2001

The specificity and sensitivity of the criteria used to measure VO2Max

Geoffrey D. Juranovich
Edith Cowan University

THE SPECIFICITY AND SENSITIVITY OF THE CRITERIA USED TO MEASURE $\dot{V}O_{2MAX}$

By

Geoffrey D. Juranovich

Bachelor of Science Honours (Sport Science)

This thesis is submitted in partial fulfilment for the award of Bachelor of Science (Sports Science) with Honours

Date of Submission:

9th November 2001

USE OF THESIS

Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

Incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

Contain any material previously published or written by another person except where due reference is made in text; or

Contain any defamatory material.

Signatur[redacted]

Date......14.3.02......

Acknowledgements

Foremost, I would like to acknowledge the support of the School of Biomedical and Sports Science staff, in particular, Dr Paul Sacco, Dr. Joram Linsten, Dr Angus Burnett, Dr Fiona Morris, Mrs Angela Johnston, Mrs Eileen Baker, Mr Peter Hope, Ms Mary Cornelius, Mr Hugh Lance and Mrs Doreen Mackie. Without the technical and administrative knowledge that these people possess, I, without a word of a lie, would never have completed the Honours year. In terms of spiritual and emotional support, the great friends that we have made and grown with over this past year have inspired our efforts to do our utmost to succeed. These people, mostly from the ECU Sports Science Honours year of 2001, have provided a wealth of knowledge, motivation, humour and esprit de corps. I wish to thank with all my heart, Messrs. Mike Newton, Andrew Lavender, Gavin Cormack, Adam Beard, Greg Morgan, Alistair Stewart, Ryan Price, Mike Denney and Paul Long, Mrs Tamika Heiden, Ms Meghan Grant, Ms Ellissa Burton, Ms Carmel Nottle, and Ms Fleta Solomon. This Honours project could not have been made possible without the direct assistance of the subjects that voluntarily offered their bodies in the name of sports science. Half the participants came from the 1st year sports science students whom I applaud for their undying enthusiasm and wish them all the best in their chosen academic paths. The volunteers from the community, I thank, not only for their participation but also for their inquiring minds and complete dedication to the task at hand. Lastly, to my supervisor, Associate Professor Robert A. Robergs, I would like to thank you for restoring my faith in the inquiring mind and for being the world leader in workaholics!

Thank you all.

Abstract

The use of $\dot{V}O_{2MAX}$ as a measure of cardiorespiratory fitness is widespread throughout the fields of exercise physiology, physiology and medicine. $\dot{V}O_{2MAX}$ is described as the maximal rate of oxygen consumption during increasing exercise intensities and is defined by a plateau or levelling off of oxygen consumption ($\dot{V}O_2$). Taylor et al. (1955) derived the primary criterion for a levelling off (plateau) of $\dot{V}O_2$ at the end of an incremental exercise test to exhaustion to be a change in $\dot{V}O_2$ ($\Delta \dot{V}O_2$) <150mL or 2.1mL/kg/min during the final minute. This primary criterion has been widely accepted and utilised since 1955. Secondary criteria have also been introduced due to the difficulty in obtaining a $\dot{V}O_2$ plateau in all subjects. The secondary criteria used to verify that $\dot{V}O_{2MAX}$ has been attained include 1) blood lactate (La) >8mmol/L, a respiratory exchange ratio (RER) >1.15, a rating of perceived exertion (RPE) > 17, and an age-predicted maximal heart rate (APMHR) ±10 beats/min from predicted using 220-age. Despite the use of such secondary criteria, none of these items have been adequately assessed for their sensitivity or specificity for coinciding with a $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$. 64 male and female subjects drawn from university sports science students and local triathalon and running clubs, between 18 and 55 years of age, performed two randomly assigned tests held on separate days. All participants completed a $\dot{V}O_{2MAX}$ test for each of cycle ergometry (CE) and treadmill (TM) running. During each test, breath-by-breath indirect calorimetry was performed to derive data of minute ventilation ($\dot{V}E$), oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and RER. Heart rate (HR) captured data was acquired by telemetry, ratings of perceived exertion (RPE) were obtained at peak exercise intensity, and finger-prick blood lactate (La) samples were taken at 30 seconds and 120 seconds post-exercise. All $\dot{V}O_2$ data was processed using a 3 breath smoothing function. Limitations of time restricted the enzymatic analysis of La samples and

therefore these results were not included in this study. Multiple regression found that there were no correlations in bivariate or multivariate conditions and that no secondary criteria could explain the variance in the presence or absence of a $\dot{V}O_2$ plateau. None of the secondary criteria could discriminate between those subjects that attained a $\dot{V}O_2$ plateau and those that did not. Sensitivity was very low, but specificity generally good for both modes of exercise (TM RER and CE RPE >90%). However only TM RER could positively predict the occurrence of a $\dot{V}O_2$ plateau, where all other secondary criteria were poor positive and negative predictors using Bayes theorem. Secondary criteria such as APMHR, RER and RPE should not be used to verify $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau as they are neither sensitive, specific nor able to predict the absence or presence of a $\dot{V}O_2$ plateau. The only valid criterion is the $\dot{V}O_2$ plateau and researchers and clinicians should consider validating alternative measures to determine $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau.

Table of Contents

List of Figures

List of Tables

CHAPTER ONE

INTRODUCTION

1.1 Background

The rate of oxygen consumption ($\dot{V}O_2$), during incremental exercise, can be used to assess the cardiorespiratory and muscular endurance fitness of an individual. The point at which $\dot{V}O_2$ levels off with continued increases in exercise intensity ($\dot{V}O_2$ plateau) is defined as the maximal oxygen uptake or $\dot{V}O_{2MAX}$ (Balady et al., 2000; McArdle, Katch, & Katch, 1991).

A.V. Hill and H. Lupton(Hill & Lupton, 1923) have been credited as the first to propose the $\dot{V}O_{2MAX}$ phenomenon. It was not until 1955, 32 years later, that Taylor et al.(Taylor, Buskirk, & Henschel, 1955) defined the parameters within which a $\dot{V}O_2$ plateau exists. They suggested a change in $\dot{V}O_2$ ($\Delta \dot{V}O_2$) during the final minute of an incremental exercise test of no more than 150 mL/min (or 2.1mL/kg of Body Mass/min) could be used as the primary criterion to determine that a $\dot{V}O_2$ plateau was evident and that the peak $\dot{V}O_2$ was $\dot{V}O_{2MAX}$.

Although testing to quantify $\dot{V}O_{2MAX}$ is widely accepted, many studies since 1955 have reported a low incidence of a plateau in $\dot{V}O_2$. This particular problem was highlighted in a review by Howley, Basset and Welch(Howley, Bassett, & Welch, 1995), that stated that the reported incidence of $\dot{V}O_2$ plateau could range from < 50% to 100% of subjects. Several explanations have been offered to explain this variability, such as the population studied, criteria used to establish a $\dot{V}O_2$ plateau, the exercise mode, testing protocol and subject motivation.

In light of the apparent difficulty in detecting a $\dot{V}O_2$ plateau, researchers have instituted other secondary criteria in order to verify that a subject has reached a point of maximal exertion. The secondary criteria include blood lactate concentration (La >8 mmol/L), respiratory exchange ratio (RER >1.15), age predicted maximal heart rate (APMHR ±10 beats/min from predicted using 220-age), and ratings of perceived exertion (RPE>17)(Cumming & Borysyk, 1972; Stachenfeld, Eskenazi, Gleim, Coplan, & Nicholas, 1992). These secondary criteria have been used in conjunction with the highest $\dot{V}O_2$ value ($\dot{V}O_{2PEAK}$) to estimate $\dot{V}O_{2MAX}$.

All of the secondary criteria have been widely published as guidelines for testing $\dot{V}O_{2MAX}$ (Balady et al., 2000). However, a small number of studies have revealed that the secondary criteria that determine $\dot{V}O_{2MAX}$ have low correlation with the other criteria or with the presence of a $\dot{V}O_2$ plateau(Figueroa-Colon et al., 2000; Freedson et al., 1986). Stachenfeld et al.(Stachenfeld et al., 1992) was the only study to attempt to quantify the sensitivity, specificity and predictive value of the secondary criteria.

The predictive value of the secondary criteria relates the accuracy of identifying an individual with or without a $\dot{V}O_2$ plateau. The predictive value is determined using Bayes' theorem, which involves calculations of the sensitivity and specificity of given criteria. In this application of Bayes' theorem, sensitivity refers to the percentage of subjects studied who have a $\dot{V}O_2$ plateau and are predicted as such. Conversely, specificity refers to the percentage of subjects who do not have a $\dot{V}O_2$ plateau, and are predicted as such(Balady et al., 2000).

The sensitivity and specificity of a given variable to predict a $\dot{V}O_2$ plateau are required to calculate the predictive value of a positive result ($\dot{V}O_2$ plateau predicted) and a negative result (no $\dot{V}O_2$ plateau predicted). A valid variable for use as a secondary criteria to verify a $\dot{V}O_2$ plateau and therefore, a true $\dot{V}O_{2MAX}$, would have a high (>90%) sensitivity and specificity.

1.2 Significance

The recommended primary and secondary criteria for $\dot{V}O_{2MAX}$ have been generated and accepted from one study that is now 56 years old(Taylor et al., 1955). The conditions that affect secondary criteria were not as well understood then as they are now and this has led certain physiological processes to be assumed rather than based on research-supported evidence.

The field of exercise physiology is now characterised by the use of modern indirect calorimetry equipment, and more sophisticated statistical procedures and research methods than that available in 1955. The widespread use and frequent application of the $\dot{V}O_{2MAX}$ test in pure and applied physiology, as well as medicine, signifies the importance for contemporary research of the validity of secondary criteria used to verify $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau.

1.3 Purpose

The purpose of this investigation was to determine the sensitivity and specificity of the secondary criteria that are being used to verify maximal oxygen consumption in the absence of a $\dot{V}O_2$ plateau. In addition, multivariate statistical techniques were used to determine if a combination of variables could improve the validity of the secondary criteria (discriminant

function), or if a combination of variables could explain the between-subjects variability in the slope of $\dot{V}O_2$ at the end of an incremental exercise test.

1.4 Research Questions

This study addressed the following research questions:

Will the secondary criteria, individually or combined, explain the between-subjects variability in the $\dot{V}O_2$ slope at the end of an incremental exercise test?

Will the secondary criteria, individually or in combination, successfully predict the positive or negative occurrence of a $\dot{V}O_2$ plateau?

Does the mode of exercise influence the incidence of the $\dot{V}O_2$ plateau?

Should the secondary criteria be utilised in the absence of a $\dot{V}O_2$ plateau?

1.5 Hypotheses

It was hypothesised that after performing the $\dot{V}O_{2MAX}$ protocol under both cycle and treadmill modalities the following outcomes will occur:

Multiple regression will show that each of the secondary criteria (independent variables) will have no or little correlation with the secondary $\dot{V}O_2$ slope (dependent variable), and that combinations of the independent variables do not significantly contribute to the explained variance of the secondary $\dot{V}O_2$ slope.

A comparison (discriminant function) between-groups (subjects who do and do not have a $\dot{V}O_2$ plateau) will determine that none of the secondary criteria, either individually or in combination, have any predictive value in classifying subjects that do or do not have a $\dot{V}O_2$ plateau.

The use of Bayes' theorem, with all the data converted to nominal values, will demonstrate that each of the secondary criteria will have poor sensitivity, specificity and predictive value.

The maximum attained scorevalue, at maximal volition, of RER, $\dot{V}CO_2$, $\dot{V}O_2$, $\dot{V}E$, RPE, Heart Rate (HR) and $\dot{V}E/\dot{V}O_2$ will not differ between cycle ergometry and treadmill testing protocols.

1.6 Definition of terms

$\dot{V}O_{2MAX}$: Rate of maximal oxygen uptake. The rate (per minute) of oxygen consumption in an individual performing maximal exercise to volitional exhaustion. It is measured in mL/kg/min, mL/min or L/min and primarily verified by the presence of a $\dot{V}O_2$ plateau.

$\dot{V}O_2$ plateau: The change in $\dot{V}O_2$ slope to a slope less than 50 mL/min that is not significantly different from zero and primarily defining a $\dot{V}O_{2MAX}$.

$\dot{V}O_{2PEAK}$: The highest value of the rate of maximal oxygen uptake without a plateau in $\dot{V}O_2$.

Bayes' Theorem. Formula utilised to identify the sensitivity, specificity and predictive value of variables to verify the presence of a defined condition.

Sensitivity: The percentage of subjects studied who have a $\dot{V}O_2$ plateau, and are predicted as such.

Specificity: The percentage of subjects studied who do not have a $\dot{V}O_2$ plateau, and are predicted as such.

Predictive value. The likelihood that a prediction of a $\dot{V}O_2$ plateau, or predicted absence of a $\dot{V}O_2$ plateau, is correct.

CHAPTER TWO

LITERATURE REVIEW

The use of exercise tests for the attainment of maximal oxygen uptake ($\dot{V}O_{2MAX}$) is common throughout exercise physiology to evaluate cardiorespiratory fitness, for medical and athletic assessment and research. Despite the preferred and widespread use of the $\dot{V}O_{2MAX}$ assessment, few researchers have adequately evaluated the criteria set down for the evaluation of $\dot{V}O_{2MAX}$ (Cumming & Borysyk, 1972; Figueroa-Colon et al., 2000; Stachenfeld et al., 1992). To appreciate the essence of these criteria, it is imperative that the development of the $\dot{V}O_{2MAX}$ test be considered.

The origin of the $\dot{V}O_{2MAX}$ test can be traced to a "classic" 1923 study by Hill and Lupton(Hill & Lupton, 1923), who found that during high intensity exercise, subjects demonstrated "an apparent steady state" of $\dot{V}O_2$, which "represents nothing more than the fact that its maximum level has been attained". In 1955, Taylor et al.(Taylor et al.. 1955) produced a widely-referenced $\dot{V}O_{2MAX}$ study which used a discontinuous protocol over several days, similar to Hill and Lupton. They determined that plateau $\dot{V}O_2$ with a change in slope of less than 2.1 mL/kg/min [or 150 mL/min – 71 kg male) was the optimal primary criterion for the attainment of maximal oxygen consumption. It seems that this is the first time that a study detailed the primary criterion for attaining $\dot{V}O_{2MAX}$.

However, many researchers found a variable incidence of the $\dot{V}O_2$ plateau, using the Taylor et al. condition(Howley et al., 1995). Some studies established their own primary criterion and found that they too were presented with a wide range in the frequency of $\dot{V}O_2$

plateau(Cumming & Borysyk, 1972; Meyer, Gabriel, & Kindermann, 1999; St Clair Gibson, Lambert, Broomhead, & Noakes, 1999; Wyndham et al., 1959). Over the past 40 years secondary criteria have been utilised to confirm that a $\dot{V}O_{2MAX}$ test is indeed maximal(Stachenfeld et al., 1992). The secondary criteria include the measurement of blood lactate (La >8mmol/L), Respiratory Exchange Ratio (RER >1.15), Age-Predicted Maximal Heart Rate (APMHR ±10beats/min 220-age) and Rating of Perceived Exertion (RPE >17) [Balady, 2000 #92).

