EFFECT OF LACTATE TOLERANCE BOARD TRAINING ON UPPER BODY ANAEROBIC PERFORMANCE

by

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DECLARATION

I certify that this thesis is the result of my own research conducted at the

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ABSTRACT

EFFECT OF LACTATE TOLERANCE BOARD TRAINING ON UPPER BODY ANAEROBIC PERFORMANCE

Seven conditioned post-pubescent male subjects ($\dot{V}O_2$peak=2.8±0.1 $l \cdot min^{-1}$) performed eight weeks of high intensity intermittent board training followed by ten days of reduced training. Subjects performed a 60 s all-out test, on a Biokinetic swim bench ergometer, on five occasions throughout the duration of the study. Performance parameters as well as oxygen deficit (OD) related data were recorded during the 60 s all-out tests. Time trials were completed pre-, mid- and post-training over distances of 75, 140 and 250 m. At the conclusion of the period of reduced training, significant improvements of 17 percent ($p<0.05$) and 60 percent ($p<0.01$) were observed for mean power and peak power, respectively. Fatigue index increased by 42 percent ($p<0.05$). Improvements in mean power reached significance after five weeks of training. A significant improvement was recorded in the OD from pre- to mid-training (40.5 percent, $p<0.05$). The quantified OD did not continue to improve from mid- to post-training which may be explained by the anaerobic capacity not being exhausted by the 60 s all-out tests. No significant change in the relative reliance upon anaerobic energy release was observed in the 60 s all-out tests, however, anaerobic work increased 35 percent ($p<0.05$). Improvements of 11 ($p<0.05$), seven ($p<0.05$) and six ($p<0.05$) percent were noted for the 75, 140 and 250 m time trials, respectively. Peak oxygen uptake improved by 5.4 percent which was almost significant at the 0.05 level ($p=0.052$). In-water performance and ergometric assessment were highly related. The period of reduced training had little effect on performance parameters assessed during the 60 s all-out tests. It was concluded that lactate tolerance training appears to be effective for developing the anaerobic energy system, and associated performance in short-lasting exercise of high intensity, with no apparent decrements in the aerobic energy system.

DEDICATION

To my parents, Peter and Shirley Morton, who have never failed to guide and support their children. The pride and joy they gain from our achievements encourages me to strive to be the best I can be.

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CHAPTER I

INTRODUCTION

At the elite level of sport performance much dedication is required of both athlete and coach. Whilst the level of achievement is determined primarily by the attributes of the athlete, coaching techniques impact significantly upon performance. Events that required near maximal effort over 30 to 10 s duration are arguably the most difficult events to prepare an athlete for as they require the development of both the aerobic and anaerobic energy systems to a high degree. Optimising the potential of the two energy systems simultaneously is no easy task as the modes of training often do not complement each other. One well applied mode of anaerobic training is lactate tolerance training, characterised by high intensity repeats of 30 to 120 s separated by work to rest ratios greater than 1:2 (Martin & Coe, 1991; Pyne & Telford, 1988; Sharp, 1991). Lactate tolerance training has been found to improve the athlete's ability to sustain anaerobic energy release despite the accumulation of high levels of lactate, essentially improving the anaerobic capacity (Sharp, 1991). Thus, lactate tolerance training is sometimes referred to as anaerobic capacity training. The anaerobic capacity is defined as the maximal amount of energy an individual can derive anaerobically during a single bout of high intensity exercise (Medbø, Mohn, Tabata, Bahr, Vaage & Sejersted, 1988). A large anaerobic capacity is advantageous for sprint athletes as exercise of high intensity can be better sustained by the relatively fast release of the anaerobic energy system in comparison to the less powerful aerobic energy system. From a coaching perspective, interest lies in how quickly improvements can be induced in the anaerobic energy system. An understanding of the response of the anaerobic energy system to training would aid coaches in structuring the training season and essentially preparing sprint athletes for competition.

An issue of interest that is not well understood is the effect of lactate tolerance training on the aerobic energy system. It could be argued that as lactate tolerance training is designed to primarily stress the anaerobic energy system, the aerobic energy system would be unaffected or detrimentally affected. It has been demonstrated, however, that athletes can achieve maximal oxygen uptake within 60 s of all-out exercise (Serresse, Lortie, Bouchard & Boulay, 1988). Thus, it would appear that the aerobic energy system may also be stressed by lactate tolerance training.

Reducing the volume of training immediately prior to competition is a strategy employed by coaches to optimise performance (Houmard, 1991). The period of reduced training allows the athlete to recover from, and adapt to, the previous training stress. Whilst the procedure is practiced moreso by endurance athletes, sprint athletes may benefit from the procedure as the concentration of adenosine triphosphate within resting muscle has been shown to be lowered as a result of sprint training (Stathis, Febbraio, Carey & Snow, 1994). Thus, a period of reduced training may improve sprint performance by allowing metabolite restoration.

The present study was concerned with the effect of lactate tolerance training and a period of reduced training on the energy systems and associated performance. To examine the response of the energy systems to a training stimulus, however, a valid technique of assessment is required.

In the past, several techniques have been used for assessment of the anaerobic energy system. Measurement of peak lactate concentration and quantification of the oxygen debt are two techniques that have been shown to not provide a valid indication of the extent of anaerobic energy release during exercise (Bangsbo, Michalsik & Petersen, 1993; Medbø et al., 1988; Scott, Roby, Lohman & Bunt, 1991). Two techniques are presently used for the assessment of the anaerobic energy system; total work or mean power achieved in an all-out test of short duration (30 to 90 s) and quantification of the oxygen deficit (OD) acquired during supramaximal exercise (McKenna, Green, Shaw & Meyer, 1987; Medbø et al., 1988; Withers, Sherman, Clark, Esselbach, Nolan, Mackay & Brinkman, 1991).

Quantification of the OD also provides a means of assessing the relative contribution of the aerobic and anaerobic energy systems during intense exercise of varying durations (Gastin, 1994; Medbø & Tabata, 1989; Withers et al., 1991). Recent research indicates that the relative importance of the aerobic energy system during short-lasting intense exercise may be more significant than presently acknowledged (Gastin, 1992; Withers et al., 1991). Both studies found that a 60 s all-out effort relied on approximately equal contributions from the aerobic and anaerobic energy systems, which is considerably greater than the 30 percent aerobic contribution previously suggested (Bouchard, Taylor, Simoneau & Dulac, 1991). Furthermore, the results of a cross-sectional study suggest that sprint trained subjects rely more on anaerobic energy release during short-lasting exhaustive exercise (Gastin & Lawson, 1994a). In accordance with the finding of Gastin and Lawson (1994a), the relative reliance upon the anaerobic energy system has been shown to increase as a result of sprint training (Troup, Barzdukas, Franciosi, Trappe & Acquisto, 1991).

Whilst several studies have examined the effect of lactate tolerance training on the lower body, the trainability of the upper body has been less well considered. Competitive board paddling, a discipline involved with Surf Lifesaving, is an upper body dominated activity that would benefit from such research as, despite a sharp increase in competitiveness, preparation for competition remains mostly unscientific. The short duration and highly intense nature of the event indicates that reliance upon anaerobic energy release is significant. Thus, lactate tolerance training may be an effective mode of training for improving performance in competition.

Presentation of the Problem

The present study examined the effect of eight weeks lactate tolerance training followed by a ten day period of reduced training on the anaerobic energy system and associated high intensity performance, in board paddling. Assessment of performance occurred both in the laboratory and in-water. Laboratory testing involved five repeated 60 s all-out tests on a Biokinetic swim bench ergometer in which several performance parameters and OD related data were assessed. Time trials were performed pre-, mid- and post-training over varying distances to detect improvements in in-water performance. A Biokinetic swim bench ergometer was selected for the laboratory assessment, as used by Morton (1992), as it closely simulated the in-water board paddling action. Changes in aerobic power as a result of the lactate tolerance training were also assessed.

Statement of the Problem

The present study examined the following questions:

1). Is lactate tolerance training an effective mode of training for improving the anaerobic capacity and associated performance in exercise of high intensity and short duration?

2). What duration of lactate tolerance training is required to elicit improvements in the anaerobic energy system and associated performance during exercise of high intensity and short duration?

3). How well do ergometric assessment procedures and in-water performance relate?

4). Do improvements in ergometric assessment parameters and in-water performance correlate highly?

5). Do improvements in the anaerobic energy system result in a greater relative reliance upon anaerobic metabolism during a 60 s all-out test?

6). Does lactate tolerance training affect aerobic power?

7). Does a ten day period of reduced training impact upon performance during exercise of high intensity and short duration?

Limitations

Listed below are limitations of the present study:

1). As the study only involved conditioned post-pubescent male subjects, results obtained may not be generalisable to other populations.

2). Calculation of the OD involves estimating the oxygen cost of supramaximal exercise from submaximal data. Thus, the calculation of the OD relies on the assumption that efficiency does not change from submaximal to supramaximal intensities. The validity of assuming no change in efficiency from submaximal to supramaximal intensity during swim bench ergometry, in which assessment of OD occurred, is unknown. Accordingly, it is difficult to assess possible changes in supramaximal efficiency on the swim bench ergometer during the course of the study. Furthermore, a decrease in efficiency from submaximal to supramaximal intensities would result in an underestimation of the OD.

3). Climatic conditions changed during the course of the study, amounting to a nine degree decrease in water temperature, which may have had an effect on in-water performance.

Definition of Terms

Adenosine triphosphate (ATP) - High energy phosphate which is used as a direct energy source by the human body. Hydrolysed to adenosine diphosphate (ADP) and free phosphate to release energy.

Aerobic - Refers to the derivation of ATP through metabolic pathways that require the presence of oxygen. Pathways include the Krebs Cycle and Electron Transport System (Mathews & VanHolde, 1991).

Anaerobic - Refers to the derivation of ATP through metabolic pathways that do not require the presence of oxygen such as glycolysis and through the release of energy from the hydrolysis of high energy phosphates (Mathews & VanHolde, 1991).

Anaerobic Capacity - The maximal amount of energy an individual can derive from the anaerobic energy system during a single bout of high intensity exercise (Medbø et al., 1988).

Anaerobic Energy System - Combination of the non-aerobic mechanisms of energy derivation which includes the ATP-CP system (alactic) and glycolytic energy pathways (lactic).

Anaerobic Performance - Assessment of performance parameters during exhaustive exercise completed within 60 s. Although used, the term may not be valid as the aerobic energy system contributes to the total energy release even during exercise of short duration.

Alactic Energy System - Responsible for anaerobic energy derivation through the hydrolysis of the high energy phosphates ATP and creatine phosphate (CP).

All-out - Implies a maximal effort from the onset to the conclusion of a test. All-out ergometry tests usually measure peak power as well as mean power.

Creatine Phosphate (CP) - High energy phosphate which acts as an immediate energy source by resynthesising ATP.

Efficiency - Ratio of internal energy release to external work completed. Improvements in efficiency result in less energy expenditure for a constant external work output.

Ergometric Performance Parameters - Variables measured during ergometric assessment procedures, including mean power, peak power, final power and fatigue index.

Lactate Tolerance Training - High intensity intermittent training designed to produce high levels of lactate. Characterised by near maximal efforts of 30 to 120 s, separated by work to rest ratios greater than 1:2 (Pyne & Telford, 1988; Sharp, 1991).

Lactic Energy System - Anaerobic energy derivation through glycolysis. Results in the accumulation of lactic acid, or lactate at physiological pH, which is formed from pyruvate in the final reaction of anaerobic glycolysis.

Peak Oxygen Uptake ($\dot{V}O_2peak$) - An expression of peak aerobic power. A measure of the maximal amount of oxygen the body can use per minute for the production of ATP through aerobic metabolic processes. Also known as the maximal oxygen uptake.

Submaximal - Refers to exercise intensities below that of a level corresponding to the maximal power of the aerobic energy system.

Supramaximal - Refers to exercise intensities above that of a level corresponding to the maximal power of the aerobic energy system.

Steady State - Distinguished by a plateau in oxygen consumption during constant intensity submaximal exercise. Assumed that energy requirements are being met entirely through aerobic processes, such that the oxygen uptake represents the energy cost for the exercise.

Theoretical Oxygen Cost - Estimated oxygen cost of supramaximal exercise. Represents the expected oxygen uptake for a supramaximal intensity if the aerobic energy system could entirely meet the energy requirements of the exercise intensity.

CHAPTER II

REVIEW OF LITERATURE

One incredible function of the human organism is its ability to convert ingested food to useable energy in the form of adenosine triphosphate (ATP). Adenosine triphosphate is essential to human life. Adenosine triphosphate can be formed by metabolic pathways that require oxygen (aerobic) or do not require oxygen (anaerobic). In humans, aerobic ATP can only be produced at a relatively low rate but for an infinite amount of time (Bouchard et al., 1991). Aerobic metabolism is responsible for meeting the majority of the body's energy requirements during rest and low intensity activity. Alternatively, the anaerobic energy system is capable of producing vast amounts of ATP at a rapid rate, however, it is limited in capacity (Serresse, Lortie, Bouchard & Boulay, 1988; Withers, Van Der Ploeg & Finn, 1993). Thus, while anaerobic metabolism is crucial for high intensity activity, it has a finite capacity that can be exhausted. Athletes spend much time and effort training the ability of their body to produce energy. Endurance athletes attempt to improve the rate of the aerobic energy system, while sprint athletes endeavour to increase the capacity and power of the anaerobic energy system. The trainability of the anaerobic energy system has been clearly demonstrated (Nevill, Boobis, Brooks & Williams, 1989; Sharp, Costill, Fink & King, 1986). Lactate tolerance training, characterised by near maximal efforts extending over durations of 30 to 120 s separated by work to rest ratios of 1:2 (Sharp, 1991), is one mode of anaerobic training that is effective for developing the anaerobic energy system.

The response of a fitness parameter to training can only be assessed with the aid of a procedure or technique that allows repeated measurement of that parameter. Several techniques have been used for the assessment of anaerobic capacity and power. Traditionally, performance was relied upon to. assess the effectiveness of training programs designed to develop the anaerobic energy system. Unfortunately, as many other physiological and biomechanical factors contribute to performance, analysis of performance did not allow the isolated assessment of the anaerobic energy system. Thus, laboratory techniques that attempted to isolate anaerobic power and capacity have been developed.

Measurement of Anaerobic Power and Capacity

Anaerobic power represents the maximal rate at which the anaerobic energy system can produce ATP (Bouchard et al., 1991). Tests of anaerobic power have typically involved measures of explosiveness such as the vertical jump (Vandewalle, Peres & Monod, 1987), or measures of peak or mean power during short lasting all-out exercise (McKenna, Green, Shaw & Meyer, 1987; Simoneau, Lortie, Boulay & Bouchard, 1983).

Anaerobic capacity is defined as the maximal amount of ATP that can be formed through anaerobic processes during a single bout of exercise (Medbø et al., 1988). Several techniques have been suggested for the quantification of anaerobic capacity, however, few are presently considered valid. Measurement of peak lactate concentration and maximal oxygen debt have been shown to not provide accurate representations of the anaerobic capacity (Green & Dawson, 1993; Hagberg, Mullin & Nagle, 1980; Medbø et al., 1988; Saltin, 1990; Scott et al., 1991). Presently, ergometric assessment during short-lasting exercise and quantification of the maximal oxygen deficit (MOD) are used to estimate anaerobic capacity. Whilst offering the most accurate estimation of the anaerobic capacity presently available, these techniques also possess limitations.

Total Work

Scott et al. (1991) stated that ergometric assessment of anaerobic power and capacity, involving measures of peak power, mean power and fatigue index, was the most used assessment procedure presently available. Durations for all-out work tests are selected to maximise the contribution of the particular energy system to be assessed while minimising the contribution of the others (Bouchard et al., 1991). Ergometric assessment of the anaerobic energy system does possess limitations, however, the most significant being a failure to isolate the relative contributions made by the aerobic and anaerobic energy systems. The validity of work tests relies upon the traditional view that the energy requirements during all-out exercise are first derived by the catabolism of high energy phosphates, and then through glycolysis until the anaerobic energy system is exhausted (Margaria, Olivia, di Prampero & Cerretelli, 1969). It is now known, however, that transition from one energy system to the next does not occur systematically. All energy systems are activated at the commencement of exercise (Jacobs, Tesch, Bar-Or, Karlsson & Dotan, 1983). Thus, although generalisations can be made concerning the predominating energy system during a specific time interval, isolating one particular energy system for assessment is difficult.

