. Furthermore, results by Mahler et al. (1985) found that VT occurred at 80±2% during the competitive season. The 10 minute and 7 minute tests described here were conducted from July to September, also coinciding with the competitive regatta season in this country.

The conclusion drawn above that 7 minutes is needed before plasma lactate concentration reaches a steady state suggests that incremental tests of only 3 or 4 minutes' duration are inadequate for measuring OBLA. This agrees with the findings and arguments put forward by other researchers (Foxdal et al., 1994; Hagberg, 1984; Orok et al., 1989). However the statistics used in the study deliberately included differences in lactate and oxygen consumption values between subjects as well as between successive trials, since it was the intention to find a value for 'X' and 'Y' that was representative of all subjects tested. With a 1-way

analysis which did not specify subjects as a treatment factor, oxygen consumption did not differ significantly from 4 minutes onwards at the 75% load and from 5 minutes onwards at the 85% $\dot{V}O_2$max intensity (Appendix Tables A5.4.1 to A5.4.5). Lactate concentrations also did not differ in the fourth minute compared to tenth minute when working at the 75% $\dot{V}O_2$max load. This suggests that 4 minutes might be adequate for determining a steady state concentration for some subjects. A study by Urhausen et al. (1993) found that the work intensity corresponding to the IAT was representative of a maximum steady state (max Lass) for most subjects (26/30 cases). A maximum steady state was defined as an increase in lactate of less than 1 mmol·l^{-1} between blood sampled after 10 minutes of exercise compared with that taken in the final minute of exercise. The method of obtaining the IAT (Stegmann and Kindermann, 1982) involves 3 minute incremental loads. Results of the study by Urhausen et al. suggest that 3 minutes of work can predict an intensity that can be sustained for more prolonged periods (30 to 45 minutes) without further increases in lactate concentration leading to fatigue. However, the IAT is also calculated from the lactate concentration taken during recovery and not solely on values at the end of each 3 minute work stage (Figure 2.1). For this reason Urhausen et al. conclude that the 3 minute incremental IAT method is reliable for predicting lactate concentration for prolonged periods of exercise.

Similarly, Foxdal (1994) also found that an IAT running protocol of 4 minute stages could be accurately used to obtain a running velocity that could be sustained for 50 minutes for 85% of subjects tested without an increase in lactate concentration occurring. However, Foxdal maintained that an 8 minute protocol was even more accurate since 90% of subjects, regardless of training status, were able to complete the 50 minute run without an increase in lactate concentration (defined by a less than 0.03 mmol·l^{-1} increase between consecutive samples taken every 5 minutes).

It seems that although 4 minute protocols can be used to obtain a work intensity that can be sustained for prolonged periods of exercise at a lactate concentration steady state for the majority of subjects tested, stages of longer duration (6 and 8 minutes) give an even better prediction of this work intensity. Furthermore, protocols with 3 or 4 minutes at each stage that also take into account lactate measurements during recovery may also prove as accurate as 6 or 8 minute protocols. The assumptions drawn in this study, that 7 minutes is required before lactate concentration reaches a steady state and possibly only 4 minutes for some subjects, agree with these findings. However, it should be re-emphasised that 7 minutes was required for all subjects tested in this study. Furthermore, the purpose of this study was to find values for 'X' and 'Y' so that further tests could be

carried out. The study did not intend to make any claims concerning these values and how they are related to lactate concentration for longer periods of exercise (more than 10 minutes), nor if values could be used to ascertain training intensities.

A lactate concentration of 4 mmol·l^{-1} has previously been used to obtain a work intensity that can be sustained for prolonged periods of exercise (Heck et al., 1985; Sjödin and Jacobs, 1981). Researchers have shown that a fixed value of 4 mmol·l^{-1} is not suitable for all subjects (Stegmann and Kindermann, 1982). Values of lactate at an exercise intensity equivalent to 80% $\dot{V}O_2$max in this study ranged widely from 3.85 to 7.01 mmol·l^{-1} confirming that lactate concentration does differ according to the individual's lactate kinetics.

In the 7 minute tests at 80% $\dot{V}O_2$max a 15 minute rest period between successive tests appeared adequate for plasma lactate concentration and heart rate to return to pre-test levels (Appendix A5.5.8 and A5.5.9). When exercising at an intensity higher than 80% $\dot{V}O_2$max for longer than 7 minutes, 15 minutes did not prove to be an adequate rest interval (Table 5.1). The order in which subjects performed the 10 minute tests equivalent 75%, 85% and 95% $\dot{V}O_2$max was randomly assigned. This might have influenced plasma lactate concentration, heart rate and oxygen consumption values. For instance, when starting with the 95% $\dot{V}O_2$max intensity, plasma lactate concentration might not have returned to resting values before the subject had to start the next 10 minute work bout. This was demonstrated with the 3 subjects who were unable to complete the full 10 minutes at a work intensity equivalent to 85% of $\dot{V}O_2$max. Subjects exercised at this intensity after having both completed 10 minutes at 75% $\dot{V}O_2$max and having attempted the 95% $\dot{V}O_2$max workload. Individual lactate concentration values were high (up to 9.03 mmol·l^{-1} for one subject). This suggests that 15 minutes is an inadequate recovery time when the preceding work is as high as 95% $\dot{V}O_2$max.

In the 7 minute tests values of plasma lactate concentration and heart rate taken one hour after the $\dot{V}O_2$max test had returned to their original pre-test values. This suggests that one hour is an adequate time period following a $\dot{V}O_2$max test. However, heart rate taken before the 10 minute tests was still significantly elevated compared to the heart rate taken prior to the $\dot{V}O_2$max test. This might be explained by an arousal effect on heart rate, since lactate concentration values *had* returned to their pre-test level.

The $\dot{V}O_2$max test proved satisfactory for establishing workloads equivalent to between 75% and 95% of $\dot{V}O_2$max. However, mean values of oxygen consumption taken in the last minute of the 7 minute tests were higher than the estimated 80% $\dot{V}O_2$max. The prior $\dot{V}O_2$max test involved 2 minutes of exercise at

each work intensity. Oxygen consumption taken at the end of 2 minutes is unlikely to be the same as that taken at the end of 7 minutes since oxygen consumption may not have reached steady state, as previously discussed. This explains why the actual percentage of maximum was higher (up to 90.1% by the final test) than 80%. Furthermore, the increase could be explained by a higher work intensity in successive trials. The mean total distance rowed in the third trial was approximately 9 m further than the mean distance achieved in the first trial (Table 5.4). Mean oxygen consumption values in the last minute of each test nor mean distance rowed did not, however, differ significantly in repeat trials (Tables A5.5.4 and A5.5.7).

This study has shown that in order to analyse the effect stroke rate has on physiological and mechanical variables, subjects could exercise at an intensity equivalent to 80% $\dot{V}O_2$max for 7 minutes. Any significant differences that are found to occur in plasma lactate concentration, heart rate and oxygen consumption taken during the last minute of successive tests will more likely be a result of the variation in stroke rate than any other variable, as long as 15 minutes is given as a recovery interval and at least one hour is given after the $\dot{V}O_2$max test.

CHAPTER 6

Direct measurements of force, stroke rate and stroke length from the Concept II rowing ergometer using computerised instrumentation

6.1 Introduction

Mechanical components of the rowing stroke thought to be important in enhancing boat progression are force, power, stroke rate and stroke length (Fukunaga et al., 1986; Martin and Bernfield, 1980; Nolte, 1991; Sanderson and Martindale, 1986). These components can, to some extent, be maximised by altering the rigging, but are largely dependent on the rower. Since there is little adjustment of moveable parts on the rowing ergometer, estimated velocity is more dependent on the subject. The studies described in this work (Chapters 3 to 5) used 500 m split time of the Concept II rowing ergometer as a guide to work intensity. The electronic performance monitor from which this information is obtained also displays a value for stroke rate ($str.min^{-1}$), but does not give information about other components of velocity, such as force applied to the handle and the length of stroke. Enforced changes in stroke rate might influence how the subject uses force and stroke length to maintain the same power output. This has not previously been analysed. To examine this effect, a system was needed that could measure all mechanical variables accurately, including stroke rate, stroke length, force at the handle, and mean and peak values of power.

Instrumentation to measure mechanical components of rowing directly has been developed in previous studies (Kinch et al., 1993; Lormes et al., 1993). Lormes et al. (1993) modified the Concept II rowing ergometer, measuring force on the handle by a strain gauge, and displacement by a proportional transducer connected via a sprocket wheel to the chain. Signals were analogue-digital converted and power calculated post-test on a personal computer. Results of 11 trained rowers (6 males and 5 females) showed that calculated power from the electronic performance monitor of the Concept II was 6.8% (range 3.2% - 7.8%) lower than the direct method of measuring power. They concluded that using measurements from the electronic performance monitor could influence calculations of metabolism. This emphasises the importance of analysing mechanical variables directly if a thorough understanding of stroke mechanics and rowing physiology is required.

Kinch et al. (1993) like Lormes et al. (1993), measured force via a strain gauge, but displacement was measured by recording photoelectrically the distance the seat moved. Problems in this latter measurement were observed, with stroke length being over-estimated by approximately 15%. Kinch et al. (1993) concluded that their system of analysing forces applied during the rowing stroke needed to be improved in order to gain a greater understanding of rowing.

The aim of this study is to design instrumentation that will produce accurate data about stroke length, stroke rate, force and power. The principles and recommendations of the two aforementioned studies will be taken into account, and

a slightly different method of obtaining stroke length will be examined. The instruments will be developed with simplicity in mind both for use and adaptation by other investigators faced with the same problem of obtaining accurate mechanical measurements.

6.2 Instrumentation

6.2.1 Force

To measure force, a strain gauge was attached between the chain and handle (Figure 6.1). This consisted of a tension transducer constructed from aluminium toroid and foil strain gauges (RA 632-146) attached at upper and lower surfaces and connected as a wheatstone bridge (Appendix 4, Figure A4.2). A universal joint prevented twisting so that force was measured in a vertical direction only. The strain gauge and joint added a total of 90 mm to the chain length. Dimensions of the box containing the gauge were 50 mm x 55 mm x 25 mm. The strain gauge was connected via a suspended cable to an amplifier (RS 435 692). Calibration was possible by suspending weights and adjusting gain potentiometers within the amplifier.

6.2.2 Stroke length

A sprocket was connected to the chain inferior to the point where the chain slide appears from the monorail (Figure 6.2). The sprocket was fitted in such a way as to create minimal resistance and interference with the rowing action. A panel mounted rotary position sensor (RS 187 337) to measure vertical displacement of the handle was linked to the sprocket (Appendix 4, Figure A4.3). The number of pulses digitally counted by computer was related to the distance the handle moved. One revolution of the sprocket (25 pulses) translated to a movement of the handle of 23.25 mm. A D-type flip-flop (LS74) provided information about the direction of handle displacement. A value for stroke rate was also obtainable from this information.

Information was fed into a data acquisition card (LPM16 - 16 analogue channels and 16 digital input/output channels). This was mounted into the ISA bus of a DCS 286 Turbo PASCAL IBM compatible computer via a DB25-way connector (Figure 6.3 and Figure A4.1). Force signals were converted from analogue into a 12 bit binary number. Pulses relating to stroke length were counted digitally. A measurement of mean power was possible from integrating under the curve of a force/time graph.

Figure 6.1 Force strain gauge.

Figure 6.2 Rotary position sensor attached via sprocket to ergometer.

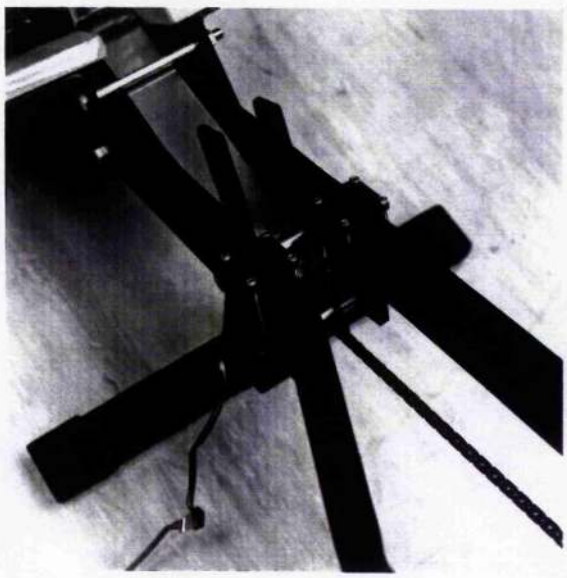


Figure 6.3 Lay-out of all instrumentation.

6.3 Discussion and Research Implications

Although the equipment was designed and made, unforeseen problems in calibration delayed the computerised instrumentation from being tested on subjects. One problem that occurred concerned the measurement of stroke length. At the finish of the stroke on the ergometer, rowers tend to move their hands in a circular motion (Pannell, 1979), imitating the action that is required for extracting the blade from the water. Additional pulses were counted at the change in direction of the handle due to this circular motion. This tended to over-estimate the value for stroke length. Further developments in the software were also required to make it suitable for the user.

In spite of these problems the method and principals used to obtain stroke length and force directly have implications for future studies. The computerised instrumentation once fully developed and calibrated, would allow post-test analysis of stroke length, force and a direct measurement of power throughout a period of exercise. Specifically, this information could be used to examine how mean and peak values of stroke length and force alter as a result of a change in stroke rate. To maintain the same work intensity (500 m split time) it is hypothesised that either stroke length and force, or both, will be altered to compensate for the stroke rate change (Martindale and Robertson, 1984; Zatsiorsky and Yakunin, 1991).

The effect of stroke rate on physiological variables could also be examined if both mechanical and physiological variables could be measured simultaneously. This would allow for the establishment of a regression equation to relate stroke rate with oxygen consumption, heart rate and lactate concentration. This could then be utilised as an effective index for evaluating performance and technical efficiency. The more efficient rower, for instance, might increase stroke length rather than stroke rate or force applied to the handle in order to increase power output or speed. A stroke rate that is optimal in terms of energy cost (a lower oxygen consumption and lactate concentration) for a given power output could be established and hence used for training purposes. It is hypothesised that there is an optimally efficient stroke rate, and exercising above this rate will lead to an abrupt or exponential increase in blood lactate concentration.

From the previous study (Chapter 5) it was established that subjects could work at an intensity equivalent to 80% of their predetermined $\dot{V}O_2max$ for 7 minutes without a significant difference in lactate concentration, oxygen consumption or heart rate occurring during the last minute of successive trials. Hence, if subjects worked at this intensity, but stroke rate was altered (for example, 24, 28 and 32 strokes per minute), any significant differences in blood lactate concentration, oxygen consumption and heart rate would more likely be due to the

change in stroke rate or the effect of changing stroke rate on the other mechanical variables of the stroke.

Not only will this computerised information allow for such an experiment, but it also provides a means of calibration, which the electronic performance monitor of the Concept II presently does not do.

CHAPTER 7

Summary and concluding remarks

Removing blood from the tip of the toe was considered to be a reasonable solution to the problem of obtaining a blood sample for lactate analysis without interrupting the rowing action. Results of the study described in Chapter 3 confirmed the hypothesis that no significant differences ($p>0.05$) in plasma lactate concentration existed between samples taken from the toe with those from the earlobe and fingertip, the two most commonly used blood sampling sites. The toe could therefore be used as a valid site for assessing the amount of lactate accumulation during rowing. Results also suggested that the toe gave a good indication of overall distribution of lactate since the legs and lower body were as equally involved in the rowing action as the upper body and arms. Furthermore, the toe proved to be less sensitive for the subjects than removing blood from the fingertip.

Certain logistical problems became apparent in this initial study. Inexperience at taking the sample meant that the time taken for collection was longer than usually recommended (mean 1.12±0.25 min.s). The experimenter must be able to position him/herself in such as way as to avoid interference with the rowing action, yet should be close enough to the subject to keep the toe still and firm during the stab of the lancet and throughout the sampling. Once this skill was mastered, the time taken for the collection was considerably reduced, taking only 20 to 30 seconds in the later studies described in Chapters 4 and 5.

The study described in Chapter 4 involved designing a $\dot{V}O_2max$ test on the Concept II rowing ergometer. It was felt that present tests used for $\dot{V}O_2max$ assessment on this type of ergometer were inadequate, either because they had not been scientifically and objectively scrutinised or because they were in principal lactate tests and did not comply to guidelines usually adopted for $\dot{V}O_2max$ tests. If a valid and reliable test was to be designed, the study had to be extensive, involving oarsmen and women of varying rowing experience and aerobic conditioning. It was proposed that the protocol could also be used for non-rowers, as long as individuals were familiar with the Concept II rowing ergometer and regularly used this mode of exercise as part of their training. Inefficiency in the rowing action could suppress performance and thus prevent a true $\dot{V}O_2max$ from being attained. A thorough warm-up or even a duplicate test a few days in advance of the actual test would therefore be a logical recommendation as a prerequisite for non-rowers.