The secondary criteria were introduced, not as a combined and researched unit of physiological makers, but individually, with no supporting evidence for their use other than they were practicable choices for that era. Considering the importance of the secondary criteria it is surprising that since Taylor et al.(Taylor et al., 1955) introduced the primary criterion, in 1955, there have been only 6 studies and 2 reviews primarily dedicated to criteria that verify $\dot{V}O_{2MAX}$ (Cumming & Borysyk, 1972; Duncan, Howley, & Johnson, 1997; Figueroa-Colon et al., 2000; Freedson et al., 1986; Howley et al., 1995; Noakes, 1998; Rivera-Brown, Rivera, & Frontera, 1992; Stachenfeld et al., 1992).

2.1 Primary criterion

As previously stated the accepted primary criterion for obtaining $\dot{V}O_{2MAX}$ is the establishment of a $\dot{V}O_2$ plateau of less than 150 mL/min or 2.1 mL/kg/min introduced by Taylor et al.(Taylor et al., 1955). Howley, Basset and Welch(Howley et al., 1995) stated that Taylor et al.'s criterion were somewhat "generous" since the majority (94%) of their subjects were able to achieve "higher $\dot{V}O_{2MAX}$ values". They also suggest that some studies have criteria that are too stringent ($\Delta\dot{V}O_2$ ±50-60 mL/min) so that it may be difficult to obtain $\dot{V}O_{2MAX}$.

A limited review of 27 $\dot{V}O_{2MAX}$ studies carried out from 1955 to the year 2000 found that 13 had employed the primary criterion of Taylor et al. Adolescents featured in 7 of those 13 articles that reported an incidence of $\dot{V}O_2$ plateau. In these articles the frequency of the primary criterion varied from 8% to 84%(Armstrong, Welsman, & Winsley, 1996; Cunningham, MacFarlane Van Waterschoot, Paterson, Lefcoe, & Sangal, 1977; Figueroa-Colon et al., 2000; Rivera-Brown & Frontera, 1998; Rivera-Brown et al., 1992; Rivera-Brown, Rivera, & Frontera, 1995), however in the remaining studies of adults, they revealed that 31% to 100%(Hermansen & Saltin, 1969; Katch, Sady, & Freedson, 1982; Myers, Walsh, Sullivan, & Froelicher Jr, 1990; St Clair Gibson et al., 1999; Stachenfeld et al., 1992; Taylor et al., 1955) achieved a $\dot{V}O_2$ plateau. The methodologies utilised by these studies varied from 15 to 120 seconds sampling periods, continuous and discontinuous treadmill and cycle ergometer ramp or graded protocols using douglas bags, mixing chambers or automated gas analysis systems.

The 14 studies outstanding, that chose not to employ Taylor et al.'s $\dot{V}O_2$ plateau criterion, used a variety of methods to verify the attainment of $\dot{V}O_{2MAX}$. Four articles did not state their $\dot{V}O_{2MAX}$ parameters(Davis et al., 1982; Froelicher Jr et al., 1974; Moffatt & Stamford, 1978; Saltin & Astrand, 1967) and 4 others did not have any criteria whatsoever, preferring to accept a $\dot{V}O_{2PEAK}$ (Cumming & Borysyk, 1972; Katch & Katch, 1973; McArdle, Katch, & Pechar, 1973; Meyer et al., 1999). The six studies that remained did not have a primary $\dot{V}O_2$ criterion and recorded $\dot{V}O_2$ peaks(Katch & Katch, 1973; McArdle et al., 1973; Meyer et al., 1999; Wyndham et al., 1959) or used their own choice of $\dot{V}O_2$ parameter such as $\Delta \dot{V}O_2 \pm<50$mL/min(Astorino, Robergs, Ghiasvand, Marks, & Burns, 2000) or $\Delta \dot{V}O_2 \pm<2$SD(Freedson et al., 1986).

2.1.1 Protocol

It is quite apparent from reviewing this imperfect list of $\dot{V}O_{2MAX}$ research that the protocols employed are so far ranging that they would be difficult to use for any degree of investigation. The protocols ranged from discontinuous and constant load(Armstrong et al., 1996; Cumming & Borysyk, 1972; Hermansen & Saltin, 1969; Taylor et al., 1955) to continuous step(Cunningham et al., 1977; Duncan et al., 1997; Figueroa-Colon et al., 2000; Katch et al., 1982; Rivera-Brown et al., 1992, 1995; Stachenfeld et al., 1992) to continuous ramp(Davis et al., 1982; Myers et al., 1990) or combinations thereof(Astorino et al., 2000; Froelicher Jr et al., 1974; McArdle et al., 1973; Saltin & Astrand, 1967; Sheehan, Rowland, & Burke, 1987; St Clair Gibson et al., 1999; Thomas, Cunningham, Rechnitzer, Donner, & Howard, 1987). Mode of exercise was usually on CE (Cycle Ergometer) or TM (Treadmill) and only one study included testing on a rowing ergometer(Rivera-Brown & Frontera, 1998).

All of the research of the secondary criteria for the verification of $\dot{V}O_{2MAX}$ used a variety of protocols to ascertain their results. Cumming et al(Cumming & Borysyk, 1972) and Stachenfeld et al.(Stachenfeld et al., 1992) used cycle ergometers over three tests the last being supramaximal. In contrast, Duncan et al.(Duncan et al., 1997) compared discontinuous vs continuous treadmill protocols and Figueroa-Colon et al.(Figueroa-Colon et al., 2000) used a progressive continuous test. The differences in the type of protocols to evaluate $\dot{V}O_{2MAX}$ must certainly have an effect on the results that are published(Howley et al., 1995).

Research that assessed protocols have suggested that $\dot{V}O_{2MAX}$ protocols should be aligned so as to be able to allow comparative reviews of research(Freedson et al., 1986; Howley et al., 1995; Myers, Walsh, Buchanan, & Froelicher, 1989; St Clair Gibson et al., 1999; Stockhausen, Grathwohl, Burklin, Spranz, & Keul, 1997). However this widely-lauded and

long-held recommendation seems to be ignored by the research community at large as no protocol has been adopted by regulatory institutions(Balady et al., 2000). The use of different protocols has invited criticism that the employment of the $\dot{V}O_{2MAX}$ assessment is somehow invalid since the incidence of $\dot{V}O_2$ plateau in many studies has been poor(Noakes, 1988).

2.1.2 Subject population

Two other factors listed by Howley et al.(Howley et al., 1995) that could affect the achievement of a plateau in $\dot{V}O_2$ are specific populations (i.e. children, elderly and the low-fit) and subject motivation of the subjects. As mentioned above, the list of literature devoted to $\dot{V}O_{2MAX}$ study reported that adolescents appeared to have a larger variance in the incidence of $\dot{V}O_2$ plateau (8% - 84%)%(Armstrong et al., 1996; Cunningham et al., 1977; Duncan et al., 1997; Figueroa-Colon et al., 2000; Rivera-Brown & Frontera, 1998; Rivera-Brown et al., 1992, 1995) and the 40 year old plus population did not fair any better (31% - 50%)(Cumming & Borysyk, 1972; Thomas et al., 1987).

In the few studies that did include a variance of populations, that is men, women, trained, untrained, it did not seem to impair or improve the ability to achieve $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$ (Freedson et al., 1986; Hermansen & Saltin, 1969). The concept of population differences in determining $\dot{V}O_{2MAX}$ has been suggested as a contributing factor to the attainment of a $\dot{V}O_2$ plateau, however, no empirical evidence has been presented to support such a statement thus far.

2.1.3 $\dot{V}O_2$ Sampling

An important aspect of the contemporary $\dot{V}O_{2MAX}$ assessment is the technology utilised in the test. In past years the $\dot{V}O_{2MAX}$ test has been carried out using Douglas bags(Hermansen & Saltin, 1969; Saltin & Astrand, 1967; Taylor et al., 1955; Wyndham et al., 1959), meteorological balloons(Katch et al., 1982; McArdle et al., 1973; Sheehan et al., 1987) or tissot method, which are all limited in their ability to measure ventilatory variables and frequency of sampling (≥60secs) during a maximal test. Currently, the most common method is to use an automated gas analysis system that measures ventilatory variables (breath by breath or by 10, 15, 20, 30 or 60 second sampling periods)(Astorino et al., 2000; Davis et al., 1982; Myers et al., 1990). It is these automated gas analysis systems that enhance the efficiency of testing and facilitate 'real-time' upload of results.

Myers et al.(Myers et al., 1990) combined the technological advances with simple regression to be able to quantifiably detect and measure a $\dot{V}O_2$ plateau. Using the mean of 8 breaths over 30 breaths they found that they had "marked variability in the slope of change in oxygen uptake" when testing the same subjects over several days. In previous cases of $\dot{V}O_{2MAX}$ testing the use of sampling over 30 or 60 seconds was common and recommended by Howley et al.(Howley et al., 1995). Robergs(Robergs, 2001) argues that breath by breath $\dot{V}O_2$ data "is theoretically the most sensitive method" used to verify a $\dot{V}O_2$ plateau and may show "true physiological variability". Astorino et al.(Astorino et al., 2000) has confirmed that "shorter sampling intervals (breath-by-breath and 15s) are most suitable for the detection of the $\dot{V}O_2$ plateau".

The identification of a $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$ has been difficult at best for the majority of exercise testing professionals. Many articles(Cunningham et al., 1977; Duncan et al., 1997; Myers et al., 1989; Myers et al., 1990; Rivera-Brown & Frontera, 1998; Rivera-Brown et al.,

1995) have argued that the $\dot{V}O_2$ plateau should be relieved of its importance of being the primary criterion and other (secondary) variable(s) should take its place.. In contrast, Robergs and Astorino et al. have commented that the $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$ is yet to be replaced by a more suitable criterion(Astorino et al., 2000; Robergs, 2001; Robergs, Icenogle, Hudson, & Greene, 1997).

2.2 Secondary criteria

2.2.1 Blood lactate

The measure of La concentration has been a longstanding assay in the assessment of moderate to high intensities of exercise as demonstrated by Hill and Lupton in 1923(Hill & Lupton, 1923). In exercise of high intensity, La has been identified as a metabolite that diffuses from working muscles along with an equal proportion of hydrogen protons (H^+) and it is the H^+ that causes acidosis(Bonen, Baker, & Hatta, 1997). Acidosis is a state of decreased pH, that limits exercise performance by reducing enzyme activity and ATP formation hence impaired muscle contractility(Hughson & Green, 1982). Since the test of $\dot{V}O_{2MAX}$ is a "maximal intensity" protocol it is presumed that La will be high (>8mmol/L) in individuals that perform to volitional exhaustion.

It was Astrand, in 1952, that was the driving force to utilise La as a secondary criterion to $\dot{V}O_2$ plateau (As cited in (Howley et al., 1995)). Duncan et al. (Duncan et al., 1997) also considered La, finding that all subjects (n = 10) attained their La criteria of >8mmol/L in a discontinuous protocol and 90% in the continuous protocol. Cumming and Byorysk(Cumming & Borysyk, 1972) found that there was no correlation between La and RER, HR or $\dot{V}O_2$, however La was found to be a highly specific but insensitive indicator of $\dot{V}O_{2MAX}$ (Stachenfeld et al., 1992).

The historical use of La as verification of $\dot{V}O_{2MAX}$ has received a mixed response in results. Although Hughson and Green's fast and slow ramp protocol study demonstrated an exponential relationship between $\dot{V}O_2$ and La, La_{max} was found to be less than 8 mmol/L in 66% of their 6 subjects(Hughson & Green, 1982). The mean average La_{max} of nine 21-26 year old subjects in a $\dot{V}O_{2MAX}$ by Prioux et al. was 8.9 mmol/L compared to 5 mmol/L in nine 60 – 74 year old subjects(Prioux, Ramonatxo, Hayot, Mucci, & Prefaut, 2000). Cumming and Byorsyk found that 51 out of 65 over-40 year old subjects exceeded the criteria of 8 mmol/L or more(Cumming & Borysyk, 1972). Duncan et al. recorded the very high values of $\bar{x}$ La_{max} of 14.3mmol/L in a discontinuous $\dot{V}O_{2MAX}$ protocol and 11.9mmol/L in a continuous $\dot{V}O_{2MAX}$ protocol(Duncan et al., 1997). These results are typified by a comparison study of African and Caucasian runners who recorded $\bar{x}$ La_{max} of 10.5 mmol/L and 11.6 mmol/L, respectively, at $\dot{V}O_{2MAX}$ (Weston, Karamizrak, Smith, Noakes, & Myburgh, 1999).

Specific attention by researchers to confirm the use of La as an indicator of maximal cardiorespiratory exercise has found no evidence that La accumulation is caused by O_2 deprivation(Brooks, 1991; Myers & Ashley, 1997). In addition, Hoogeveen and Schep found that plasma lactate may not be indicative "of endurance performance a: raining management"(Hoogeveen & Schep, 1997). Stanley et al. provides a contrast concluding that the rates of La appearance and disappearance are exponential functions of $\dot{V}O_2$, inferring a relationship between O_2 uptake and La(Hughson, Green, & Sharratt, 1995; Stanley et al., 1985).

The opposing views of Myers and Ashley, Brooks, and Hoogeveen and Schep to Hughson and Stanley et al. show on the one hand that La is not affected by oxygen consumption or lack thereof and on the other hand that there is an exponential relationship when performing

incremental exercise(Brooks, 1991; Casaburi, Storer, Sullivan, & Wasserman, 1995; Hoogeveen & Schep, 1997; Hughson et al., 1995; Myers & Ashley, 1997; Stanley et al., 1985). There seems to be a lack of knowledge of what the measure of La actually means, as Myers and Ashley reiterate "the mechanism, interpretation, and application of these changes continue to rely more on tradition and convenience than science."(Myers & Ashley, 1997). Therefore research of the relationship between La concentrations and the $\dot{V}O_2$ plateau should be conducted to objectively consider the value of the use of La as verification of $\dot{V}O_{2MAX}$.

2.2.2 Age-predicted maximal heart rate (APMHR)

It is possible that the suggested linear relationship between $\dot{V}O_2$ and HR in incremental exercise and a possible plateau of HR at maximal exertion could be considered as evidence that HR is a good predictor of $\dot{V}O_{2MAX}$ (Mitchell & Blomqvist, 1971; Noakes, 1998; Pokan et al., 1995; Wyndham et al., 1959). However, Howley et al.(Howley et al., 1995) state that this variable to be the most "problematic", because of its large difference amongst the population (±11 beats/min as a standard deviation). Figueroa-Colon et al.(Figueroa-Colon et al., 2000) used different criteria than recommended by available literature. Their criteria validation was >85% of predicted MHR (Maximal Heart Rate) of which 81% of 58 girls attained. Another adolescent study utilised >95% of MHR(Hughson et al., 1995).