It is generally accepted that the catabolism of high energy phosphates (ATP and creatine phosphate) is responsible for meeting the majority of the energy requirements at the commencement of maximal intensity exercise (Hirvonen, Rehunen, Rusko & Harkonen, 1987). As energy derivation by the phosphate energy system does not require oxygen or result in the accumulation of lactate, it is often referred to as the anaerobic alactic energy system. The use of a 10 s all-out work test has been used to assess the capacity for alactic energy release (Serresse, Ama, Simoneau, Lortie, Bouchard & Boulay, 1989; Simoneau et al., 1983; Simoneau, Lortie, Boulay, Marcotte, Thibault & Bouchard, 1986). The tri-level fitness test, developed at the Australian Institute of Sport, involves such a procedure (Minikin & Telford, 1991). Although, as it is not clearly known how quickly the alactic system is depleted, it is difficult to assert how representative the work performed in a 10 s all-out work test is of alactic capacity. Simoneau et al. (1983) found that 88 percent of creatine phosphate (CP) was depleted in working muscles after 5.5 s, suggesting that the phosphate energy system is exhausted well before 10 s (Jacobs et al., 1983). Jacobs et al. (1983) found that after 10 s of all-out exercise lactate levels can be five times that of rest, indicating a significant level of glycolytic activity. Similarly, in response to six seconds of all-out bicycle exercise, Boobis, Williams and Wooton (1982) noted a prominent increase in muscle lactate concentration (9.3± 1.8 to 28.4±7.7 mmol.kg^{-1} dry wt.). After 10 s of all-out exercise Jones, McCartney, Graham, Spriet, Kowalchuk, Heigenhauser and Sutton (1985) reported lactate concentrations of approximately 61 percent of those achieved during 30 s of all-out exercise. The results obtained by Jones et al. (1985) are comparable with the findings of Jacobs et al. (1983) who reported 10 s lactate concentrations of 59 and 46 percent of 30 s concentrations for males and females, respectively. Serresse et al. (1988) suggested that the alactic system was responsible for only 55 to 60 percent of the energy expenditure during a 10 s all-out test. Thus, it would appear that glycolysis may be responsible for a significant portion of the energy release during all-out tests even as short as 10. s. Due to the inaccuracies involved with quantifying the capacity of the alactic energy system, the maximal rate of the anaerobic energy system, refered to as anaerobic power, is alternatively used (Boulay, Lortie, Simoneau, Hamel, Leblanc & Bouchard, 1985; Cerretelli, 1992). On a bicycle ergometer peak power is achieved in the initial three to six s of all-out exercise (Boobis et al., 1982).

Ergometric assessment of anaerobic lactic capacity has involved all-out work tests of durations ranging from 30 to 90 s (Boulay et al., 1985; Coggan & Costill, 1984; Serresse et al., 1988; Serresse et al., 1989; Tharp, Johnson & Thorland, 1984). As it is impossible to exclude the contribution of the alactic system, longer duration anaerobic tests are often referred to as tests of anaerobic capacity which includes both the alactic and lactic systems (Green & Dawson, 1993). Two considerations need to be made when selecting the duration of a work test for the assessment of anaerobic capacity. Firstly, the test needs to be long enough to exhaust the anaerobic capacity. Secondly, the test should be short enough to minimise the contribution made by the aerobic energy system. Table 1 summarises the findings of recent research with emphasis on the percent aerobic contribution and percent anaerobic capacity exhausted during various durations of maximal exercise.

Table 1: Aerobic and anaerobic energy system contribution and/or percentage of anaerobic capacity exhausted during intense short-lasting exercise of varying durations.

Researcher(s)	Mode	Time (s)	% aerobic	% anaerobic	% exhausted
Åstrand, 1981	Bicycle ergometer	60	32	68	
		120	50	50	
Lawson & Golding, 1981	Bicycle ergometer	60	44	56	
Medbo & Sejersted, 1985	Treadmill	56	47	53	
Stevens & Wilson, 1986	Bicycle ergometer	30	44	56	
Kavanagh & Jacobs, 1987	Bicycle ergometer	30	18	82	
Medbø et al., 1988	Treadmill	15			34
		30			50
Serresse et al., 1988	Bicycle ergometer	30	28	72	
		90	46	54	
Medbø & Tabata, 1989	Bicycle ergometer	30	40	60	77
		60	50	50	93
		120	65	35	100
Smith & Hill, 1991	Bicycle ergometer	30	16	84	

Table 1 continued:

Researcher(s)	Mode	Time (s)	% aerobic	% anaerobic	% exhausted
Withers et al., 1991	Bicycle ergometer	30	28	72	85
		60	49	51	100
		90	61	39	100
Gastin, 1992	Isokinetic bicycle ergometer	62	49	51	98
Morton, 1992	Swim bench ergometer	45	50	50	77
Withers et al., 1993	Bicycle ergometer	45	40	60	93
		60	47	53	100
		75	54	46	100
		90	60	40	100

Carefully controlled studies indicate that the anaerobic capacity can be nearly exhausted in 60 s of all-out exercise (Gastin & Lawson, 1994b; Withers et al., 1991; Withers et al., 1993). Whilst a 60 s all-out test may be an appropriate duration for assessment of anaerobic capacity, it must be realised that the aerobic energy system may be responsible for as much as 50 percent of the total work achieved. The significance of the aerobic energy system in short duration work tests is further apparent when the high percentages of maximal oxygen uptake ($\dot{V}O_2max$) attained are considered. Kavanagh and Jacobs (1988) reported a mean oxygen consumption of 1.67 *l* during a 30 s Wingate test, with 85 percent of $\dot{V}O_2max$ being attained during the last five seconds of the test. Similarly, Serresse et al. (1988) found that $\dot{V}O_2max$ was achieved after 60 s of all-out exercise. In consideration of the aerobic contribution to exercise and percentage of the anaerobic capacity exhausted during all-out exercise of varying durations, Withers et al. (1991) concluded that 60 s may be the most appropriate duration for ergometric assessment of the anaerobic energy system, moreso than the extensively used 30 s Wingate test.

Although many concerns exist in regards to the validity of ergometric assessment of anaerobic capacity, work tests involving all-out efforts for durations ranging between 30 to 90 s remain popular as they are easily conducted and offer immediate feedback. Furthermore, work tests have been shown to be reliable ($r=0.96$, $p<0.05$, Lawson & Golding, 1981). In a study conducted by Coggan and Costill (1984) no significant difference was found in either peak power or mean power during 30 and 60 s all-out tests over a four week period with four repeated measures. The high degree of reliability makes ergometric assessment procedures appropriate for training studies.

Oxygen Deficit

The oxygen deficit (OD) is defined as the difference between the theoretical oxygen cost of exercise and the actual oxygen uptake (Medbø et al., 1988). Oxygen deficits are acquired at the commencement of exercise before the aerobic energy system adjusts to meet the energy demand, and during supramaximal exercise where the energy cost of the intensity exceeds the power of the aerobic energy system. Quantification of the maximal oxygen deficit (MOD) has been suggested as the most valid technique for measuring anaerobic capacity as it separates the anaerobic and aerobic components of work (Lawson & Golding, 1981). Medbø et al. (1988) stated that MOD is a direct quantitative expression of anaerobic capacity. It has been suggested that the MOD technique is the only method with the potential to quantify anaerobic capacity (Saltin, 1990; Withers et al., 1993). Whilst the technique may possess the potential to provide the most valid assessment of the anaerobic energy system, assumptions involved with the procedure have raised concerns (Bangsbo, 1992; Bangsbo et al., 1993; Medbø, 1992).

The OD represents ATP formation through the catabolism of high energy phosphates, glycolysis and changes in the body's oxygen stores (Green & Dawson, 1993). As stored oxygen is used for the derivation of energy through aerobic pathways, the MOD contains an aerobic component. Medbø and Tabata (1989), however, suggest that the contribution made by stored oxygen to MOD is small, with as much as 90 percent of MOD due to true anaerobic ATP formation. Medbø et al. (1988) showed the MOD to be directly related to the anaerobic energy system by demonstrating that the MOD remained unchanged during testing procedures performed in an atmosphere of reduced oxygen concentration (13.5 percent). Maximal oxygen uptake was reduced by 22 percent, however, no significant difference was noted for the MOD indicating that it was independent of the aerobic energy system.

The validity of the MOD as an expression of anaerobic capacity has been further supported by the findings of both cross-sectional and training studies. Medbø and Burgers (1990) found no significant difference in the magnitude of the MOD between untrained and endurance trained subjects, however, sprint trained subjects were shown to possess a 30 percent ($p<0.001$) larger MOD. Similarly, Scott et al. (1991) reported higher mean MOD for sprint and middle distance runners (78 & 74 $ml \cdot kg^{-1}$ respectively) in comparison with long distance runners (56 ml·kg^{-1}) and control subjects (56 ml·kg^{-1}). The MOD has also been shown to increase in response to sprint training (Medbø & Burgers, 1990; Troup et al., 1991). Thus, the MOD behaves in a way that would be expected for the anaerobic capacity, as indicated by both training and cross-sectional studies. Scott et al. (1991) also attempted to validate the MOD as an expression of anaerobic capacity by studying the correlation between the MOD and other popular methods of assessing anaerobic capacity such as the Wingate test, peak lactate concentration and a variety of running performance trials. Although significant correlations were found, such a procedure does not provide conclusive evidence as to the validity of the MOD as a measure of anaerobic capacity as the parameters used for the standard of comparison do not necessarily provide a valid representation of the anaerobic capacity themselves.

It has been demonstrated that the magnitude of the MOD is related to the muscle mass involved in exercise (Barzdukas, Hollander, D'Acquisto & Troup, 1991; Bangsbo et al., 1993; Walker, Cureton, DuVal, Prior, Sloniger & Weyand, 1994). Weyand, Cureton, Conley and Higbie (1993) reported a strong linear relationship ($r=0.94$) between the MOD and estimated active muscle mass. Furthermore, the MOD achieved during one-legged cycling was almost exactly half (52 percent) of that achieved during two-legged cycling. Withers et al. (1993) found a significant relationship on a bicycle ergometer between MOD and both fat free mass ($r=0.73$, $p<0.01$) and leg volume ($r=0.77$, $p<0.01$). Olesen (1992) found that the slope of inclination in treadmill running increased the magnitude of the MOD, which they partly attributed to an increase in active muscle mass. Accordingly, the magnitude of the MOD varies with the ergometer used, with the highest values attained during whole body exercise. Depending on the ergometer used and subject involved, values for the MOD range between 32 and 100 ml·kg^{-1} (Gastin, 1994).

Two modes of tests are presently used for the determination of the MOD: constant load and all-out. Constant load tests involve the subject maintaining a supramaximal intensity to exhaustion. Intensities selected for constant load tests usually range between 110 and 130 percent $\dot{V}O_2max$ (Gastin, Costill, Krzymenski & McConell, 1991), however, Medbø et al. (1988) used unreported intensities which subjects failed to maintain for 15 s. As the constant load test is supramaximal in nature, subjects are forced to rely on anaerobic energy production. It is assumed that the anaerobic energy system is exhausted, and therefore the MOD achieved, when the subject can no longer perform at an intensity greater than the maximal power of the aerobic energy system (see Figure 1). Medbø et al. (1988) conducted a series of constant load tests on a treadmill, ranging in duration from 15 s to in excess of four minutes. They found that the OD plateaued after two minutes, concluding that the MOD can be achieved in two to three minutes of intense exercise. Time to exhaustion during a constant load test has also be used as an expression of anaerobic status (Graham & McLellan, 1989). Figure 1 graphically represents an idealistic constant load test.

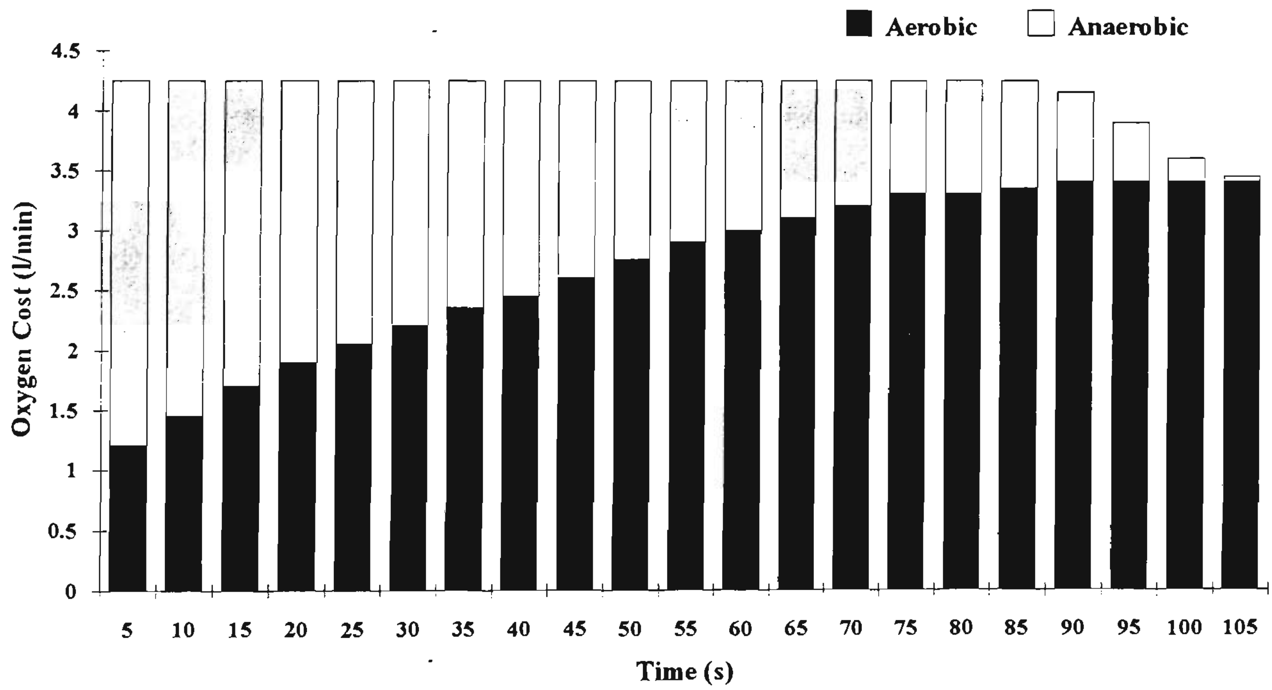

Figure 1: Aerobic and anaerobic contribution to exercise during an idealistic constant load test. Time intervals along the abscissa represent five second values (ie. 0-5 s, 5-10 s, etc).

All-out tests involve the subject performing a maximal effort over a predetermined duration. All-out test durations typically range from 30 to 90 s. Difficulties associated with all-out tests arise as it can not be assured whether the MOD has been achieved, however, the exhaustion of the anaerobic capacity has been shown to be associated with a decrease in the intensity of exercise to that corresponding to $\dot{V}O_2max$ (Gastin, 1992; Withers et al., 1991). As expected, it would appear that the aerobic energy system is solely responsible for meeting the energy requirements of exercise after the anaerobic energy system has been exhausted. Whilst it is difficult to assess how representative the OD achieved during an all-out test is of the MOD, research by Gastin et al. (1991) found no significant difference between the OD of two constant load tests (110 and 130 percent) and a 62±2 s all-out test performed on a cycle ergometer. Furthermore, Withers et al. (1993) demonstrated that the OD was unchanged from 60 to 90 s of all-out bicycle exercise. Thus, it would appear that the MOD can almost be achieved during one minute of all-out exercise (Gastin & Lawson, 1994b; Withers, 1991), which is substantially less than the two to three minute time period suggested by Medbø et al. (1988) for constant load tests. Figure 2 illustrates the power output and oxygen kinetics of an idealistic all-out test. Performance parameters including total work, peak power and fatigue index are assessed during all-out tests (Ama, Lagasse, Bouchard & Simoneau, 1990; Froese & Houston, 1987).