The test protocol did not comply to BASS recommendations (Hale et al., 1988) for testing elite athletes, since the step increments were of 2 minutes in duration and the test lasted between 8 and 16 minutes (mean 11.9±2.6 min). The warm-up was at a higher intensity than recommended, but was used so that an initial work intensity, corresponding to a blood lactate concentration of 2 $mmol \cdot l^{-1}$ or less,

could be calculated. In spite of this, the work intensities selected seemed to provide a large enough range to cater for the differences in rowing experience and aerobic conditioning of the subjects tested in this study. To cater for non-rowers and for differences in size and weight of subjects, recommendations were put forward for additional 500 m split times at both lower and higher work intensities.

Twenty nine percent of subjects satisfied all 4 criteria proposed by BASS to verify that a true $\dot{V}O_2$max had been achieved. This apparent low percentage could not solely be explained by inadequacies in the method of gas analysis, nor in discrepancies among subjects, but may be because the criteria set by BASS, especially concerning the RER value, are unrealistic. In spite of having low RER values, most subjects achieved a plateau for $\dot{V}O_2$max identified by a less than 5% increase in oxygen consumption with an increase in workload. Low values of lactate after maximal exercise were explained by nutritional status, prior training load or physical conditioning of the athlete. It was recommended that an RER value closer to 1.10 is preferred as a criterion for $\dot{V}O_2$max achievement. The test gave reliable results for $\dot{V}O_2$max, and no significant differences were found for all measured variables, for the 11 subjects who were re-tested. Of additional interest was the finding that maximum heart rate was closer to 215-age for most subjects when exercising on the ergometer as opposed to the 220-age usually quoted for other exercise modes, or 211-age as recommended in a recent study relating to rowing by Lakomy and Lakomy (1993). In light of the results, modifications were made to the design of the $\dot{V}O_2$max test protocol to produce a test which is valid and reliable for measuring $\dot{V}O_2$max using the Concept II rowing ergometer.

The study described in Chapter 5 attempted to establish a work intensity that corresponded to a maximum or near maximum steady state lactate concentration. The objective was also to find the minimum time required for this steady state lactate concentration to be reached. Results suggested that exercising for 7 minutes at an intensity equivalent to 80% $\dot{V}O_2$max would produce values of lactate concentration, heart rate and oxygen consumption that did not differ significantly in repeat tests, as long as 15 minutes was given as a rest interval.

To examine the effect of stroke rate change on the mechanical variables of force on the handle, stroke length and power, which are considered to be essential elements of boat progression, a method of direct and precise analysis was also required. The design of a computerised system as reported in Chapter 6 was initiated.

With clarification of test procedures it is now possible to test the hypothesis that stroke rate has an effect on mechanical and physiological variables. This hypothesis has important implications for the rower. For instance, as in cycling and

swimming, there may be an optimal or more efficient stroke rate according to work intensity, and to the individual. When competing, selecting this optimal stroke rate might enhance performance, since the rower will be able to exercise at the highest possible intensity without an excessive accumulation of lactate.

An additional study that may be possible as a result of this research concerns the establishment of blood lactate concentration levels by non-invasive methods, such as using heart rate (Korzeniowski, 1987), or, as has been more recently investigated, the critical power (CP). CP represents the maximum power output that can be sustained for prolonged periods of time without a substantial contribution from anaerobic processes, and has been used to estimate the IAT (McLellan and Cheung, 1992). The main advantage of using CP over the IAT is that no blood sampling is required.

This study has several limitations that could also induce further research. A greater number of subjects and a wider range of work intensities could have been used when examining differences in blood lactate concentration between the ear, finger and toe. This could have improved the validity of the data. Experience in taking blood samples, especially from the toe, and the use of an automated analyser, may have reduced the time required for sampling and lactate analysis in this initial investigation (Chapter 3).

The research contained several assumptions. In chapter 3 it was assumed that a relative intensity of estimated maximum heart rate could be used to establish work intensity, rather than oxygen consumption, which may have given a more accurate measurement. In determining steady state in Chapter 5, changes in oxygen consumption were assumed to represent changes in lactate concentration. It would have been preferable to measure lactate concentration throughout the entire test rather than at only the fourth and tenth minutes of exercise. Blood sampling every 2 minutes, for instance, would have given a more accurate indication of when steady state was reached.

Due to problems of calibration, the equipment used to measure stroke length was not fully tested and delayed the progression of further investigation. As a generally point, all information produced in this study relates to the Concept II rowing ergometer. Different results may be apparent when testing on water.

REFERENCES

Affeld, K., Schichl, K. and Ziemann, A. (1993). Assessment of rowing efficiency. *International Journal of Sports Medicine*, **14**, Suppl. 1, S39-S41.

Andrea, B, Ward, J.L. and Mahler, D.A. (1986). Comparison of exercise performance on rowing and cycling ergometers. *Medicine and Science in Sports and Exercise.*, **18**, 58. Abstract.

Åstrand, P.-O. and Rodahl, K. (1986). *Textbook of Work Physiology. Physiological Bases of Exercise.* International Edition:McGraw-Hill.

Bassett, D. R. Smith, P.A. and Getchel, L.H. (1984). Energy cost of simulated rowing using a wind-resistance device. *The Physician and Sports Medicine*, **12** (8) 113-118.

Beaver, W.L.K., Wasserman, K. and Whipp, B.J. (1986). A new method for detecting anaerobic threshold by gaseous exchange. *Journal of Applied Physiology*, **60**, 2020-2027.

Bishop, P.A., May, M., Smith, J.F., Kime, J., Mayo, J. and Murphy, M. (1992). Influence of blood handling techniques on lactic acid concentrations. *International Journal of Sports Medicine*, **13** (1), 56-59.

Bloomfield, J. and Roberts, A.D. (1972). A correlation and trend analysis of strength and aerobic power scores in the prediction of rowing performance. *Australian Journal of Sports Medicine*, **4**, 25-36.

Böning, D., Gönen Y. and Maassen, N. (1984). Relationship between workload, pedal frequency and physical fitness. *International Journal of Sports Medicine*, **5**, 92-97.

Brikci, A, Saidi, D., Belleville, J. and Helal, H. (1980). Comparaison de 3 épreuves de détermination de la consommation maximale d'oxygène effectuées chez des rameurs (Comparison of 3 methods of determining maximum oxygen uptake in rowers). *Médicine du Sport*, **54** (4), 227-231.

Brien, D.M. and McKenzie, D.C. (1989). The effect of induced alkalosis and acidosis on plasma lactate and work output in elite oarsmen. *European Journal of Applied Physiology and Occupational Physiology*, **58** (8), 797-802.

Brooks, G.A. (1985). Anaerobic threshold: review of the concept and directions for the future. *Medicine and Science in Sports and Exercise*, **17** (1), 22-31.

Buchanan, M. and Weltman, A. (1985) Effects of pedal frequency on $\dot{V}O_2$ and work output at Lactate Threshold (LT), fixed blood lactate concentrations of 2 mM and 4 mM, and max in competitive cyclists. *International Journal of Sports Medicine*, **6** (3), 163-168.

Bunc, V., Heller, J., Leso, J., Sprynarova, S. and Zdanowicz, R. (1987). Ventilatory threshold in various groups of highly trained athletes. *International Journal of Sports Medicine*, **8** (4), 275-280.

Buono, M and Yeager, J. (1986). Intraerythrocyte and plasma lactate concentrations during exercise in humans. *European Journal of Applied Physiology*, **55**, 326-329.

Caiozzo, V.J., Davis, J.A., Ellis, J.F., Azus, J.L., Vandagriff, R., Prietto, C.A. and McMaster, W.C. (1982). A comparison of gas exchange indices used to detect the anaerobic threshold. *Journal of Applied Physiology*, **53** (5), 1184-1189.

Carey, P., Stensland, M. and Hartley, L.H. (1974). Comparison of oxygen uptake during maximal work on the treadmill and rowing ergometer. *Medicine and Science in Sports and Exercise*, **6** (2), 101-103.

Celentano, F., Cortili, G., Di Prampero, P.E. and Cerretelli, P. (1974). Mechanical aspects of rowing. *Journal of Applied Physiology*, **36** (6), 642-647.

Chénier, D. and Léger, L. (1991). Mesure du $\dot{V}O_2$max sur deux ergomètres-avirons et sur l'eau en skiff. *Canadian Journal of Sports Science* , **16** (4), 258-263.

Coen, B. Schwarz, L., Urhausen, A. and Kindermann, W. (1991). Control of training in middle and long-distance running by means of the individual anaerobic threshold. *International Journal of Sports Medicine*, **12** (6), 519-524.

Concept II, inc. (1992). *World Ranking Figures*, 7th Annual Edition.

Cunningham, D.A., Goode, P.B. and Critz, J.B. (1975). Cardiorespiratory responses to exercise on a rowing and bicycle ergometer. *Medicine and Science in Sports*, 7 (1), 37-43.

Davis, J.A., Vodak, P., Wilmore, J. H., Vodak, J. and Kurtz, P. (1976). Anaerobic threshold and maximal aerobic power for three modes of exercise. *Journal of Applied Physiology*, **41**, 544-550.

Davis, H.A., Bassett, J., Hughes, P. and Gass, G.C. (1983). Anaerobic threshold and lactate turnpoint. *European Journal of Applied Physiology*, **50**, 383-392.

Davis, J.A. (1985). Anaerobic threshold: review of the concept and directions for the future. *Medicine and Science in Sports and Exercise*, **17** (1), 6-18.

di Prampero, P.E. (1986). The energy cost of human locomotion on land and in water. *International Journal of Sports Medicine*, **7**, 55-72.

di Prampero, P.E., Cortili, G, Celentano, F. and Cerretelli, P. (1971). Physiological aspects of rowing. *Journal of Applied Physiology*, **31** (6), 853-857.

Doherty, M. (1992). Practical applications of lactate testing - Rowing. *Coaching Focus*, **July**, 7-9.

Douglas, C.G. and Haldane, J.S. (1905). The regulation of normal breathing. *Journal of Physiology*, **xxxviii**, 420-440.

Droghetti, P., Jensen, K. and Nilsen, T.S. (1991). The total estimated metabolic cost of rowing. *FISA Coach*, **2** (2), 1-4.

Dunbar, J. (1991). Lactate explained (Part 2). *Peak Performance*, **November**, 4-8.

Dunbar, G.M.J., Heagarty, R., Warrington, G and White, J. (1995) The effects of different protocols on heart rate and lactate values during graded exercise tests for middle-distance runners. BASES Conference Communications. *Journal of Sports Sciences*, **13** (1), 25-26.

El-Sayed, M.S., George, K.P., Wilkinson, D., Mullan, N., Fenoglio, R. and Flannigan, J. (1993). Fingertip and venous blood lactate concentration in response to graded treadmill exercise. *Journal of Sports Sciences* , **11**, 139-143.

Farrell, P.A., Wilmore, J., Coyle, E., Billing, J. and Costill, D. (1979). Plasma lactate accumulation and distance running performance. Medicine and Science in Sports, 11 (4), 338-344.

Farrell, S.W. and Ivy, J.L. (1987). Lactic acidosis and the increase in $\dot{V}E/\dot{V}O_2$ during incremental exercise. *Journal of Applied Physiology*, **62** (4), 1551-1555.

Forrest, A.R.W., Morton, S. and Lambardarios, C. (1990). Blood or plasma lactate? *British Journal of Sports Medicine*, **24** (2), 132.

Fox, E.L. and Mathews, D.K. (1981) *The Physiological Basis of Physical Education and Athletics*, 3rd. Edition: CBS College Publishing, p181.

Foxdal, P. Sjödin, B. Rudstam, H., Östman, C., Östman, B. and Hedenstierna, G.L. (1990). Lactate concentration differences in plasma, whole blood, capillary finger blood and erythrocytes during submaximal graded exercise in humans. *European Journal of Applied Physiology*, **61**, 218-222.

Foxdal, P., Sjödin, A., Östman, B. and Sjödin, B. (1991). The effect of different blood sampling sites and analyses on the relationship between exercise intensity and 4.0 $mmol.l^{-1}$ blood lactate concentration. *European Journal of Applied Physiology and Occupational Physiology*, **63** (1), 52-54.

Foxdal, P. (1994). *Prediction of Maximal Lactate Steady State Using Incremental Blood Lactate Accumulation Tests with Emphasis on Methodological Problems*. Comprehensive Summaries of Upsala Dissertations from the Faculty of Medicine, 502.

Foxdal, P., Sjödin, B., Sjödin, A. and Östman, B. (1994). The validity and accuracy of blood lactate measurements for prediction of maximal endurance running capacity. *International Journal of Sports Medicine*, **15** (2), 89-95.

Fritsch, F. (1985). Trainingssteuerung im Rudern. *Rudersport*, **34**: Trainerjournal 80:I-XI.

Fukunaga. T., Matsuo, A., Yamamoto, K. and Asami, T. (1986). Mechanical efficiency in rowing. *European Journal of Applied Physiology and Occupational Physiology*, **55** (5), 471-475.

Gaesser, G.A. and Poole, D.C. (1986). Lactate and ventilation thresholds: disparity in the course of adaptation to training. *Journal of Applied Physiology*, **61**, 999-1004.

Hagberg, J.M., Mullin, J.P. Giese, M. D. and Spitznagel, E. (1981). Effect of pedalling rate on submaximal exercise response of competitive cyclists. *Journal of Applied Physiology*, **51**, 447-451.

Hagberg, J.M. (1984). Physiological implications of the lactate threshold. *International Journal of Sports Medicine*, Supplement, 106-109.

Hagerman, F.C. and Howie, G.A. (1971). Use of certain physiological variables in selection of the 1967 New Zealand crew. *Research Quarterly*, **42**, 264-273.

Hagerman, F.C., Addington, W.W. and Gaensler, E.A. (1972). A comparison of selected physiological variables among outstanding competitive oarsmen. *Journal of Sports Medicine and Physical Stress*, **12**, 12-22.

Hagerman, F.C., Connors, M.C., Gault, J.A., Hagerman, G.R. and Polionski, W.J. (1978). Energy expenditure during simulated rowing. *Journal of Applied Physiology*, **45** (1), 87-93.

Hagerman, F.C., Hagerman, G.R. and Mickelson T.C. (1979). Physiological profiles of elite rowers. *The Physician and Sports Medicine*, **7** (7), 74-83.

Hagerman, F.C. (1984). Applied physiology of rowing. *Sports Medicine*, **1**, 303 - 326.

Hagerman, F.C. and Mansfield, M.C. (1984). A comparison of energy cost and mechanical efficiency at identical power outputs between a mechanical variable-resistance rowing ergometer and a mechanical fixed-resistance bicycle ergometer. *Medicine and Science in Sports and Exercise*, **16**, 125. Abstract.

Hagerman F.C. and Hagerman, M.T. (1990). A comparison of energy output and input among elite rowers. *FISA Coach* , **1** (1), 5-8.

Hahn, A.G., Tumilty, D.M., Shakespear, P., Rowe, P. and Telford, R.D. (1988). Physiological testing of oarswomen on Gjessing and Concept II rowing ergometers. *Excell* , **5**, 19-22.

Hale, T., Armstrong, N., Hardman, A., Jakeman, P., Sharp, C. and Winter, E. (1988). *Position Statement on the Physiological Testing of the Elite Competitor.* Leeds: British Association of Sports Sciences, 2nd Edition.

Harris, R and Dudley, G. (1989). Exercise alters the distribution of ammonia and lactate in the blood. *Journal of Applied Physiology*, **66**, 313-317.

Hartmann, U., Mader, A. and Hollman, W. (1990). Heart rate and lactate during endurance training programmes in rowing and its relation to the duration of exercise by top elite rowers. *FISA Coach*, **1** (1), 1-3.

Heck, H., Mader, A., Hess, G., Müche, S., Müller, R and Hollmann, W. (1985). Justification of the 4-mmol/l lactate threshold. *International Journal of Sports Medicine*, **6**, 117-130.

Henderson, T. and Haggard, H.W. (1925). The maximum of human power and its fuel. *American Journal of Physiology*, **72**, 264-482.

Herberger, E., Beyer, G., Harre, D., Kruger, H-O, Querg, H. and Sieler, G. (1990). *The GDR Textbook of Oarsmanship*. 4th Updated Edition: Toronto, Sport Books Publisher.

Hollings, S., Robson, G., Hadfield, L. and Ready, J. (1989). Lactic acid and power output: a comparison between New Zealand elite and colt rowers. *New Zealand Journal of Sports Medicine*, **17** (1), 5-7. Abstract.

Hollmann, W. (1988) Allgemeine Sportmedizinische Aspekte zum Rudern. In J.M. Steinacker (Ed.). *Rudern, Sportmedizinische und Sportwissenschaftliche Aspekte.* Berlin, Heidelberg, New York: Springer-Verlag, pp15-17.