A confounding experience occurred in Stachenfeld et al.'s study when >85% of APMHR was deemed very sensitive to the $\dot{V}O_2$ plateau criteria, however when the common APMHR criteria were applied the figures showed that APMHR were only 83% sensitive and low in specificity(Stachenfeld et al., 1992). Freedson et al.(Freedson et al., 1986) were more forgiving when defining their criteria that resulted in a degree of freedom of ±15 beats/min

from 220-age. Most frequently cited are the criteria of 220 – age, which could be a very difficult target to reach, particularly on a cycle ergometer because of its isolated muscle group effect(Cumming & Borysyk, 1972; Duncan et al., 1997). Although there is a massive range of APMHR criteria employed to verify $\dot{V}O_{2MAX}$, the ACSM (American College of Sports Medicine) currently recommend ±10beats/min 220-age(Balady et al., 2000).

2.2.3 Respiratory Exchange Ratio (RER)

The metabolic measure of respiratory exchange ratio increases whilst exercising, in progressive intensity exercise. The ratio is the product of carbon dioxide produced divided by oxygen consumed and in high intensity exercise exceeds a value of 1.0. Two different RER criteria used to predict $\dot{V}O_{2MAX}$ were compared in the study by Stachenfeld(Stachenfeld et al., 1992) found that they both had high sensitivity but very low specificity, demonstrating an inability by RER to correctly establish those subjects that could not attain $\dot{V}O_{2MAX}$.

Duncan et al.(Duncan et al., 1997) used the recommended RER of >1.15, which is reiterated by Howley et al.(Howley et al., 1995), showed excellent ability to attain the criteria (90-100% of subjects), however the small number of subjects distort the evidence. Cumming et al. however used >1.12 only to find that 50% of subjects could meet that criterion(Cumming & Borysyk, 1972). Whereas, 77% of subjects surpassed the RER criterion of >1.0 for Figueroa-Colon at al.(Figueroa-Colon et al., 2000). These studies demonstrate that RER can have a large variance in exercise research and that this particular criterion may need to reconsidered as verification of $\dot{V}O_{2MAX}$ in the absence of a plateau of $\dot{V}O_2$.

2.2.4 Rating of Perceived Exertion (RPE)

Rating of perceived exertion is a somatic stress, subjective scale that allows the subject to impart the intensity of the workload to the investigator at hand(Balady et al., 2000). Originally the scale formulated by Borg had a rating from 6-20, however this has been since modified to a 10-point scale(Borg, 1982). The RPE has not been a common criterion to use for the verification of $\dot{V}O_{2MAX}$ even though Borg did state "that the RPE scale is the best one...for predictions...of exercise intensities". In secondary criteria research there has been little if any research performed on the relationship of RPE to $\dot{V}O_{2MAX}$. However, the ACSM guidelines state that a RPE value of more than 17 indicates the attainment of $\dot{V}O_{2MAX}$ (Balady et al., 2000).

2.3 Statistics

The use of statistics in published exercise research has developed into a realm that is both informative and confusing. The effectiveness of the statistical method used can have a profound effect on the result. Early research shows the use of bivariate linear correlation by Cumming and Borysyk(Cumming & Borysyk, 1972), which failed to find correlations between La and RER and La and APMHR. Whereas Freedson et al.(Freedson et al., 1986) compared the number of subjects (percentage) that attained certain nominated criteria, that are used to verify $\dot{V}O_{2MAX}$, to evaluate the most effective methodology.

Rivera-Brown et al.(Rivera-Brown et al., 1992) employed a one-way ANOVA to assess RER (>1.0), HR (>95%) and incidence of $\dot{V}O_2$ plateau against neuromuscular power measures. Stachenfeld et al.(Stachenfeld et al., 1992) employed Bayes' theorem(Balady et al., 2000) of sensitivity, specificity and predictive value to evaluate the secondary criteria of RER (>1.1; >1.15), La and APMHR against the $\dot{V}O_2$ plateau. Duncan et al.(Duncan et al., 1997) utilised a Chi-squared test to establish "statistical differences in the frequency of criteria achievement between protocols". A MANOVA (Multiple Analysis Of Variance)

plus an ANOVA (Analysis Of Variance) assisted Figueroa-Colon et al.(Figueroa-Colon et al., 2000) to identify which variable contributed to difference between repeated tests.

Use of bivariate correlation, as demonstrated by Cumming and Borysyk(Cumming & Borysyk, 1972), can demonstrate the relationship between variables but does not explain the contribution each independent variable has to the dependent variable(Coakes & Steed, 2001). The ANOVA's used by Rivera-Brown et al.(Rivera-Brown et al., 1992) and Figueroa-Colon et al.(Figueroa-Colon et al., 2000) to locate differences that may have existed in their data, however under these terms (ANOVA) the predictive ability of the secondary criteria are unknown(Norman & Streiner, 1999).

Duncan et al.'s(Duncan et al., 1997) Chi-squared test points out differences between protocols, however HR had a frequency of less than five (occurrences) which is considered to be inaccurate(Norman & Streiner, 1999). Admittedly, the ability of the secondary criteria to verify $\dot{V}O_{2MAX}$ was not the primary question of Duncan et al. study, which was initiated to observe any differences between continuous and discontinuous $\dot{V}O_{2MAX}$ protocols. Of all the studies above only one attempted(Stachenfeld et al., 1992) to confirm the predictive ability of the secondary criteria to verify $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau. However Bayes' theorem was not designed to establish relationships between criteria nor be able to explain any variance in incidence of $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$ (Balady et al., 2000). Similarly the other studies limited their discussion of the secondary criteria because of the particular statistical method employed, whereas they may have obtained more information by including or utilising other more comprehensive statistical methods.

2.4 Summary

In summary, it has been demonstrated that the use of secondary criteria to predict $\dot{V}O_{2MAX}$ is a much-neglected area of an important testing procedure. The use of metabolic measures such as blood lactate and RER has limited use as the former is a very individual-specific indicator and is difficult to generalise across a wide population. The latter has been found to be variable across differing populations in several studies. APMHR was found to be specific but insensitive by the majority of studies and suggested that it was probably inappropriate to use as a measure of $\dot{V}O_{2MAX}$. RPE has had insufficient research to be appropriately utilised as an estimate of $\dot{V}O_{2MAX}$.

The differences in methods and statistics also prove to confound the issue of the reliability and validity of using the secondary criteria. Although the amount and quality of the reviews and studies of the criterion of $\dot{V}O_{2MAX}$ were limited, most recommended that further research into the applicability of the criteria used to measure $\dot{V}O_{2MAX}$ was required. It is hoped that this current study of the sensitivity and specificity of the previously mentioned criteria on a relatively varied, active and large population will be able shed some light on an often-mistaken construct.

CHAPTER THREE

MATERIALS AND METHODS

Ethics, questionnaires, consent forms, and project approval were granted by Faculty of Communications, Health and Science Ethics Committee at Edith Cowan University on the 28th of March 2001 (Appendices A, B, C, D). All subjects were informed that they were free to withdraw from the study at any time without prejudice.

3.1 Subject Population

A cohort (n=64; 25 females, 39 males) was obtained for this study that ranged from 18-51 years of age (Table 3.1). The participants were sourced from the university students (sports science), university staff, and local community sporting groups (marathon and triathlon). Medical and demographic questionnaires and consent forms were completed (Appendices A-C) and the information assessed to ensure no cardiovascular or musculo-skeletal risk was evident. All subjects had no more than one risk factor for cardiovascular disease, were free from musculo-skeletal injury, and were active for three or more times per week.

The participants that were new (n = 37) to $\dot{V}O_{2MAX}$ testing attended a single mock trial on the first randomly assigned exercise modality for testing familiarisation prior to formal testing. Testing was otherwise completed in two trials with a two to seven day rest period between.

Table 3.1
Demographic data of participants in both TM and CE

Female					Male				
Subject Number	Age (years)	Height (cm)	Mass (kg)	Body Fat (%)	Subject Number	Age (years)	Height (cm)	Mass (kg)	Body Fat (%)
1	41	162.0	53.0	13.96	26	28	171.5	73.0	7.84
2	27	161.5	60.0	15.46	27	20	170.5	70.0	9.68
3	42	162.0	58.0	18.02	28	18	172.5	89.0	18.12
4	18	169.5	57.0	18.23	29	21	175.5	83.3	16.53
5	45	172.0	66.3	17.82	30	19	176.0	61.3	6.61
6	30	162.5	56.0	15.03	31	22	179.5	65.5	5.23
7	18	165.7	55.0	15.46	32	18	184.0	75.8	10.74
8	31	167.0	62.9	15.67	33	20	176.5	63.5	4.89
9	28	162.0	52.6	15.81	34	28	190.0	81.5	10.99
10	35	151.5	50.7	13.67	35	19	188.5	79.5	7.36
11	47	158.0	58.9	23.15	36	18	174.0	62.9	9.16
12	32	165.0	59.0	15.46	37	18	174.5	102.0	26.35
13	22	165.0	72.3	23.34	38	20	174.3	78.8	11.49
14	47	167.7	57.4	12.59	39	37	174.0	78.0	23.06
15	27	167.0	59.7	15.32	40	23	173.0	62.6	9.03
16	26	171.3	61.4	16.65	41	29	175.5	78.4	11.71
17	33	156.0	52.8	17.48	42	43	165.4	63.4	12.96
18	34	167.5	58.5	15.60	43	26	164.0	67.8	15.04
19	18	169.5	60.4	16.85	44	29	185.5	79.6	10.18
20	33	182.5	72.9	19.91	45	44	175.5	78.0	13.13
21	22	154.2	67.3	28.49	46	44	180.0	84.5	23.93
22	21	167.0	68.2	29.50	47	30	175.0	60.7	4.94
23	38	163.4	62.1	16.44	48	23	170.5	87.1	11.52
24	22	154.5	53.5	22.32	49	30	185.5	75.6	8.06
25	28	172.8	54.6	19.98	50	31	180.7	79.2	12.77
					51	31	188.0	86.1	10.65
					52	28	186.0	86.9	7.52
					53	39	172.5	73.8	14.38
					54	31	185.0	90.7	12.83
					55	23	192.0	87.2	14.82
					56	46	168.2	68.1	18.40
					57	38	181.0	82.9	12.04
					58	39	168.0	77.7	11.60
					59	51	172.5	63.2	11.62
					60	43	167.0	74.3	15.49
					61	24	178.0	75.5	7.84
					62	23	180.6	76.6	7.29
					63	45	164.7	64.7	11.08
					64	38	174.7	75.0	10.99
$\bar{x}$	***30.46***	***164.95***	***60.13***	***17.69***		***29.63***	***176.81***	***76.07***	***12.11***
SD	***8.87***	***6.79***	***6.45***	***4.67***		***9.84***	***7.29***	***9.71***	***4.97***

3.2 Anthropometry

At the first appointment prior to exercise, every participant was weighed using a model ID1s weighing scale (Mettler-Toledo Inc., OH) and height was measured with a standard laboratory stadiometer. Body fat (BF) was assessed in the first appointment using Harpenden SKF calipers and applied to 3 sites (Pectoral, Abdomen, and Mid-thigh) on males and 3 sites on females (Tricep, Suprailiac, and Mid-thigh). Standard Body Density (Db) equations were employed for Anglo-Celtic men from Jackson and Pollock's 3-site method (Chest, Abdomen, Mid-Thigh) and Jackson et al.'s 3-site method (Triceps, Suprailiac, Mid-Thigh) for Anglo-Celtic women(Heyward & Stolarczyk, 1996). All Db values were converted to BF percentage using the following equations (Heyward & Stolarczyk, 1996): $[(4.95/Db)-4.50] \times 100$ = BF percentage for males; $[(5.01/Db)-4.57] \times 100$ = BF percentage for females. The anthropometric data for all subjects are displayed in Table 3.1.

3.3 Equipment

The JAS motorised treadmill (JAS Fitness Systems, TX) was modified so that it could be controlled externally by another device, namely the Medgraphic CPX/D metabolic cart (Medical Graphics Corp., MN). The cycle ergometer (CE) utilised in this study is a Monark 829E electronic belt-braked cycle ergometer (Monark Exercise AB, Sweden) that was programmed to a pre-determined resistance. This type of CE is a commonly used ergometer for research. Daily calibration was carried out on the CE as per manual specifications. Heart rate was measured by a Polar PE4000 heart rate monitor (Polar, Finland) and the information that was saved on the monitor watch was downloaded to a personal computer by Polar precision performance V2.1 software.

For blood lactate measurements, whole blood from finger prick samples was drawn into 30μL heparinised capillary tubes. These samples were then transferred into 150μL of 6%

perchloric acid, and then frozen until subsequent enzymatic assay. The samples were removed from the freezer, thawed, centrifuged and assayed by enzymatic spectrophotometry. RPE scales were utilised as a subjective measure of exercise intensity using both the original 20-point Borg scale and modified 10-point scale.

Software applications used were Microsoft® Excel 97 SR-2 (MS Excel – Microsoft Corporation, WA) for data formatting and calculation, SPSS© v10.0.7 (SPSS®, SPSS Inc, IL) for statistical data analysis and Graphpad Prism© v3.02 (Graphpad Software, CA) for curve-fitting and data graphic presentation.

The Medgraphic CPX/D is an automated expired gas analyser that was calibrated prior to every test of $\dot{V}O_{2MAX}$. Calibration consisted of the recording of barometric air pressure and wet and dry temperature via a whirling hygrometer (Zeal, UK), that allowed the calculation of humidity and air water vapour pressure. Once these variables were obtained and entered, flow calibration of the Medgraphic pneumotach was executed by 5 repeated inspirations and expirations from an engineered 3L syringe.

Calibration gases were used from 2 separate gas bottles, bottle 1 (Oxygen: 16.5%; Carbon Dioxide: 4.1%; balance Nitrogen) and bottle 2 (Oxygen: 21.2%; balance Nitrogen). Both reference and calibration gases were passed through the gas analysers as well as using room air (20.93% oxygen and 0.03% carbon dioxide) to complete a 3-point gas calibration.

3.4 Design

The study was a randomised crossover design of two different continuous, incremental $\dot{V}O_{2MAX}$ tests. Measured variables included expired minute ventilation ($\dot{V}_E$), minute oxygen consumption ($\dot{V}O_2$), minute carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), $\dot{V}O_2$ slope (primary and secondary), ratings of perceived exertion (RPE), heart rate

(HR), body fat (BF), mass (WT), height (HT) and training specificity in hours (TS). Age predicted maximum heart rate (APMHR) was calculated by subtracting the subjects' age from the nominal figure of 220.

The methodology of sampling of $\dot{V}O_2$ was also considered and a comparison was made between raw data and two methods of averaging breath-by-breath data. The differences between contemporary methods of $\dot{V}O_2$ plateau calculation ($\Delta \dot{V}O_2 \pm 50$ mL/min) and historical ($\Delta \dot{V}O_2 \pm 150$mL/min) were also compared. The intention was to ascertain the most appropriate sampling method(s) for future reference.