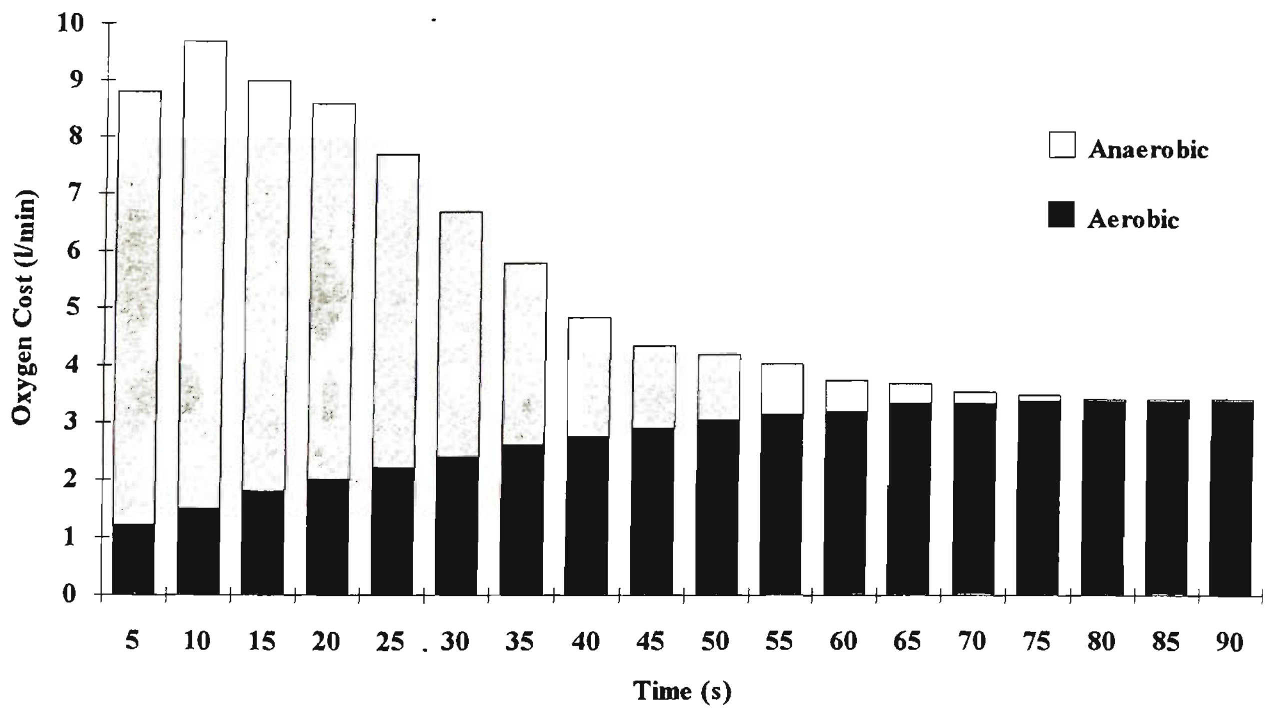

Figure 2: Aerobic and anaerobic contribution to exercise during an idealistic all-out test. Time intervals along the abscissa represent five second values (ie. 0-5 s, 5-10 s, etc).

Calculation of Oxygen Deficit

As stated previously, calculation of the OD involves computing the difference between the theoretical oxygen cost of exercise and the actual oxygen uptake (Medbø et al., 1988). The actual oxygen uptake during exercise can be easily determined through the collection of expired air in Douglas bags for later analysis. The theoretical oxygen cost of supramaximal exercise is more difficult to ascertain as steady state values can not be obtained at the supramaximal intensities required to exhaust the anaerobic energy system. Thus, in the calculation of the OD the theoretical oxygen cost of the exercise must be estimated. Lawson and Golding (1981) assumed a constant mechanical efficiency of 22.5 percent for bicycle ergometer exercise which they used for the estimation of the oxygen cost of supramaximal exercise. In assuming a constant mechanical efficiency, individual differences in efficiency are ignored (Cavanagh & Kram, 1985). Neglecting the individual variation in efficiency would likely result in significant errors as Medbø et al. (1988) noted a 16 percent variation between individuals. In an attempt to personalise the estimation of the oxygen cost of supramaximal exercise, Medbø et al. (1988) constructed individual efficiency functions depicting work intensity against oxygen demand. Construction of individual efficiency functions has been used extensively since the work of Medbø et al. (1988) (Gastin, 1992; Medbø & Burgers, 1990; Medbø & Tabata, 1989; Scott et al., 1991; Withers et al., 1991).

Construction of the individual efficiency function involves a series of submaximal tests, at a variety of intensities, in which steady state oxygen consumption is determined. Medbø et al. (1988) suggested that a minimum of 10 to 15 data points are required for the accurate construction of the efficiency function, however, in later investigations he only used four (Medbø & Burgers, 1990). Other researchers have used as few as five data points (Scott et al., 1991; Withers et al., 1991). An individual estimation of the oxygen cost for supramaximal intensities is determined by substituting the intensity into the individually constructed efficiency function. Figure 3 illustrates the relationship between work intensity and oxygen

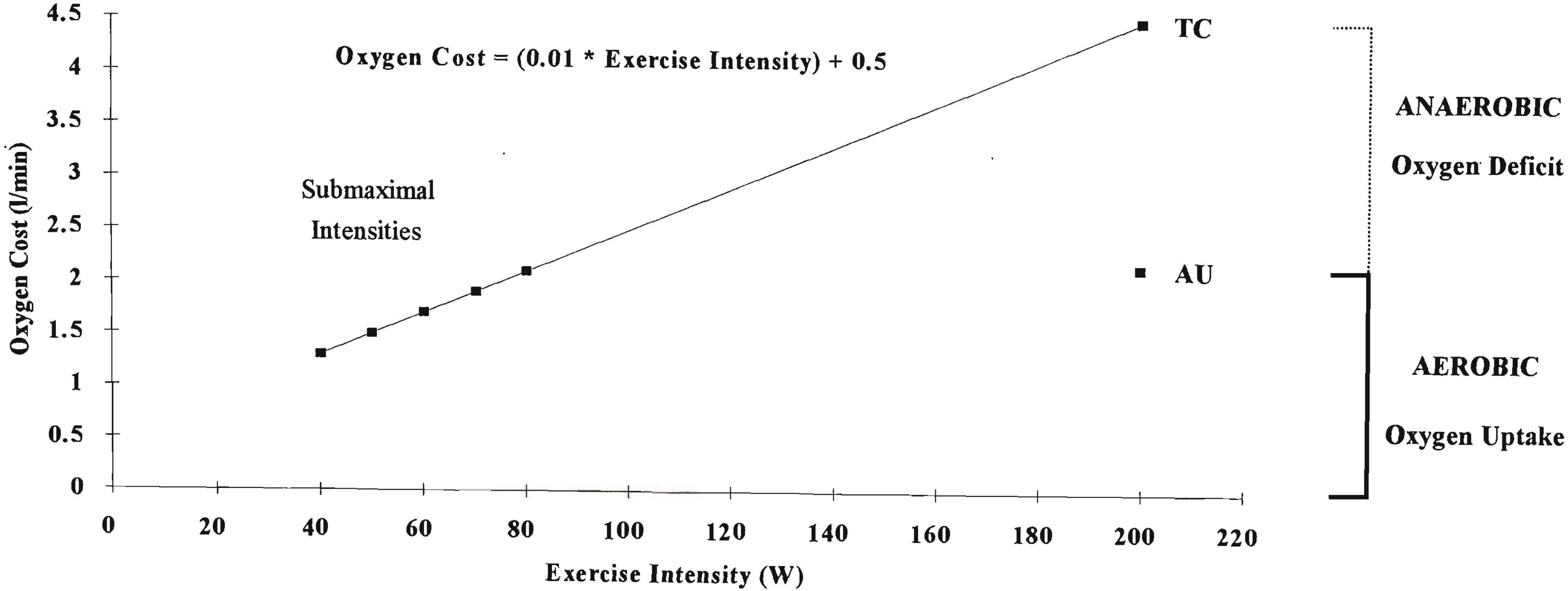

Figure 3: Graphical determination of the oxygen deficit using the extrapolation procedure.
TC: Theoretical oxygen cost of the 60 s all-out test.
AU: Actual oxygen uptake during the 60 s all-out test.

cost with extrapolation to a supramaximal intensity. A sample calculation of the OD is included in Appendix C.

Validity of linear extrapolation to supramaximal intensities

The validity of the extrapolation procedure rests upon the assumption that a positive linear relationship exists between work intensity and oxygen cost, essentially suggesting that efficiency does not change from submaximal to supramaximal intensities. Evaluating the validity of the assumption is difficult as no direct method for assessment of supramaximal efficiency is available. Bangsbo et al. (1993) found that during treadmill running oxygen uptake at the highest submaximal intensities were significantly ($p<0.05$) higher than that predicted by an efficiency function derived from measurements at lower intensities. Gladden and Welch (1978) reported simular observations during bicycle ergometry. They suggested that the disproportionate increase in oxygen consumption during higher intensity exercise may be attributable to either a decrease in muscular efficiency or an increase in metabolism not directly related to the external work. Gladden and Welch (1978) concluded that a slight exponential relationship may exist between oxygen consumption and workrate. In consideration of these findings, Bangsbo et al. (1993) suggested that the lack of linearity between oxygen consumption and workrate for submaximal intensities questions the validity of extrapolating to supramaximal intensities. Medbø (1992) defended the linear extrapolation procedure, claiming that when low intensity measures are excluded from the construction of the efficiency function the relationship is linear. Low intensities may give nonlinear results as environmental factors impact more significantly on oxygen uptake, and in the case of treadmill running locomotion is not natural at extremely low intensities (Medbø, 1992).

Whilst the linear extrapolation procedure may be justified for exercise slightly above the submaximal intensities used for the construction of the efficiency function, it is difficult to comment on the validity of extrapolating to supramaximal intensities. The margin for error becomes evident when it is recognised that the mean power during a 30 s all-out test can be in excess of 200 percent $\dot{V}O_2max$ (Gastin, 1992). Thus, the mean power substituted into the efficiency function for the determination of the theoretical oxygen cost of exercise can be nearly three times greater than the highest steady state intensity used for the construction of the function. In another study Gastin, Costill, Lawson, Krzeminski and McConell (1994) reported no difference in the MOD achieved during exercise at 107 percent $\dot{V}O_2max$ (43.9± 3.0 $ml \cdot kg^{-1}$), 125 percent $\dot{V}O_2max$ (44.1±1.8 $ml \cdot kg^{-1}$) and 149 percent $\dot{V}O_2max$ (42.0±2 $ml \cdot kg^{-1}$). Such a finding would suggest that the extrapolation procedure is justified for these intensities.

It is likely that efficiency would be less susceptible to change in exercise that involves predetermined movement patterns, such as cycling and arm cranking. Treadmill running and swim bench ergometry allow more flexibility in movement patterns, thus, perhaps lending themselves to greater changes in efficiency with varying intensities. Accordingly, the use of low skill based ergometers would be preferable in the determination of the MOD. Secondly, the individually constructed efficiency function should include measurements as close as possible to the intensity of the supramaximal test in which the MOD is to be determined. Thus, the efficiency function should be constructed using the highest intensities in which steady state data can be achieved. Constant load tests may also be preferable to all-out tests as the controlled intensity during a constant load test is lower.

Oxygen Kinetics

Quantifying the OD provides a technique for estimating the relative contributions of the aerobic and anaerobic energy systems. Table 1 (page 12) displays the findings of several studies, most of which used the oxygen deficit technique. Several general functions portraying the behaviour of the energy systems at the onset of supramaximal exercise, from which the relative contributions of the energy systems could be estimated, have been constructed

(Bouchard et al., 1991). In the light of recent research, it appears that the general functions have consistently underestimated the contribution made by the aerobic energy system during short-lasting exercise. Furthermore, it has been demonstrated, that several factors affect oxygen kinetics, and thus the contribution made to exercise by the aerobic energy system. Accordingly, considerable variation may exist in the relative contributions of the aerobic and anaerobic energy systems for a given duration and/or intensity of exercise.

Prior exercise appears to affect oxygen kinetics (Barstow & Mole, 1991; di Prampero, Mauler, Giezendanner & Cerretelli, 1989; Hickson, Bomze & Holloszy, 1978; Morton, 1987), however, conflicting results have been published pertaining to the exact effect. In general, it appears that prior exercise improves oxygen kinetics at the commencement of exercise. McKenna et al. (1987) reported that a warm up improved sprint performance which he attributed to greater aerobic energy release as a consequence of accelerated oxygen kinetics. di Prampero et al. (1989) concluded that the oxygen kinetic response may depend on several metabolic factors, including the depletion of body oxygen stores and the rate of anaerobic metabolism during the priming exercise.

It has been demonstrated that higher intensity exercise results in correspondingly faster oxygen kinetics at the commencement of exercise (Barstow & Mole, 1991; Hagberg, Nagle & Carlson, 1978). Gastin et al. (1994) found that the oxygen uptake during the first 30 s of exercise significantly increased as the intensity increased from a constant load of 110 percent $\dot{V}O_2max$ (22±1 ml·kg^{-1}) to an all-out effort of mean intensity 143±5 percent $\dot{V}O_2max$ (32±1 ml·kg^{-1}). Similar trends have been reported for submaximal intensities by Hagberg et al. (1978). Interestingly, Gastin (1992) observed faster oxygen kinetics in sprint trained subjects at the commencement of an all-out test on a bicycle ergometer in comparison with endurance trained, despite the endurance trained subjects naturally possessing a more developed aerobic energy system. This unexpected result may be attributable to the greater intensities attained by sprint trained subjects at the commencement of all-out exercise (Gastin, 1992; Minikin &

Telford, 1991). Thus, the relative contributions of the energy systems for a given time interval may vary according to the intensity of the exercise.

The oxygen kinetic response is also related to training status (Cerretelli, Pendergaust, Paganelli & Rennie, 1979). Hagberg et al. (1978) found that during bicycle ergometry the oxygen consumption response at the commencement of exercise was significantly faster ($p<0.05$) in trained subjects (mean $\dot{V}O_2max = 70.2$ ml·kg^{-1}·min) in comparison with untrained subjects (mean $\dot{V}O_2max = 49.7$ ml·kg^{-1}·min). Similar trends were observed when exercise intensity was selected relative to $\dot{V}O_2max$. Furthermore, Yoshida, Udo, Ohmori, Matsumoto, Uramoto & Yamamoto (1991) found accelerated oxygen kinetics at the commencement of exercise following three weeks of strenuous endurance training. Similarly, Hickson et al. (1978) found that after 10 weeks of endurance training the time required to attain 50, 75 and 90 percent of the steady state value significantly decreased ($p<0.05$) at the commencement of the same absolute exercise intensities.

Yoshida et al. (1992) suggested that the more rapid response of the aerobic energy system to exercise would result in a reduction of lactate accumulation during exercise due to less reliance upon anaerobic metabolism. Essentially, faster oxygen kinetics, induced by a warm up or training, would allow greater aerobic energy release, thus resulting in a reduced reliance on anaerobic energy release during the initial phases of exercise, which in turn may lead to improved performance during exhaustive exercise.

Training

Training refers to the procedures an individual undertakes in preparation for an event with the objective being to optimise performance. Two important principles must be considered before planning a training program: specificity and overload (Martin & Coe, 1991). The principle of specificity asserts that a training program must be structured to accommodate the fitness components required for the targeted event. According to the overload principle, to elicit a training response, it is necessary to stress the selected fitness components beyond a level to which they are accustomed.