Hughes, E.F., Turner, S.C. and Brooks, G.A. (1982). Effects of glycogen depletion and pedalling speed on "anaerobic threshold". *Journal of Applied Physiology*, **52**, 1598-1607.

Jackson, R.C. and Secher, N.H., (1976). The aerobic demands of rowing in two Olympic rowers. *Medicine and Science in Sports and Exercise*, **8** (3), 168-170.

Jacobs, I. (1981). Lactate, muscle glycogen and exercise performance in man. *Acta Physiologica Scandinavian Supplementum*, **495**, 1-35.

Jacobs, I. (1986). Blood lactate: implications for training and sports performance. *Sports Medicine*, **3**, 10-25.

Jensen, R.L. (1989). Relationship of peak blood lactate to decrease in power during 6 minute rowing exercise. *Medicine and Science in Sports and Exercise*, S34, Abstract.

Jensen, K. Nilsen, T.S. and Smith, M. (1990). Analysis of the Italian national training programme for rowing. *FISA Coach*, **1**(2), 1-5.

Jensen, R.L. and Katch, F.I. (1991). A new approach to rowing ergometry: establishing exercise intensity relative to maximum force output. *European Journal of Applied Physiology*, **62** (1), 44-48.

Jensen, R.L., Freedson, P.S. and Hamill, J. (1991). Predicting near-maximal rowing power and economy. *Medicine and Science in Sports and Exercise*, S166, Abstract.

Johnson, M., Leutkemeier, J. and Basset, S.H. (1991). Differences between simultaneous finger puncture and antecubital venous post-exercise lactate values. *International Journal of Sports Medicine*, **12**, 343. Abstract.

Karlsson, J. and Jacobs, I. (1982). Onset of blood lactate accumulation during muscular exercise as a threshold concept. Theoretical considerations. *International Journal of Sports Medicine*, **3**, 190-201.

Kasch, F.W., Wallace J.P., Huhn, R.R., Krogh, L.A. and Hurl, P.M. (1976). $\dot{V}O_2$max during horizontal and inclined treadmill running. *Journal of Applied Physiology*, **40**, 982-983.

Keith, S.P., Jacobs, I. and McLellan, T.M. (1992). Adaptations to training at the individual anaerobic threshold. *European Journal of Applied Physiology and Occupational Physiology*, **65**, 316-323.

Keul, J., Simon, G., Berg, A., Dickhuth, H.H., Goertler, I. and Kübel, R. (1979). Bestimmung der Individuellen Anaeroben Schwelle zur Leistungsbewertung und Trainingsgestaltung. *Deutsche Zeitschrift für Sportsmedizin*, **30**, 212-218.

Kinch, R.F.T., Walter, S.J., Craven, R.P., Parker, D.F. and Howells, K.F. (1993). Biomechanical analysis during simulated rowing using an air-braked (Concept II) rowing ergometer. Unpublished document, Oxford Brookes University.

Kindermann, W., Simon, G. and Keul, J. (1979). The significance of the aerobic-anaerobic threshold transition for the determination of work load intensities during endurance training. *European Journal of Applied Physiology*, **42**, 25-34.

Klusiewisz, A., Sitkowski, D., Bienko, A., Furdal, S. and Skwarczynski, T. (1992). Optimizing the selection of indices for assessing the work capacity of rowers. *Biology of Sport* , **8** (4), 167-175.

Knowlton, R.G., Brown, D.D., Hetzler, R.K. and Sikora, L.M. (1990). Venous and fingertip blood to calculate plasma volume shift following exercise. *Medicine and Science in Sports and Exercise*, **22** (6), 854-857.

Korzeniowski, K. (1987). Anaerobic threshold - some practical applications. American Rowing, **18** (3), 40-41.

Korzeniowski, K. (1989). Rowing physiology for the not-too-scientific. Part II: aerobics - utilization and anaerobic threshold. *American Rowing*, **21** (4), 42-44.

Koutedakis, Y. and Sharp, N.C.C. (1985). Lactic acid removal and heart rate frequencies during recovery after strenuous rowing exercise. *British Journal of Sports Medicine*, **19** (4), 199-202.

Koutedakis, Y., Raafat, A., Sharp, N.C.C., Rosmarin, M.N., Beard, M.J. and Robbins, S.W. (1993). Serum enzyme activities in individuals with different levels of physical fitness. *Journal of Sports Medicine and Physical Fitness*, **33**, 252-257.

LaFontaine, T.P., Londeree, B.R. and Spath, W.K. (1981). The maximal steady state versus selected running events. *Medicine and Science in Sports and Exercise*, **13**, 190-192.

Lakomy, H.K.A. and Lakomy, J. *Endurance Fitness and the Concept II Rowing Ergometer*. Manual produced for Concept II.

Lakomy, H.K.A. (1985). The measurement of power output during simulated rowing. *Journal of Physiology*, **361**, 3P.

Lakomy, H.K.A. and Lakomy, J. (1993). Estimation of maximum oxygen uptake from submaximal exercise on a Concept II rowing ergometer. *Journal of Sports Sciences*, **11** (3), 227-232.

Lakomy, H.K.A. (1993). Verification of the Concept II rowing ergometer. ARA Senior Rowing Coaches Conference, *Conference Papers*, Autumn, 1993.

Langill, R.H. and Rhodes, E.C. (1992). Comparison of the lactate and ventilatory responses during a progressive intensity test. *The Australian Journal of Science and Medicine in Sport*, **24** (4), 100-102.

Larsson, L. and Forsberg, A. (1980). Morphological muscle characteristics in rowers. *Canadian Journal of Applied Sports Sciences*, **5**, 239-244.

Liljestrand, G and Lindhard, J. (1920). Zur Physiologie des Ruderns. *Skandinavisches Achiv für Physiologi,* **39**, 215-235.

Löllgen, H., Graham, T. and Sjogaard, G. (1980). Muscle metabolites, force and perceived exertion bicycling at varying pedal rates. *Medicine and Science in Sports and Exercise*, **12** (5), 345-351.

Lormes, W., Buckwitz, R., Reihbein, H. and Steinacker, J.M. (1993). Performance and blood lactate on Gjessing and Concept II rowing ergometer. *International Journal of Sports Medicine*, **14**, Suppl. 1, S29-S31.

Lout, C.E.R. and Rhodes, E.C. (1993). Relationship between the lactate and ventilatory thresholds during prolonged exercise. *Sports Medicine*, **15** (2), 104-115.

MacDougall, J.D., Wenger, H.A. and Green, H.J. (1992). *Physiological Testing of the Elite Athlete*. New York: Mouvement Publication, pp44-46.

MacLaren, D. (1994). Aerobic measurements of fitness. *BASES Newsletter* , **4** (3), 15-16.

Mader, A. Liesen, H., Heck, H., Philippi, H., Rost, R., Schürch, P. and Hollmann, W. (1976). Zur Beurteilung der Sportartspezifischen Ausdauerleistungsfähigheit im Labor. *Sportarzt Sportmedizin*, **27**, 108-112.

Mader, A. (1991). Evaluation of the endurance performance of marathon runners and theoretical analysis of test results. *Journal of Sports Medicine and Physical Fitness*, **31**, 1-19.

Mahler, D.A., Andrea, B.E. and Andresen, D.C. (1984a). Comparison of 6-minute "all-out" and incremental exercise tests in elite oarsmen. *Medicine and Science in Sports and Exercise*, **16** (6), 567-571.

Mahler, D.A., Nelson, W.N. and Hagerman, F.C. (1984b). Mechanical and physiological evaluation of exercise performance in elite national rowers. *Journal of the American Medical Association,* **252**, 496-499.

Mahler, D.A., Parker, H.W. and Andresen, D.C. (1985). Physiological changes in rowing performance associated with training in collegiate women rowers. *International Journal of Sports Medicine*, **6** (4), 229-233.

Mahler, D.A., Andrea, B.E. and Ward, J.L. (1987). Comparison of Exercise performance on rowing and cycle ergometers. *Research Quarterly for Exercise and Sport*, **58** (1) 41-46.

Mahler, D.A., Stuhart, C.R., Brew, E. and Stukel, T.A. (1991a). Ventilatory responses, and entrainment of breathing during rowing . *Medicine and Science in Sports and Exercise*, **23** (2), 186-192.

Mahler, D.A., Hunter, B., Lentine, T. and Ward, J. (1991b). Locomotor-respiratory coupling develops in novice female rowers with training. *Medicine and Science in Sports and Exercise*, **23** (12), 1362-1366.

Martin, T.P. and Bernfield, J.S. (1980). Effect of stroke rate on velocity of a rowing shell. *Medicine and Science in Sports and Exercise*, **12** (4), 250-256.

Martindale, W.O. and Robertson, D.G.E. (1984). Mechanical energy in sculling and in rowing an ergometer. *Canadian Journal of Applied Sport Science*, **9** (3), 153-163.

Mazzone, T. (1988). Kinesiology of the rowing stroke. *NSCA Journal* , **10** (2), 4-11.

McKenzie, D.C. and Rhodes, E.C. (1982). Cardiorespiratory and metabolic responses to exercise on a rowing ergometer. *Australian Journal of Sports Medicine*, **14** (1), 21-23.

McLellan, T.M. and Cheung, K.S.Y. (1992). A comparative evaluation of the IAT and the critical power. *Medicine and Science in Sports and Exercise*, **24**, 543-550.

Mickelson, T.C. and Hagerman, F.C. (1982). Anaerobic threshold measurements of elite oarsmen. *Medicine and Science in Sports and Exercise*, **14** (6), 440-444.

Millward, A. (1987). A study of forces exerted by an oarsman and the effect on boat speed. *Journal of Sports Sciences*, **5** (2), 93-103.

Myers, J., Walsh, D., Buchanan, N., McAuley, P., Bowes, E. and Froelicher, V. (1994). Increase in blood lactate during ramp exercise: comparison of continuous and threshold models. *Medicine and Science in Sports and Exercise*, **26** (11), 1413-1419.

Neary, P.J., MacDougall, J.D., Bachus, R. and Wenger, H.A. (1985). The relationship between lactate and ventilatory thresholds: coincidental or causal effect? *European Journal of Applied Physiology*, **54**, 104-108.

Nilsen, T.S. and Nolte, V. *Basic and Intermediate Rigging*. FISA Development Commission.

Noll, F. (1974). L-(+)-Lactate. Determination with LDH, GPT & NAD. In: H.U. Bergmeyer (Ed). *Methods of Enzymatic Analysis*. New York and London, 2nd. Edition (Translated from 3rd. German Edition): Verlag Chemie Weinheim and Academic Press Inc.

Nolte, V (1991). Introduction to the biomechanics of rowing, *FISA Coach,* **2** (1), 1-6.

Norwacki, P. Krause, R. and Adam, K. (1969). Maximal oxygen uptake by the rowing crew winning the Olympic gold medal, 1968. *Plugers Archiv*, **312**, R66-R67.

Orok, C.J., Hughson, R.L., Green, H.J. and Thomson, J.A. (1989). Blood lactate responses in incremental exercise as predictors of constant load performance. *European Journal of Applied Physiology*, **59**, 262-267.

Osbourne, K. (1995). *British Rowing Almanac*. Chester: Evans.

Owles, W.H. (1930). Alterations in the lactic acid content of the blood as a result of light exercise, and associated changes in CO_2-combining power of the blood and in the alveolar CO_2 pressure. *Journal of Physiology*, **69**, 214-237.

Pannell, W. J. (1979). Mechanics of oar, boat and body. *Sports Coach*, **3** (4), 14-20.

Peltonen, J. and Rusko, H. (1993). Interrelations between power, force production and energy metabolism in maximal leg work using a modified rowing ergometer. *Journal of Sports Sciences*, **11** (3), 233-240.

Powers, S., Dodd, S. Deason, R., Bird, R. and McKnight, T. (1983). Ventilatory threshold, running economy and distance running performance of trained athletes. *Research Quarterly*, **54**, 179-182.

Raglin, J.S., Morgan, W.P. and Luchsinger, A.E. (1990). Mood and self-motivation in successful and unsuccessful female rowers. *Medicine and Science in Sports and Exercise*, **22** (6), 849-853.

Rasmussen, J., Hanel, B., Diamant, B. and Secher, N.H. (1991). Muscle mass effect on arterial desaturation after maximal exercise. *Medicine and Science in Sports and Exercise*, **23** (12), 1349-1352.

Rieu, M., Miladi, J., Ferry, A. and Duvallet, A. (1989). Blood lactate during submaximal exercises. Comparison between intermittent incremental exercises and isolated exercises. *European Journal of Applied Physiology*, **59**, 73-39.

Robergs, R.A., Chwalbinska-Moneta, J., Mitchell, J.B., Pascoe, D.D., Hournard, J. and Costill, D.L. (1990). Blood lactate threshold differences between arterialized and venous blood. *International Journal of Sports Medicine*, **11**, 446-451.

Robinson, S., Edwards, H.T. and Dill, D.B. (1937). New records in human power. *Science*, **85**, 409-410.

Rodriquez, F.A. Banquells, M., Pons, V. Drobnic, F. and Galilea, P.A. (1992). A comparative study of blood lactate analytic methods. *International Journal of Sports Medicine*, **13** (6), 462-466.

Rosiello, R.A., Mahler, D.A. and Ward, J.L. (1987). Cardiovascular responses to rowing. *Medicine and Science in Sports and Exercise*, **10** (3), 239-245.

Roth, W. (1991). Physiological-biomechanical aspects of the load development and force implementation in rowing. *FISA Coach*, **2** (4), 1-9.

Sanderson, B. and Martindale, W. (1986). Towards optimizing rowing technique. *Medicine and Science in Sports and Exercise*, **18** (4), 454-468.

Schwanitz, P. (1991). Applying biomechanics to improving rowing. *FISA Coach*, Summer, **2** (3).

Secher, N.H., Clausen, J.P., Klausen, K., Noer, I. and Jensen, J. (1977). Central and regional circulatory effects of adding arm exercise to leg exercise. *Acta Physiologica Scandinavia*, **100**, 288-297.

Secher, N.H., Vaage, O. and Jackson, R.C. (1982). Rowing performance and maximal aerobic power of oarsmen. *Scandinavian Journal of Sports Science*, **4** (1), 9-11.

Secher, N.H. (1983). The physiology of rowing. *Journal of Sports Sciences*, **1**, 23-53.

Secher, N.H. (1993). Physiological and biomechanical aspects of rowing: Implications for training. *Sports Medicine*, **15** (1), 24-42.

Sjödin, B. and Jacobs, I. (1981). Onset of blood lactate accumulation and marathon running performance. *International Journal of Sports Medicine*, **2**, 23-26.

Sjödin, B., Jacobs, I. and Svedenbag, J. (1982). Changes in onset of blood lactate accumulation (OBLA) and muscle enzymes after training at OBLA. *European Journal of Applied Physiology*, **49**, 45-57.

Smith, M. Hale, T., Harley, R., Keen, P., Northcott, S. and Palfreeman, R. (1991). Blood lactates sampled form different sites. *Journal of Sports Sciences*, **9**, Conference Communications, 431.

Spinks, W.L. (1986). *Rowing Physiology*. Unpublished monograph/microfiche.

Stamford, B.A. (1975). Maximal oxygen uptake during treadmill walking and running at various speeds. *Journal of Applied Physiology*, **39**, 386-389.

Stegmann, H., Kindermann, W. and Schnabel, A. (1981). Lactate kinetics and individual anaerobic threshold. *International Journal of Sports Medicine*, **2**, 160-165.

Stegmann, H. and Kindermann, W. (1982). Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 $mmol \cdot l^{-1}$ lactate. *International Journal of Sports Medicine*, **3** (2), 105-110.

Steinacker, J.M., Marx, T.R. and Thiel, U. (1984). A rowing ergometer test with stepwise increased workloads. In: L. Bachl, Prokop and R. Suckert. (Eds.). *Current Topics in Sports Medicine*. München Wien Baltimore: Urban and Schwarzenberg, pp175-187.

Steinacker, J.M., Marx, U, Grünert, M., Lormes, W. and Wodick, R.E. (1985). Vegleichsuntersuchungen über den Zweistufentest und den Mehrstufentest bei der Ruderspiroergometrie. *Leistungssport*, **6**, 47-51.

Steinacker, J.M., Marx, T.R., Marx, U. and Lormes, W. (1986). Oxygen consumption and metabolic strain in rowing ergometer exercise. *European Journal of Applied Physiology and Occupational Physiology*, **55** (3), 240-247.

Steinacker, J.M., Lormes, W. and Stauch, M. (1991). Sport specific testing in rowing. In: L. Bachl, T.E. Graham and H. Lollgen (Eds.). *Advances in Ergometry*. Berlin: Springer-Verlag, pp443-454.

Steinacker, J.M. (1993). Physiological aspects of training in rowing. *International Journal of Sports Medicine*, **14**, Suppl. 1, S3-S10.

Steinacker, J.M., Both, M. and Whipp, B.J. (1993). Pulmonary mechanics and entrainment of respiration and stroke rate during rowing. *International Journal of Sports Medicine*, **14**, Suppl. 1, S15-S19.