3.5 Exercise Testing

3.5.1 Cycle Ergometer (CE) testing

A ramp protocol was used on the CE and the workload chosen was dependent on the activity history and the gender of the subject. This allowed each subject to achieve maximal volition on a relative basis (Table 3.2) and was founded on previous $\dot{V}O_{2MAX}$ research held at this institution. The CE was set at a seat height that allowed only slight flexion of the thigh at the hip for ease of movement at higher workloads.

Table 3.2
Allocation of CE workload to voluntary participants based on training history.

Gender	Untrained (W/min)	Trained (W/min)	Elite (W/min)
Female	15	20	25
Male	20	25	30

The gas analyser was calibrated and gas-sampling tubes attached to the pneumotach and mouthpiece. A nose clip was worn in combination with the mouthpiece and two minutes of resting breath-by-breath data were collected before the exercise protocol began. A fan was provided to reduce the risk of the subject overheating in the laboratory environment.

When the two minutes of resting data had been collected the subject was instructed to begin pedalling at a previously agreed pedal cadence (70-90 rpm). The CE test began on a workload of zero and, being a ramp protocol, increased in workload every 3 seconds at the programmed resistance. For example, a 25W/min workload increasing every 3 seconds = 1 Watt every 1.25 seconds. No formal warmup was effected as the workload began at 0 Watts and increased gradually over 15 minutes. This therefore instituted a warmup within the CE ramp protocol and every subject followed the same procedure.

Cadence was maintained throughout the test until the workload became so heavy that the subject was no longer able to maintain the speed. At this time verbal encouragement was provided to assist in further motivating the subject to continue to their maximal volition. The test was stopped, once the cadence slowed to a rate that was 20 rpm less than that maintained by the subject throughout the test or until the subject refused to continue, , the post-test stopwatch was started, the mouthpiece removed from the subject, and the heart rate monitor watch stopped.

A warm-down ensued from the finish of the test until the heart rate reached below 120 beats/min or until the subject was comfortable. The participant gave an estimation of their RPE status, of both the 20-point Borg scale and the modified 10-point Borg scale, at the time when they reached maximal effort. The metabolic data from gas analysis was saved onto the hard drive and as a text file on a 3.5 floppy disk under the participants code, and was then transferred to a PC for data analysis.

3.5.2 Treadmill (TM) Testing

A true ramp protocol could not be scripted into the external control of the treadmill, therefore an incremental graded protocol was introduced. Prior to the incremental protocol, a warm-up assisted in establishing the subjects' fastest running speed that they would be able to endure for between 3-5 minutes. This "fast" running speed was an individual measure that ensured that the subject would be able to continue for at least ten minutes but less than 15 minutes.

A protocol was then devised that increased the running velocity at 1 km/h every minute until the "fast" running velocity was attained and then speed remained constant as the elevation was increased by 1.5% per minute until volition. To reach true maximal exhaustion volition the subject was advised to stop the test by either straddling the treadmill belt and/or pulling the emergency "stop" cord. Then the same post-test procedure, as the cycle ergometer test, was followed. If indications to terminate testing were present both CE or the TM would have been terminated by the technician present. These indications are published in the ACSM's guidelines for exercise testing and prescription(Balady et al., 2000). The subject was warned to prepare to stop the test and then power was cut to the treadmill. No test required this procedure to be actioned as all $\dot{V}O_{2MAX}$ tests were terminated by the subjects.

3.6 Data and statistical analysis

Raw data was saved as a text file and imported to Excel file and then expanded to include 3-point moving averages of $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$ and raw $\dot{V}_E/\dot{V}O_2$. HR, and RPE were added to the Excel data along with the subjects anthropometric (eg HT, Mass, SKF) and personal details (eg gender, age, TS). This information was then imported into Prism® curve-fitting software to be analysed for $\dot{V}O_2$ slope (primary and secondary), $\dot{V}O_{2MAX}$, and slope

intersections of $\dot{V}_E / \dot{V}O_2$ values. Differences between the cycle and treadmill protocols for data at $\dot{V}O_{2MAX}$ ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, RER) were analysed by multivariate t-test.

3.6.1 Statistical analysis of $\dot{V}O_2$ plateau

The presence of a $\dot{V}O_2$ plateau was verified based on a slope of the final 30 seconds of $\dot{V}O_2$ data of less than ± 0.05 L/min and it is the detection of the plateau that defined the $\dot{V}O_{2MAX}$. Once the data was analysed in Prism, the results are transferred back into Excel to be coded as nominal data whether they attained a $\dot{V}O_2$ plateau (1=YES, 2=NO) and whether each of the secondary criteria ie RERmax, HRmax, and RPEmax had been reached (1=YES, 2=NO).

3.6.2 Bayes' Theorem

The nominal data of the secondary criteria were calculated for their frequency of occurrence within the primary criteria. Measures of sensitivity, specificity, positive and negative predictive value were derived from the implementation of Bayes' theorem on the secondary criteria expressed as nominal data (RER >1.15 = 1; RPE >17 = 1; Hrmax = ±10 beats/min APMHR; all other secondary criteria data = 2)(Balady et al., 2000).

3.6.3 Multiple Regression

Multiple regression was performed on each of the TM and CE data groups in SPSS. The secondary $\dot{V}O_2$ slope ($\Delta \dot{V}O_2$) was the dependent variable, and the secondary criteria at $\dot{V}O_{2MAX}$, expressed as continuous variables, were the independent variables.

3.6.4 Discriminant Function Analysis (DFA)

DFA of TM and CE data sets used group coding (plateau=1,no plateau=2) as a dependent variable to determine which of the raw secondary criteria data combined accurately classified the presence or absence of a $\dot{V}O_2$ plateau. DFA was carried out in SPSS and the

casewise statistics (weighted scores) transferred into Prism via MS Excel to be graphically presented.

3.7 Limitations

The number of subjects was important to ensure the power of the study. Preferably a 10:1 to 20:1 ratio of participants to independent variables is required when using multivariate statistics. Thus a number of subjects between 40-80 was the objective for this study.

The subject population available may not be a true random population as they were volunteers that may have had an interest in exercise and would normally step forward for projects such as this. However, every care was taken to access a subject population that was as wide a sample as could be drawn from the local region. A large variation in training specificity, fitness levels, age, diet and gender, was required to better apply the statistics used in this investigation and to have a more realistic sample .

The Medgraphics CPXD metabolic cart is an automated gas analysis system that has an inherent analysis error of ±3%. The CPXD was calibrated prior to each $\dot{V}O_{2MAX}$ test and all care was taken by the observer to replace consumables and carry out maintenance where possible.

All $\dot{V}O_{2MAX}$ tests were carried out at sea level and data should be considered as such before being generalised for higher altitude environments.

Healthy subjects with no current injury or contraindicatory disease were selected for this study, therefore the information related may be useful but not directly applicable to populations that are predisposed to pathology or physical limitations.

CHAPTER FOUR

RESULTS

Due to limitations in available time, the La results were not available for publishing at the time of printing this thesis. Therefore the following text will not discuss La in any detail.

4.1 Multiple regression of primary and secondary criteria

The secondary criteria of RER, HR and RPE (IV's) were compared against the secondary $\dot{V}O_2$ slope (DV) in univariate regression in Table 4.1 (below). There were significant relationships between TM RPE and TM $\dot{V}O_2$ slope and between TM RPE and TM RER, however the very low correlation (-0.224 and –0.225 respectively) shows little in the way of a predicted relationship. Similar findings can be established for the significance of CE RER and CE $\dot{V}O_2$ slope and between CE HR and CE RPE (R = -0.251 and 0.238 respectively). Little relationship exists between the secondary slope and the secondary criteria.

Multivariate regression data found that neither TM nor CE secondary criteria could explain the variance in the presence or absence of a $\dot{V}O_2$ plateau (Table 4.2). Very low F-values and insignificant t-values confirm the inability of the secondary criteria, as a multivariate regression analysis, to predict the $\dot{V}O_2$ plateau in either mode of exercise (TM or CE).

Table 4.1

Bivariate correlation between the secondary $\dot{V}O_2$ slope and $\dot{V}O_{2MAX}$ criteria. (figures in brackets represent significance)

	Slope	RER	HR	RPE
Treadmill (TM)				
Slope	1.000			
RER	0.026 (0.419)	1.000		
HR	0.064 (0.307)	0.206 (0.051)	1.000	
RPE	-0.224 *(0.037)	-0.225 *(0.037)	0.102 (0.212)	1.000
Cycle Ergometer (CE)				
Slope	1.000			
RER	-0.251 *(0.023)	1.000		
HR	-0.010 (0.468)	0.136 (0.142)	1.000	
RPE	0.186 (0.070)	-0.046 (0.360)	0.238 *(0.029)	1.000

*(P<0.05)

Table 4.2

Multivariate analysis of the influence upon $\dot{V}O_2$ plateau

	R^2	F-value	Sig.	t-value	Sig.
Treadmill (TM)	0.060	1.281	0.289	1.010	0.316
RER	0.001				
HR	0.004				
RPE	0.056				
Cycle (CE)	0.094	2.073	0.113	0.471	0.639
RER	0.063				
HR	0.001				
RPE	0.030				

NB All secondary criteria are combined for this analysis

4.2 Discrimination Function Analysis of plateau and non-plateau subjects

Discriminant Function Analysis assisted in the analysis of the secondary criteria as valid determinants of the presence or absence of the $\dot{V}O_2$ plateau. The raw data from both exercise modalities are allocated a nominal integer, 1 = within the parameters of both primary or secondary criteria and 2 = outside the parameters for both primary or secondary criteria. With the independent variable being the primary criterion (Plateau achieving: 1; Non-plateau achieving: 2) and the secondary criteria (DV's) combining to ascertain whether these grouped variables could verify a plateau of $\dot{V}O_2$.

Discriminant scores were derived from the combination of the independent variables and grouped as non-plateau and plateau achieving. Thus a spread of scores within each group would be able to classify specific discriminant scores as being factors that influence the positive or negative outcome of a $\dot{V}O_2$ plateau. There are an even spread of data points across the range (-3.0 to +3.0) between groups in the cycle ergometer modes (Figure 4.1) and treadmill (Figure 4.2).

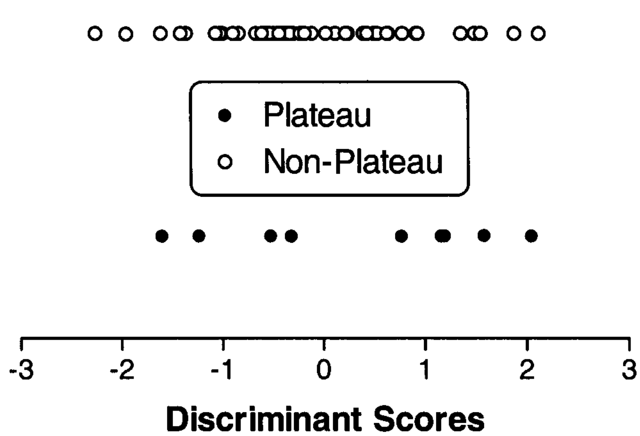


Figure 4.1 Cycle ergometer discriminant function scores for plateau and non-plateau subjects

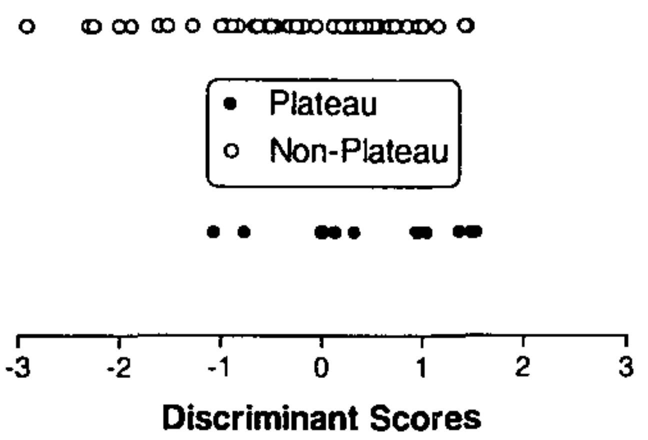


Figure 4.2 Treadmill discriminant function scores for plateau and non-plateau subjects

Twenty-three (35.9%) subjects in the CE and 31 (48.4%) subjects in the TM were misclassified according to case-wise diagnostics of the nominal data.

4.3 Sensitivity, specificity and predictive value of secondary criteria

Primary and secondary criteria were transformed into nominal format and used in Bayes' theorem as a method of estimating the probability of events occurring from testing data and a hypothesis. The theorem is utilised, in this case, to find the sensitivity, specificity, and predictive ability of the secondary criteria.

Both TM RER and CE RPE were found to be specific (>90%) to the primary criterion (Table 4.2). That is, the percentage of subjects who achieved the $\dot{V}O_2$ plateau *and* also surpassed the secondary criteria standards demonstrate a specificity for $\dot{V}O_{2MAX}$. In contrast, there was very low sensitivity of the secondary criteria demonstrating a limited capacity to identify those subjects that did not attain $\dot{V}O_2$ plateau *and* did not reach the secondary criteria for $\dot{V}O_{2MAX}$.

It is the function of the predictive ability of the Bayes' test to ascertain the *accuracy* of the secondary criteria compared to the $\dot{V}O_{2MAX}$. Positive predictions of more than 90% could only be found in TM RER of the secondary criteria, although there were high positive predictions in all but CE HR (55.56%). The negative predictions, that is, the ability to predict the *non-occurrence* of a $\dot{V}O_2$ plateau, never reached more than 30% other than HR in the cycle ergometer (56.36%).