Anaerobic Training

A variety of anaerobic training modes have been developed. In recognition of the overload principle, it is necessary to exhaust the anaerobic energy system to elicit a training effect (Martin & Coe, 1991). Due to the highly intense nature of the exercise required to exhaust the anaerobic energy system, training is structured intermittently. Thus, athletes perform intense efforts separated by recovery periods. The structure of the session, in terms of number of repeated efforts, intensity of effort, recovery between repeats, and most significantly the duration of effort, determines the energy system stressed (Martin & Coe, 1991; Powers & Howley, 1990). The phosphate energy system is responsible for meeting the majority of energy requirements during the first 10 s of maximal intensity exercise, thus it is stressed by near maximal effort repeats of a similar duration. Such training develops an athlete's ability to exert force at a high rate, termed anaerobic power. The lactic energy system contributes significantly to energy release during the first 60 s of all-out exercise. Accordingly, exercise resulting in exhaustion within a similar time interval is responsible for improving the capacity of the lactic energy system. One mode of anaerobic training endorsed by coaches for the development of anaerobic capacity is lactate tolerance training. Lactate tolerance training involves intense efforts (>95% of maximum effort) of 30 to 120 s with a minimum work to rest ratio of 1:2 (Martin & Coe, 1991; Pyne & Telford, 1988; Sharp, 1991). As it appears that the anaerobic capacity can be exhausted within 90 s of all-out exercise it may be more appropriate to suggest that 120 s all-out repeats are not required. Characteristic of lactate tolerance training are near maximal heart rates and blood lactate concentrations (Jenkins & Quigley, 1993; Pyne & Telford, 1988). Lactate tolerance training improves the ability of the athlete to sustain anaerobic energy production despite the accumulation of high levels of lactate, essentially improving the anaerobic capacity (Sharp, 1991).

Effect of Anaerobic Training on Anaerobic Power and Capacity

Cross sectional studies have been used to demonstrate the trainability of the anaerobic energy system (Medbø & Burgers, 1990). Medbø and Burgers (1990) found sprint trained subjects to possess a 30 percent ($p<0.001$) larger MOD than endurance trained subjects. Similar trends have been reported by Medbø and Sejersted (1985) and Scott et al. (1991) who reported sprint trained subjects to possess 37 and 38 percent higher MODs than endurance trained subjects, respectively. Medbø and Burgers (1990) suggested that the larger MOD recorded for the sprint trained subjects was a consequence of the years of anaerobic training completed by the subjects, genetic factors, or a combination of both. As it is difficult to estimate the contribution of genetic factors to the large difference observed in the magnitude of the MOD, determination of the training effect is equally as difficult. Thus, cross-sectional studies do not provide conclusive evidence of the trainability of the anaerobic energy system. Longitudinal training studies, however, have extensively demonstrated the trainability of the anaerobic energy system.

Table 2 summarises a number of studies that have examined the response of indices of anaerobic power (peak power) and capacity (mean power, time to exhaustion, MOD) to high intensity intermittent training. Research by Jacobs et al. (1987) is the only cited study not to have observed significant improvements in anaerobic capacity, anaerobic power or both. Jacobs et al. (1988) were unable to explain this lack of improvement in performance, however, they did make a subjective statement claiming that the subjects performed and coped better with the progressively more difficult training sessions throughout the duration of the six weeks. As can be seen in Table 2, improvements of up to 30 percent ($p<0.05$) have been recorded in mean power in response to six weeks (Troup et al., 1991), and 26 percent

Table 2: Improvement in peak power and anaerobic capacity in response to lactate tolerance training.

Researcher(s)	Duration	Density (Work:Rest)	Exercise	Assessment	AC (%)	PP (%)
Houston & Thomson, 1977	6 weeks	90 sec:3 min 60 sec:2 min 6 sec:24 sec	Treadmill	TE	16.7 *	
Weltman et al., 1978	6 weeks	40 sec:10 min	Bicycle ergometer (40 seconds)	MP, PP	12 *	13 *
Boobis et al., 1986	8 weeks		Wingate test	MP, PP	5.6 *	12.3 *
Sharp et al., 1986	8 weeks	30 sec:4 min	Bicycle ergometer (45 seconds)	MP, PP	28 *	26 *
Jacobs et al., 1987	6 weeks	15 sec:45 sec 30 sec:15 min	Wingate test	MP, PP	no change	
Nevill et al., 1989	8 weeks	2 min:5min 30 sec:10 min 6 sec:54 sec	Treadmill	MP, PP	6	12 *
Medbø & Burgers, 1990	6 weeks	3-3.5 min:8 min 20 sec:4.5-5 min	Treadmill	MAOD	10	
Troup et al., 1991	6 weeks		Swimming	MAOD	30 *	
Stathis et al., 1994	7 weeks	30 sec:3 min	Wingate test	MP, PP	12.1 **	13.5 **
Jenkins & Quigley, 1993	8 weeks	60 sec:5 min	Bicycle ergometer (60 seconds)	TW	16 **	

AC: Anaerobic capacity, MP: Mean Power, PP: Peak Power, TE: Time to exhaustion, MAOD: Maximal accumulated oxygen deficit. TW: Total Work, * ($p<0.05$), ** ($p<0.01$).

($p<0.05$) in peak power following eight weeks of sprint training (Sharp et al., 1986). As most training studies have involved six to eight weeks of training, it is unclear as to how quickly significant improvements in the anaerobic energy system can be expected following high intensity training.

Scott et al. (1991) reported no difference in the MOD of endurance trained and untrained subjects (56.9±5.1 vs 56.1±10.5 ml·kg^{-1}). Similar observations were made by Medbø and Burgers (1990). Within the context of the cross-sectional study it would appear that, as expected, endurance training does not develop the anaerobic energy system. Accordingly, the specificity of training is apparent.

Physiological Effect of Anaerobic Training

Several factors associated with anaerobic energy release have been examined to assess adaptations in response to sprint training. Physiological effects of anaerobic training that have been examined include changes in muscle metabolites, buffer capacity, fibre type and enzymatic concentrations. Whilst it appears that some definitive conclusions can be made, the response of other factors is not clear. It is noteworthy that the factors in which research have shown conflicting results often involve the muscle biopsy technique. Thus, intra-individual variability may be observed when using the muscle biopsy technique, arising as a result of small differences in site or depth of the incision.

Noteworthy is the observation that anaerobic training can result in improvements in the aerobic energy system. Several researchers have recorded improvements in $\dot{V}O_2max$ in response to anaerobic training (Bell & Wenger, 1988; Sharp et al., 1986). Bell and Wenger (1988) noted an 11 percent ($p<0.05$) improvement in one-legged $\dot{V}O_2max$ following seven weeks of anaerobic training which they suggested may be a result of the demnds placed upon the aerobic energy system during the high intensity efforts.

ATP & CP - With the phosphate energy system being primarily responsible for the immediate release of energy at the commencement of exercise, it would be expected that decreases in post-exercise phosphate levels would be observed following intense exercise. Cheetham, Boobis, Brooks and Williams (1986) recorded a decrease of 64 percent ($p<0.05$) in muscle CP and 37 percent ($p<0.05$) in muscle ATP following 30 s of all-out exercise. Jacobs, Bar-Or, Karlsson, Dotan, Tesch, Kaiser and Inbar (1982) found similar declines in muscle CP (60 percent, $p<0.001$) and ATP (33 percent, $p<0.001$) concentrations following 30 s of all-out exercise. Likewise, Stathis et al. (1994) observed a 68 percent ($p<0.05$) decrease in muscle CP concentrations and 40 percent in ATP concentrations following a 30 s all-out effort. Thus, it appears evident that significant declines in both CP and ATP concentrations occur following exhaustive exercise, with the more pronounced decreases occurring in CP. In appreciation of the overload principle it could be hypothesised that sprint training, involving efforts that repeatedly stress the alactic system, would result in a compensatory training effect in which resting ATP and CP concentrations would be elevated. Conflicting results have been presented in regards to the effect of sprint training on resting muscle metabolite concentrations with reports of increases (Houston & Thomson, 1977), decreases (Hellsten-Westing, Balsom, Norman & Sjodin, 1992; Stathis et al., 1994) and no change (Boobis, Brooks, Cheetham & Williams, 1986). Results obtained by Sharp et al. (1986) indicated that sprint trained subjects may possess an enhanced ability to use their phosphate pool during intense exercise as the sprint trained subjects recorded a 63 percent decline in muscle CP concentrations as opposed to 38 percent for a similar endurance trained group. Thus, while sprint training may not be responsible for increasing the phosphate pool, it may better develop the athletes ability to use high energy phosphates.

Buffer capacity - The literature consistently indicates that sprint training results in an increase in peak lactate concentration following exhaustive exercise (Houston & Thomson, 1977; Jacobs et al., 1987; Stathis et al., 1994). Whilst it is acknowledged that peak lactate concentration does not provide an accurate representation of anaerobic capacity, it does give an indication of the extent of anaerobic metabolism. Increases in the muscle lactate concentration result in a decrease in muscle pH (Boobis et al., 1986; Nevill et al., 1989) which is presently believed to be a primary cause of fatigue within the working muscle (Vøllestad & Sejersted, 1988). It has been hypothesised that the ability of the body to neutralise hydrogen ions associated with the accumulation of lactate, referred to as buffering, is improved with sprint training. Sharp et al. (1986) found the muscle buffer capacity to improve by 37 percent ($p<0.05$) in response to eight weeks of sprint training. Bell and Wenger (1988) observed buffer capacity to improve by 15.8 percent ($p<0.05$) following seven weeks of one-legged bicycle ergometer sprint training. No change was noted by Bell and Wenger (1988) in the buffer capacity of the untrained leg. Contrary to these findings, Nevill et al. (1989) recorded no change in muscle buffer capacity following eight weeks of high intensity training on a treadmill. In a cross-sectional study conducted by Medbø and Sejersted (1985), no difference was noted in the blood buffer capacity of a group of sprint and endurance trained subjects despite the sprint trained group recording 34 percent ($p<0.005$) higher peak lactate concentrations following exhaustive exercise. Thus, the response of the muscle buffer capacity to sprint training is not well understood.

Fibre type - Conflicting findings examining the effect of sprint training on muscle fibre type proportions have been presented. Esbjornsson, Sjodin, Westing and Jansson (1992) noted a decrease in the proportion of type I (slow twitch) fibres from 45 to 37 percent, with an increase in the proportion of type IIa (fast twitch oxidative) fibres from 40 to 53 percent after six weeks of sprint training. The same researchers found similar results in a previous study reporting a decrease in type I fibres (57 to 48 percent) and an increase in type IIa fibres (32 to 38 percent) after four to six weeks of sprint training (Jansson, Esbjornsson, Holm & Jacobs, 1990). In further support of muscle fibre type proportion changes, Houston, Wilson, Green, Thomson and Ranney (1981) reported an increase in the percentage of type IIa fibres from 28 to 36 percent but no change in the percentage of type I or IIb fibres following 6.5 weeks of sprint training. Whilst other researchers have reported apparent increases in the proportion of type IIa fibres and decreases in type I fibres (Jacobs, Esbjornsson, Sylven, Holm and Jansson, 1987), there is an equal amount of literature to suggest that sprint training results in no change in these parameters (Fournier, Ricci, Taylor, Ferguson, Montpetit & Chaitman, 1982; Houston & Thomson, 1977; Thorstensson, Sjodin & Karlsson, 1975). Thus, it is difficult to draw conclusions from the literature in regards to the effect of sprint training on muscle fibre type proportions, however, the more recent research appears to be supportive of potential changes.

Enzymatic concentrations - The activity of phosphofructokinase (PFK) primarily determines glycolytic flux (Mathews & VanHolde, 1991). Fournier et al. (1982) and Jacobs et al. (1987) found sprint training to significantly increase the activity of PFK by 21 percent ($p<0.05$) and 16 percent ($p<0.05$), respectively. Sharp et al. (1986) reported PFK activity levels to increase by as much as 46 percent ($p<0.05$) in response to eight weeks of sprint training. Simoneau, Lortie, Boulay, Marcoote, Thibault and Bouchard (1987) reported increases in the activity of the enzymes hexokinase (33 percent, $p<0.05$), lactate dehydrogenase (22 percent, $p<0.05$) and malate dehydrogenase (53 percent, $p<0.05$) after 15 weeks of sprint training. Increases in the activity of other enzymes including phosphorylase and succinate dehydrogenase have also been reported (Houston et al., 1981). Thus, it has been clearly demonstrated that enzyme activity is increased in response to sprint training which would partly account for improvements in performance.

Reduced Training

In preparation for competition, athletes often reduce the total volume of training by either decreasing training frequency or duration (Johns, Houmard, Kobe, Hortobagyi, Bruno, Wells & Shinebarger, 1992). The period of reduced training is often referred to as tapering. Training volume during taper can be reduced by as much as 70 percent (Houmard, 1991; Houmard, Costill, Mitchell, Park, Fink & Burns, 1990). The effect of taper durations lasting up to 45 days have been studied in swimmers (Yamamoto, Mutoh & Miyashita, 1988), however, taper periods usually last approximately 10 to 14 days (Houmard & Johns, 1994).

Whilst the practice is more common among endurance athletes, it appears that sprint athletes may benefit from the procedure.

In a study conducted by Costill, King, Thomas and Hargreaves (1985) on 17 male collegiate swimmers, an average improvement of 3.1 percent ($p<0.05$) was noted in swim performance following 14 days of reduced training. The distance over which in-water performance was assessed varied from 50 to 1650 yards. Furthermore, Costill et al. (1985) found power, as measured on a swim bench ergometer, to increase by 17.7 percent ($p<0.05$). Increases in muscular strength following a reduction in training volume have also been reported by Neary, Martin, Reid, Burnham and Quinney (1992). Improvements in muscular strength would serve to optimise sprint performance (Sharp, Troup & Costill, 1982). It has been reported that muscular strength can be maintained for as long as 28 days (Neufer, Fielding, Flynn & Kirwan, 1987) and 12 weeks (Graves, Pollock, Leggett, Braith, Carpenter & Bishop, 1988) of reduced training. Research also indicates that $\dot{V}O_2max$, which can be achieved during prolonged high intensity efforts, can be maintained for as long as 15 weeks when training volume is reduced by two-thirds (Hickson & Rosenkoetter, 1981; Hickson, Kanakis, Davis, Moore & Rich, 1982).

Whilst the physiological effects of tapering are not well understood (Neufer, 1989), taper may allow muscle metabolites to be fully restored. For example, Stathis et al. (1994) found resting ATP concentrations to be significantly lower than pre-training levels (19 percent, $p<0.05$) two days after the completion of a seven week sprint training program. Thus, a period of reduced training may allow time for metabolite restoration. Finally, Wittig, Houmard and Costill (1989) found that a period of reduced training can induce positive psychological effects by increasing mood state and vigour. Essentially, a taper period allows the athlete to recover from, and adapt to, the preceding weeks of training (Fry, Morton & Keast, 1992).

Conclusion

The trainability of the anaerobic energy system has been demonstrated. Lactate tolerance training appears to be an effective mode of training for improving performance in high intensity short-lasting exercise. The duration of training required to induce significant improvements in the anaerobic energy system is not well understood. Presently, the measurement of performance parameters and the quantification of OD achieved during an all-out ergometry test stand as the most valid techniques for assessing the anaerobic energy system.

CHAPTER III

METHODS AND PROCEDURES

Sample

Seven postpubescent male subjects ranging in age from 18 to 23 years were recruited for the present study. All subjects had been involved in board paddling of some description for the past two years and presently participated in the activity at least twice per week. The subjects were selected according to their performance in a preliminary peak oxygen uptake ($\dot{V}O_2$peak) test on a Biokinetic swim bench ergometer. Table 3 displays the physical characteristics of the subjects.

Table 3: Physical characteristics of the subjects.