Strømme, S.B., Inger, F. and Meed, H.D. (1977). Assessment of maximal aerobic power in specifically trained athletes. *Journal of Applied Physiology*, **42** (6), 833-837.

Sutton, J.R. (1992). Limitations to maximal oxygen uptake. *Sports Medicine*, **13** (2), 127-133.

Szal, S.E. and Schoene, R.B. (1989). Ventilatory responses to rowing and cycling in elite oarswomen. *Journal of Applied Physiology*, **67** (1), 264-269.

Tesch, P.A., Sharp, D.S. and Daniels, W.L. (1981). Influence of fiber type composition and capillary density on OBLA. *International Journal of Sports Medicine*, **2** (4), 252-255.

Tumilty, D., Hahn, A. and Telford, R. (1987). Effect of test protocol, ergometer type and state of training on peak oxygen uptake of rowers. *Excel*, **3** (3), 12-14.

Urhausen, A., Müller, M, Förster, H.J., Weiler, B and Kindermann, W. (1986). Trainingssteuerung im Rudern (Control of training intensity in rowing). *Deutsche Zeitschrift für Sportmedizin*, **37** (11), 340-346.

Urhausen, A., Weiler, B. and Kindermann, W. (1987). Behaviour of lactate and catecholamines in different rowing ergometric test procedures. *Deutsche Zeitschrift für Sportmedizin*, **38**, October, 11-19.

Urhausen, A. and Kindermann, W. (1992). Biochemical monitoring of training. *Clinical Journal of Sports Medicine*, **2**, 52-61.

Urhausen, A., Coen, B., Weiler B. and Kindermann, W. (1993). Individual anaerobic threshold and maximum lactate steady state. *International Journal of Sports Medicine*, **14** (3), 134-139.

Vermulst, L.J.M., Vervoorn, C., Boelens-Quist, A.M., Koppeschaar, H.P.F., Erich, W.B.M., Thijssen, J.H.H. and DeVries, W.R. (1991). Analysis of seasonal training

volume and work capacity in elite female rowers. *International Journal of Sports Medicine*, **12** (6), 567-572.

Wakayoshi, K., D'Acquisto, L.J., Cappaert, J.M. and Troup, J.P. (1995). Relationship between oxygen uptake, stroke rate and swimming velocity in competitive swimming. *International Journal of Sports Medicine*, **16** (1), 19-23.

Walsh, M.L. and Banister, E.W. (1988). Possible mechanisms of the anaerobic threshold: a review. *Sports Medicine*, **5**, 269-302.

Warrington, G.D., Faulmann, L.K., Hughes, M.G., Godfrey, R.J., Hunter, A., Fullerton, F.M. and Sharp, N.C.C. (1992). Selected physiological changes in rowing performance during a 3-month conditioning phase in elite female rowers. *Journal of Sports Science*, **10** (6), 575-576.

Wasserman, K. and McIlroy, M. (1964). Detecting the threshold of anaerobic metabolism of cardiac patients during exercise. *American Journal of Cardiology*, **14**, 844-852.

Wasserman, K., Whipp, B.J., Koyal, S.N. and Beaver, W.L. (1973). Anaerobic threshold and respiratory gas exchange during exercise. *Journal of Applied Physiology*, **35** (2), 236-243.

Weltman, A. (1989). The lactate threshold and endurance performance. *Advances in Sports and Medical Fitness*, **2**, 91-115.

Weltman, A., Snead, D., Stein, P., Seip, R., Schurrer, R., Rutt, R. and Weltman J. (1990). Reliability and validity of a continuous incremental treadmill protocol for the determination of lactate threshold, fixed blood lactate concentrations and $\dot{V}O_2$max. *International Journal of Sports Medicine*, **11** (1), 26-32.

Williams, J.R., Armstrong, N. and Kirby, B.J. (1992). The influence of sampling and assay medium upon the measurement and interpretation of blood lactate responses to exercise. *Journal of Sports Science*, **10**, 95-107.

Wolf, W.V. and Roth, W. (1987). Validität Spiroergometrischer Parameter für die Wettkampfleistung im Rudern. *Medizin und Sport*, **27**, 162-166.

Womack, C.J., Davis, S.E., Wood, C.M., Alvarez, K, Sauer, A., Weltman, A. and Gaesser, G.A. (1989). The blood lactate response during rowing ergometry as a predictor of rowing performance. *Medicine and Science in Sports and Exercise*, 731, Abstract.

Wright, G.R., Bompa, T. and Shephard, R.J. (1976). Physiological evaluation of winter training programme for oarsmen. *Journal of Sports Medicine and Physical Fitness*, **16**, 22-37.

Yeh, M.P. Gardner, R.M., Adams, T.D., Yanowitz, F.G. and Crapo, R.O. (1983). 'Anaerobic threshold'; problems of determination and validation. *Journal of Applied Physiology*, **55** (4), 1178-1186.

Yoshida, T., Takeuchi, N. and Suda, Y. (1982). Arterial versus venous blood lactate increase in the forearm during incremental bicycle exercise. *European Journal of Applied Physiology*, **50**, 87-93.

Zatsiorsky, V.M. and Yakunin, N. (1991). Mechanics and biomechanics of rowing - a review. *International Journal of Sport Biomechanics*, **7** (3), 229-281.

Zhou, D. (1990). A study of the dynamic heart rate anaerobic threshold of Chinese elite oarswomen. *Sports Science*, **10** (6), 56-58.

APPENDICES

Appendix 1

Four minute test

Table A1.1 Example of exercise intensity prediction table taken from "Endurance Fitness and the Concept II Rowing Ergometer", H.K.A. Lakomy and J. Lakomy.

Age Range = 16 to 26 *(or known maximum rowing heart rate of 186 to 195)*

Exercise Heart Rate	125	130	135	140	145	150	155	**160**	165	170	175	180	185	190
Percentage	50	53	57	61	65	69	73	**76**	80	84	88	92	96	100
	2:06	2:02	1:59	1:56	1:53	1:50	1:48	1:45	1:43	1:41	1:39	1:38	1:36	1:35
	2:13	2:09	2:05	2:02	1:59	1:56	1:53	1:51	1:49	1:47	1:45	1:43	1:41	1:40
	2:19	2:15	2:11	2:08	2:05	2:02	1:59	1:57	1:54	1:52	1:50	1:48	1:46	1:45
	2:26	2:22	2:18	**2:14**	**2:11**	**2:08**	**2:05**	**2:02**	**2:00**	**1:58**	**1:55**	**1:53**	1:51	1:50
	2:33	2:28	2:24	2:20	2:17	2:14	2:11	2:08	2:05	2:03	2:01	1:59	1:57	1:55
	2:40	2:35	2:30	2:26	2:23	2:19	2:16	2:13	2:11	2:08	2:06	2:04	2:02	2:00
500 m Split Times	2:46	2:41	2:36	2:32	2:28	2:25	2:22	2:19	2:16	2:13	2:11	2:09	2:07	2:05
	2:53	2:48	2:43	2:39	2:35	2:31	2:28	2:25	2:22	2:19	2:16	2:14	2:12	2:10
	2:59	2:55	2:49	2:45	2:41	2:37	2:33	2:30	2:27	2:24	2:22	2:19	2:17	2:15
	3:06	3:00	2:55	2:51	2:46	2:43	2:39	2:36	2:32	2:30	2:27	2:24	2:22	2:20
	3:13	3:07	3:02	2:57	2:53	2:49	2:45	2:41	2:38	2:35	2:32	2:30	2:27	2:25
	3:19	3:13	3:08	3:03	2:58	2:54	2:50	2:47	2:44	2:40	2:37	2:35	2:32	2:30
	3:26	3:20	3:14	3:09	3:05	3:00	2:56	2:53	2:49	2:46	2:43	2:40	2:37	2:35
	3:33	3:26	3:21	3:15	3:11	3:06	3:02	2:58	2:55	2:51	2:48	2:45	2:42	2:40

This information was used to predict exercise intensities corresponding to estimated heart rates of 60% and 90% of maximum. Tables in the manual also include work intensities for age ranges 27 to 36 years (or a known maximum rowing heart rate of 176 to 185 b·min^{-1}), 37 to 46 years (or a known heart rate maximum of 166 to 175 b·min^{-1}), and 47 or more years (or known maximum heart rate of 156 to 165 b·min^{-1}).

Example of how to use table (shown in bold type): If exercise heart rate in the last minute of a 4 minute bout of exercise is 160 b·min^{-1} when rowing at a 500 m split time of 2:02 (min:s), then approximately 60% of estimated heart rate maximum would be equivalent to a 500 m split time of 2:14 min:s. The 500 m split time at approximately 90% of estimated heart rate maximum would be 1:53 min:s.

Appendix 2

Test protocols from BOMC and National Sports Medicine Institute

A2.1 BOMC Submaximal Discontinuous Incremental Step Test

A2.1.1 Protocol

Women

500 m Time (min:s)	Power Output (watts)	Increment (watts)	Step	Stroke Rate (Str·min^{-1})
2:14	146	-	1.	18-20
2:10	163	17	2.	22
2:06	181	18	3.	22-24
2:02	199	18	4.	24-26
1:58	216	17	5.	26-28
1:54	234	18		
1:50	252	18		

Men

500 m Time (min:s)	Power Output (watts)	Increment (watts)	Step	Stroke Rate (Str·min^{-1})
1:55	230	-	1.	18-20
1:49	256	26	2.	22
1:46	283	27	3.	22-24
1:43	311	27	4.	24-26
1:40	338	27	5.	26-28
1:37	366	28		
1:34	400	34		

A2.1.2 Procedures

Following a 5 minute warm up at a split time of 2:20 min:s for women and 2:05 min:s for men, subjects attempt to complete five discontinuous 3 minute bouts of exercise at fixed intensities and stroke rates as given above. Subjects either continue until volitional exhaustion, or until they are unable to maintain the required work intensity.

The seven increments have been selected to take individual variability into account. The 5 increments utilised and thus the starting point of the test are based on the athlete's level of conditioning. This is ascertained both from how the subjects rate themselves, and from the heart rate response during the warm-up. The gearing for the ergometer is fixed on the large cog with the fan closed. There are fixed stroke rates during the test and each individual athlete is encouraged to remain as close to these rates as possible.

A2.2 National Sports Medicine Institute, $\dot{V}O_2$ Peak/Lactate Profile Protocol

A2.2.1 Protocol

MEN 500 m Time	WOMEN 500 m Time
1:49	2:05
1:44	2:00
1:40	1:55
1:37	1:52
1:34	1:50
1:31	1:48
1:28	1:46

A2.2.2 Procedures

Following a standardised warm-up (unspecified), subjects perform five 3 minute bouts of exercise at fixed intensities, as above, to volitional exhaustion. Each exercise bout is followed by a 30 second recovery for blood sampling.

Appendix 3

Pilot work on $\dot{V}O_2max$ protocol

A3.1 Introduction

To devise a $\dot{V}O_2max$ test, various protocols were tested using heart rate to examine the effect of work intensity. Protocols included:

Protocol A 1 minute protocol with decreasing watt increments.

Figure A3.1 Protocol A.

Women

500 m Time (min:s)	Power Output (watts)	Increment (watts)
(2:21)	(123)	-
2:13	150	(27)
2:07	177	27
2:01	203	26
1:57	221	18
1:53	238	17
1:51	247	9
1:49	256	9
1:48	265	9
etc.		

Men

500 m Time (min:s)	Power Output (watts)	Increment (watts)
(2:01)	(203)	-
1:55	230	(27)
1:49	256	26
1:46	283	27
1:44	302	19
1:42	320	18
1:40	338	18
1:39	347	9
1:38	357	10
1:37	366	9
1:36	375	9
etc.		

The first 2 work stages last 2 minutes. Each stage thereafter lasts 1 minute with lower watt increments.

Protocol B 1 minute protocol with smaller decreasing watt increments.
Similar to protocol A but increments are smaller (9 or 10 W) once exercising at 1 minute stages.

Protocol C 3 minute continuous protocol.
This test is exactly as for the BOMC protocol (A2.2) but steps are continuous.

Protocol D 2 minute protocol with decreasing watt increments.

Figure A3.2 Protocol D.

Women

500 m Time (min:s)	Power Output (watts)	Increment (watts)
2:17	132	-
2:11	159	27
2:05	185	26
1:59	212	27
1:55	230	18
1:51	247	17
1:49	256	9
etc.		

Men

500 m Time (min:s)	Power Output (watts)	Increment (watts)
1:55	230	-
1:49	256	26
1:46	283	27
1:43	309	26
1:41	327	18
1:39	335	18
1:38	346	9
1:37	365	9
etc.		

Protocol E 2 minute protocol with same watt increment (Figure 4.2).
This test is described in Chapter 4.

A3.2 Methods and Results

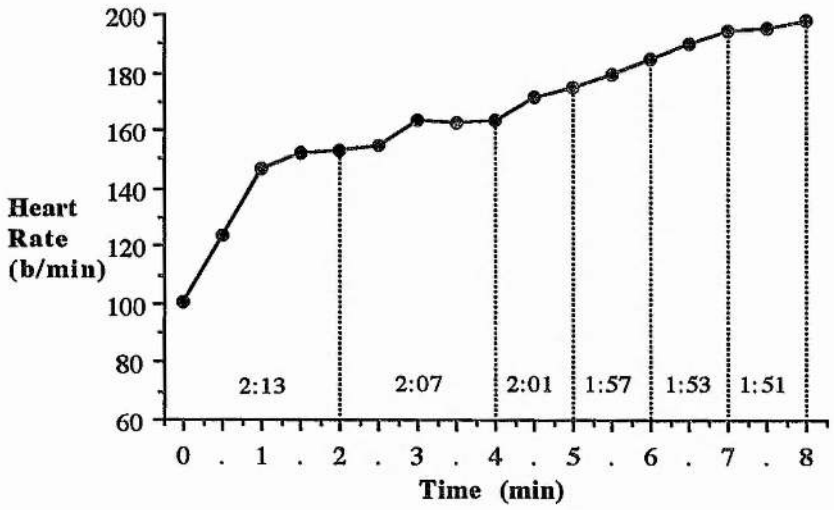
Subjects were 5 male and 4 female university rowers. Graphs of heart rate taken from 3 subjects for each protocol are presented as examples in Figures A3.3 to A3.8. The data from the subjects chosen as examples are representative of the data

collected from other subjects.

Figure A3.3

Protocol A Heart rate response of 1 female subject to protocol A.

Subject is female, 'highly trained', aged 27, height 1.76 m and weight 71 kg.

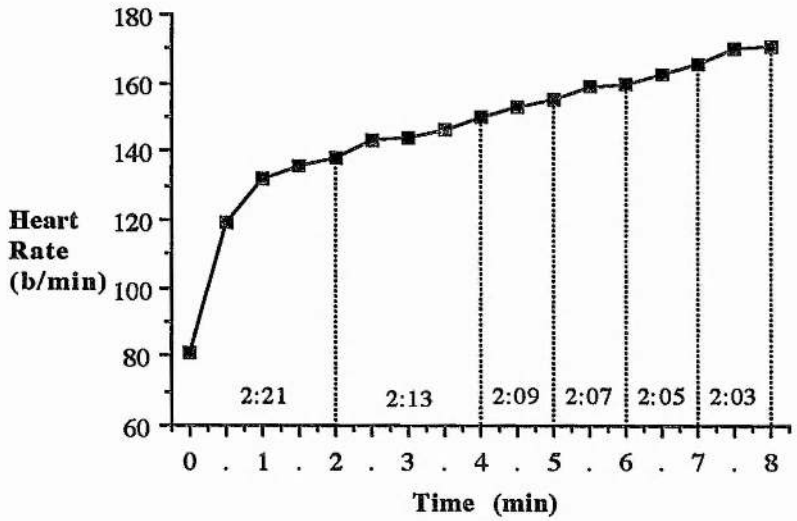


Figures inside graph refer to 500 m split time (min:s)

Figure A3.4

Protocol B Heart rate response of 1 female subject to protocol B.

Subject is female, 'moderately fit', aged 34, height 1.62 m and weight 56.2 kg.