Table 4.3

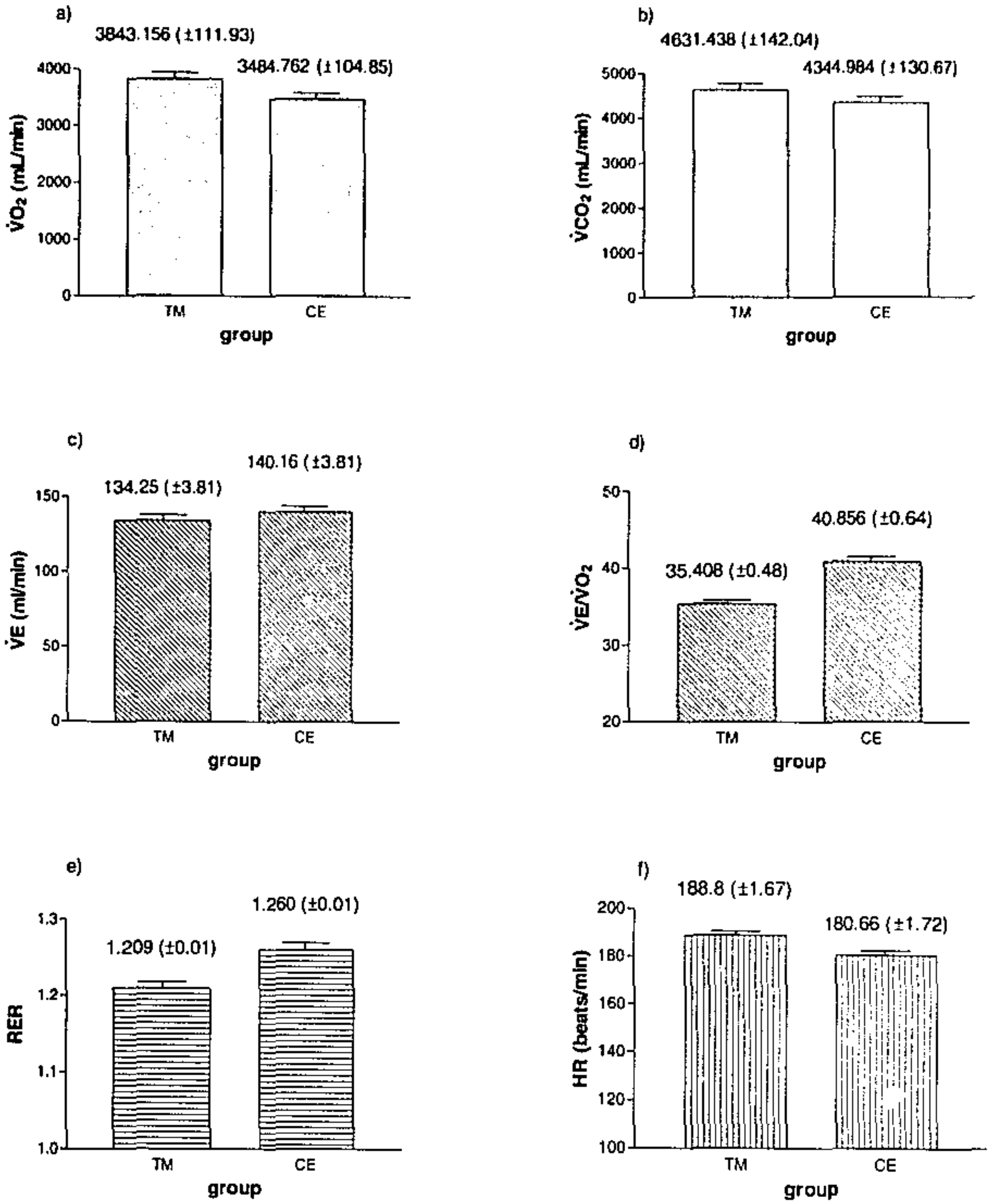
Sensitivity, Specificity and Predictive ability of three secondary criteria for $\dot{V}O_{2MAX}$

	RER	HR	RPE
Treadmill (TM)			
Sensitivity	22.22%	21.28%	20.00%
Specificity	90.00%	82.35%	77.78%
PPV	92.31%	76.92%	84.62%
NPV	17.65%	27.45%	13.73%
Cycle (CE)			
Sensitivity	12.90%	17.24%	15.38%
Specificity	50.00%	88.57%	91.67%
PPV	88.89%	55.56%	88.89%
NPV	1.82%	56.36%	20.00%

PPV = Positive Predictive Value, NPV = Negative Predictive Value

4.4 Comparison of variables between exercise modalities

Figure 4.3 (a-g) displays the difference between variables ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$, $\dot{V}E/\dot{V}O_2$, HR, RER and RPE) measured in the test for $\dot{V}O_{2MAX}$. $\dot{V}O_2$, $\dot{V}CO_2$ and HR are all higher in TM compared to CE, however $\dot{V}E$, RER, $\dot{V}E/\dot{V}O_2$ and RPE demonstrate a mean tendency to be depressed in the TM when compared to the CE. RPE was very similar (TM = 18.18; CE = 18.22) between exercise modalities and whose mean was above the secondary criteria cut-off point (>17).



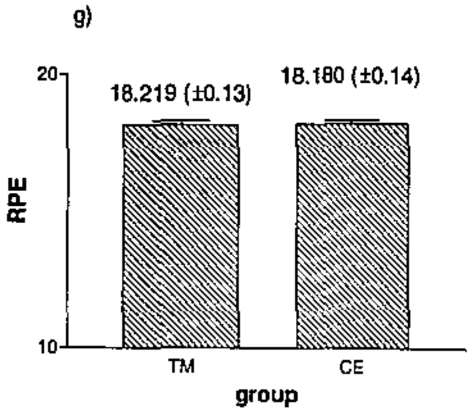


Figure 4.3
Comparison of mean values (±SEM) at volitional exhaustion, with error bars indicated, between TM and CE of a) $\dot{V}O_2$, b) $\dot{V}CO_2$, c) $\dot{V}E$, d) $\dot{V}E/\dot{V}O_2$, e) RER, f) HR and g) RPE

The lack of significant difference between modalities in $\dot{V}CO_2$ can assist in explaining the higher RER and $\dot{V}E$ in the CE condition. $\dot{V}CO_2$ is a determining factor in the calculation of RER and there is a physiological effect of $\dot{V}CO_2$ on $\dot{V}E$ causing a higher ventilation rate when $\dot{V}CO_2$ is raised.

The three variables that did not differ significantly ($P>0.025$) were $\dot{V}CO_2$, $\dot{V}E$ and RPE. Two subjects (3.1%), of the 64 participants assessed, achieved a $\dot{V}O_2$ plateau in both CE and TM, whereas 18 subjects (28.1%) achieved a plateau in either the CE or TM. More than half did not achieve a $\dot{V}O_2$ plateau in either mode of exercise ($n = 44$).

4.5 Analysis of the primary criterion

The primary criterion of a secondary $\dot{V}O_2$ slope that did not significantly differ from zero or more than ± 50 mL/min was found in only 14 (21.8%) treadmill tests and 11 (17.2%) of the cycle ergometer tests (Table 4.1). It was a requirement of this study that there were participants that did and did not attain the primary criterion to analyse both negative and positive results.

It was found that the 3-point moving average gave a much closer account of the variation of the raw $\dot{V}O_2$ data points and also more appropriate curve of the secondary $\dot{V}O_2$ slope than an 11-point moving average. The 11-point moving average smoothed data to a point that frequently underestimated the $\dot{V}O_{2MAX}$. Both 11-point moving averages and 3-point moving averages were used to determine the degree of the $\dot{V}O_2$ slope and neither method was any different than the other when compared under the $\Delta \dot{V}O_2 \pm 50$ mL/min conditions. Although the 11-point average decreased variability in the $\dot{V}O_2$ data it confirmed less subjects obtaining the $\dot{V}O_{2MAX}$ than the raw data.

If the parameters for obtaining a $\dot{V}O_{2MAX}$ were more lenient as per the ACSM guidelines ($\Delta \dot{V}O_2 \pm$ 150 mL/min) then the results would be thus: 28 (43.75%) and 26 (40.6%) subjects that achieved the primary criterion in the treadmill and cycle ergometer respectively. It is interesting to note that the 3-point moving average demonstrated a good median between the raw and 11-point moving average and at times bettered the methods of sampling. An example of the process of confirming a plateau utilising the curve-fitting programme, "Prism", can be seen in figure 4.4 below. Differences can clearly be observed in figure 4.3 between the plateau and non-plateau by the spread of raw $\dot{V}O_2$ data points (variation) from the secondary $\dot{V}O_2$ slope (differing from zero) and the attitude of the slope ($\Delta \pm$ 50 mL/min).

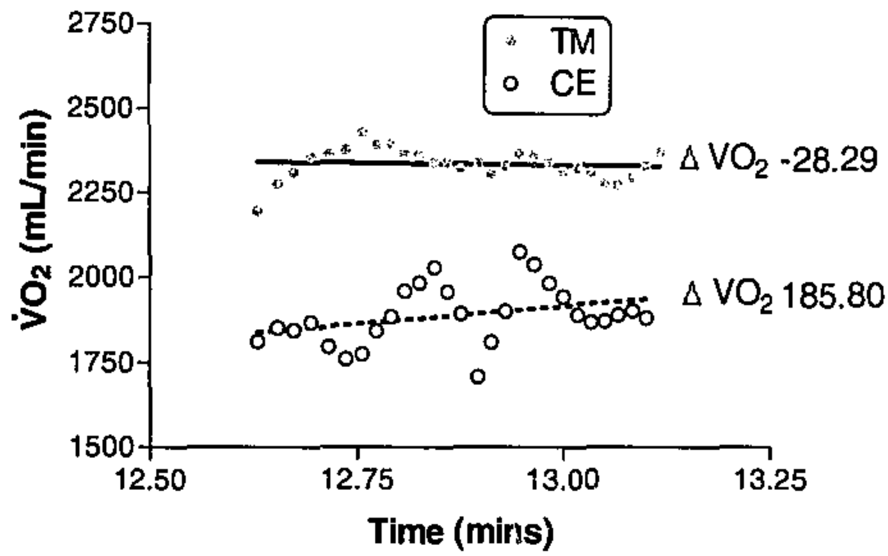


Figure 4.4 Example of a TM $\dot{V}O_2$ plateau and CE $\dot{V}O_2$ non-plateau from subject 141 (female) using 3-point moving average data points.

Table 4.4

A comparison in the incidence of $\dot{V}O_2$ plateau by three different sampling methods and two $\dot{V}O_2$ slope conditions.

	Treadmill			*Cycle*		
	Raw	**3-point**	**11-point**	**Raw**	**3-point**	**11-point**
$\Delta\dot{V}O_2$ ±50 mL/min						
Plateau	14 (21.9%)	13 (20.3%)	13 (20.3%)	11 (17.2%)	11 (17.2%)	9 (14.1%)
Non-plateau	50 (78.1%)	51 (79.7%)	51 (79.7%)	53 (82.8%)	53 (82.8%)	55 (85.9%)
$\Delta\dot{V}O_2$ ±150mL/min						
Plateau	28 (43.8%)	32 (50.0%)	34 (53.1%)	26 (40.6%)	28 (43.8%)	26 (40.6%)
Non-plateau	36 (56.2%)	32 (50.0%)	30 (46.9%)	38 (59.4%)	36 (56.2%)	38 (59.4%)

NB. Breath-by-breath gas analysis used
3-point: Three point moving average
11-point: Eleven point moving average

4.6 Summary of Results

Neither univariate nor multivariate regression found a high correlation with any of the secondary criteria. DFA showed a poor predictive ability (CE = 35.9%;TM = 48.4%) of the secondary criteria and highlighted the secondary criteria's failure to distinguish whether a $\dot{V}O_2$ plateau had or had not occurred. Similar results were obtained with the use of Bayes' theorem and demonstrated that though some results were able to show specificity, none were able to be sensitive to the $\dot{V}O_2$ plateau.

In addition, the lack of sensitivity and specificity, on the whole, detrimentally affected the positive and negative predictive ability of the secondary criteria which was insufficient in all but one criterion (TM RER). None of the secondary criteria were able to predict the absence of a $\dot{V}O_2$ plateau. There was little statistical difference between the exercise modalities, however CE data was significantly higher ($P<0.05$) in both RER and $\dot{V}E/\dot{V}O_2$ but lower in $\dot{V}O_2$ and HR.

CHAPTER FIVE

DISCUSSION

The purpose of this study was to determine the sensitivity and specificity of the secondary criteria (Bayes' Theorem) that are being used to verify maximal oxygen consumption in the absence of a $\dot{V}O_2$ plateau. Contemporary multivariate statistical techniques were implemented to determine if univariate as well as multivariate factors influenced the validity of the secondary criteria (discriminant function), or if a combination of variables could explain the between-subjects variability (multiple regression) in the slope of $\dot{V}O_2$ at the end of an incremental exercise test. Differences between exercise modalities (CE and TM) were observed to allow comparison with other studies that may use a single mode of exercise.

The frequent use of the $\dot{V}O_{2MAX}$ test to estimate cardiorespiratory function behoves its importance in the repertoire of the exercise scientist whether in research, applied or clinical fields. It is important to maintain high standards of methodology when implementing tests such as the $\dot{V}O_{2MAX}$ to ensure the validity of the results.

The test of the maximum consumption of oxygen ($\dot{V}O_{2MAX}$) in exercise is primarily determined by the change in $\dot{V}O_2$ (plateau) of less than $\pm$150 mL/min under an increasing workload(Taylor et al., 1955). A plateau in $\dot{V}O_2$ may not appear due to technical or observer error, inter-individual and intra-individual differences, diverse protocols, equipment variants, and the criteria used to indicate a plateau(Astorino et al., 2000; Howley et al., 1995; Myers et al., 1990; Robergs, 2001).

Due to the apparent lack of a consistent occurrence of a $\dot{V}O_2$ plateau in $\dot{V}O_{2MAX}$ research, some secondary criteria have been formulated to objectively judge whether the subject has

attained maximal work. There has been a moderate amount of conjecture as to the appropriateness of the secondary criteria that are applied to the $\dot{V}O_{2MAX}$ test when a $\dot{V}O_2$ plateau has not been present(Cumming & Borysyk, 1972; Noakes, 1988).

The secondary criteria were accrued over time, since Hill and Lusk in 1923, and many researchers have contributed to their inception(Astrand, 1952; Issekutz & Rodahl, 1961). Studies of the secondary criteria are few in number, the most outstanding attempts have been by Cumming and Borsyk, Freedson et al., Stachenfeld et al. and Howley, and Basset and Welch's' 1995 review(Cumming & Borysyk, 1972; Freedson et al., 1986; Howley et al., 1995; Stachenfeld et al., 1992).

Today, the use of advanced technology and the power of hindsight allows us to be able to employ more sensitive equipment and effective experimental protocols to determine the validity of the secondary criteria.

5.1 Multiple regression of primary and secondary criteria

Multiple regression (Table 4.1) showed that bivariate results had a very low correlation (between -0.251and 0.238) in both modes, most of which were insignificant. This result is born out by the correlations carried out by Cummings and Borysyk's study of over-40 year old males where no secondary variable showed significant correlation with each other or $\dot{V}O_2$ (Cumming & Borysyk, 1972).

When the secondary criteria were combined as a group of either two or three variables none of these groups could be attributed to the variance of the presence of a $\dot{V}O_2$ plateau (Table 4.2). This data confirms the non-predictive nature of the secondary criteria and serves to explain that factors that are not related should not be utilised to verify each other. No study

could be found that had utilised multiple regression and therefore have not been able to completely investigate the intricacies of the secondary criteria. It is information of this type that has not been provided by previous researchers that is most effective in demonstrating that the secondary criteria should not be used as verification of $\dot{V}O_{2MAX}$.

5.2 Discrimination Function Analysis of plateau and non-plateau subjects

The ability of the secondary criteria to discriminate between plateau and non-plateau groups was assessed through the application of DFA (Figures 4.1 and 4.2). The raw secondary criteria could not discriminate between groups and found that it misclassified more than 35% of subjects and 48% of subjects in the CE and TM, respectively. The large spread of data throughout the range of possible scores demonstrates that none of the criteria could successfully discriminate between plateau and non-plateau groups. Again, no previous study had made use of this form of parametric statistic.