	Pre-training		Post-training	
	Mean	SE	Mean	SE
Age (yrs)	21	1	21	1
Mass (kg)	72.5	2.0	72.8	2.2
Height (cm)	176.3	1.7	176.1	1.8
$\dot{V}O_2$peak ($l \cdot min^{-1}$)	2.78	0.10	2.94	0.14

Research approval was granted by the University of Ballarat Ethics Committee. All subjects were made aware of the research procedures. Written consent was received from all participants and medical questionnaires were completed (Appendix A).

The study was conducted over a 12 week period consisting of one week pre-testing, eight weeks training, ten days reduced training, and one week post-testing. Throughout the duration of the study the subjects were required to perform a series of laboratory tests including $\dot{V}O_2$peak, efficiency and 60 s all-out tests which were completed on separate days. Laboratory testing occurred at five separate time intervals throughout the duration of the study: Pre - before the commencement of training; Mid1 - during the third week of training; Mid2 - during the sixth week of training; Mid3 - following the eight weeks of training; Post - following the ten days of reduced training. Details of the scheduling of laboratory testing is included in Table 4.

Laboratory Testing Procedures

Laboratory tests were conducted on a Biokinetic swim bench ergometer (Pacer 2A). Setting four was selected on the Biokinetic swim bench ergometer for all tests. A double arm action, in which subjects pulled simultaneously with both arms, was performed. In the days leading up to the commencement of data collection, the selected subjects spent time familiarising themselves with the Biokinetic swim bench. A heart rate monitor (Polar Electro Oy, Model 45920, Finland) was used to measure heart rate during the laboratory tests. Subjects were instructed to eat a consistent diet for 24 hours leading up to all tests and to fast for four hours prior to the test. Care was taken to ensure that repeated tests were conducted the same time of day and week (Hill, Borden, Darnaby, Hendricks & Hill, 1992).

The Biokinetic swim bench ergometer was interfaced to a computer (16 Hz, IBM compatible, micro computer) by the technical staff at the University of Ballarat. An Analog to Digital (A to D) board (CIODAS16) was used to convert the analog output from the Biokinetic swim bench ergometer to digital which was input into the computer. Calibration procedures are given in Appendix B. The computer software recorded total work, peak power, number of strokes, average distance per stroke, time, peak and instantaneous stroke velocity, and instantaneous power throughout the duration of the test. The computer monitor was positioned directly in front of the swim bench, allowing the subject to visually monitor workrate. Workrate could be varied by either altering the stroke rate (strokes·min^{-1}) or work

Table 4: Testing Time Scale.

Week	0	1	2	3	4	5	6	7	8	9	10	11
	Pre			Mid1			Mid2			Mid3		Post
	$\dot{V}O2peak$											$\dot{V}O2peak$
	60 second All-out			60 second All-out			60 second All-out			60 second All-out		60 second All-out
	Efficiency						Efficiency					Efficiency
	Time Trials						Time Trials					Time Trials

per stroke (J). The software had a built in audible metronome and cue indicating when the required level of work had been achieved during a given stroke. A visual metronome cue was also available to the subject.

An open circuit spirometry metabolic system was used for the determination of oxygen uptake ($\dot{V}O_2$) during the peak oxygen uptake ($\dot{V}O_2$peak) and efficiency tests. Calibration occurred immediately prior to the commencement of each testing session with the use of known concentration gas (16.7$\pm$0.1 percent O_2, 4.10$\pm$0.08 percent CO_2) and a fixed volume cylinder pump. The system measured volume of inspired air (P.K. Morgan ventilation monitor, Series 225A, England), fraction of expired oxygen (P.K. Morgan Zirconia Oxygen Analyser, Model 022, England), and fraction of expired carbon-dioxide (P.K. Morgan FM2 Carbon-dioxide Analyser, Model 038, England). Oxygen uptake was determined at 30 s intervals.

Peak Oxygen Uptake Test

Prior to the $\dot{V}O_2$peak test subjects completed a five minute non-exhaustive warm up at 40 watts. Five minutes was allowed after the warm up for individual subject preparation. The intensity of the test commenced at 40 watts and was increased each minute by either increasing the stroke rate or work to be performed each stroke. Table 5 displays the protocol used and the subsequent increments in exercise intensity. Performance in the $\dot{V}O_2$peak test was used to select appropriate subjects. Subjects with a $\dot{V}O_2$peak greater than 2.4 $l \cdot min^{-1}$ were accepted for the study as the $\dot{V}O_2$peak for trained subjects during upper body exercise has been shown to typically range between 2.4 $l \cdot min^{-1}$ (Obert, Falgairette, Bedu & Coudert, 1992) and 3.6 $l \cdot min^{-1}$ (Morton, 1992).

Table 5: Incremental exercise protocol for the assessment of peak oxygen uptake.

Minute	Work per Stroke (J)	Metronome Interval (sec)	Intensity (W)
1	80	2.0	40.0
2	100	2.0	50.0
3	120	2.0	60.0
4	140	2.0	70.0
5	140	1.8	77.8
6	160	1.8	88.9
7	160	1.6	100.0
8	180	1.6	112.5
9	180	1.5	120.0
10	180	1.4	128.6
11	200	1.4	142.9
12	200	1.3	153.9
13	200	1.2	166.7
14	200	1.1	181.8
15	200	1.0	200.0

Efficiency Testing

Efficiency testing was completed pre-, mid- and post-training. On each occasion subjects performed five submaximal tests in which steady state $\dot{V}O_2$ was determined. Intensities ranged between 35 and 75 watts, being the range which steady state values could be obtained, and were selected according to the perceived exertion of the subject during the previous submaximal test. Each submaximal test was conducted over a duration of six minutes, with five to ten minutes of recovery between tests. Heart rate returned to within ten percent of pre-test heart rate during the recovery periods. Attempts were made to control for the effect of increases in body temperature on $\dot{V}O_2$ by allowing adequate recovery time, ensuring the laboratory was adequately ventilated, and fanning the subjects throughout the tests. Mean power for the submaximal test was calculated by dividing the total work by time. Steady state $\dot{V}O_2$, which was usually achieved by the third minute, was determined by averaging the $\dot{V}O_2$ during the last two minutes of the test. The steady state $\dot{V}O_2$ was assumed to represent the oxygen cost of the exercise intensity.

The determinants obtained during the pre-, mid- and post- efficiency testing sessions were pooled for each individual to construct a single regression function depicting the linear relationship between $\dot{V}O_2$ ($l \cdot min^{-1}$) and exercise intensity (watts) for that individual. The developed linear function was used for the estimation of the theoretical oxygen cost of the supramaximal 60 s all-out tests. A further discussion of the rationale behind pooling the data is included in Chapter V. Additional analysis of the 60 s all-out tests using efficiency functions derived separately for the pre-, mid- and post- efficiency testing sessions is presented in Appendix D. Analyses included in Appendix D were based on the use of the pre-efficiency function for Pre and Mid1, mid-efficiency function for Mid2, and post-efficiency function for Mid3 and Post.

60 s All-out test

Subjects performed a 60 s all-out test on five occasions throughout the duration of the training program as illustrated in Table 4 (page 35). In preparation for the test, subjects completed a five minute warm up at 40 watts ($\dot{V}O_2$peak < 2.6 $l \cdot min^{-1}$) or 50 watts ($\dot{V}O_2$peak > 2.6 $l \cdot min^{-1}$). The warm up was interspersed with several hard strokes; two at two minutes, three at three minutes, and four at four minutes. Approximately five minutes of preparation was allowed after the warm up before the commencement of the performance test. Velcro straps were used to hold the subject in position during the test. Heart rate was monitored at five second intervals throughout the 60 s all-out test by a heart rate monitor (Polar Electro Oy, Model 45920, Finland). Expired air was collected using a Hans-Rudolf valve (model 2700) and Douglas bag. The $\dot{V}O_2$ for the test was determined by analysis of the Douglas bag for fraction of expired oxygen and carbon-dioxide, volume expired and gas temperature. The subjects were instructed to perform maximally from the onset of the 60 s all-out test. Two researchers were present during the test and verbal encouragement was allowed.

The number of strokes and average distance per stroke were given by the swim bench software. Data from the 60 s all-out tests, in tenth of a second intervals, were imported into Microsoft EXCEL for Windows (Version 4.0, Microsoft Corporation 1985-1992) for analysis. Performance parameters including mean power, peak power, time to peak power, final power and fatigue index were determined. Peak power was calculated as the second in which the most amount of work was achieved, with time to peak power representing the middle of the second. Final power was defined as the highest one second power output within the last three seconds of the test. Fatigue index was calculated using the equation: Fatigue Index = (Peak Power-Final Power)/Final Power.

The OD of the test was calculated as the difference between the theoretical oxygen cost and the actual $\dot{V}O_2$. The theoretical oxygen cost was estimated by substituting the mean power into the individually developed efficiency functions. Actual $\dot{V}O_2$ was determined through analysis of the respiratory gases collected throughout the 60 s all-out test in a Douglas bag (Appendix C). The Douglas bag was analysed using a temperature probe (Yellow Springs, Series 400) for bag temperature and the P.K. Morgan ventilation monitor for gas volume. A sample calculation of the OD is presented in Appendix C. The OD was assumed to represent energy release through non-aerobic processes, thus the relative contribution of the anaerobic energy system was determined by expressing the OD as a percentage of the theoretical oxygen cost (which represents the total energy expenditure as an oxygen equivalent).

Reliability Testing

Six subjects (age=20±1 years, weight=75.3±3.1 kg, height=178.2±2.4 cm, $\dot{V}O_2$peak=2.59±0.12 $l \cdot min^{-1}$), separate to those involved in the training study, were involved in the reliability testing. Subjects performed a $\dot{V}O_2$peak test, two 60 s all-out tests and two efficiency testing sessions. The 60 s all-out tests, as well as the efficiency testing sessions, were conducted exactly one week apart. Subjects were required to practice the same pre-test procedures as outlined for the subjects involved in the training study and testing occurred under the same conditions. The performance parameters mean power and peak power were shown to be highly reliable with test-retest correlations of 0.98 ($p<0.01$) and 0.96 ($p<0.01$), respectively. A poor relationship was noted between test-retest efficiency data ($r=0.49$, TEM=0.38 l) which amounted to a nine percent mean difference in the theoretical oxygen cost at 200 watts.

In-water Performance

Time trials were conducted pre-, mid- and post-training over distances of 75, 140 and 250 m. The time trials were conducted on a sheltered section of Lake Wendouree (Ballarat, Victoria).

Subjects knelt on the board with both arms entering and leaving the water simultaneously. The subjects were given choice of clothing which was required for all testing sessions. Attempts were made to make the form drag of the board consistent by ensuring that the subjects always used the same board and positioned themselves in the same position for the time trials. Before the commencement of the time trials the subjects performed a 500 m non-exhaustive warm up followed by stretching exercises. The trials were completed from shortest to longest with approximately ten minutes rest separating the three. Subjects were timed individually and were instructed to perform the trial as they would in race conditions. A hand held stopwatch was used to record time. As discussed in Chapter V, a considerable decline in water temperature occurred over the duration of the study (from 18 to 9 °C) which may have impacted upon in-water performance.

Training

Training sessions were scheduled three times each week during the eight week program and twice per week during the ten days of reduced training. A day recovery was allowed between training sessions with the usual training days being Monday, Wednesday and Friday. All training was structured intermittently and commenced with a 500 m warm up followed by stretching. Training involved repeated efforts of 30, 60 and 90 s with a work to rest ratio of 1:2 as it has been demonstrated that the anaerobic lactacid energy system is stressed by this mode of training (Martin & Coe, 1991; Pyne & Telford, 1988; Sharp, 1991). Subjects were instructed to perform a 95 percent or greater effort for every repeat. Distance achieved during the repeat was measured randomly to ensure that the effort requirement was being met. Training volume was increased for the first six weeks of the program after which it was maintained until the taper period. Training volume during the period of reduced training was approximately 40 percent of that performed during weeks seven and eight. Training session details are included in Table 6.

Statistical Analysis

SuperANOVA (Abacus Concepts) statistical software was used to analyse the data. Statistical significance refers to the 0.05 level of significance unless otherwise stated. All data were expressed as mean ± standard error. Repeated measures analysis of variance (ANOVA) was used to assess changes in the 60 s all-out tests in relation to the performance parameters, OD, percent anaerobic contribution and anaerobic work, as well as the time trials. Significance of post-hoc analysis was determined according to the Student-Newmans-Keuls method of analysis. Linear regression was used to construct the efficiency functions depicting the relationship between work intensity and oxygen cost.

Correlation analysis was used to assess the relationship between the performance parameters of the 60 s all-out test, OD related data, and time trials. The correlations between the selected variables were determined using data from: Pre and Post for $\dot{V}O_2$peak correlates; Pre, Mid2 and Post for time trial correlates; all tests for performance and OD related data correlates.

Table 6: Training session details.

Week	Session	Training
1	1	Time trials - 75, 140 and 250 metres
	2	2 * 90 s, 2 * 60 s
	3	2 * 90 s, 2 * 60 s, 1 * 30 s
2	4	2 * 90 s, 2 * 60 s, 2 * 30 s
	5	2 * 90 s, 2 * 60 s, 3 * 30 s
	6	2 * 90 s, 2 * 60 s, 4 * 30 s
3	7	3 * 90 s, 3 * 60 s
	8	3 * 90 s, 3 * 60 s, 1 * 30 s
	9	3 * 90 s, 3 * 60 s, 2 * 30 s
4	10	3 * 90 s, 3 * 60 s, 3 * 30 s
	11	3 * 90 s, 3 * 60 s, 3 * 30 s
	12	3 * 90 s, 3 * 60 s, 4 * 30 s
5	13	Time trials - 75, 140 and 250 metres
	14	4 * 90 s, 4 * 60 s
	15	4 * 90 s, 4 * 60 s, 1 * 30 s
6	16	4 * 90 s, 4 * 60 s, 2 * 30 s
	17	4 * 90 s, 4 * 60 s, 2 * 30 s
	18	4 * 90 s, 4 * 60 s, 3 * 30 s
7	19	4 * 90 s, 4 * 60 s, 4 * 30 s
	20	4 * 90 s, 4 * 60 s, 4 * 30 s
	21	4 * 90 s, 4 * 60 s, 4 * 30 s
8	22	4 * 90 s, 4 * 60 s, 4 * 30 s
	23	4 * 90 s, 4 * 60 s, 4 * 30 s
	24	4 * 90 s, 4 * 60 s, 4 * 30 s
9	25	1 * 90 s, 2 * 60 s, 4 * 30 s
	26	1 * 90 s, 2 * 60 s, 4 * 30 s
10	27	Time trials - 75, 140 and 250 metres

CHAPTER IV

RESULTS

The following chapter reports all findings of the study. Individual data is contained in Appendix D.

Peak Oxygen Uptake

Peak oxygen uptake ($\dot{V}O_2$peak) increased from 2.78±0.10 $l{\cdot}min^{-1}$ to 2.94±0.14 $l{\cdot}min^{-1}$ over the duration of the study. The 5.4 percent improvement in $\dot{V}O_2$peak was almost significanct at the 0.05 level ($p=0.052$). An increase in $\dot{V}O_2$peak was not anticipated as the training was structured to predominantly stress the anaerobic energy system and the subjects selected were aerobically conditioned at the commencement of the study.

60 s All-Out Tests

More significant improvements were observed in the performance parameters of the 60 s all-out tests in comparison to the oxygen deficit related data.

Mean Power, Peak Power and Fatigue Index

Mean power significantly improved by 17.3 percent ($p<0.05$) from Pre to Post. The improvement in mean power reached significance in Mid2 (11 percent, $p<0.05$). No change in mean power was noted for the reduced training period. The progressive improvement in mean power over the five tests can be seen in Table 7 and is expressed as total work in Figure 4. The greatest improvement in mean power occurred between Mid1 and Mid2. Reliability testing found mean power to be highly test-retest correlated ($r=0.98$, $p<0.01$).