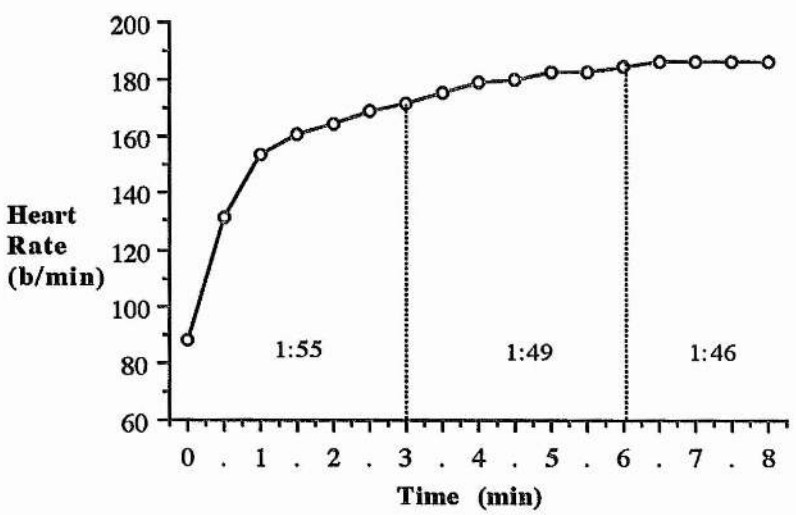


Figures inside graph refer to 500 m split time (min:s)

Subjects were asked how they rated the test, since all subjects completed at least two different types of protocol on separate days. Both 1 minute protocols (Figures A3.3 and A3.4) show increases in heart rate without steady state being achieved. This could signify that a peak rather than a maximum $\dot{V}O_2$ value is attained. Subjects also did not feel they could settle during the test. The 3 minute continuous test (protocol C) seemed to be too demanding. The subject whose data are shown in Figure A3.5 was also tested on protocol E (Figure A3.8) and as can be seen was able to achieve a higher maximum heart rate (191 $b \cdot min^{-1}$) in the two minute protocol compared to 185 $b \cdot min^{-1}$ in the 3 minute protocol, and to complete a higher workload (1:43 min:s). Two minute protocols (D and E) seemed to result in a steady state heart rate at each workload, but increments needed to be fairly large to achieve a higher end work intensity. Protocol E was preferred since subjects were able to complete a higher work intensity, to exercise for longer and to achieve a higher maximum heart rate.

Figure A3.5

Protocol C Heart rate response of 1 male subject to protocol C.
Subject is 'highly trained' aged 30, height 1.77 m and weight 73.7 kg.

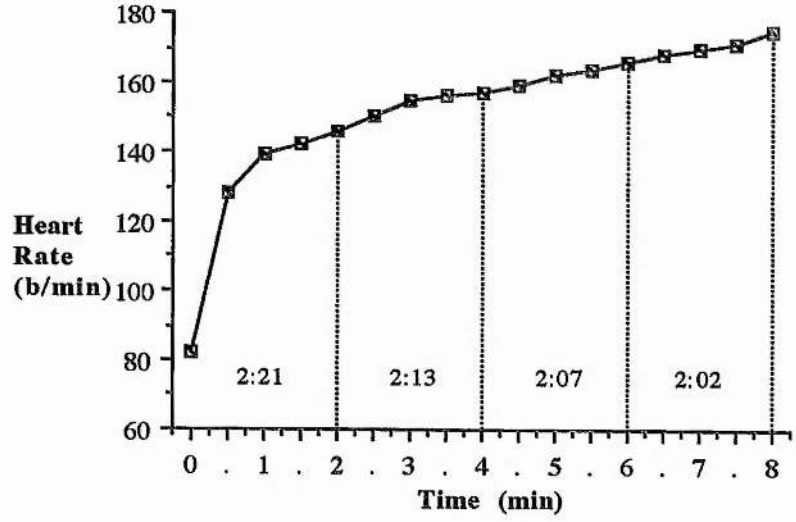


Figures inside graph refer to 500 m split time (min:s)

Figure A3.6

Protocol D Heart rate response of female subject to protocol D.

Same subject as in Figure A3.4

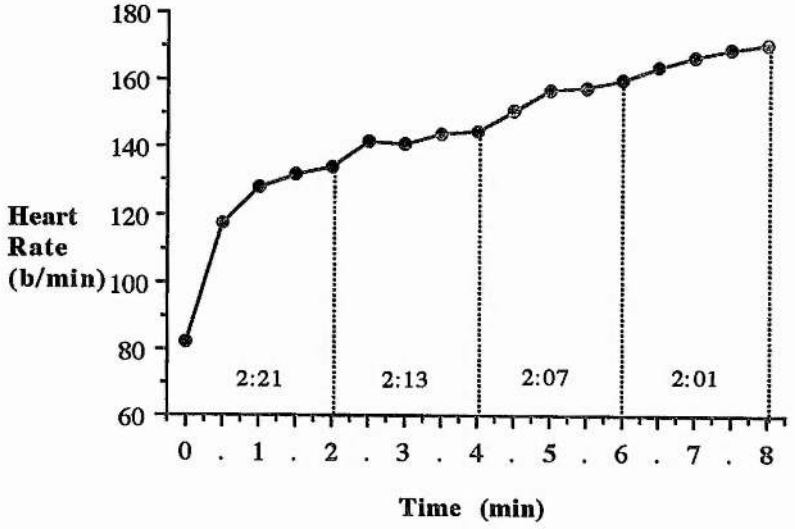


Figures inside graph refer to 500 m split time (min:s)

Figure A3.7

Protocol E Heart rate response of female subject to protocol E.

Same subject as in Figure A3.4

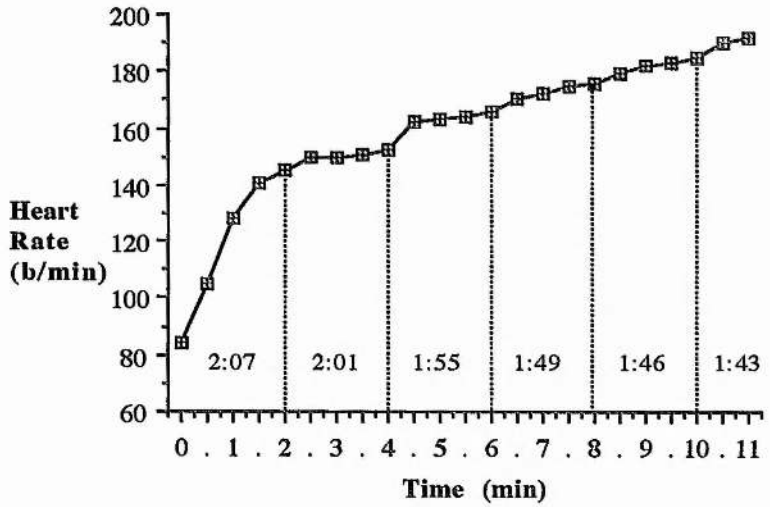


Figures inside graph refer to 500 m split time (min:s)

Figure A3.8

Protocol E Heart rate response of male subject to protocol E.

Same subject as in Figure A3.5



Figures inside graph refer to 500 m split time (min:s)

Appendix 4

Design of computerised instrumentation and software

A4.1 Software Programme

```
program LPM_16_test_1;
{Rowing Ergometer interface test program written Sept 1994 by Murray Coutts.
  Uses PC-LPM-16 DAQ board from National Instruments set to receive input
  voltages in the range 0 to +10V on channel 0.
  Uses digital port0 as output & port1 as input  }

uses Strings, nidaq, crt;


const
   MAX_PORT        = 2;
   DIR_IN          = 0;     (* direction to be used in DIG_Prt_Config () function.
 *)
   DIR_OUT         = 1;
   COUNT_DIST      = 4.65;
   SAMPLE          = 15;    (* code to be sent to DIG_out_Port to enable sample/ho
ld chip to sample *)
   HOLD            = 14;    (* code to be sent to DIG_out_Port to enable sample/ho
ld chip to hold *)



(*****************************************************************************)


procedure update_counter(       devNum      : integer;
                            var count       : integer;
                            var last_level : Boolean );
var port,
    value,
    errNum       : integer;
    now_level    :Boolean;

begin
  port := 1;
  now_level := false;

  errNum := DIG_In_Port (devNum, port, value);
  if (value AND 1) = 1 then
  now_level := true;
  if (value AND 2) = 2 then
  begin
    if  NOT last_level  AND now_level then
    begin
      count := count + 1;
      gotoxy(27, 12);
      writeln('         ');
      gotoxy(10, 12);
      writeln('Counter value = ',count );
      gotoxy(27, 13);
      writeln('              ');
      gotoxy(10, 13);
      writeln('Distance      = ',count*COUNT_DIST:5:1,' mm' )
    end{ if };
  end{ if }
  else
  begin
    if NOT last_level AND now_level then
```

```
      begin
        count := count - 1;
        gotoxy(27, 12);
        writeln('         ');
        gotoxy(10, 12);
        writeln('Counter value = ',count );
        gotoxy(27, 13);
        writeln('               ');
        gotoxy(10, 13);
        writeln('Distance       = ',count*COUNT_DIST:5:1,' mm' )
      end{ if };
    end{ if };

    last_level := now_level;
  end{ update_counter };


  procedure update_strain( dev,
                           chan,
                           gain : integer;
                           var maximum : double);
  var value,
      port,
      errNum  : Integer;
      volts   : Double;
  begin
    value := 0;
    volts := 0;
    port  := 0;

    errNum := DIG_out_Port(dev, port, HOLD);
    AI_Read(dev, chan, gain, value );
    errNum := DIG_out_Port(dev, port, SAMPLE );
    AI_VScale(dev, chan, gain, 1.0, 0.0, value, volts );
    gotoxy(10, 9);
    writeln('Voltage = ',volts:8:2);
    gotoxy(10, 10);
    writeln('Strain =  ',volts*10:8:1,' Kg' );
    if volts > maximum then
    begin
      maximum := volts;
      gotoxy(10
      , 15);
      writeln('Maximum strain = ',maximum*10:8:1,' Kg' );
    end{ if };
  end{ update_strain };



  procedure main;

  var

     devNum,          (* slot/ID number of device *)
     chan,            (* chan for input; range 0 to (n-1) where n
                         is number of chans on device (n = 8 .. 16);
```

```
                    Also chan for output; range 0 to 1          *)
    gain,           (* gain for input; set to default gain of 1  *)
    errNum,         (* error returned from library function calls *)
    patternOut,     (* output pattern *)
    i,              (* loop index *)
    count
    : Integer;
    max,
    volts : double;
    dir: array [0..(MAX_PORT-1)] of Integer;        (* direction of each port *)
    key : Char;
    last : Boolean;

begin
  devNum := 1;
  chan := 0;
  gain := 1;
repeat
  clrscr;
  max := 0;
  count := 0;
  last := true;
  i := 0;
  dir[1] := DIR_IN;
  dir[0] := DIR_OUT;
  patternOut := 15;
  errNum := DIG_out_Port(devNum, i, patternOut);
  gotoxy(10, 12);
  writeln('Counter value = ',count );
  AI_Configure(devNum, -1, 1, 10, 1, 1);
repeat
  update_strain(devNum, chan, gain, max );
  update_counter( devNum, count, last );
until keypressed;
key := readkey;
until key = char(32);
end{ main };


begin
  main
end{ program }.
```

Figure A4.1 Interface block system diagram.

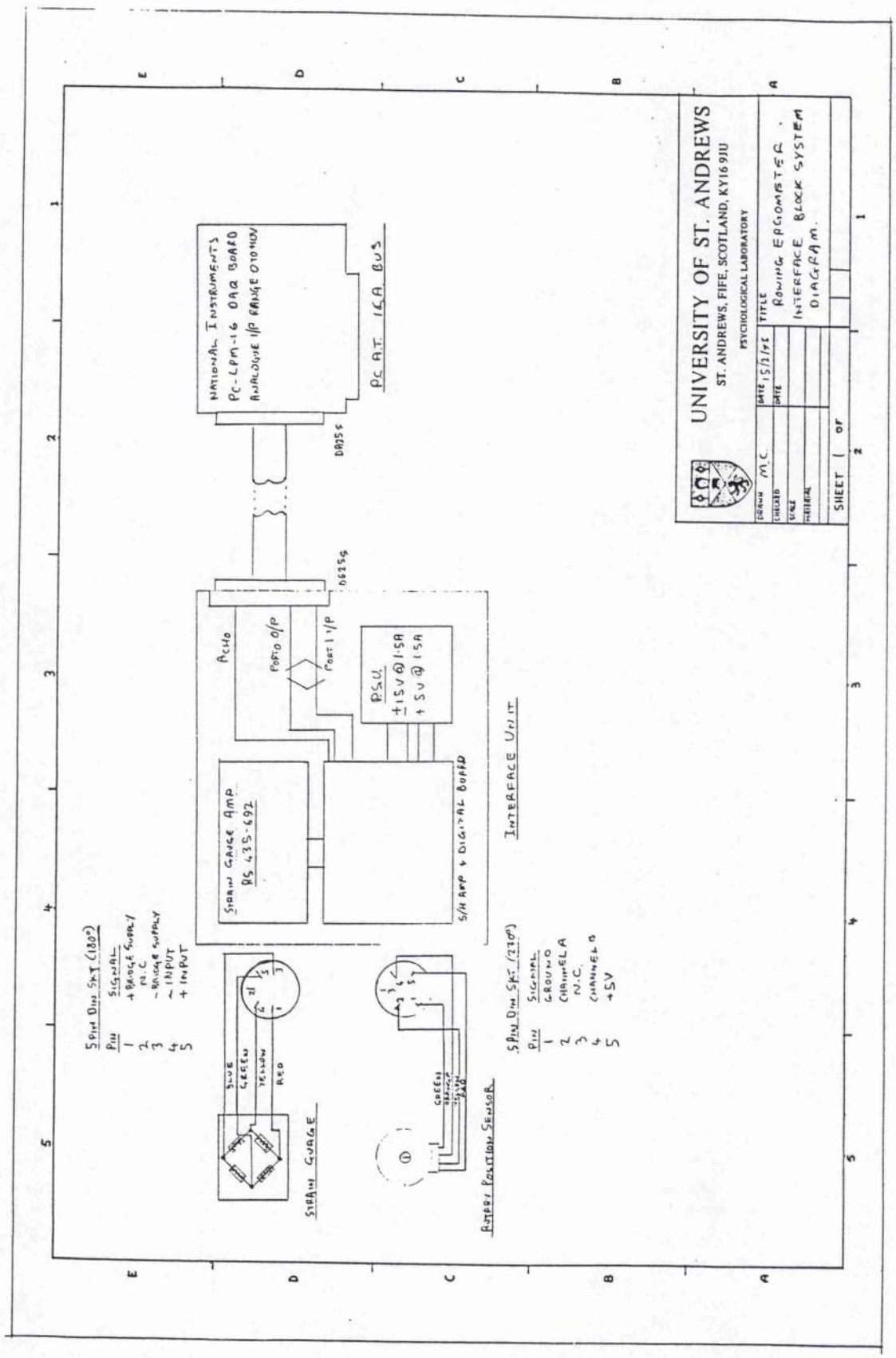


Figure A4.2 Strain gauge amplifier.