5.3 Sensitivity, specificity and predictive value of secondary criteria

Sensitivity and specificity are factors that are used to effectively measure the obstensive effectiveness of the secondary criteria. Sensitivity calculates the percentage of subjects that have a $\dot{V}O_2$ plateau and can be predicted by the secondary criteria, whereas specificity is the percentage of subjects that did not attain a $\dot{V}O_2$ plateau and are predicted as such, which is used to measure prediction by the secondary criteria.

A positive predictive value of the criteria dictates that the secondary criteria verification of a $\dot{V}O_2$ plateau concurs with an *actual* plateau in $\dot{V}O_2$. A negative prediction means that the secondary criteria have confirmed the *absence* of a $\dot{V}O_2$ plateau. The use of sensitivity, specificity and predictive value of criteria are more commonly used for the detection of Coronary Artery Disease (CAD)(Balady et al., 2000).

Table 4.3 showed the results of the application of Bayes' theorem to the criteria used to verify a $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$. Although some criteria (RER TM and RPE CE) were specific (>90%), none of them were sensitive. The ability of the three secondary criteria was as inept at predicting whether a plateau would or would not occur (eg RER TM PPV>90%, RER TM NPV<17%).

Stachenfeld et al. were the only other authors to employ an analysis such as Bayes' theorem, however their use of very different exercise protocols to other researchers reduced the ability to draw conclusions from the results. It was interesting to note that they did not utilise any other statistical method to assess the secondary criteria (Stachenfeld et al., 1992).

5.4 Comparison of variables between exercise modalities

Differences between modes of exercise were obvious and significant between $\dot{V}O_2$, $\dot{V}E/\dot{V}O_2$, RER and HR, where $\dot{V}O_2$ and HR were high in the TM and $\dot{V}E/\dot{V}O_2$ and RER were high in the CE. Because there was no significant difference in $\dot{V}CO_2$, it was thought that this might have contributed to the higher RER in the CE and an insignificant difference in $\dot{V}E$.

It is possible that the localised muscular work that is required in the CE modality produces higher concentrations of acidosis and produced similar levels of $\dot{V}CO_2$ and $\dot{V}E$ between modalities, however O_2 consumption was reduced in the cycle which increased RER (significant difference) and resulted in a decreased $\dot{V}O_{2MAX}$ $\bar{x}$ for the CE condition,

Since RPE is subjective and therefore difficult to compare between subjects it's insignificant difference is expected. Almost every subject reported that local muscle pain and fatigue in the quadriceps was most probably the most common reason for stopping the $\dot{V}O_{2MAX}$ CE

test. However, feelings of instability, respiratory discomfort and exhaustion were common reasons for terminating the TM $\dot{V}O_{2MAX}$ test.

5.5 Analysis of the primary criterion

The incidence of $\dot{V}O_2$ plateau (TM = 21.8%; CE = 17.2%) was low using the more restrictive parameter of $\Delta\dot{V}O_2 < \pm 50$mL/min and was higher when the conservative criterion of $\Delta\dot{V}O_2 < \pm 150$mL/min was applied (TM = 43.8%; CE = 40.6%). Although this frequency of $\dot{V}O_2$ plateau could be considered low, the reported incidence is recorded as being under 50% up to 100%(Howley et al., 1995) and a range of less than 50% up to 78%(Noakes, 1988). The low incidence has prompted Myers et al. to describe the $\dot{V}O_2$ plateau presence as "random"(Myers et al., 1989).

5.5.1 Sampling period and interval

A more direct affect on the $\dot{V}O_2$ plateau was the sampling duration and interval used to acquire $\dot{V}O_{2MAX}$. A sampling period of 30 seconds was used instead of the 60-seconds as recommended by Howley et al.(Howley et al., 1995). This smaller sampling period was chosen to decrease the chance of passing over a plateau, which is possible with longer (eg 60-seconds) sampling intervals(Astorino et al., 2000).

The sampling interval within a sampling period is used to discover whether a $\dot{V}O_2$ slope fits within the stated parameters ($\Delta\dot{V}O_2 < \pm 50$mL/min or $\Delta\dot{V}O_2 < \pm 150$mL/min). Researchers have used varying intervals from breath-by-breath (in recent times) to time averaging across 15-, 20-, 30- or 60-second sampling intervals. It has led some authors to believe that sampling of 30-seconds or more could, in fact, produce more variability in $\dot{V}O_2$ slope(Astorino et al., 2000; Myers et al., 1989).

Myers et al. found that there is more variability in $\dot{V}O_2$ with breath-by-breath data, however the smaller sampling averages were similar to 15 second or 30 second sampling intervals and therefore may "be considered reasonable"(Myers et al., 1990). Longer sampling averages were also found to consistently estimate a lower $\dot{V}O_{2MAX}$ (Astorino et al., 2000). As can be demonstrated by Table 4.4, the raw breath-by-breath $\dot{V}O_2$, 3-point moving average and 11-point moving average had no significant difference between each other ($P>0.025$) under the 50 mL/min and 150 mL/min conditions.

5.5.2 Effect of testing protocol

Up until the end of the 1980's a discontinuous protocol was commonly used (in both cycle ergometry and treadmill) for tests of $\dot{V}O_{2MAX}$ (Cumming & Borysyk, 1972; Froelicher Jr et al., 1974; Mitchell & Blomqvist, 1971; Taylor et al., 1955). The ramp protocol became popular for its ability to provide a constantly increasing workload over time(Myers et al., 1990). Duncan, Howley and Johnson supported the suggestion of McArdle at al.(McArdle et al., 1973) to use continuous instead of discontinuous test protocols(Duncan et al., 1997).

In contrast, Thomas et al.(Thomas et al., 1987) reported significant differences in only some of their repeated protocols in the elderly whereas there were no significant differences between protocols in young boys(Sheehan et al., 1987). Howley et al. suggested that protocols should have more uniformity to enable valid comparisons to be made between studies(Howley et al., 1995).

5.5.3 Effect of inter-individual differences

The population used in this experiment was varied in gender, age (adult population only), training history, and were only related by geographical location and a predominantly Anglo-Celtic heritage. It can be therefore reasonable to assume that the population used was random so far as subject populations can be. The subjects also ranged from low level activity

(training 2-3 times per week at most) to high level triathletes and this inter-individual difference may also have an effect on the presence of a $\dot{V}O_2$ plateau at $\dot{V}O_{2MAX}$.

Investigator error could also play a part in the non-occurrence of a plateau in $\dot{V}O_2$, however this type of error should have been reduced with training in the pilot study and as well as previous experience handling subjects in maximal effort work. The same researcher provided verbal encouragement to give each subject every opportunity to find motivation to complete every test to maximal volition. In spite of these procedures other researchers(Duncan et al., 1997; Howley et al., 1995; Stachenfeld et al., 1992) reported that the incidence of $\dot{V}O_2$ plateau can be influenced by methodology, protocol, sampling duration and interval, subject population and motivation.

5.6 Conclusion

The infrequency of the $\dot{V}O_2$ plateau (primary criterion) at $\dot{V}O_{2MAX}$ has led researchers and clinicians to employ secondary criteria in order to estimate maximal oxygen consumption. The secondary criteria are RER, APMHR and RPE, however these secondary criteria have been presumed and not adequately assessed for their sensitivity, specificity and predictive ability. Few studies have investigated the true relationship of the secondary criteria used to verify $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau. Those papers that did investigate have not fully utilised contemporary technology and/or appropriate statistical methods to completely analyse the secondary criteria.

This study tested a healthy active population with a wide range of ages that performed two separate $\dot{V}O_{2MAX}$ tests on two different modes of exercise. A $\dot{V}O_2$ plateau was present in approximately one fifth of subjects in both modes under the $\dot{V}O_2$ slope parameter of $\Delta\dot{V}O_2 < \pm 50$mL/min. Using multiple regression, Bayes' theorem and DFA this researcher

was able to conclude that none of secondary criteria, used to verify $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau, were valid. None of the secondary criteria could predict that a $\dot{V}O_2$ plateau could or could not occur nor could the secondary criteria discriminate between plateau and non-plateau groups.

In addition, the significant difference between the CE and TM exercise groups could be attributed to the non-significant difference of $\dot{V}CO_2$ in exercise modes which altered RER and $\dot{V}E$ variables. This is most probably caused by the non-weight bearing isolated working muscle groups employed in the CE compared to the TM mode. The use of a 3-point moving average on raw $\dot{V}O_2$ data demonstrated that it was not significantly different in determining $\dot{V}O_{2MAX}$.

In conclusion, the secondary criteria involving HR, RPE, and RER should not be used to verify $\dot{V}O_{2MAX}$ in the absence of a $\dot{V}O_2$ plateau as they are neither sensitive, specific nor able to predict the absence or presence of a $\dot{V}O_2$ plateau. Investigators should first consider the effect of methodology, protocol, sampling duration and interval, subject population and motivation prior to testing for $\dot{V}O_{2MAX}$. All researchers should state their methodology, protocol, sampling duration and interval and if they use a secondary criteria policy clearly for the benefit of interested parties that should want to repeat the study.

The $\dot{V}O_2$ plateau at volition in maximal exercise is the only valid criteria to assess $\dot{V}O_{2MAX}$. Should a $\dot{V}O_2$ plateau not occur then the highest $\dot{V}O_2$ measure should be used to determine a $\dot{V}O_{2PEAK}$. If secondary criteria should be utilised then researchers or clinicians should ensure that they are valid for the test that they are administrating by utilising statistical methods such as those described above. Academics and clinicians alike should consider the fallibility

of accepting constructs, such as relationships between primary and secondary criteria, as 'fact' when they are no more than a concept. This can lead to an endorsement of fundamental errors that will ultimately impact negatively on the field of exercise physiology.

References

Armstrong, N., Welsman, J., & Winsley, R. (1996). Is peak VO_2 a maximal index of childrens aerobic fitness? *International Journal of Sports Medicine, 17*(5), 356-359.

Astorino, T., Robergs, R., Ghiasvand, F., Marks, D., & Burns, S. (2000). Incidence of the oxygen plateau at VO_2max during exercise testing to volitional fatigue. *Journal of Exercise Physiologyonline, 3*(4).

Astrand, P. (1952). *Experimental studies of physical working capacity in relation to sex and age*. Copenhagen: Ejnar Munksgaard.

Balady, G., Berra, K., Golding, L., Gordon, N., Mahler, D., Myers, J., & Sheldahl, L. (2000). *ACSM's Guidelines for Exercise Testing and Prescription* (6th ed.). Philadelphia: Lippincott Williams & Wilkins.

Bonen, A., Baker, S., & Hatta, H. (1997). Lactate transport and lactate transporters in skeletal muscle. *Canadian Journal of Applied Physiology, 22*(6), 531-552.

Borg, G. (1982). Psychophysical bases of perceived exeterion. *Medicine and Science in Sports and Exercise, 14*(5), 377-381.

Brooks, G. (1991). Current concepts in lactate exchange. *Medicine and Science in Sports and Exercise, 23*(8), 895-906.

Casaburi, R., Storer, T., Sullivan, C., & Wasserman, K. (1995). Evaluation of blood lactate elevation as an intensity criterion for exercise training. *Medicine and Science in Sports and Exercise, 27*(6), 852-862.

Coakes, S., & Steed, L. (2001). *SPSS: analysis without anguish: version 10.0 for Windows*. Milton: John Wiley & Sons Australia, Ltd.

Cumming, G., & Borysyk, L. (1972). Criteria for maximum oxygen uptake in men over 40 in a population survey. *Medicine and Science in Sports and Exercise, 4*(1), 18-22.

Cunningham, D., MacFarlane Van Waterschoot, B., Paterson, D., Lefcoe, M., & Sangal, S. (1977). Reliability and reproducibility of maximal oxygen uptake measurement in children. *Medicine and Science in Sports and Exercise, 9*(2), 104-108.

Davis, J., Whipp, B., Lamarra, N., Huntsman, D., Frank, M., & Wasserman, K. (1982). Effect of ramp slope on determination of aerobic parameters from the ramp exercise test. *Medicine and Science in Sports and Exercise, 14*(5), 339-343.

Duncan, G., Howley, E., & Johnson, B. (1997). Applicability of VO_2max criteria: discontinuous protocols. *Medicine and Science in Sports and Exercise, 29*(2), 273-278.

Figueroa-Colon, R., Hunter, G., Mayo, M., Alridge, R., Goran, M., & Weinsier, R. (2000). Reliability of treadmill measures in criteria to determine VO_{2max} in prepubertal girls. *Medicine and Science in Sports and Exercise, 32*(4), 865-869.

Freedson, P., Kline, G., Porcari, J., Hintermeister, R., McCarron, R., Ross, J., Ward, A., Gurry, M., & Rippe, J. (1986). Criteria for defining VO_2max : A new approach to an old problem. *Medicine and Science in Sports and Exercise, 18*(2 Supp), S36.

Froelicher Jr, V., Brammell, H., Davis, G., Noguera, I., Stewart, A., & Lancaster, M. (1974). A comparison of three maximal treadmill exercise protocols. *Journal of Applied Physiology, 36*(6), 720-725.

Hermansen, L., & Saltin, B. (1969). Oxygen uptake during maximal treadmill and bicycle exercise. *Journal of Applied Physiology, 26*(1), 31-37.

Heyward, V., & Stolarczyk, L. (1996). *Applied body composition assessment.* Champaign, IL: Human Kinetics.

Hill, A., & Lupton, H. (1923). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quarterly Journal of Medicine, 16*, 135-171.

Hoogeveen, A., & Schep, G. (1997). The plasma lactate response to exercise and endurance performance: relationships in elite triathletes. *International Journal of Sports Medicine, 18*(7), 526-530.

Howley, E., Bassett, D., & Welch, H. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and Science in Sports and Exercise, 27*(9), 1292-1301.

Hughson, R., & Green, H. (1982). Blood acid-base and lactate relationships studied by ramp work tests. *Medicine and Science in Sports and Exercise, 14*(4), 297-302.

Hughson, R., Green, H., & Sharratt, M. (1995). Gas exchange, blood lactate, and plasma catecholamines during incremental exercise in hypoxia and normoxia. *Journal of Applied Physiology, 79*(4), 1134-1141.

Issekutz, B., & Rodahl, K. (1961). Respiratory quotient during exercise. *Journal of Applied Physiology, 16*(16), 606-610.

Katch, V., & Katch, F. (1973). The relationship between aerobic power and measured work-output on a progressive step increment bicycle ergometer test. *Medicine and Science in Sports and Exercise, 5*(1), 23-28.

Katch, V., Sady, S., & Freedson, P. (1982). Biological variability in maximum power. *Medicine and Science in Sports and Exercise, 14*(1), 21-25.

McArdle, W., Katch, F., & Katch, V. (1991). *Exercise Physiology: Energy, Nutrition, and Human Performance* (3rd ed.). Philadelphia: Lea & Febiger.

McArdle, W., Katch, F., & Pechar, G. (1973). Comparison of continuous and discontinuous treadmill and bicycle tests for max VO_2. *Medicine and Science in Sports and Exercise, 5*(3), 156-160.