Peak power was achieved on average 4.2 s into the test. Improvement in peak power reached significance in Mid1 (20 percent, $p<0.05$). A 59.7 percent ($p<0.01$) improvement from the pre-training state was achieved by Post. The greatest mean peak power was recorded in Mid3. No change in peak power occurred as a result of the period of reduced training. Reliability for peak power was 0.96 ($p<0.01$).

Fatigue index increased by 42.1 percent ($p<0.05$) from Pre to Post as a result of the large increase in peak power and relatively small increase (6.1 percent) in final power. The fatigue index reached a maximum value of 67.7 percent in Mid2 due to the lowest recorded mean final power being recorded in Mid2.

Oxygen deficit related data

The OD reached a maximum in Mid2 as shown in Table 7. Improvement in the OD from Pre to Mid2 amounted to 40.5 percent ($p<0.05$). The large OD achieved in Mid2 appears to be a consequence of a low oxygen uptake. As discussed in Chapter V, failure to see a further increase in the OD may be a result of the anaerobic capacity not being exhausted in Mid3 and Post by the 60 s all-out effort.

Associated with the highest OD being recorded in Mid2, the greatest relative reliance upon the anaerobic energy system (49.3 percent) and magnitude of anaerobic work (6289 J) was observed in Mid2. Both parameters were significantly increased from Pre in Mid2. Improvement in anaerobic work was the only OD related parameter that maintained significance from Pre to Post, amounting to 28.6 percent.

Table 7: Mean data for the 60 second all-out tests.

	Pre	Mid1	Mid2	Mid3	Post
MP (W)	192.3 ± 11.3	197.0 ± 7.6	213.5 ± 2.6 *	220.1 ± 5.8 *	221.2 ± 4.9 *
PP (W)	326.4 ± 29.9	391.4 ± 20.6 *	447.9 ± 22.7 *	503.8 ± 14.4 *	499.6 ± 10.5 *
FP (W)	167.3 ± 14.3	174.5 ± 8.6	142.0 ± 8.5 *	178.9 ± 14.9	174.1 ± 20.2
FI (%)	47.8 ± 3.6	55.2 ± 1.4 *	67.7 ± 2.8 *	64.6 ± 2.5 *	65.4 ± 3.5 *
$\dot{V}O2$ (l)	2.39 ± 0.08	2.24 ± 0.04	2.18 ± 0.09	2.47 ± 0.09	2.46 ± 0.05
OD (l)	1.58 ± 0.12	1.85 ± 0.32	2.22 ± 0.30 *	2.03 ± 0.35	2.08 ± 0.34
% Anaerobic	39.6 ± 2.4	43.5 ± 4.3	49.3 ± 3.3 *	43.7 ± 4.9	44.2 ± 3.9
Anaerobic Work (J)	4541.8 ± 355.0	5161.6 ± 551.4	6288.7 ± 356.8 *	5672.9 ± 603.0 *	5838.2 ± 480.0 *

MP: Mean Power, PP: Peak Power, FP: Final Power, FI: Fatigue Index, OD: Oxygen Deficit,
* denotes significant difference ($p<0.05$) from Pre.

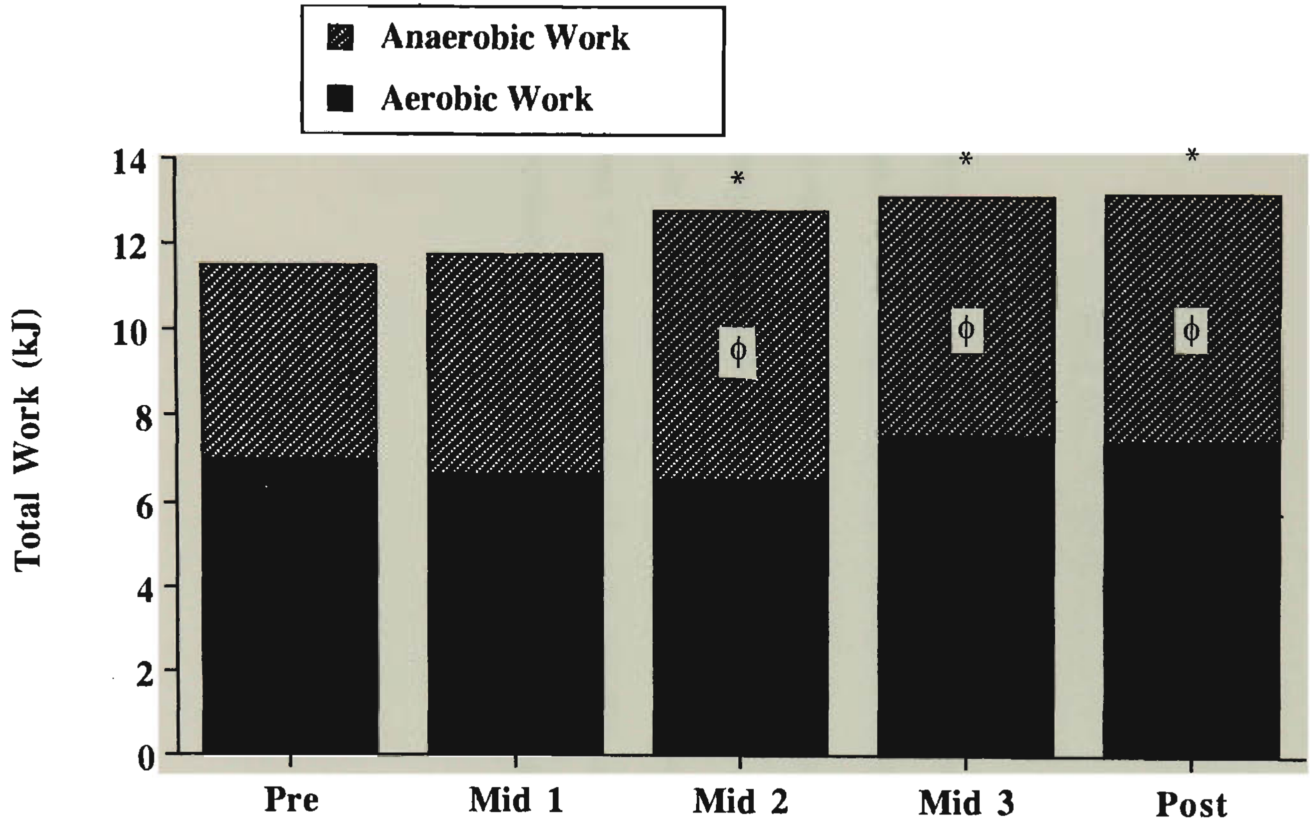

Figure 4: Mean aerobic and anaerobic contribution to exercise during the 60 s all-out tests.

* Total work significantly different ($p<0.05$) from Pre.

ϕ Anaerobic work significantly different ($p<0.05$) from Pre.

Reduced Training

The reduced training period appeared to have no effect, positive or negative, on any of the parameters assessed during the 60 s all-out test. Nonsignificant differences were noted between Mid3 and Post in mean power ($p=0.81$), peak power ($p=0.30$) and fatigue index ($p=0.75$).

In-water Performance

Significant improvements of 10.4, 8.9 and 6.2 percent were recorded from pre- to mid-training for the 75, 140 and 250 m time trials, respectively. An additional improvement from mid- to post-training was only observed in the 75 m time trial which may be associated with a dramatic nine degree Centigrade decrease in water temperature (18 to 9°C) encountered from mid- to post- training. At the conclusion of the period of reduced training, improvements amounted to 11.0, 7.3 and 5.5 percent for the 75, 140 and 250 m time trials, respectively. Figure 5 graphically illustrates the changes in the mean time for pre-, mid- and post- time trials.

Correlations

Table 8 summarises the relationships between selected parameters using the data collected pre-, mid- and post-training (N=21). Significant relationships mostly occurred within the time trials, within the OD related data, and between the time trials and the performance parameters mean power and peak power. A significant relationship was recorded between $\dot{V}O_2$peak and performance in the 250 m time trial (mean duration 145 s). Tables 9 and 10 display the relationship between the improvement of selected performance parameters from pre- to mid-training and pre- to post-training, respectively. More significant

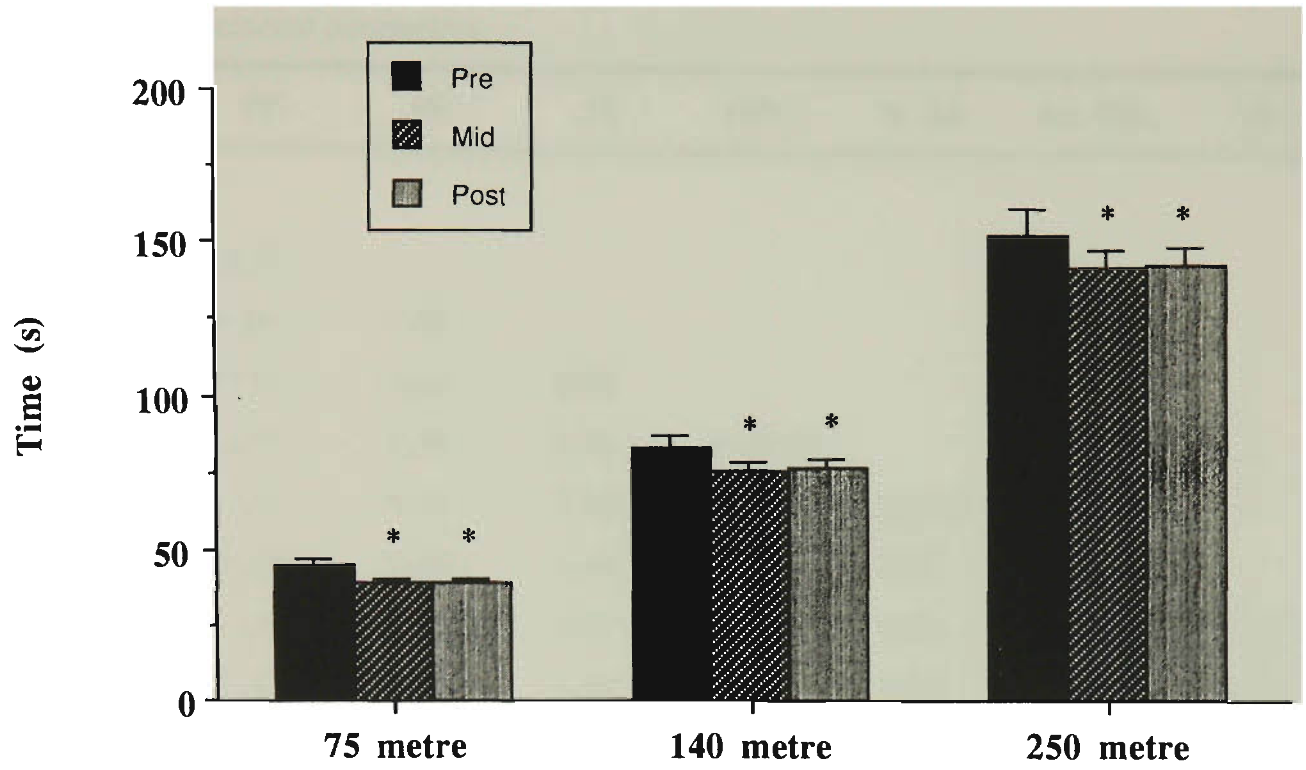

Figure 5: Mean time for pre-, mid- and post-time trials.
* denotes significant difference ($p<0.05$) from Pre.

Table 8: Correlation matrix of selected parameters.

	MP	PP	FP	FI	OD	% An.	An. Wk.	75	140	250
PP	0.82 *									
FP	0.46	0.31								
FI	0.42	0.64	-0.51							
OD	-0.02	0.15	-0.23	0.32						
% An.	-0.08	0.07	-0.34	0.32	0.96 **					
An. Wk.	0.28	0.36	-0.19	0.48	0.91 **	0.93 **				
75	-0.74 *	-0.68 *	-0.32	-0.34	-0.03	0.02	-0.28			
140	-0.79 *	-0.58	-0.28	-0.37	0.06	0.08	-0.25	0.79 *		
250	-0.66	-0.45	-0.40	-0.10	0.18	0.20	-0.08	0.81 *	0.90 **	
$\dot{V}O2$peak	0.50	0.44	0.52	0.01	-0.29	-0.34	-0.07	-0.48	-0.66	-0.75 *

MP: Mean Power, PP: Peak power, FP: Final power, FI: Fatigue index, OD: Oxygen deficit, % An.: % anaerobic contribution to exercise, An. Wk.: Anaerobic work, 75: 75 metre time trial, 140: 140 metre time trial, 250: 250 metre time trial, $\dot{V}O2$peak: Peak oxygen uptake, * $p<0.05$, ** $p<0.01$

Table 9: Correlation matrix of improvement in selected parameters from pre- to mid-training.

	MP	PP	FP	FI	75	140	250	Efficiency	OD	% An
PP	0.89 **									
FP	0.44	0.69 *								
FI	0.64	0.36	-0.35							
75	0.35	0.48	0.73 *	-0.32						
140	0.58	0.25	0.21	0.36	0.40					
250	0.43	0.58	0.81 *	-0.32	0.97 **	0.36				
Efficiency	0.06	-0.16	-0.68 *	0.64	-0.19	0.14	-0.28			
OD	0.93 **	0.74 *	0.12	0.80 *	0.08	0.48	0.17	0.29		
% An	0.60	0.37	-0.29	0.73 *	-0.19	0.24	-0.09	0.50	0.85 **	
An. Wk.	0.89 **	0.69 *	0.04	0.80 *	0.05	0.44	0.14	0.35	0.99 **	0.90 **

MP: Mean Power, PP: Peak power, FP: Final power, FI: Fatigue index, 75: 75 metre time trial, 140: 140 metre time trial
250: 250 metre time trial, Efficiency: Efficiency at 200 watts, OD: Oxygen deficit,
% An: % anaerobic contribution to exercise, An. Wk.: Anaerobic work, * $p<0.05$, ** $p<0.01$

Table 10: Correlation matrix of improvement in selected parameters from pre- to post-training.

	MP	PP	FP	FI	75	140	250	$\dot{V}O2peak$	Efficiency	OD	% An
PP	0.90 **										
FP	0.25	0.28									
FI	0.62	0.65	-0.50								
75	0.27	0.38	-0.08	0.19							
140	0.65	0.78 *	0.01	0.59	0.53						
250	0.48	0.50	0.13	0.16	0.95 **	0.60					
$\dot{V}O2peak$	-0.32	-0.34	0.14	-0.58	0.08	0.06	0.04				
Efficiency	0.25	0.17	0.06	0.28	-0.07	0.25	0.12	-0.49			
OD	0.96 **	0.83 *	0.06	0.71 *	0.14	0.64	0.31	-0.27	0.19		
% An	-0.13	0.09	0.58	-0.23	-0.55	-0.06	-0.49	-0.06	0.13	-0.18	
An. Wk.	0.95 **	0.79 *	0.10	0.65	0.09	0.60	0.28	-0.23	0.22	0.99 **	-0.17

MP: Mean Power, PP: Peak power, FP: Final power, FI: Fatigue index, 75: 75 metre time trial, 140: 140 metre time trial
250: 250 metre time trial, $\dot{V}O2peak$: Peak oxygen uptake, Efficiency: Efficiency at 200 watts, OD: Oxygen deficit,
% An: % anaerobic contribution to exercise, An. Wk.: Anaerobic work, * $p<0.05$, ** $p<0.01$

relationships between improvements in the selected parameters were recorded from pre- to mid-training than from pre- to post-training. A highly significant relationship existed ($p<0.01$) between mid- and post-training improvements in mean and peak power ($r=0.89$ and $r=0.90$, respectively) as well as between the 75 and 250 m time trials ($r=0.97$ and $r=0.95$, respectively). Improvements in mean power and OD were highly correlated from pre- to mid-training ($r=0.93$, $p<0.01$) and pre- to post-training ($r=0.96$, $p<0.01$) despite the magnitude of the OD and mean power being poorly correlated ($r=-0.02$). As shown in Tables 9 and 10, no other relationships between improvements from pre- to mid-training and pre- to post-training were consistently significant.