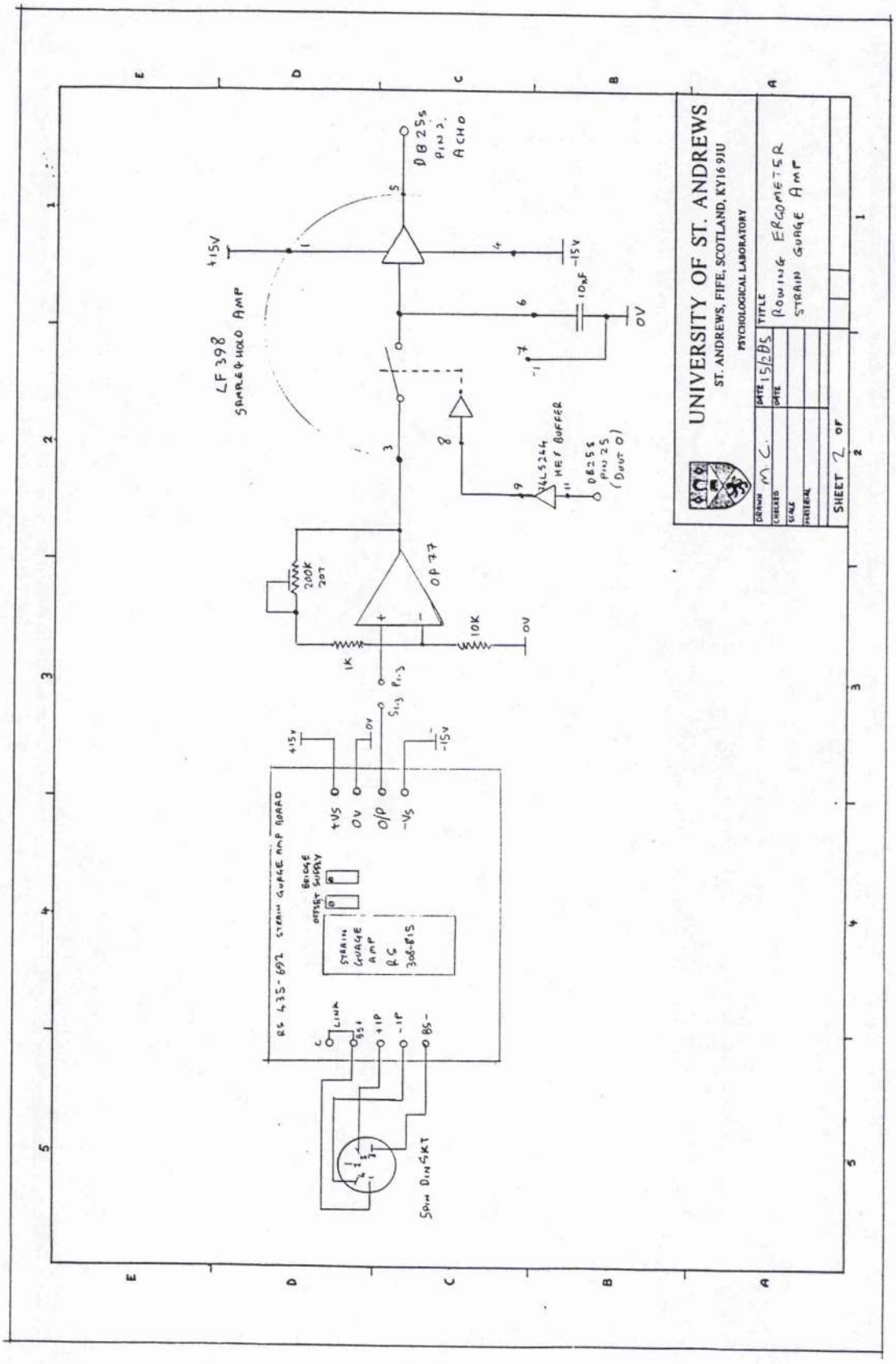
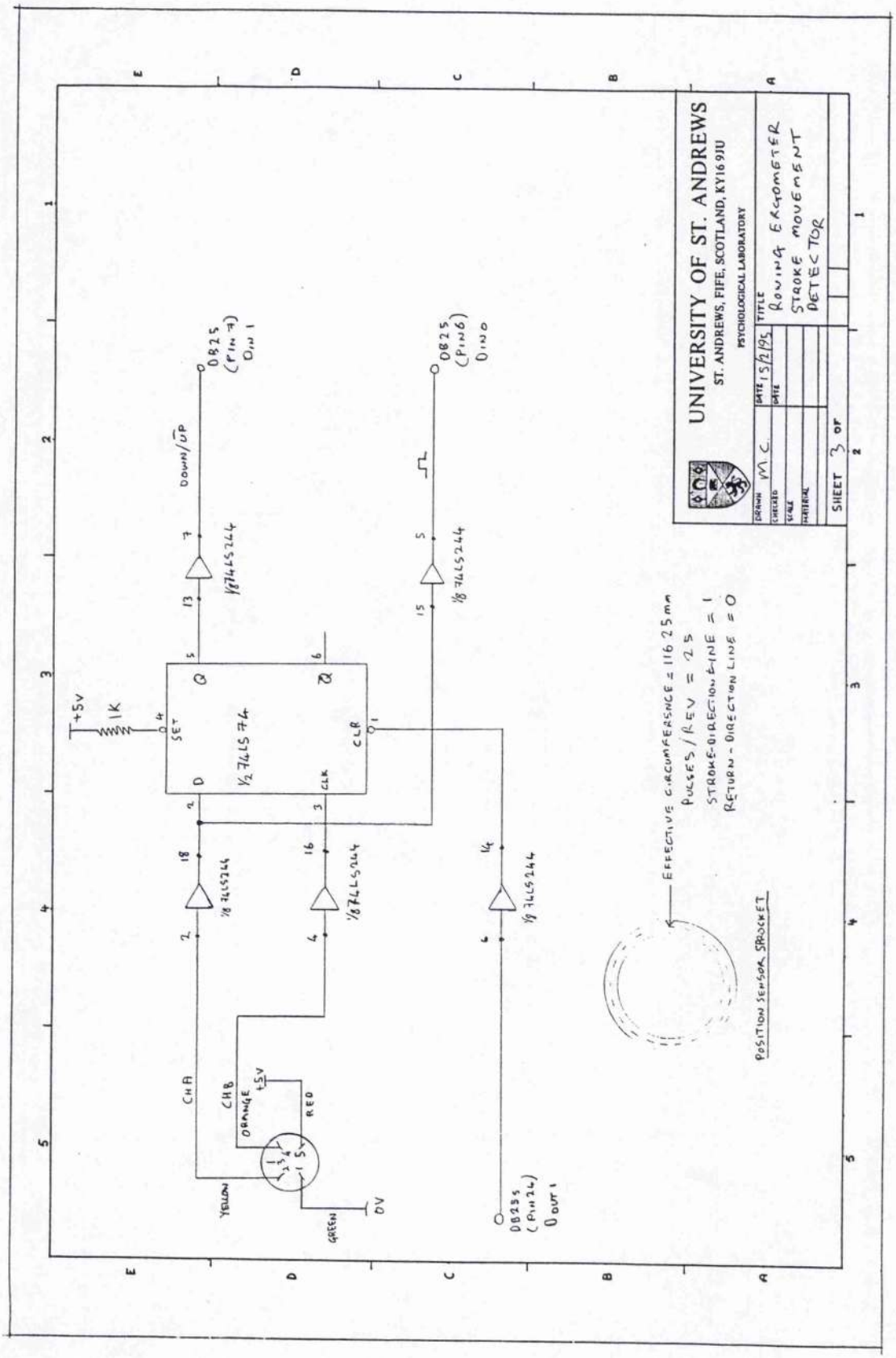


Figure A4.3 Stroke movement detector.



Appendix 5

ANOVA tables

A5.1 ANOVA Tables for Chapter 3

Table A5.1.1

ANOVA 3-way analysis of variance for plasma lactate concentration ($mmol \cdot l^{-1}$) taken from the earlobe, fingertip and toe (= site) at work intensities corresponding to 76.4% and 91.9% of estimated heart rate maximum (= workload) and for each subject (= subject).

Source	DF	SS	MS	F	p
Site	2	4.8840	2.4420	2.88	0.085
Workload	1	103.1967	103.1967	121.80	0.000
Subject	8	65.2034	8.1504	9.62	0.000
Site*Workload	2	0.9957	0.4979	0.59	0.567
Workload*Subject	8	42.6129	5.3266	6.29	0.001
Site*Subject	16	22.0630	1.3789	1.63	0.170
Error	16	13.5566	0.8473		
Total	53	252.5124			

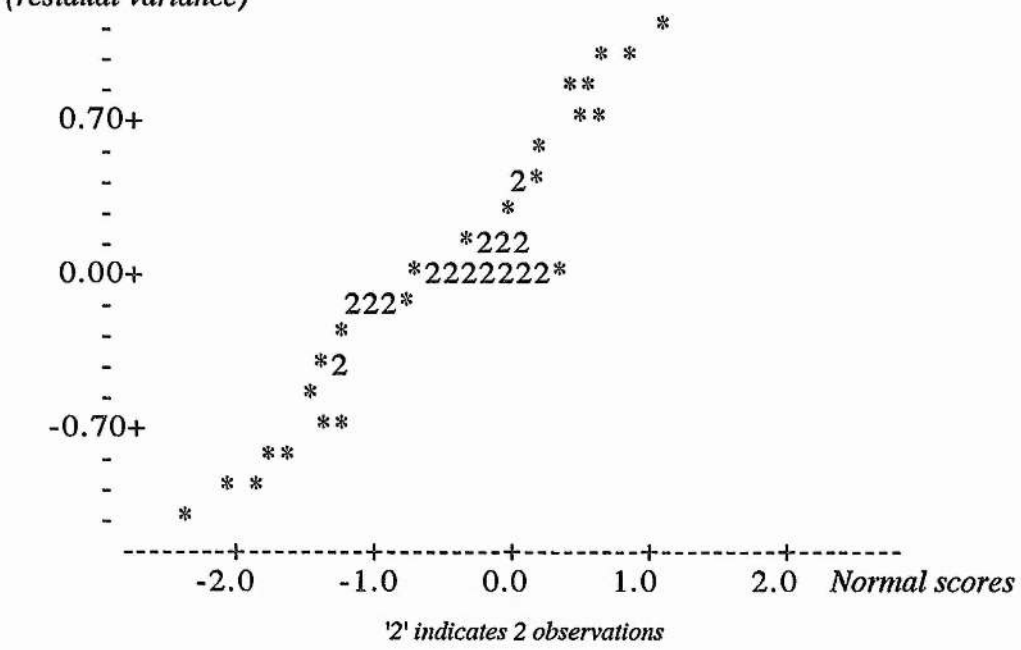
Table A5.1.2

ANOVA 3-way analysis of variance and interaction analysis for time taken to collect all samples from the ear, toe and fingertip at both work intensities

Source	DF	SS	MS	F	p
Site	2	85031	42516	16.97	0.000
Workload	1	52267	52267	20.86	0.000
Subject	8	86965	10871	4.34	0.006
Site*Workload	2	7453	3727	1.49	0.256
Workload*Subject	8	38216	4777	1.91	0.129
Site*Subject	16	96272	6017	2.40	0.045
Error	16	40086	2505		
Total	53	406290			

Figure A5.1.1

Normal probability plot to show distribution of lactate values in plasma, sampled at the toe, fingertip and earlobe for 9 subjects.



Normal scores plot is used to check hypothesis that sample values for ear, toe and fingertip have a Normal distribution. A straight line would signify an exact Normal distribution. Correlation of values = 0.980 > 0.96 for normality at p=0.05.

A5.2 Chapter 5 ANOVA Tables for Resting Values

Table A5.2.1

ANOVA 1-way analysis of variance on resting plasma lactate concentration ($mmol \cdot l^{-1}$) from blood sampled prior to $\dot{V}O_2max$ test and after one hour of recovery.

Source	DF	SS	MS	F	p
FACTOR	1	4.439	4.439	4.57	0.049
ERROR	58	56.304	0.971		
TOTAL	59	60.743			

Table A5.2.2

ANOVA 1-way analysis of variance on plasma lactate concentration ($mmol \cdot l^{-1}$) taken in the last minute of each 15 minute rest period, following 10 minute exercise bouts equivalent to 75%, 85% and 95% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
FACTOR	2	90.49	45.25	26.06	0.000
ERROR	87	151.05	1.74		
TOTAL	89	241.54			

				INDIVIDUAL 95% CI's FOR MEAN BASED ON POOLED STDEV
LEVEL	N	MEAN	STDEV	---+---------+---------+---------+---
post-75%	30	4.271	1.141	(----*---)
post-85%	30	5.363	1.225	(----*---)
post-95%	30	6.722	1.551	(----*----)
				---+---------+---------+---------+---
POOLED STDEV =		1.318		4.0 5.0 6.0 7.0 $mmol \cdot l^{-1}$

Table A5.2.3

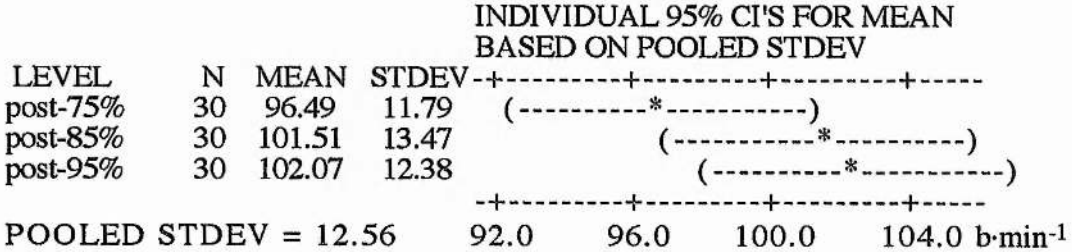
ANOVA 1-way analysis of variance on resting heart rate ($b \cdot min^{-1}$) taken prior to $\dot{V}O_2max$ test and at rest after 1 hour of recovery.

Source	DF	SS	MS	F	p
FACTOR	1	1769	1769	9.13	0.004
ERROR	58	11235	194		
TOTAL	59	13004			

Table A5.2.4

ANOVA 1-way analysis of variance on resting heart rate taken in the last minute of each 15 minute recovery following 10 minute exercise bouts equivalent to 75%, 85% and 95% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
FACTOR	2	566	283	1.79	0.173
ERROR	87	13734	158		
TOTAL	89	14299			



A5.3 Chapter 5 ANOVA Tables: 2-way Analysis on Oxygen Consumption

Table A5.3.1

ANOVA 2-way analysis of variance for oxygen consumption values ($ml \cdot kg^{-1} \cdot min^{-1}$) between 6, 7, 8 and 10 minutes of exercise corresponding to 75% $\dot{V}O_2max$

Source	DF	SS	MS	F	p
Subjects	26	5876.68	226.03	99.02	0.000
6 to 10 min	4	29.41	7.35	3.22	0.016
Error	104	237	39		
Total	134	6143.48			

Table A5.3.2

ANOVA 2-way analysis of variance for oxygen consumption values ($ml \cdot kg^{-1} \cdot min^{-1}$) between 7 and 10 minutes at 75% $\dot{V}O_2max$

Source	DF	SS	MS	F	p
Subjects	26	4794.67	184.41	85.06	0.000
7 to 10 min	3	10.89	3.63	1.67	0.179
Error	78	169.11	2.17		
Total	107	4974.67			

Table A5.3.3

ANOVA 2-way analysis of variance for oxygen consumption values ($ml \cdot kg^{-1} \cdot min^{-1}$) between 8 and 10 minutes at 75% $\dot{V}O_2max$

Source	DF	SS	MS	F	p
Subjects	26	3627.36	139.51	74.44	0.000
8 to 10 min	2	1.21	0.60	0.32	0.726
Error	52	97.46	1.87		
Total	80	3726.02			

Table A5.3.4

ANOVA 2-way analysis of variance for oxygen consumption values ($ml \cdot kg^{-1} \cdot min^{-1}$) between 6 and 10 minutes at 85% $\dot{V}O_2max$

Source	DF	SS	MS	F	p
Subjects	26	5787.60	222.60	83.80	0.000
6 to 10 min	4	35.75	8.94	3.36	0.012
Error	104	276.25	2.66		
Total	134	6099.60			

Table A5.3.5

ANOVA 2-way analysis of variance for oxygen consumption values ($ml \cdot kg^{-1} \cdot min^{-1}$) between 7 and 10 minutes at 85% $\dot{V}O_2max$

Source	DF	SS	MS	F	p
Subjects	26	4597.46	176.83	73.68	0.000
7 to 10 min	3	14.55	4.85	2.02	0.118
Error	78	187.20	2.40		
Total	107	4799.21			

Table A5.3.6

ANOVA 2-way analysis of variance for oxygen consumption values ($ml \cdot kg^{-1} \cdot min^{-1}$) between 8 and 10 minutes at 85% $\dot{V}O_2max$

Source	DF	SS	MS	F	p
Subjects	26	3571.56	137.37	66.32	0.000
8 to 10 min	2	2.30	1.15	0.55	0.578
Error	52	107.70	2.07		
Total	80	3681.56			

A5.4 Chapter 5 ANOVA Tables: 1-way Analysis of Oxygen Consumption at 75% and 85% $\dot{V}O_2max$

Table A5.4.1

ANOVA 1-way analysis of variance on oxygen consumption data, comparing differences in values at 3 minutes of exercise with grouped values at 4, 5, 6, 7, 8, 9 and 10 minutes of exercise. Level of intensity is 75% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
Factor	1	272.0	272.0	5.61	0.019
Error	238	11531.9	48.5		
Total	239	11803.9			

LEVEL	N	MEAN	STDEV	INDIVIDUAL 95% CI'S FOR MEAN BASED ON POOLED STDEV
3 min	30	41.867	7.660	(----------*----------)
5-10 min	210	45.086	6.858	(---*----)
POOLED STDEV =		6.961		40.0 42.0 44.0 46.0

$ml \cdot kg^{-1} \cdot min^{-1}$

Table A5.4.2

ANOVA 1-way analysis of variance on oxygen consumption data, comparing differences in values at 4 minutes of exercise with values between 5 and 10 minutes of exercise. Level of intensity is 75% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
Factor	1	80.8	80.8	1.72	0.191
Error	208	9749.7	46.9		
Total	209	9830.5			

LEVEL	N	MEAN	STDEV	INDIVIDUAL 95% CI'S FOR MEAN BASED ON POOLED STDEV
4 min	30	43.567	6.569	(----------*----------)
5-10 min	180	45.339	6.890	(-----*------)
POOLED STDEV =		6.846		42.0 43.5 45.0 46.5

$ml \cdot kg^{-1} \cdot min^{-1}$

Table A5.4.3

ANOVA 1-way analysis of variance on oxygen consumption data, comparing differences in values at 3 minutes of exercise with values between 4 and 10 minutes of exercise. Level of intensity is 85% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
Factor	1	324.8	324.8	7.29	0.007
Error	228	10154.1	44.5		
Total	229	10478.8			

				INDIVIDUAL 95% CI'S FOR MEAN BASED ON POOLED STDEV
LEVEL	N	MEAN	STDEV	-------+---------+---------+---------
3 min	30	47.067	6.762	(-----------*-----------)
4-10 min	200	50.595	6.661	(----*----)
				-------+---------+---------+---------
POOLED STDEV =		6.673		46.0 48.0 50.0
				$ml \cdot kg^{-1} \cdot min^{-1}$

Table A5.4.4

ANOVA 1-way analysis of variance on oxygen consumption data, comparing differences in values at 4 minutes of exercise with values at between 5 and 10 minutes of exercise. Level of intensity is 85% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
Factor	1	243.8	243.8	5.62	0.019
Error	198	8584.4	43.4		
Total	199	8828.2			

				INDIVIDUAL 95% CI'S FOR MEAN BASED ON POOLED STDEV
LEVEL	N	MEAN	STDEV	---+---------+---------+---------+---
4 min	30	47.967	5.968	(-----------*-----------)
5-10 min	170	51.059	6.685	(----*----)
				---+---------+---------+---------+---
POOLED STDEV =		6.584		46.0 48.0 50.0 52.0
				$ml \cdot kg^{-1} \cdot min^{-1}$

Table A5.4.5

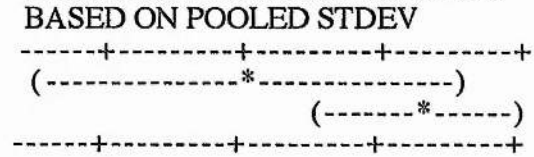
ANOVA 1-way analysis of variance on oxygen consumption data, comparing differences in values at 5 minutes of exercise with values at between 6 and 10 minutes of exercise. Level of intensity is 85% $\dot{V}O_2max$.