Meyer, T., Gabriel, H., & Kindermann, W. (1999). Is determination of exercise intensities as percentages of VO_{2max} or HR_{max} adequate? *Medicine and Science in Sports and Exercise, 31*(9), 1342-1345.

Mitchell, J., & Blomqvist, G. (1971). Maximal oxygen uptake. *The New England Journal of Medicine, 284*(18), 1018-1022.

Moffatt, R., & Stamford, B. (1978). Effects of pedalling rate changes in macximal oxygen uptake and perceived effort during bicycle ergometer work. *Medicine and Science in Sports and Exercise, 10*(1), 27-31.

Myers, J., & Ashley, E. (1997). A perspective on exercise, lactate, and the anaerobic threshold. *Chest, 111*(H3), 787-795.

Myers, J., Walsh, D., Buchanan, N., & Froelicher, V. (1989). Can maximal cardiopulmonary capacity be recognized by a plateau in oxygen uptake? *Chest, 96*(6), 1312-1316.

Myers, J., Walsh, D., Sullivan, M., & Froelicher Jr, V. (1990). Effect of sampling on variability and plateau in oxygen uptake. *Journal of Applied Physiology, 68*(1), 404-410.

Noakes, T. (1988). Implications of exercise testing for prediction of athletic performance: a contemporary perspective. *Medicine and Science in Sports and Exercise, 20*(4), 319-330.

Noakes, T. (1998). Maximal oxygen uptake: "classical" versus "contemporary" viewpoints: a rebuttal. *Medicine and Science in Sports and Exercise, 30*(9), 1381-1398.

Norman, G., & Streiner, D. (1999). *PDQ Statistics*. Hamilton: BC Decker Inc.

Pokan, R., Schwaberger, G., Hofmann, P., Eber, B., Toplak, H., Gasser, R., Fruhwald, F., Pessenhofer, H., & Klein, W. (1995). Effects of treadmill exercise protocol with constant and ascending grade on levelling-off O_2 uptake and VO_{2max}. *International Journal of Sports Medicine, 16*(4), 238-242.

Prioux, J., Ramonatxo, M., Hayot, M., Mucci, P., & Prefaut, C. (2000). Effect of ageing on the ventialtory response and lactate kinetics during exercise in man. *European Journal of Applied Physiology, 81*(1-2), 100-107.

Rivera-Brown, A., & Frontera, W. (1998). Achievement of plateau and reliability of VO_2max in trained adolescents tested with different ergometers. *Pediatric Exercise Science, 10*, 164-175.

Rivera-Brown, A., Rivera, M., & Frontera, W. (1992). Applicability of criteria for VO_2max in active adolescents. *Pediatric Exercise Science, 4*(4), 331-339.

Rivera-Brown, A., Rivera, M., & Frontera, W. (1995). Reliability of VO2max in adolescent runners: A comparison between plateau achievers and nonachievers. *Pediatric Exercise Science, 7*, 203-210.

Robergs, R. (2001). An exercise physiologist's "contemporary" interpretations of the "ugly and creaking edifices" of the VO_2max concept. *Journal of Exercise Physiologyonline, 4*(1).

Robergs, R., Icenogle, M., Hudson, T., & Greene, E. (1997). Temporal inhomogeneity in brachial artery blood flow during forearm exercise. *Medicine and Science in Sports and Exercise, 29*(8), 1021-1027.

Saltin, B., & Astrand, P. (1967). Maximal oxygen uptake in athletes. *Journal of Applied Physiology, 23*(3), 353-358.

Sheehan, J., Rowland, T., & Burke, E. (1987). A comparison of four treadmill protocols for determination of maximum oxygen uptake in 10- to 12-year-old boys. *International Journal of Sports Medicine, 8*(1), 31-34.

St Clair Gibson, A., Lambert, M., Broomhead, S.-A., & Noakes, T. (1999). Measurement of maximal oxygen uptake from two different laboratory protocols in runners and squash players. *Medicine and Science in Sports and Exercise, 31*(8), 1226-1229.

Stachenfeld, N., Eskenazi, M., Gleim, G., Coplan, N., & Nicholas, J. (1992). Predictive accuracy of criteria used to assess maximal oxygen consumption. *American Heart Journal, 123*(4), 922-925.

Stanley, W., Gertz, E., Wisneski, J., Morris, D., Nesse, R., & Brooks, G. (1985). Systemic lactate kinetics during graded exercise in man. *American Journal of Physiology, 249*(12), E595-E602.

Stockhausen, W., Grathwohl, D., Burklin, C., Spranz, P., & Keul, J. (1997). Stage duration and increase of work load in incremental testing on a cycle ergometer. *European Journal of Applied Physiology, 76*(4), 295-301.

Taylor, H., Buskirk, E., & Henschel, A. (1955). Maximal oxygen uptake as an objective measure of cardiorespiratory performance. *Journal of Applied Physiology, 8*, 73-80.

Thomas, S., Cunningham, D., Rechnitzer, P., Donner, A., & Howard, J. (1987). Protocols and reliability of maximal oxygen uptake in the elderly. *Canadian Journal of Sport Sciences, 12*, 144-151.

Weston, A., Karamizrak, O., Smith, A., Noakes, T., & Myburgh, K. (1999). African runners exhibit greater fatigue resistance, lower lactate accumulation, and higher oxidative enzyme activity. *Journal of Applied Physiology, 86*(3), 915-923.

Wyndham, C., Strydom, N., Maritz, J., Morrison, J., Peter, J., & Potgieter, Z. (1959). Maximum oxygen intake and maximum heart rate during strenuous work. *Journal of Applied Physiology, 14*(6), 927-936.

Appendix A

Informed Consent Form

Informed Consent Form

Project Title-: ***Sensitivity and Specificity of the Criteria Used to Verify*** $\dot{V}O_{2MAX}$

Purpose of the Investigation
The purpose of this study is to measure the maximal rate your body can consume oxygen ($\dot{V}O_{2MAX}$) during both cycling and running. In addition we will measure additional variables that researcher and doctors use, as supporting criteria to verify your peak $\dot{V}O_2$ value was indeed maximal.

Scope and Procedures of the study
Preliminary Questionnaires
Prior to our ability to conduct exercise tests on you in this study, we first need to question you on your health and medical status. This initial contact is to verify that your health and fitness status is adequate to enable you to exercise to vigorous intensities without exposing you to increased risk for experiencing cardiovascular abnormalities and musculo-skeletal injury. Assuming that you pass all criteria in this initial assessment, you will then be able to progress to the exercise testing sessions of the study

Procedures
You will be required to complete all three sessions in the exercise physiology research laboratory. The first session will consist of the administration of the aforementioned questionnaires, and measurement of your height, weight, and skinfold thickness at various body sites. In addition, you will be familiarised to all equipment (treadmill, bicycle ergometer, and equipment for blood lactate, expired gas analysis, and heart rate). Finally, you will be allowed to exercise on each of the cycle ergometer and treadmill for at least 10 min. When on the treadmill, we will also determine a comfortable running speed that we will use in developing a protocol of your test to $\dot{V}O_{2MAX}$.

If you have not completed a prior test of $\dot{V}O_{2MAX}$ before, a mock trial will be conducted on the exercise mode most unfamiliar to you. This trial will require you to ware all items needed for an actual test, but no data will be collected.

Cycle ergometry test of $\dot{V}O_{2MAX}$
You will need to arrive at the exercise physiology laboratory wearing appropriate clothing for a test to $\dot{V}O_{2MAX}$ (Shorts, Loose fitting shirt, jogging shoes) (Showers available and towel will be provided). You will then be prepared for heart rate determination using a chest strap, which emits signals received by our computer. The cycle ergometer will be adjusted to suit your body size, and the gas analysis equipment will be calibrated. As we need to sample expired air, and measure the rate at which you inhale and exhale air during exercise, you will have to have a mouthpiece placed in your mouth (similar to a snorkel valve) and wear a nose clip.

When finally connected to the equipment, we will acquire 2 min of data while you just sit on the bike. You will be instructed to exercise, and data will be acquired continuously during the test. The exercise protocol will require to exercise at a gradually increasing intensity until you can no longer continue to exercise. Near the end of the test you will receive verbal encouragement to continue to ensure that you do not prematurely end the test prior to your true maximal values being attained.

During the exercise test you will be asked to report how hard you feel you are exercising every minute. All other data collection during the test is automated. Immediately after ending the exercise test, you will exercise at a low intensity as an active recovery. In addition, we will need to prick your fingertip to extracting a small sample of blood as soon after the test as possible. Additional finger pricking and blood sampling will occur at 2 minutes of recovery.

Treadmill test of $\dot{V}O_{2MAX}$

The treadmill test of $\dot{V}O_{2MAX}$ will be administered, and data will be collected, exactly the same as for the cycle ergometry test. However the exercise mode will be treadmill walking and running, rather than cycle ergometry.

Time commitment

The three sessions will require approximately 45, 60, and 60 min, respectively. The order of the two tests to $\dot{V}O_{2MAX}$ will be randomised and each will be separated by no less than 2 days, and no more than 7 days.

Discomforts and Possible Risks

Exercise testing to $\dot{V}O_{2MAX}$ has been scientifically and clinically proven to be safe so along as you do not currently have multiple factors for cardiovascular disease, and no recent history of leg or joint pain/injury. It is for these reasons we conduct the initial questionnaires as previously described. The cardiovascular risk factors of interest to us consist of 1) family members (<55 male, <65 female) who have had a heart attack, coronary bypass or angioplasty, or sudden, 2) if you currently smoke cigarettes, 2) if you have high blood pressure (<140/90 mmHg), 4) if you have high blood lipids (Cholesterol > 5.2 mmol/L, HDL <0.9 mmol/L, LDL > 3.4 Mmol/L), 5) high fasting blood glucose (>6.1 mmol/L, 6) are over fat, 7) are sedentary, and 8) are above sex-specific ages (male > 45 and female >55 years).

To participate in this study, you need to have no current leg or pain or injury that would prevent you from cycling or running at high intensities, meet the age criteria (Males < 45, females <55) and have no more than 1 additional cardiovascular risk factor. We also require that you currently exercise at least 3 times /week for at least 30 min per session, and have done this for the last 3 months.

During exercise testing to $\dot{V}O_{2MAX}$ you will experience leg discomfort, heavy breathing, and increased body temperature causing you to sweat profusely. Finger tip blood sticks cause minor pain, and remain slightly sore at the sire of incision for 1-2hrs. We follow sterile and aseptic procedures to minimise the risk of infection to you and all technicians.

Potential Benefits

Exercise testing to volitional exhaustion, using gas analysis equipment to measure oxygen consumption and carbon dioxide production, can provide you with valuable data from which to quantify your level of cardiovascular and muscular endurance. In addition, data will be provided to you that will assist in how you devise an implement an exercise training program. Similar testing conducted in a retail environment would cost ~ $1,000.00.

The data obtained from this study will be used to write manuscripts submitted for publication in a scientific research journal. The data will help all scientists (cardiologists and pulmonologists) to better understand how to measure $\dot{V}O_{2MAX}$.

Freedom to Discontinue Participation
Participation is voluntary and you may withdraw at any time, for any reason to your current position will not be prejudiced in any way by your refusal to participate.

Questions Concerning Participation
If you have any questions or concerns concerning this investigation, or would like to talk to an independent person, you may contact;

Robert Robergs, Ph.D. Project supervisor (6400 5642, email: (r.robergs@ecu.edu.au)

Geoff Juranovich, B.ScProject Honours Student (9400 5158, email:g.juranovich@ecu.edu.au)

Jerry Linsten, Ph.D. Chair – Sports Science (9400 55778, email: jlinsten@ecu.edu.au)

Signatures
I (the participant) have read the information above and have been informed about all aspects of the above research project, and any questions I have asked have been answered to my satisfaction.

I agree to participate in this activity, realising I may withdraw at any time.

I agree that the research data gathered for this study may be published provided that I am not identifiable.

Participant: ____________________ Date: ____________________

Investigator: ____________________ Date: ____________________

Appendix B

Medical Questionnaire

MEDICAL QUESTIONNAIRE

Code#: ________

The following questionnaire is designed to establish a background of your medical history and identify any injury or illness that may influence your testing or performance, or any condition that may cause you undue risk during intense exercise. Please answer all questions as accurately as possible; if you are unsure about anything please ask. All information provided is strictly confidential.

Medical History

If you answer YES please give details (eg date, condition)

	YES	NO
Are you presently on any form of medication?	☐	☐
Has your doctor ever told you that you have a heart problem or condition?	☐	☐
Do you frequently experience pains or tightness in your heart and/or chest?	☐	☐
Do you often feel faint or have spells of dizziness?	☐	☐
Has your doctor ever said that your blood pressure is too high?	☐	☐
Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by/or may be made worse with exercise?	☐	☐

Have you ever had, or do you currently have any of the following?

	YES	NO
High or abnormal blood pressure? (> 140/90 mmHg)	☐	☐
High blood cholesterol? (>5.2 mmol/L)	☐	☐
Rheumatic fever?	☐	☐
Asthma?	☐	☐
Diabetes?	☐	☐
Epilepsy?	☐	☐
Back Pain?	☐	☐
Neck Pain?	☐	☐
Severe Allergies?	☐	☐
Any infectious diseases?	☐	☐
Have you had the flu in the last two weeks?	☐	☐
Injuries or accidents?	☐	☐

____

Current and/or recurring muscle or joint injuries?	☐	☐

____

Is there any other condition, not previously mentioned, which may affect your exercise performance?	☐	☐

____

Family History

Are you able to provide information on the medical history of immediate family members (parents, siblings)?

	YES	NO
	☐	☐

If "No", please mention this to the research technician, and then continue answering below.

If "Yes", continue answering below.

Are any of the following known to exist in your family?

If you answer yes please give details (eg. date, condition, age of diagnosis)

	YES	NO
Cardiac disease	☐	☐
Pulmonary disease	☐	☐
Stroke	☐	☐

Life style habits

	YES	NO
To be a subject in this study, you need to be exercising at least 3 times/week, for at least 30 min per session.		
Are you currently this active?	☐	☐

When you exercise, how many minutes of these activities per week is running, and how much is cycling?

Running	Cycling
_____	_____

If you run and cycle, please provide estimates of the frequency (number/week), duration (min/session) and intensity (easy, moderate, hard, intense) you perform these exercises per week.

Running

Frequency	Duration	Intensity
________	________	________

Cycling

Frequency	Duration	Intensity
________	________	________

	Yes	No
Do you smoke tobacco or any other nicotine products?	☐	☐
If YES, please indicate how many per day?	________	
Do you consume alcohol?	☐	☐
If YES, how many standard drinks per week?	________	
Do you consume tea or coffee? If YES, how many cups per day?	☐	☐
	________	

Declaration

I have read, understood and completed this questionnaire.

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health. Any questions I had were answered to my full satisfaction.

Name: ______________________ Date: ____________

Signature: ______________________

Witness: ______________________

Appendix C

Demographics Questionnaire

DEMOGRAPHICS QUESTIONNAIRE

The following questionnaire is designed to record your personal details, and provide a code which is to be used for labelling additional questionnaires, and all your files and data of this study. There will only be one copy of the code-name key sheet, and this will be kept in the possession of Geoff Juranovich, the Honours student who is conducting this study.