CHAPTER V

DISCUSSION

Contained within this chapter is a discussion of the results obtained from the present study. The findings are discussed according to the Statement of the Problem and questions addressed in Chapter I.

Peak Oxygen Uptake

The mean peak oxygen uptake ($\dot{V}O_2$peak) values of 2.78±0.10 $l \cdot min^{-1}$ (pre) and 2.94± 0.14 $l \cdot min^{-1}$ (post) are comparable with the findings of research involving the assessment of upper body aerobic power. Lowdon, Bedi and Horvath (1989) reported a mean $\dot{V}O_2$peak of 2.8±0.04 $l \cdot min^{-1}$ for 12 surfboard paddlers during tethered board paddling and 2.95±0.38 $l \cdot min^{-1}$ during arm cranking exercise. Several other researchers have reported upper body $\dot{V}O_2$peak values ranging from 2.4 to 3.5 $l \cdot min^{-1}$ (Bonen, Wilson, Yarkony & Belcastro, 1980; Morton, 1992; Obert et al., 1992). More specifically, Morton (1992) found a mean $\dot{V}O_2$peak of 3.2±0.2 $l \cdot min^{-1}$ on a Biokinetic swim bench ergometer for eight well conditioned male swimmers.

The near significant 5.4 percent increase in $\dot{V}O_2$peak was not anticipated. As discussed previously, the mode of training was selected specifically to stress the anaerobic energy system. The increase in training volume as a result of the requirements of the study may have induced slight improvements in $\dot{V}O_2$peak, however, the structure of the sessions were low in volume in comparison to that which the subjects were accustomed. The increase in $\dot{V}O_2$peak is most likely attributable to the longer duration repeats (60 and 90 s) that were incorporated into the training sessions as the aerobic system contributes significantly to the total energy release over these durations (Gastin, 1992; Withers et al., 1991). Serresse et al. (1988) found that $\dot{V}O_2$peak can be achieved after 60 s of all-out exercise. Small nonsignificant improvements in $\dot{V}O_2$peak have been reported in response to high intensity training programs similar in nature to the present study (Houston & Thomson, 1977; Nevill et al., 1989). Programs involving shorter repeats would stress the aerobic system to a lesser degree. Fox, Bartels, Klinzing and Ragg (1977) reported greater improvements in $\dot{V}O_2$peak in response to a low power interval training program involving 120 s repeats in comparison to an alternative high power training program of similar volume involving 30 s efforts. However, improvements in $\dot{V}O_2$peak have been reported in response to programs involving shorter repeats of 30 s (Sharp et al., 1986) and 40 s (Weltman, Moffatt & Stamford, 1978). No research has indicated that short term lactate tolerance training has an adverse effect on aerobic power. The fact that decreases in $\dot{V}O_2$peak have not been associated with lactate tolerance training suggests that maintenance of aerobic power may not be a concern while lactate tolerance training is being performed (Troup et al., 1991). Thus, it would appear that lactate tolerance training can be endorsed for a period of up to ten weeks without resulting in decrements in the aerobic system. The response of the aerobic system to excessively prolonged periods of lactate tolerance training warrants further investigation.

Efficiency

The efficiency function derived from the pooled data of all efficiency testing sessions and all subjects was: Oxygen Cost (l) = 0.019463 * Mean Power (W) + 0.32497 (SEE=0.0608). Assuming one litre of oxygen releases 21 kJ of energy (Jenkins & Quigley, 1993), the function indicates that the mechanical efficiency of swim bench ergometry is approximately 15 percent. The efficiency value is less than the 22 percent used by Lawson and Golding (1981) for bicycle ergometry. The lower efficiency may in part be due to a greater amount of work performed during swim bench ergometry that is not externally recorded, such as the external work required during the recovery phase of the stroke.

60 s All-out Tests

Improvements in the performance parameters of the 60 s all-out test are consistent with the findings of previous research (Houston & Thomson, 1977; Medbø & Burgers, 1990; Stathis et al., 1994; Weltman et al., 1978), indicating that the upper and lower body are similarly trainable.

Mean Power

Mean power has been used as an expression of anaerobic capacity as it provides an indication of the ability of an athlete to maintain supramaximal intensities and thus sustain anaerobic energy release. The mean improvement of 17.3 percent was similar in magnitude to that reported by previous researchers (Stathis et al., 1994; Weltman et al., 1978). Houston and Thomson (1977) recorded a 16.7 percent ($p<0.05$) improvement in response to a similarly structured training study. Most significantly, an improvement of 11 percent in mean power was recorded in Mid2. From a coaching perspective, it would appear that minor peaking for sprint events could be adequately achieved by a four to five week mesocycle with an emphasis on lactate tolerance training. Thus, athletes could plan a mid-season peak without disturbing to a large extent their preparation for the climax of the season.

Peak Power

Peak power experienced a far larger improvement than any other performance parameter examined (59.7 percent, $p<0.01$). The substantial improvement may be due to the all-out structure of the training sessions as the subjects were encouraged to not pace the in-water repeats during the training sessions. Thus, the phosphate energy system would have been stressed during every repeat. Furthermore, increases in muscular strength have been reported in aerobically conditioned subjects following intensified training (Houston & Thomson, 1978). A significant improvement in peak power was recorded in Mid1 which corresponded to just three weeks of training. Thus, the phosphate system appears to be highly trainable in aerobically conditioned subjects.

Peak power and mean power were significantly correlated ($r=0.82$, $p<0.05$) which was expected as both are used as expressions of anaerobic status. A similarly high correlation ($r=0.72$, $p<0.01$) between peak power and mean power was observed by Scott et al. (1991). Improvements in peak and mean power were also highly correlated ($r=0.90$, $p<0.01$).

Fatigue Index

Fatigue indices of approximately 60 percent have been reported during 30 s of all-out exercise on a bicycle ergometer (McCartney, Heigenhauser & Jones, 1983; Sharp et al., 1986). Cheetham et al. (1986) documented fatigue indices of up to 70 percent during 30 s of treadmill sprinting. The highest recorded mean fatigue index of 68 percent, recorded in Mid2, compares with that reported during only 30 s of all-out exercise on the bicycle ergometer and treadmill. In comparison, the mean fatigue index over the first 30 s of Mid2 was approximately 33 percent. The less substantial fatigue indices found with swim bench ergometry may in part be due to the recovery phase of the stroke. As the subjects in the present study performed a paired arm action, there was a refractory period during the recovery of each stroke in which no external work was recorded. Thus, the refractory period may have allowed time for the working muscles to recover slightly. Conversely, bicycle ergometry and treadmill running require constant force application. A second factor that may have influenced the magnitude of the fatigue index is muscle mass involved in exercise. A large muscle mass working maximally would stress the central aspect of fitness, such as the oxygen delivery power of the cardio-vascular system, moreso than a smaller muscle mass (Åstrand & Rodahl, 1986).

An increase in the fatigue index of 42 percent ($p<0.05$) was noted from Pre to Post. Similarly, Nevill et al. (1989) reported a 22 percent increase in the fatigue index in response to eight weeks of sprint training. The large increase recorded in the present study was a result of the highly significant increase in peak power in conjunction with a nonsignificant change in final power. Nonsignificant improvements in the final power of a 30 s all-out bicycle ergometer test were also noted by Stathis et al. (1994) following seven weeks of lactate tolerance training.

Oxygen Deficit Related Data

Morton (1992) recorded the mean OD of eight highly trained swimmers during a 45 s all-out test on the Biokinetic swim bench ergometer to be 1.96 ± 0.15 l (25.1 ± 1.9 $ml \cdot kg^{-1}$). The highest mean OD of 2.22 ± 0.30 l (30.4 ± 4.1 $ml \cdot kg^{-1}$) achieved in the present study is comparable to the findings of Morton (1992) given that the test was an additional 15 s in duration. Additionally, Morton (1992) found the maximal OD of the swimmers, determined during a 110 percent $\dot{V}O_2$peak constant intensity test, to be 2.5 ± 0.2 l (32.1 ± 2.6 $ml \cdot kg^{-1}$).

The magnitude of the OD was not observed to increase incrementally as did mean power. The OD increased by 41 percent ($P<0.05$) from Pre (1.58 ± 0.12 l) to Mid2 (2.22 ± 0.30 l) and then decreased from Mid2 to Post (2.08 ± 0.34 l), resulting in a net increase from Pre to Post of 32 percent. The improvement is comparable to the findings of Troup et al. (1991) who reported a 30 percent increase in the maximal accumulated OD in response to six weeks of sprint training. A possible explanation for the decrease in the OD from Mid2 to Post may be that the anaerobic capacity was not exhausted by the 60 s all-out tests. It has been documented that after the exhaustion of the anaerobic capacity during all-out exercise, power output falls to a level corresponding to $\dot{V}O_2$peak (Gastin, 1992). In the present study the final power during the 60 s all-out tests ranged between 103 percent (Mid2) and 127 percent (Post) of post-training $\dot{V}O_2$peak. Accordingly, the OD achieved during the 60 s all-out tests, particularly those that displayed a final power well in excess of that equivalent to $\dot{V}O_2$peak, may not have been a valid representation of the anaerobic capacity. The highest OD, percent reliance upon the anaerobic energy system and anaerobic work were recorded in Mid2 in which the final power was only marginally greater than $\dot{V}O_2$peak (103 percent). Thus, it would appear that the anaerobic capacity was exhausted to a greater degree in Mid2 as a result of a greater reliance upon the anaerobic energy system. The suggested hypothesis may account for the OD not being observed to improve incrementally from Pre to Post as did mean power. The anaerobic capacity and associated maximal OD may have continued to increase throughout Mid3 and Post but not be recorded as the 60 s all-out tests did not elicit maximal OD values.

The finding that the anaerobic capacity was not exhausted by 60 s of all-out exercise is contrary to the findings of Gastin and Lawson (1994b) and Withers et al. (1991) on a bicycle ergometer. Recent research by Withers and associates found no difference between the OD during 60 s (3.75 l), 75 s (3.80 l) and 90 s (3.75 l) of all-out exercise on a bicycle ergometer (Withers et al., 1993). The 60, 75 and 90 s OD values were significantly greater ($p<0.01$) than the OD achieved in 45 s of similar exercise.

The relative contribution of the anaerobic energy system during the 60 s all-out tests ranged from 40 to 49 percent. The results are comparable to the findings of Gastin (1992) and Withers et al. (1991) who reported a 50 percent contribution of the anaerobic energy system during 60 s of all-out bicycle ergometry. The greatest relative reliance upon the anaerobic energy system was recorded in Mid2 (49 percent) which was significantly different from Pre (40 percent). The increase in the relative contribution of the anaerobic energy system amounted to 13 percent from Pre to Post. Similarly, Troup et al. (1991) reported an 11 percent increase in the relative reliance upon the anaerobic energy system, during a maximal swim test, in response to six weeks of sprint training. Increases in the relative reliance upon anaerobic energy release do not necessarily imply that the aerobic system is less active. In the present study it was the disproportionate increase in the quantity of anaerobic work (35 percent) to aerobic work (six percent) from Pre to Post that resulted in an overall increase in the relative reliance upon the anaerobic energy system. In accordance with the observed increase in the relative reliance upon anaerobic energy release, as a result of the development of the anaerobic energy system, it would be anticipated that sprint trained athletes would demonstrate a greater reliance upon anaerobic energy release over a given period of time in comparison to endurance trained subjects. Gastin and Lawson (1994a) found that during 90 s of all-out bicycle ergometry, sprint and endurance trained subjects completed similar levels of total work. Interestingly, the sprint trained subjects appeared to rely more on anaerobic metabolism in comparison to the endurance trained (47 vs 42 percent). Thus, both training and cross-sectional studies indicate that a larger anaerobic capacity may result in a greater reliance upon anaerobic energy release during all-out exercise.

The greatest reliance upon the anaerobic energy system during Mid2 appears to be related to a low mean oxygen uptake (2.18 l). It is difficult to comment on the mechanism responsible for the low oxygen uptake observed in Mid2 as consistent warm up procedures were performed for all five 60 s all-out tests, time of day and week were similar, and ambient conditions experienced no significant changes. Due to the improvements recorded in the performance parameters of Mid2, oxygen kinetics would be expected to increase (Cerretelli et al., 1979; Hagberg et al., 1978; Yoshida et al., 1991), although this does not appear to be the case.

A strong relationship was noted between improvements in mean power and OD from Pre to Mid2 ($r=0.93$, $p<0.01$) and Pre to Post ($r=0.96$, $p<0.01$). Improvements in anaerobic work were also significantly ($p<0.01$) related to improvements in mean power from Pre to Mid2 ($r=0.89$) and Pre to Post ($r=0.95$). Despite the highly significant relationship between the improvement in mean power and OD, no relationship existed between mean power and OD as a raw measure. The correlation between the mean power and OD achieved in the five 60 s all-out tests was $r=-0.02$. This non-relationship is contrary to the findings of Morton

(1992) who reported a significant correlation ($r=0.78$, $p<0.05$) between the OD and total work achieved during a 45 s all-out test on a Biokinetic swim bench ergometer.

Reduced Training

The ten days of reduced training, often referred to as a taper, resulted in no difference in any of the parameters assessed during the 60 s all-out tests. Whilst the period of reduced training did not produce any improvement, the procedure was not detrimental to performance in any way. Comparison with the literature is difficult, as most research investigating the effect of reduced training involves endurance training. The most significant conclusion that can be drawn from the present study is that there appears to be no danger in allowing sprint trained athletes to reduce the volume of training in preparation for sprint events, allowing for optimum individual psychological preparation (Wittig et al., 1989).

In-water Performance

Analysis of the relationship between in-water performance and ergometric assessment parameters reveals an interesting trend (Table 8). A change in the contribution made by the energy systems was seen over the three distances. Peak power was only significantly correlated with the shortest time trial which would be expected as explosive power is required moreso over short durations (Boulay et al., 1985; Serresse et al., 1988; Tharp et al., 1984). Mean power, used as an expression of the anaerobic capacity, correlated significantly ($p<0.05$) with both the 75 ($r=0.74$, mean post-training time=39 s) and 140 ($r=0.79$, mean post-training time=77 s) m time trials. The slightly higher correlation with the 140 m time trial may be a result of the duration of the 140 m time trial being closer to that of the 60 s test in which mean power was derived. Mean power did not correlate significantly with the 250 m time trial (mean post-training time=142 s). The 250 m time trial was the only trial that possessed a significant relationship with $\dot{V}O_2$peak, testifying to the importance of the aerobic energy system over such a duration. Thus, the correlations illustrate the progressive importance of anaerobic power during explosive efforts, anaerobic capacity for 60 to 90 s efforts, and aerobic power for the longer duration efforts.

The mean time for all three time trials was improved from pre- to mid-training. A further improvement from mid- to post-training was only recorded in the 75 m trial. It is likely that the dramatic nine degree Centigrade decline in water temperature experienced from mid- to post-testing was responsible for the lack of improvement in the 140 and 250 m distances. Subjects complained of an inability to 'grip' the water (related to the 'feel' for the water developed by swimmers) due to excessively cold hands and forearms. Furthermore, blood flow through the working muscles of the arm and shoulder girdle may have been compromised in the cold as circulation may have been diverted away from the extremities (Åstrand & Rodahl, 1986). It was noted that complaints of not being able to 'grip' the water were more prevalent following the longer distances, most likely due to the fact that the arms spent more time in the water. Furthermore, the trials were completed in order from shortest to longest. As biomechanical factors are highly significant in determining swim success (Costill, King, Holdren & Hargreaves, 1983), it is likely that the possible loss in effective hydrodynamics would detrimentally affect in-water performance.

Relationships between improvements in ergometric assessment and in-water performance would be affected if the cold exposure significantly impacted upon in-water performance post-training. Relationships between improvements from pre- to mid-training gained significance as opposed to those from pre- to mid-training, suggesting that the cold environment did effect post in-water performance. The only significant relationship observed between improvements in the time trials from pre-to post- training occurred between peak power and the 140 m time trial. As peak power is a measure of short term explosiveness it would be anticipated that improvements in peak power would be more highly correlated with the 75 m time trial.