Source	DF	SS	MS	F	p
Factor	1	84.8	84.8	1.91	0.169
Error	168	7466.6	44.4		
Total	169	7551.4			

LEVEL	N	MEAN	STDEV
5 min	30	49.533	6.776
6-10 min	140	51.386	6.644

POOLED STDEV = 6.667

INDIVIDUAL 95% CI'S FOR MEAN BASED ON POOLED STDEV



$ml \cdot kg^{-1} \cdot min^{-1}$

A5.5 ANOVA Tables for 7 Minute Tests at 80% $\dot{V}O_2max$

Table A5.5.1

ANOVA 2-way analysis of variance on plasma lactate concentration ($mmol \cdot l^{-1}$) taken in the last minute of exercise equivalent to 80% $\dot{V}O_2max$, with subjects and trials as treatment factors.

Source	DF	SS	MS	F	p
Subjects	10	18.5111	1.8511	3.67	0.006
Trials	2	1.5088	0.7544	1.50	0.248
Error	20	10.0853	0.5043		
Total	32	0.5043			

Table A5.5.2

ANOVA 1-way analysis of variance on plasma lactate concentration ($mmol \cdot l^{-1}$) taken in the last minute of exercise of the three successive trials.

Source	DF	SS	MS	F	p
Factor	2	1.509	0.754	0.79	0.462
Error	30	28.596	0.953		
Total	32	30.105			

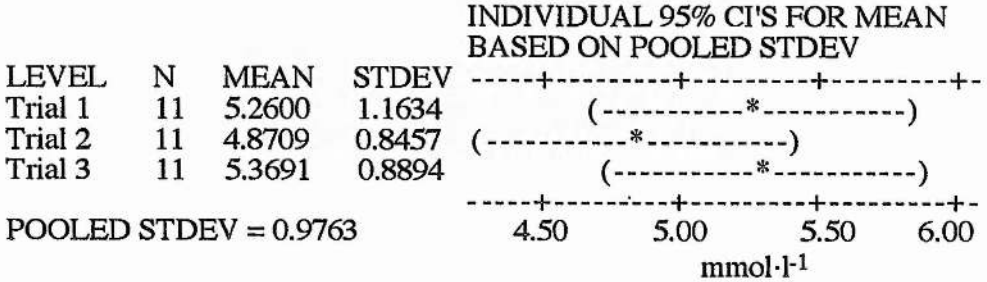


Table A5.5.3

ANOVA 2-way analysis of variance on oxygen consumption ($l \cdot min^{-1}$) in the last minute of each work period at an exercise intensity equivalent to 80% $\dot{V}O_2max$, with subjects and trials as treatment factors.

Source	DF	SS	MS	F	p
Subjects	10	15.9290	1.5929	95.40	0.000
Trials	2	0.5387	0.2694	16.13	0.000
Error	20	0.3340	0.0167		
Total	32	16.8016			

Table A5.5.4

ANOVA 1-way analysis of variance on oxygen consumption ($l \cdot min^{-1}$) taken in the last minute of successive trials.

Source	DF	SS	MS	F	p
Factor	2	0.539	0.269	0.50	0.613
Error	30	16.263	0.542		
Total	32	16.802			

				INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV
LEVEL	N	MEAN	STDEV	--+---------+---------+---------+----
Trial 1	11	3.5664	0.6930	(-----------*-----------)
Trial 2	11	3.6991	0.7400	(-----------*-----------)
Trial 3	11	3.8782	0.7736	(-----------*-----------)
				--+---------+---------+---------+----
POOLED STDEV =		0.7363		3.15 3.50 3.85 4.20 $l \cdot min^{-1}$

Table A5.5.4

ANOVA 2-way analysis of variance on heart rate ($b \cdot min^{-1}$) in the last minute of each work period equivalent to 80% $\dot{V}O_2max$, with subjects and trials as treatment factors.

Source	DF	SS	MS	F	p
Subjects	10	3945.21	394.52	192.38	0.000
Trials	2	276.65	138.33	67.45	0.000
Error	20	41.02	2.05		
Total	32	4262.88			

Table A5.5.5

ANOVA 1-way analysis of variance on heart rate ($b \cdot min^{-1}$) taken in the last minute of successive trials.

Source	DF	SS	MS	F	p
Factor	2	277	138	1.04	0.365
Error	30	3986	133		
Total	32	4263			

LEVEL	N	MEAN	STDEV
Trial 1	11	166.18	11.59
Trial 2	11	170.86	11.46
Trial 3	11	173.14	11.54

POOLED STDEV = 11.53

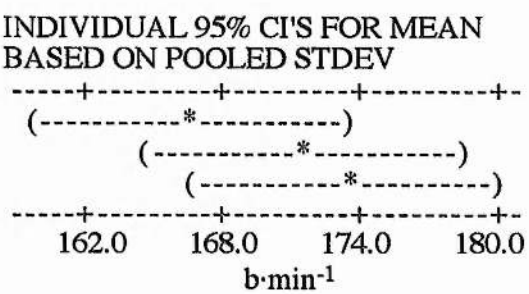


Table A5.5.6

ANOVA 2-way analysis of variance on distance completed (m) when exercising at an intensity equivalent to 80% $\dot{V}O_2max$, with subjects and trials as treatment factors.

Source	DF	SS	MS	F	p
Subjects	10	504275	50427	1084.04	0.000
Trials	2	455	227	4.89	0.019
Error	20	930	47		
Total	32	505660			

Table A5.5.7

ANOVA 1-way analysis of variance on distance covered (m) in the 3 successive trials.

Source	DF	SS	MS	F	p
Factor	2	455	227	0.01	0.987
Error	30	505205	16840		
Total	32	505660			

```
                                    INDIVIDUAL 95% CI'S FOR MEAN
                                    BASED ON POOLED STDEV
LEVEL    N   MEAN   STDEV  -----+---------+---------+---------+-
Trial 1. 11 1806.2   128.6  (---------------*---------------)
Trial 2. 11 1811.8   130.8    (---------------*---------------)
Trial 3. 11 1815.2   129.8      (---------------*---------------)
                            -----+---------+---------+---------+-
POOLED STDEV =  129.8          1750      1800      1850      1900 m
```

Table A5.5.8

ANOVA 1-way analysis of variance on plasma lactate concentration (mmol·l^{-1}) taken pre-test and in the last minute of 15 minute rest interval following the 3 successive trials at 80% $\dot{V}O_2$max for 7 minutes.

Source	DF	SS	MS	F	p
Factor	3	1.82	0.61	0.57	0.638
Error	40	42.68	1.07		
Total	43	44.51			

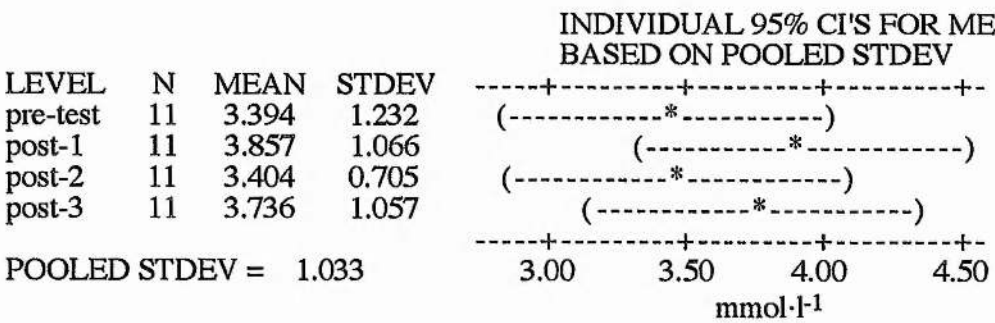
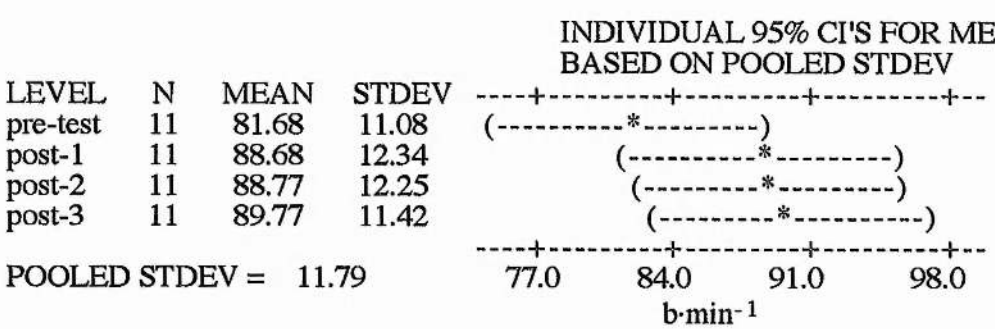


Table A5.5.9

ANOVA 1-way analysis of variance on heart rate (b·min^{-1}) taken pre-test and in the last minute of 15 minute rest interval following the 3 successive trials.

Source	DF	SS	MS	F	p
Factor	3	459	153	1.10	0.360
Error	40	5556	139		
Total	43	6015			



Appendix 6
Additional materials

A6.1 Information for subjects

A6.1.1 Chapter 3 information

MAIN STUDY
The effect of stroke rate on lactate accumulation and threshold in competitive rowing.
J.J. Forsyth
Department of Physical Education, University of St. Andrews.

PILOT STUDY: A comparison of blood lactate at different sampling sites following simulated rowing exercise.

The pilot experiment, which you have volunteered to be a part of, aims to determine whether lactate accumulation in the blood differs according to sampling site, following submaximal exercise on the Concept II rowing ergometer.

After a brief practice session, you will be required to exercise for 4 minutes at a low work intensity, in order to familiarise yourself with the equipment, and to determine workloads for the subsequent tests. After five minutes of rest, you will exercise for a further 4 minutes at approximately 60% of your estimated workload maximum. Blood lactate will then be determined by removing a very small sample of capillary blood from 3 different sites - the finger, the toe and the earlobe, in accordance with British Association of Sport Sciences' guidelines. Following another rest interval, you will again row for 4 minutes, but this time at approximately 90% of your estimated workload maximum. The same blood sampling procedure will follow the test. Heart rate using a sports tester will be monitored throughout.

The total time spent in the lab, including familiarisation, will be approximately 45 minutes; you will be required to visit the lab only once.

Due to the nature of the activity, please do not exercise strenuously 24 hours prior to testing, nor eat or drink anything during the preceding 2 hours.

If you have any questions or require any further information about the study, do not hesitate to ask.

Statement of Willingness to Participate

"I have read and fully understand the requirements as a subject for this experiment. As far as I am aware, I meet all the conditions necessary, and I give my consent to participate in the test. However, I understand that I do so at my own risk and that I can stop the test at any time."

Signature of subject _____ Date _____

Signature of tester _____

Thank you for your co-operation

UNIVERSITY OF ST ANDREWS

Telephone St Andrews (S.T.D. Code 01334) 476161
ext. 2180
ext.
ext.

Fax (01334) 474322

DEPARTMENT OF PHYSICAL EDUCATION,
THE UNIVERSITY,
ST ANDREWS,
FIFE KY16 9DY.

(A6.1.2 Letter to rowers)

Dear

Thank you for expressing an interest in the rowing study which is taking place at St. Andrews University. This document contains more detailed information about what you will be asked to do should you decide to volunteer.

The study is in two parts, the first being a $\dot{V}O_2$max test lasting between 8 and 16 minutes, and the second consisting of 3 sets of 10 minute rows. You will only need to visit the laboratory on one occasion for a total of 3 hours. You will need to avoid strenuous exercise 24 hours prior to testing and should avoid a large meal, caffeine, smoking, alcohol and any drugs or medication during the preceding 2 hours. All the data information collected will be treated as highly confidential and will not be available in any form to anyone outside the study.

Part A: You will be asked to warm up at a 500 m split time of 2:21 for women and 2:01 for men for 3 minutes, in order to familiarise yourself with the equipment, and so that your initial workload for the test can be determined. Throughout the test, you will be breathing through a tube, in order to measure how much oxygen you are consuming and utilising. To determine your blood lactate, a very small sample of capillary blood will be removed from the toe by a painless pin prick, before the test, during the last 60 seconds of the warm-up and 4 to 5 minutes post-exercise. Blood is sampled from the toe to avoid interference with the rowing action. Heart rate will be monitored using a conventional sports tester.

Women

	500 m Time (min.s)	Power Output (watts)	Increment (watts)
a	2:34	96	-
b	2:21	123	27
	2:13	150	27
	2:07	177	27
	2:01	203	26
	1:55	230	27
	1:49	256	26
	1:46	283	27

Men

	500 m Time (min.s)	Power Output (watts)	Increment (watts)
a	2:07	177	-
b	2:01	203	26
	1:55	230	27
	1:49	256	26
	1:46	283	27
	1:43	311	27
	1:40	338	27
	1:37	366	28
	1:34	400	34

The above protocol shows the 500 m split times at which you are to row, starting at either 'a' or 'b', depending on your heart rate response during the warm-up. You will be required to increase the work intensity every 2 minutes, until you are unable to maintain the stated split time. The final workload should be equivalent to what you are capable of doing maximally. You will be able to select your own stroke rate in the range of 24 to 32 strokes per minute. The ergometer will be set with the fans closed and on the larger of the two drive cogs.

Part B: After a one hour rest period, you will attempt to perform 3 sets of 10 minute steady state pieces at 75%, 85% and 95% of your established maximum. Heart rate and respiratory variables will be measured as for the VO_2max test, and blood will be sampled prior to, and twice during each 10 minute piece. The rest interval between the tests will be 15 minutes.

Feedback on all the data collected will be sent at a later date. This will include your VO_2max, heart rate profile related to ergometer 500 m split time, and your estimated individual lactate threshold. Exercising at this last level has been shown to improve endurance capacity and in turn performance. The tests will therefore be extremely beneficial in assessing your aerobic capacity and for establishing training intensities.

You will need to make an appointment in advance and can do so by ringing me on **0334 462184** any time during the day and early evening, or alternatively replying to the above address. A suitable and convenient time can be arranged for you to visit the laboratory and a contribution towards your travel expenses will be offered. If you require any further information or are concerned about any aspect of the testing, please do not hesitate to contact me.

I look forward to hearing from you shortly,

Jacky J. Forsyth
Project Researcher

A6.2 Pre-test Questionnaires and Consent Forms

A6.2.1 Pre-test questionnaire for Chapter 3

(Adapted from BASS informed consent & Par-Q)

Date of Test ___/___/___ **Time of Test** _____

Full Name _____

Date of Birth ___/___/___ **Age** _____ years

As a subject for this experiment, could you please complete the following questionnaire. Your co-operation is most appreciated.

Please circle the appropriate response:

1. How would you describe your present level of activity?
   sedentary
   moderately active
   active
   highly active

2. How would you describe your present level of fitness?
   very unfit
   moderately fit
   trained
   highly trained

3. Do you, or have you ever suffered from any of the following:

Epilepsy	yes	no
Bronchitis	yes	no
Diabetes	yes	no
Asthma	yes	no

4. Do you, or have you ever suffered from any form of heart complaint?
   yes no

5. Do you currently have any form of muscle or joint injury, that might be made worse with exercise?
   yes no
   If yes, please specify .....

6. Do you often feel faint or have spells of severe dizziness?
   yes no

7. Has a doctor ever told you that you have high blood pressure?
   yes no

8. Have you had any cause to suspend your normal training for the past 2 weeks prior to this test date?
   yes no
   If yes please specify .....

9. Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you?
   yes no
   If yes please specify .....

Signature of subject _____ Date ___/___/___

Signature of tester _____

A6.2.2 Questionnaire and consent, Chapters 4 and 5

UNIVERSITY OF ST. ANDREWS
DEPARTMENT OF PHYSICAL EDUCATION

PRE-TEST QUESTIONNAIRE

FULL NAME .....

DATE OF BIRTH ...../...../..... **AGE** ..... years

As a subject for this experiment could you please complete the following questionnaire. Your co-operation is greatly appreciated.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL

Please circle the appropriate response:

1. How would you describe your present level of activity? moderately active / active / highly active

2. How would you describe your present level of fitness? moderately fit / trained / highly trained

3. Do you suffer, or have you ever suffered from:

Epilepsy?	yes	no
Bronchitis?	yes	no
Diabetes?	yes	no
Asthma?	yes	no

4. Do you, or have you ever suffered from any form of heart complaint? yes no

5. Do you currently have any form of muscle or joint injury, that might be made worse with exercise? yes no

If yes, please give details .....

6. Do you often feel faint or have spells of severe dizziness? yes no

7. Has a doctor ever told you that you have high blood pressure? yes no

8. Have you had any cause to suspend your normal training for the past 2 weeks prior to this test date? yes no

If **yes** please give details .....

9. Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you? yes no

If **yes** please give details .....

Signature of subject ..... Date ...../...../.....

Signature of tester .....

Please circle the appropriate response

IN THE LAST **TWO** HOURS HAVE YOU:

1. Had any tea or coffee?	yes	no
2. Eaten a main meal?	yes	no
3. Taken any drugs or medication?	yes	no
4. Smoked any cigarettes?	yes	no

and in the last 24 hours....

5. Done any strenuous exercise?	yes	no
6. Consumed any alcohol?	yes	no

Statement of Willingness to Participate

"I have read and fully understand the requirements as a subject for this experiment. As far as I am aware, I meet all the conditions necessary, and I give my consent to participate in the tests. However, I understand that I do so at my own risk and that I can stop the tests at any time."

Signature of subject _____ Date _____

Signature of tester _____

Thank you for your co-operation

A6.3 Sample Data Recording Forms

A6.3.1 Chapter 3 data form

RESULTS

Number .....
Name .....
Sex .....
Age ..... yrs
Height ..... m
Weight ..... kg

Date ...../...../.....
Time .....
Ambient temp. .....
Rel. humidity .....%
Pressure ..... mmHg

Estimated 50% heart rate .....b·min^{-1}
Heart rate prior to testing .....b·min^{-1}

Warm-up

Actual heart rate (b·min^{-1})		500 m split time per stroke in last min min/500m		
10secs.....	1	11	21	
20secs.....	2	12	22	
30secs.....	3	13	23	
40secs.....	4	14	24	
50secs.....	5	15	25	
60secs.....	6	16	26	
	7	17	27	
X=	8	18	28	
	9	19	29	
	10	20	30	
			X=	

Excluded from test yes no

Estimated 60% workload min/500
Heart rate prior to test .....b·min^{-1}

60% TEST

Actual heart rate (b·min^{-1})		500 m split time per stroke in last min min/500m		
10secs.....	1	11	21	
20secs.....	2	12	22	
30secs.....	3	13	23	
40secs.....	4	14	24	
50secs.....	5	15	25	
60secs.....	6	16	26	
	7	17	27	
X=	8	18	28	
	9	19	29	
	10	20	30	
			X=	

Blood lactate	mmol·l^{-1}	Time to complete	Sampler
finger	.....	.....	.....
toe	.....	.....	.....
earlobe	.....	.....	.....

Other comments

Estimated 90% workload min/500m
Heart rate prior to test .....b·min^{-1}

90% TEST

Actual heart rate (b·min^{-1})		500 m split time per stroke in last min **min/500m**		
10secs.....	1	11	21	
20secs.....	2	12	22	
30secs.....	3	13	23	
40secs.....	4	14	24	
50secs.....	5	15	25	
60secs.....	6	16	26	
	7	17	27	
X=	8	18	28	
	9	19	29	
	10	20	30	
			X=	

Blood lactate	mmol·l^{-1}	Time taken	Sampler
finger	.....	.....	.....
toe	.....	.....	.....
earlobe	.....	.....	.....

Other comments

A6.5.2 Chapters 4 and 5 data forms

RESULTS

No. .....
Name .....
Sex .....
Age ..... yrs
Ht. ..... m
Wt. ..... kg

Date ...../...../.....
Time .....
Ambient temp. ..... °C
Rel. humidity .....%
Pressure ..... mmHg

Estimated heart rate max. (211-Age) .....b/min **(z)**
65% of est. heart rate max. .....b/min **(y)**

Pre-test: heart rate **(x)** .....b/min *lactate* ***(A)***.....*mmol/l*

Warm-up: heart rate **(w)** .....b/min *lactate* ***(B)***.....*mmol/l*
total distance .....m
split *500m*

Protocol: **a** **b**

Load	Metres	*Actual*	Load	Metres	*Actual*
.....	1.....	.....	.....	9.....	.....
	2.....	.....		10.....	.....
.....	3.....	.....	.....	11.....	.....
	4.....	.....		12.....	.....
.....	5.....	.....	.....	13.....	.....
	6.....	.....		14.....	.....
.....	7.....	.....	.....	15.....	.....
	8.....	.....		16.....	.....

End: Time .....min,s *Post-lactate* ***(C)***. ..... *mmol/l*
RER .....l/min H.R.**(v)** .....b/min
VO_2 1.....ml/kg/min VO_2 .....l/min
2.....ml/kg/min Difference (2-1) .....l/min

Ambient temp. .....°C
Rel. humidity .....%
Pressure ..... mmHg

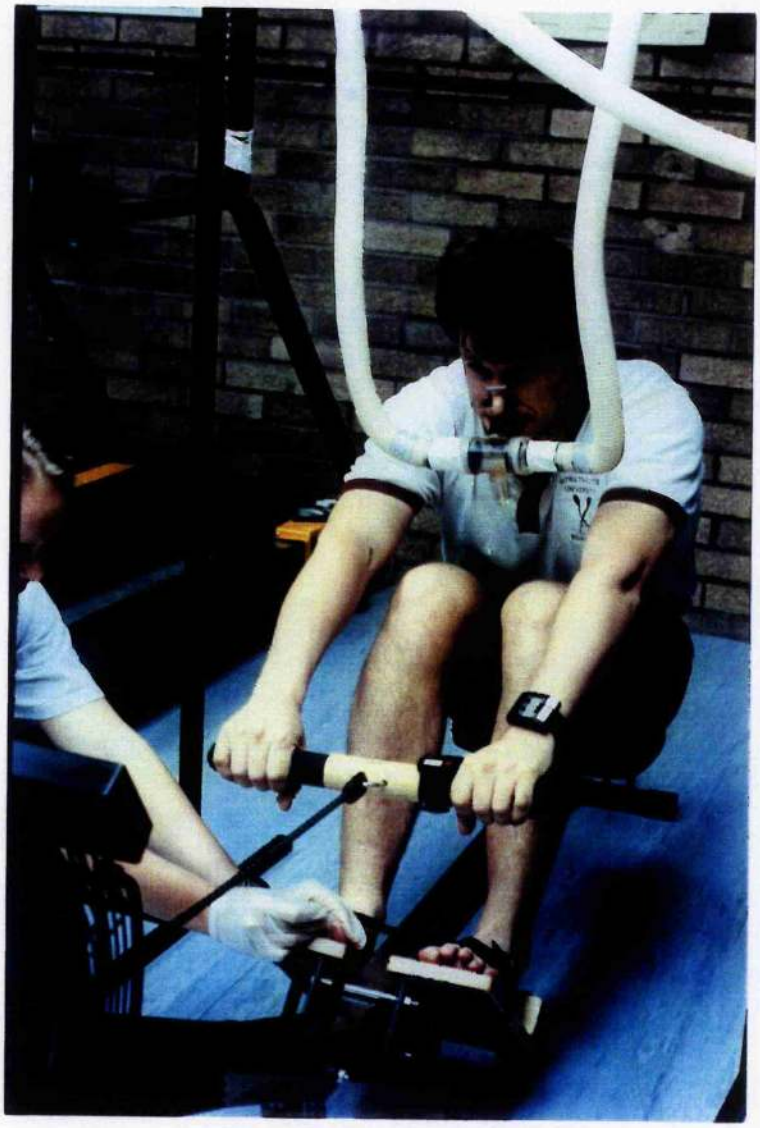
VO_2max .....ml/kg/min.

Expected:	VO_2 (ml/kg/min)	500 m split	H.R. (b/min)
75%	.....	.....	.....
85%	.....	.....	.....
95%	.....	.....	.....

Order of test: 789 798 987 978 879 897

		Lactate (mmol/l)	*H.R.(b/min)*	*Distance (m)*
Pre-test:		..... ***(D)***	..... ***(d)***	
75%	*mid*	..... ***(E)***	..... ***(e)***	
	end	..... ***(F)***	..... ***(f)***	.....
	rest	..... ***(G)***	..... ***(g)***	.....*500m*
85%	*mid*	..... ***(H)***	..... ***(h)***	
	end	..... ***(I)***	..... ***(i)***	.....
	rest	..... ***(J)***	..... ***(j)***	.....*500m*
95%	*mid*	..... ***(K)***	..... ***(k)***	
	end	..... ***(L)***	..... ***(l)***	.....
	rest	..... ***(M)***	..... ***(m)***	.....*500m*

Figure A6.1 Blood sampling from the toe whilst rowing



APPENDIX 7

Correspondence regarding $\dot{V}O_2$max test

LONGWOOD

Farmville, Virginia 23901

March 7, 1994

Jacky Forsyth
Department of Physical Education
The University.
St. Andrews.
FIFE KY16 9DY
Scotland. G.B.

Dear Dr. Forsyth,

Thank you for your letter of inquiry. I am very sorry that my reply is so late in arriving. Our rowing protocol involved decreases in 500 m rowing time of 5 s every 3 min, until volitional exhaustion. The protocol began at a 500 m rowing time of 2 min and 30 s. In retrospect, however, I would think it necessary to standardize the work increases for each stage. Therefore, I would generally recommend beginning at 100 W and increasing 30 W per stage. As to the question of stroke frequency, we did not control this, as we were not measuring efficiency and the elite rowers that we worked with were very capable of achieving the same stroke rate at a given power output with repeated testing.

I should point out that these recommendations are for a protocol involving elite rowers. If untrained subjects are used, a lower initial power output with smaller increments in work rate may be necessary. In addition, some standardization of stroke rate may be necessary. This standardization should obviously involve increases in stroke rate with increased work.

I hope that this information was of some help. Please contact me if this was not sufficient, or if you have any further questions. In addition, I would love to learn more about your research and the results of this project.

Sincerely,

Christopher J. Womack, Ph.D.

Longwood College Health, Physical Education and Recreation Department (804) 395-2533 (Health and Physical Education)
(804) 395-2534 (Theraceutic Recreation)

Dartmouth-Hitchcock Medical Center

Section of Pulmonary and Critical Care Medicine

James C. Leiter, M.D.
Donald A. Mahler, M.D.
Harold L. Manning, M.D.
H. Worth Parker, M.D.

One Medical Center Drive
Lebanon, New Hampshire 0375

603-650-5533
Fax # 603-650-4437

January 31, 1994

Jacky Forsyth
Department of Physical Education
University of St Andrews
Fife Scotland G.B.
KY16 9DY

Dear Mr. or Ms. Forsyth:

I am writing to you in response to your letter of January 21, 1994, concerning exercise testing protocol on the rowing ergometer.

Enclosed are reprints of selected articles which you may find useful in your study.

As you are aware, it is difficult to design an exercise testing protocol for unfit and fit individuals. The ideal exercise testing duration should be 8-12 minutes to provide peak values for oxygen consumption and other physiological variables. Therefore, different work loads may be necessary for fit and unfit individuals.

In a recent study of healthy, physically active males with a $VO_{2\ max}$ of 53±5 ml/kg/min, we used a one minute incremental exercise protocol on the Concept II rowing ergometer. There was a one minute warm-up period, then the initial power production was 50 watts for the first minute, and then the target intensity was increased by 25 watts each minute. Each subject continued to exercise until exhaustion or inability to maintain the target level of power production. For this group of individuals with a mean age of 21±5 years, the exercise duration ranged from 6-9 minutes. It is possible that for a less fit group of individuals you might want to start at 0 watts for the first minute as a warm-up, and then increase by 25 watts each minute. Alternatively, a 15 watt increment might be appropriate. Certainly, you may need to do a brief "pilot study" in order to determine the most appropriate increments in order to achieve the 8-10 minutes of exercise duration.

In all of our testing protocols we have allowed the individual subject (rower) to select his/her stroke rating in order to maintain a given target power production. Thus, some individuals would have a lower or higher stroke rate based on the level of effort/power of the individual. Because we have mainly used a progressive incremental exercise protocol, I do not have any specific information on 500 meter split time. In general, increments are one minute, although two or three minute increments could be used if desired.

I hope this information is helpful to you. Please do not hesitate to contact me if you have additional comments or questions.

Sincerely yours,

Donald A. Mahler, MD
Associate Professor of Medicine

DAM/pbh
Enclosures

RIGSHOSPITALET

Department of Anaesthesia

Dr. Jacky Forsyth
Department of Physical Education
The University of St. Andrews
St Andrews
Fife KY 16 9 DY
Great Britain

Ward no.: 2034
Ext. no.: 35452034
Re.:

Date: 17th June 1994

Dear Dr. Jacky Forsyth.

Thank you for your letter of June 14. I am not quite sure what your problems is. The almost universal international standard is to perform a 6 minutes "all out" test. The oarsmen are from their training during the winter most often very well aquanted with this procedure, so that physiological measurements are a nice continuation of their "daily" practice. Things may now change because of the World Champinonship in Rowing on an ergometer, where time for "2000 meter" is recorded, but this has not yet been tranfered to the physiologic litterature.

You may find help in my most recent review and also in the supplementum we made for international Journal Sports Medicine, where split time are dealt with in detail. I do hope this can be of some help for you.

Yours sincerely,

Niels H. Secher
Associate Professor, MD, DMS

9 Blegdamsvej
DK-2100 Copenhagen O
Denmark

Telephone +4535453545
Telefax

Direct dialing +453545
and ext. no.

9443

APPENDIX 8

Method of lactate estimation in plasma

A8 Lactate Estimation in Blood (Fully Enzymatic)

A8.1 Test principle

$$\text{L-LACTATE} + \text{NAD} \overset{\text{LDH}}{\rightleftharpoons} \text{PYRUVATE} + \text{NADH} + \text{H}^+$$

$$\text{PYRUVATE} + \text{L-GLUTAMATE} \overset{\text{GPT}}{\rightleftharpoons} \text{L-ALANINE} + \alpha\text{-OXYGLUTARATE}$$

Normal values in plasma are 5.7-22 mg/100 ml (0.63-2.44 mmol·l^{-1})

A8.2 Solutions

1. Fluoride/EDTA (ethylenediaminetetra-acetic acid) reagent, (Boehringer 243710)
2. 4.6 mmol·l^{-1} NAD = 32 mg/10 ml H_20 (SIGMA N3886).
3. Buffer - sodium carbonate, 0.5 mol·l^{-1} = 13.24 g (FISONS S-2929-53)
   L-glutamate, 63 mmol·l^{-1} = 2.31 g/ 250 ml/ pH 10 (SIGMA G6904)
4. LDH/GPT suspension mixture: LDH 1632 μ/ml (SIGMA L25000)
   GPT 102 μ/ml (SIGMA G8255)

A8.3 Methods

Blood was collected in 50 μl micropipettes, and emptied into small Eppendorf tubes containing 4 μl of fluoride/EDTA reagent (1). This was centrifuged for 5 minutes at full speed within 2 hours of the collection, and the supernatant plasma removed.

For the reagent solution 32 mg of NAD was dissolved in 10 ml of H_20 (2). To this, 40 ml of 0.5 mol·l^{-1} sodium carbonate/ 63 mmol·l^{-1} L-glutamate, were added (3). Disposable cuvettes (1 cm light path) were filled with 1 ml of the reagent solution. A 10 μl sample of plasma was added, mixed by careful inversion and analysed using a spectrophotometer (L.K.B. ULTRASPEC) set at 340 nm. The optical density (OD) was recorded (A_1). A 10 μl sample of enzyme solution (4) was added and again mixed by inversion. For the reaction to proceed, a time period of approximately 20 to 30 minutes was allowed (depending on the amount of lactate in the sample). The OD was noted (A_2) and the change (A_2-A_1) was used to calculate the amount of lactate (i.e. A_2-A_1 x 16.39 for samples of 10 μl. The value 16.39 is a dilution factor derived from the extinction coefficient of NADH and the solutions used in the assay. Units are μM/ml).