Once the study is complete, the code-name key will be kept on file by the supervisor of this project until data is prepared for publication. Once published, the sheet will be destroyed by shredding. After an additional year after publication, all disk copies of data will be destroyed by reformatting.

Personal details

Name: ______________________________________

DOB: _____/_____/_____ Sex: _______

Height: ____________ cm Weight: _______ kg

Subject Code #: ________

Appendix D

Results Proforma

$\dot{V}O_{2MAX}$ TESTING SHEET

CODE:

HEIGHT: WEIGHT: DOB:

Date: Time: Date: Time:

TREADMILL	
Time	Intensity
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	

LACTATE
30 sec
120 sec

RPE	
Original	Modified

CYCLE
Increment (W)
RPM

LACTATE
30 sec
120 sec

RPE	
Original	Modified

SKINFOLDS	
Triceps	
Biceps	
Pectoral	
Subscapular	
Abdominal	
Suprailiac	
Mid-thigh	
Calf	
TOTAL (mm)	

NOTES:

Appendix E

Summary of Formal Results

Individual TM criteria and gas analysis results for female participants

Code	Primary Slope $\dot{V}O_2$ (mL/min)	Secondary Slope $\dot{V}O_2$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/kg/min)	At $\dot{V}O_{2MAX}$ $\dot{V}E$ (L/min)	$\dot{V}E/\dot{V}O_2$	HR	RPE	RER
101	153.70	-89.51	3068.33	57.89	107.70	35.94	174.00	18.00	1.14
102	188.30	19.17	3132.33	52.21	97.20	31.25	188.00	19.50	1.16
103	140.70	49.09	2619.67	45.17	106.90	41.19	177.00	18.00	1.21
105	129.40	-156.70	2832.33	49.69	94.90	33.33	196.00	18.00	1.10
107	194.90	-5.96	3384.00	51.04	137.60	39.88	176.00	19.00	1.24
108	57.30	181.30	2886.00	51.54	94.10	32.61	195.00	19.00	1.17
112	63.53	184.80	2484.00	45.16	99.80	39.70	204.00	18.00	1.20
115	230.90	279.40	3147.00	50.03	106.70	33.91	180.00	17.50	1.15
116	163.50	-94.08	2806.67	53.36	107.50	39.25	197.00	19.00	1.21
117	168.00	-199.50	2598.00	51.24	91.80	34.88	199.00	19.00	1.31
119	144.40	69.11	2266.33	38.48	77.30	35.43	166.00	19.00	1.17
120	186.20	63.29	3057.00	51.81	108.50	36.12	194.00	18.00	1.22
126	105.10	36.66	3246.33	44.90	111.90	34.59	179.00	20.00	1.10
128	157.00	-89.32	3014.33	52.51	117.50	39.52	187.00	18.50	1.18
129	111.40	-23.47	2817.33	47.19	88.20	31.62	188.00	20.00	1.19
130	190.60	195.50	3752.00	61.11	130.20	34.98	187.00	19.00	1.20
132	166.90	142.20	2755.33	52.18	109.30	38.31	186.00	17.00	1.27
133	158.40	-73.62	2832.70	48.42	105.50	38.62	194.00	19.00	1.23
134	324.00	-271.00	3216.33	53.25	100.70	32.47	192.00	19.00	1.07
135	236.80	-84.77	3643.67	49.98	131.00	34.87	195.00	18.00	1.20
137	226.00	231.50	2750.67	40.87	100.50	37.25	199.00	18.00	1.19
138	154.80	-14.68	2654.30	38.92	101.30	36.88	190.00	17.00	1.21
140	179.20	142.70	3138.67	50.54	107.50	34.26	194.00	19.00	1.21
141	121.80	-28.29	2427.33	45.37	81.10	34.50	180.00	19.00	1.18
142	137.20	177.70	2789.33	51.09	103.80	38.83	189.00	17.50	1.30

Individual CE criteria and gas analysis results for female participants

Code	Primary Slope $\dot{V}O_2$ (mL/min)	Secondary Slope $\dot{V}O_2$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/kg/min)	At $\dot{V}O_{2MAX}$ $\dot{V}E$ (L/min)	$\dot{V}E/\dot{V}O_2$	HR	RPE	RER
101	247.40	-23.07	2676.00	50.49	106.80	38.65	164.00	17.00	1.22
102	187.60	249.70	2725.73	45.43	101.00	37.30	184.00	20.00	1.23
103	169.00	133.60	2364.67	40.77	107.00	45.00	176.00	17.50	1.18
105	193.90	-48.12	2440.48	42.82	109.20	44.72	182.00	19.00	1.40
107	182.2	-42.40	3244.33	48.93	148.40	45.12	178.00	19.00	1.28
108	175.10	183.40	2774.67	49.55	104.20	37.64	183.00	17.00	1.31
112	149.70	-35.28	2429.67	44.18	119.10	37.27	209.00	19.00	1.33
115	175.00	1.86	3246.00	51.61	137.20	40.56	181.00	19.00	1.16
116	211.80	86.09	2569.00	48.84	127.40	49.28	195.00	18.50	1.21
117	201.70	165.40	2471.67	48.75	115.80	47.54	187.00	18.50	1.42
119	114.90	-58.92	1862.00	31.61	79.20	43.40	163.00	19.00	1.33
120	204.00	130.00	2827.67	47.93	115.23	41.76	178.00	19.00	1.18
126	196.70	382.10	2692.18	37.24	99.20	37.59	175.00	18.00	1.22
128	244.10	-185.70	2851.00	49.67	122.80	43.38	183.00	19.00	1.27
129	167.60	-290.10	2432.33	40.74	112.50	43.79	178.00	20.00	1.34
130	179.10	50.82	3464.67	56.43	146.10	37.88	182.00	20.00	1.19
132	181.30	299.50	2440.00	46.21	96.50	36.71	178.00	18.00	1.24
133	184.30	248.50	2514.00	42.97	118.20	48.05	192.00	19.00	1.30
134	210.30	47.74	3168.00	52.45	119.80	34.90	195.00	18.00	1.13
135	182.20	88.49	3005.00	41.22	130.50	45.03	182.00	18.50	1.28
137	177.90	164.70	2381.67	35.39	99.50	41.81	185.00	19.00	1.35
138	188.80	240.50	2665.67	39.09	122.50	44.97	181.00	18.00	1.23
140	149.70	309.90	3138.67	50.54	92.60	33.33	183.00	19.00	1.16
141	187.10	185.80	2073.00	38.75	82.60	39.96	175.00	19.00	1.18
142	171.30	-6.05	2290.00	41.94	110.10	43.45	177.00	17.50	1.33

Individual TM criteria and gas analysis results for male participants

Code	Primary Slope $\dot{V}O_2$ (mL/min)	Secondary Slope $\dot{V}O_2$ (mL/min)	At $\dot{V}O_{2MAX}$ $\dot{V}O_{2MAX}$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/kg/min)	$\dot{V}E$ (L/min)	$\dot{V}E/\dot{V}O_2$	HR	RPE	RER
203	233.80	-3.04	4495.00	61.58	140.30	31.25	183.00	18.00	1.22
204	94.36	-250.50	3645.33	52.08	120.80	33.30	194.00	19.00	1.17
205	251.50	-69.44	4311.33	48.44	136.10	31.50	197.00	18.00	1.25
208	172.90	-180.90	3817.67	45.86	140.40	36.43	213.00	18.00	1.18
209	163.40	163.80	3563.67	58.13	119.60	33.17	195.00	17.50	1.28
210	225.00	146.70	5007.00	76.44	172.80	34.63	193.00	17.50	1.24
211	228.50	10.19	4227.67	55.77	137.60	33.36	212.00	19.00	1.26
212	144.50	-259.10	3556.00	56.00	138.30	39.70	244.00	18.00	1.23
213	187.00	-159.50	4505.00	55.28	172.50	38.95	184.00	19.00	1.20
214	328.50	11.74	4494.67	56.54	195.30	44.30	184.00	19.00	1.24
215	244.10	258.00	4194.33	66.68	131.30	30.92	192.00	18.50	1.14
216	304.40	243.60	4637.67	45.47	174.00	37.84	192.00	18.00	1.22
218	240.40	-9.58	4624.67	58.69	168.60	36.70	199.00	18.50	1.27
222	213.80	131.10	4382.00	56.18	147.40	33.49	184.00	19.00	1.16
224	167.70	189.40	3976.00	63.51	188.10	49.80	189.00	19.00	1.22
225	201.90	106.90	5005.33	63.84	155.60	31.05	210.00	18.00	1.24
226	173.30	62.20	3543.67	55.89	123.90	35.14	183.00	19.00	1.26
231	172.90	245.90	3682.00	54.31	152.80	39.74	202.00	19.00	1.29
234	262.40	240.10	5353.33	67.25	157.10	30.42	185.00	19.00	1.17
237	214.20	-596.40	3619.67	46.41	130.80	36.03	165.00	18.50	1.15
238	229.40	-890.40	4389.67	51.95	121.90	27.88	171.00	19.00	1.11
239	163.10	-62.31	3821.33	62.95	153.30	40.11	171.00	18.00	1.25
240	241.30	320.80	4597.67	52.79	144.30	31.49	193.00	19.00	1.19
242	198.00	1711.00	4760.67	62.97	171.90	37.61	183.00	17.50	1.18
246	228.70	-190.00	5518.33	69.68	186.30	30.76	187.00	18.50	1.22
248	238.70	420.30	5412.67	62.86	151.50	28.11	181.00	19.00	1.21
250	252.20	-228.40	5741.33	66.07	200.90	36.69	181.00	19.00	1.30
252	284.10	-88.15	4605.00	62.40	155.90	33.77	171.00	15.00	1.31
253	332.60	206.50	4498.00	49.59	147.50	32.95	184.00	16.00	1.09
254	228.80	338.80	4442.67	50.95	151.20	35.49	205.00	16.00	1.36
255	204.70	-81.27	3965.67	58.23	124.90	31.50	163.00	18.00	1.23
256	270.80	-24.61	4964.00	59.88	167.80	34.36	185.00	18.00	1.21
257	310.90	335.80	4983.67	64.14	175.10	35.63	163.00	15.00	1.15
258	248.60	-150.30	3863.33	61.13	151.70	39.25	170.00	15.00	1.32
259	221.00	-11.00	3766.33	50.69	139.00	37.80	187.00	17.00	1.25
260	232.40	222.60	5237.67	69.37	168.00	32.25	199.00	19.00	1.19
261	206.20	104.70	4561.00	59.54	167.80	36.79	199.00	19.00	1.37
262	303.50	781.10	4004.00	61.89	120.90	30.78	202.00	15.50	1.20
263	244.40	118.50	4867.00	64.89	170.30	34.99	203.00	17.50	1.25

Individual CE criteria and gas analysis results for male participants

Code	Primary Slope $\dot{V}O_2$ (mL/min)	Secondary Slope $\dot{V}O_2$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/min)	$\dot{V}O_{2MAX}$ (mL/kg/min)	At $\dot{V}O_{2MAX}$ $\dot{V}E$ (L/min)	$\dot{V}E/\dot{V}O_2$	HR	RPE	RER
203	347.70	-326.70	4354.00	59.64	150.80	34.72	180.00	18.50	1.29
204	227.90	30.79	3414.00	48.77	149.90	43.97	181.00	18.50	1.39
205	254.30	-401.60	3705.33	41.63	167.00	44.18	187.00	17.00	1.31
208	195.20	-181.50	3351.33	40.26	134.10	43.67	200.00	18.00	1.22
209	276.00	149.70	3676.67	59.98	127.20	36.60	190.00	18.00	1.29
210	301.00	-62.23	4303.33	65.70	182.90	42.00	183.00	18.00	1.24
211	228.30	199.70	3716.33	49.03	154.70	42.62	205.00	18.50	1.31
212	229.90	-64.28	3175.67	50.01	127.90	41.47	244.00	19.00	1.27
213	302.30	242.40	4113.67	50.47	188.40	45.74	171.00	18.00	1.23
214	234.90	94.02	4705.67	59.19	204.10	40.34	192.00	20.00	1.22
215	285.60	340.40	3511.00	55.82	122.40	35.09	184.00	19.50	1.18
216	208.60	544.30	3614.33	35.43	120.70	32.33	181.00	18.00	1.18
218	239.40	-33.69	3954.00	50.18	169.40	43.41	186.00	17.50	1.28
222	272.10	324.00	3865.67	49.56	146.30	37.97	174.00	18.00	1.18
224	215.30	-78.68	3222.00	51.47	182.30	63.94	181.00	18.00	1.18
225	302.50	667.10	4585.00	58.48	140.80	32.50	192.00	18.00	1.30
226	211.10	-314.70	3182.00	50.19	136.50	42.99	175.00	17.00	1.24
231	241.60	234.50	3265.67	48.17	162.50	48.64	189.00	18.50	1.39
234	280.00	177.10	5072.67	63.73	177.90	36.39	183.00	19.00	1.26
237	218.80	253.60	3425.67	43.92	145.40	41.96	150.00	18.50	1.20
238	284.70	151.60	4032.00	47.72	135.50	33.61	162.00	19.00	1.24
239	253.70	-76.22	3770.00	62.11	150.50	39.93	159.00	18.00	1.19
240	229.60	-63.84	3477.33	39.92	150.10	42.21	177.00	17.00	1.33
242	309.00	324.60	4493.00	59.43	170.40	39.02	173.00	18.50	1.19
246	342.80	-289.50	4302.00	54.32	155.90	36.11	171.00	15.00	1.26
248	284.30	127.90	5667.67	65.83	169.10	30.57	178.00	17.00	1.31
250	290.10	-205.00	5189.67	59.72	212.60	41.85	172.00	18.50	1.28
252	316.80	-60.64	4270.33	57.86	176.90	42.56	173.00	17.00	1.36
253	287.90	294.50	4271.33	47.09	176.10	41.63	182.00	17.00	1.21
254	204.70	382.40	4387.00	50.31	169.40	39.61	197.00	18.00	1.26
255	312.00	268.60	3772.00	55.39	143.00	37.91	157.00	17.00	1.25
256	309.60	-122.20	4340.33	52.36	173.90	39.75	175.00	15.00	1.29
257	306.60	-462.80	4369.67	56.24	180.60	42.61	166.00	17.00	1.28
258	275.90	-24.37	3603.00	57.01	123.40	36.18	160.00	19.00	1.31
259	204.80	137.70	3263.33	43.92	136.40	38.90	166.00	18.00	1.12
260	287.40	-321.40	4549.33	60.26	164.90	36.64	185.00	19.00	1.17
261	305.30	283.80	4483.00	58.52	180.00	40.33	185.00	18.00	1.26
262	303.50	-179.40	3512.00	54.28	117.80	41.79	188.00	19.00	1.41
263	301.90	-228.20	4309.67	57.46	169.20	43.98	168.00	18.00	1.33