Methodological Concerns

The validity of the OD as a measure of anaerobic energy release rests upon the assumption that a linear relationship exists between exercise intensity and oxygen cost of exercise from submaximal to supramaximal intensities. While Medbø (1992) maintained that the assumption is justified on the bicycle ergometer and during treadmill running, swim bench ergometry may not behave in a similar way for at least two reasons. Firstly, when compared to well rehearsed activities such as running and cycling, swim bench ergometry is not a well established motor pattern, thus rendering itself more vulnerable to change under the stressful conditions of exhaustive exercise. Secondly, swim bench ergometry allows for greater diversity in technique as the action of the hands is not fixed in the same way as the feet are during bicycle exercise.

Further analysis of the efficiency data suggests that at the submaximal level, improvements in efficiency occurred throughout the duration of the study. A significant difference was recorded between the efficiency functions constructed for the pre-, mid- and post-efficiency testing sessions (Appendix D). When a standard mean power of 200 Watts was substituted into the efficiency functions developed from the three testing sessions, the mean decrease in the theoretical oxygen cost was 14 percent from pre- to mid-testing and 24 percent from pre- to post-testing.

Whilst it could be argued that the observed improvement in submaximal efficiency was a result of a lack of familiarisation, several of the subjects had been involved in previous research on the swim bench ergometer (Morton, 1992). The trend towards improvement in submaximal efficiency would suggest, however, that a learning effect may have occurred. Accordingly, the importance of only using highly skilled subjects for research involving skill based ergometers is evident.

As swim bench ergometry is a skilled action, scope for improvement in efficiency is present, however, it may be that improvements in efficiency would occur to a greater extent at the submaximal level in comparison to the supramaximal level due to the skill being practiced more at the lower intensities during the efficiency testing sessions. Thus, while efficiency at the submaximal level appeared to improve, it is difficult to determine the extent to which improvements, if any, occurred at the supramaximal level. Unrealistic values are obtained for the OD and percent anaerobic contribution to exercise when calculated using efficiency functions derived separately from the pre-, mid- and post-efficiency testing sessions (Appendix D), suggesting that changes in supramaximal efficiency may not have been of the same order as that experienced in submaximal efficiency. For example, the use of the post-efficiency function indicates that during Mid3 and Post, some subjects acquired ODs as low as 0.82 *l* and relied on the aerobic energy system as much as 76 percent. These results are inconsistent with the literature (Gastin, 1994; Withers et al., 1991). Thus, it would appear that at this time submaximal efficiency did not correspond well with supramaximal efficiency. Additionally, when the OD is calculated for Pre, Mid2 and Post using the separate efficiency functions developed from the pre-, mid- and post-efficiency testing sessions, respectively, unexpected results are obtained. For example, determination of the OD using the separate efficiency functions indicates a 27 percent decrease in the OD from pre- to post-training. Given that a relatively large increase occurred in mean power (17.3 percent) from pre- to post- training, in conjunction with a nonsignificant change in the oxygen uptake during the 60 s all-out tests, it would follow that the additional energy release was anaerobic in nature and thus the OD would be expected to increase. These results further support the concept that supramaximal efficiency may deviate from submaximal efficiency for swim bench ergometry. It was in response to the discussed concerns that the data from the pre-, mid- and post-efficiency testing sessions were pooled for each subject to establish an individual efficiency function which was then used for all the 60 s all-out tests.

The other issue of concern involving the calculation of OD is the reliability of efficiency, which may account partly for the significant change in efficiency observed from pre-to post-training. Green and Dawson (1993) found poor reliability for efficiency (r=0.20) which resulted in a ten percent difference in the calculation of OD for a standard test. In the reliability testing of the present study, a similarly poor relationship (r=0.49) was noted between test-retest efficiency data which amounted to a nine percent mean difference in the theoretical oxygen cost at 200 Watts. Additionally, the poor test-retest reliability does not appear to be related to lack of familiarisation as only three of the six subjects involved in the reliability testing were more efficient in the second trial.

In light of the poor reliability reported for efficiency, the issue of performing efficiency testing (for the construction of the efficiency function used for the estimation of the theoretical oxygen cost of exercise) and a performance test (in which the OD is calculated) during separate testing sessions can be raised. In an attempt to combine efficiency and performance testing, the modified procedure suggested by Medbø et al. (1988), involving a line being drawn between one or two efficiency data points and a known Y intercept, could be used. Medbø et al. (1988) acknowledged, however, that deriving the efficiency function on such few data points renders the procedure vulnerable to errors.

Green and Dawson (1993) partly attributed variation in efficiency to a small range of intensities used for the construction of the efficiency function. Similar difficulties were confronted in the present study as the range of intensities over which steady state determinants can be achieved during swim bench ergometry is small in comparison to that available on other ergometers, due to the relatively small muscle mass involved in exercise. Furthermore, as the extrapolation procedure amplifies small variations in submaximal efficiency, small variations at the submaximal level can result in large differences in the theoretical oxygen cost of supramaximal exercise and consequent calculation of the OD.

The OD will be underestimated if efficiency decreases from submaximal to supramaximal intensities, however, the use of a single efficiency function for the determination of the OD during all five 60 s all-out tests maintained consistency throughout the present study. Thus, while the OD data may be consistently underestimated, the results provide an indication of improvement trends assuming that supramaximal efficiency does not change. Collection of the efficiency data on several occasions throughout the study, as practiced in the present study and by Medbø et al. (1988), may be useful for reducing apparent day to day variability. The problems proposed by genuine changes in efficiency, however, are acknowledged in collecting on-going efficiency data.

In conclusion, the validity of the OD as a measure of anaerobic energy release during upper body exercise is yet to be established. Whilst the errors associated with estimating the theoretical cost of exercise by extrapolating from submaximal data are unknown, the use of individual efficiency functions is more personal in comparison to assuming a constant mechanical efficiency. Thus, for isolating anaerobic energy release, calculation of the OD with the use of the extrapolation technique appears to be the most useful. While the OD technique used correctly may potentially be the most valid approach presently available for quantifying the anaerobic energy system, it is unlikely that the procedure will ever be employable by coaches. Findings in regards to the relative importance of the energy systems during maximal exercise of varying durations will be of interest to coaches, however, the use of the OD technique (as it stands) is not appropriate as a coaching tool due to the time required. Effort should therefore be concentrated into using the technique for assessing energetic capacities and energy release as opposed to simplifying the procedure to make it more easily administrable. For this reason, research involving OD analysis may more appropriately be conducted on low skill based ergometers as it appears that the OD determined on the swim bench ergometer may be open to greater variability than that experienced on the treadmill or bicycle ergometer.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present study demonstrated the trainability of performance in short-lasting exercise of high intensity as suggested by previous research. The magnitude of improvements in the anaerobic status of the upper body are consistent with the reported response of the lower extremities. The assessment of performance parameters measured during all-out swim bench ergometry may be the most useful technique for assessing the anaerobic energy system as the errors associated with the calculation of oxygen deficit during swim bench ergometry are unknown. Ergometric assessment on the Biokinetic swim bench ergometer relates well to in-water performance. Improvements were recorded in the oxygen deficit (OD) related data, however, results were not entirely as expected which may be explained by several factors including; the anaerobic capacity not being exhausted by the 60 s all-out effort, and variability in oxygen kinetics and efficiency.

In response to the questions identified in Chapter I, the following conclusions can be drawn from the present study:

1). *Is lactate tolerance training an effective mode of training for improving the anaerobic capacity and associated performance in exercise of high intensity and short duration?* Lactate tolerance training appers to be an effective mode of training for improving the anaerobic capacity and associated performance in exercise of high intensity and short duration. Improvements in mean power (17.3 percent, $p<0.05$) and peak power (59.7 percent, $p<0.01$) were observed in response to the lactate tolerance training. The OD achieved in Mid2 was significantly greater than in Pre (40.5 percent, $p<0.05$) but then decreased resulting in a nonsignificant difference from Pre to Post. It was suggested that the anaerobic capacity was not exhausted by the 60 s all-out tests resulting in non-maximal ODs being recorded, resulting in a nonsignificant improvement between Pre and Post. In-water performance was improved by the lactate tolerance training over the 75 (11.0 percent, $p<0.05$), 140 (7.3 percent, $p<0.05$) and 250 m (5.5 percent, $p<0.05$) time trials.

2). *What duration of lactate tolerance training is required to elicit improvements in the anaerobic energy system and associated performance during exercise of high intensity and short duration?* Five weeks of lactate tolerance training appears to be an adequate duration for eliciting a significant improvement in the anaerobic energy system and associated performance during exercise of high intensity and short duration. Improvements in mean power (13.2 percent, $p<0.05$) and the 75 m (10.4 percent, $p<0.05$), 140 m (8.9 percent, $p<0.05$) and 250 m (6.2 percent, $p<0.05$) time trials were observed after five weeks of the lactate tolerance training. Explosiveness, as measured by peak power, experienced significant improvements (20 percent, $p<0.05$) after three weeks of training.

3). *How well do ergometric assessment procedures and in-water performance relate?* Peak power correlated significantly ($r=-0.68$, $p<0.05$) with the 75 m time trial (mean post-training time=39 s). Significant relationships ($p<0.05$) were recorded between mean power and performance in both the 75 m ($r=-0.74$) and 140 m ($r=-0.79$, mean post-training time=77 s) time trials. The 250 m time trial (mean post-training time=143 s) only correlated significantly with $\dot{V}O_2$peak. Evident is the transition in the relative importance of the energy systems from anaerobic power to anaerobic capacity to aerobic power as the duration of the event increases. Thus, ergometric assessment procedures and in-water performance relate well.

4). *Do improvements in ergometric assessment parameters and in-water performance correlate highly?* No significant relationships were observed between improvements in ergometric assessment parameters and in-water performance from pre- to mid-training, and the only significant relationship from pre- to post-training occurred between peak power and the 140 m time trial. Thus, improvement correlations were poor.

5). *Do improvements in the anaerobic energy system result in a greater relative reliance upon anaerobic metabolism during a 60 s all-out test?* The relative reliance upon anaerobic energy release during the five 60 s all-out tests ranged between 40 and 49 percent. The greatest relative reliance upon the anaerobic energy system occurred in Mid2 which was significantly higher than Pre. Whilst the anaerobic contribution to exercise was approximately four percent higher in Post compared with Pre, no definitive conclusions can be drawn from the data. Anaerobic work was improved by 35 percent ($p<0.05$) from Pre to Post.

6). *Does lactate tolerance training affect aerobic power?* It appears that aerobic power can be improved by lactate tolerance training. Aerobic power increased from 2.78 ± 0.10 to 2.94 ± 0.14 $l \cdot min^{-1}$ from pre- to post-training which amounted to 5.4 percent ($p=0.052$). Most importantly, the results of the present study do not suggest that lactate tolerance training has a detrimental effect on aerobic power.

7). *Does a ten day period of reduced training impact upon performance during exercise of high intensity and short duration?* No change in any of the parameters assessed during the 60 s all-out tests were observed between Mid3 and Post. Thus, a ten day period of reduced training appears to have no effect on performance during a 60 s all-out effort.

Recommendations for Future Research

The trainability of the anaerobic energy system is an area open to further research. A similar training study with more regular assessment of the anaerobic energy system, such as once per week, would provide valuable results in determining the exact duration of training required to elicit a significant response. The effect of sustained lactate tolerance training, focusing on the aerobic energy system, would also be worthwhile. Due to the difficulties associated with estimating the theoretical oxygen cost of supramaximal exercise on the Biokinetic swim bench ergometer, further research is required in the area of efficiency. It is advisable that further research is conducted on a more low skill based, fixed pattern ergometer such as the bicycle or arm crank ergometer. The validity of quantifying OD rests upon the assumption that the theoretical oxygen cost of supramaximal exercise can be determined by extrapolating from submaximal efficiency determinants. As conflicting opinions on the validity of the procedure exist, further research is required to address the issue.

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APPENDIX A

- Consent Form
- Subject Instructions
- Medical Questionnaire

BALLARAT UNIVERSITY COLLEGE

CONSENT FORM

For the Investigator -

I, Darren Morton have fully explained the aims, risks and procedures of the project to the person consenting named herein.

Signed: .... Date: ....

For the Person Consenting -

I, ... voluntarily consent to take part in the project entitled: "Effect of lactate tolerance board training on upper body anaerobic performance", being conducted by Darren Morton (B.ED). The aims of the project, procedures (attachment one) and any risks to me have been explained to my full satisfaction by Darren Morton. I understand that I am free to withdraw from this project at any time. I understand that I will be withdrawn from the test if my health is seen to be at risk.

Signed: (Subject) .... Date: ....

For the Witness -

I, ... of .... as an independent witness, confirm that the aims and procedures of the project and any risks to the person consenting have been adequately explained to that person whose signature I witness. In my opinion the person is acting rationally and voluntarily.

Signed: (Witness) .... Date: ....

ATTACHMENT ONE

Aims -

The aim of this study is to examine the effect of lactate tolerance training on the anaerobic systems and associated performance in short-lasting exercise.

Procedures -

Subjects will be required to meet for training three times per week. Additionally, three different laboratory tests will be performed on a Biokinetic swim bench ergometer a total of ten times. The three tests are outlined below:-

1. Peak Oxygen Uptake Test.

Each subject will first complete a peak oxygen uptake test on the Biokinetic swim bench. Subjects will begin stroking at an easy pace which will be made more difficult each minute. During the test, subjects will be required to wear a mouthpiece through which expired air will be directed into the Morgan Metabolic System for analysis. The mouthpiece is accompanied by a nose-peg so that all air is expired into the mouthpiece. The intensity will progressively be increased until the subject can no longer continue. The test lasts approximately 10 to 15 minutes.

2. Efficiency Test.

Subjects will be required to perform five separate tests in a single session. Each test will be six minutes in duration. The first test will be at an easy intensity, with the following tests being performed at progressively higher intensities. All tests will be submaximal, and separated by a 10 minute rest period. As with the peak oxygen uptake test, a mouthpiece and nose-peg will be used.

3. 60 Second All-Out Test.

After a warm up consisting of easy stroking and short sprints, the subjects will be required to perform an all out effort for 60 seconds. During this time, a mouthpiece will be fitted with the expired air being collected in a Douglas bag for later analysis. The subject will be encouraged to go as hard as possible for the duration of the test.

Pre-test Procedures -

Subjects will be required to adhere to several pre-testing procedures. Firstly, strenuous exercise should be refrained from in the 24 hour period leading up to a laboratory test. Secondly, subjects must eat a consistent diet during the 24 hour pre-testing period, fasting for four hours immediately prior to the test.

Risks to the Subjects -

1. Possible exhaustion and/or delayed soreness from training and the peak oxygen uptake and 60 second all-out test.
2. Possible nausea from accumulation of lactate during the 60 second all-out test.

MEDICAL QUESTIONNAIRE

In order to be able to participate in the battery of tests involved with this research, you are required to complete the following questionnaire.

Name:.. Age:......................

Date:............... Height:............................ Weight:..................

Please circle the correct response to the following questions.

1. Do you smoke? Yes No
2. Has your family a history of cardiovascular problems (eg. heart attack, stroke, etc)?
   Yes No
3. Do you suffer from any cardiovascular abnormalities (heart murmur, arrhythmic heart beat, etc)? Yes No Don't know
4. Are you a diabetic? Yes No
5. Have you suffered from a cold in the past week? Yes No
6. Have you suffered from any viral infections in the past month? Yes No
7. Do you have high blood pressure? Yes No Don't know
8. Are you currently taking any medication? Yes No
   If Yes, please state...
9. Are you suffering from any bone or muscle injuries? Yes No
10. Do you suffer from any bone or muscle injuries? Yes No
11. Do you have any medical complaint, or any reason which you know of, which you think may prevent you from participating in strenuous exercise? Yes No
    If Yes, please state...

I, ... believe the above answers to be true and correct.

Signed .... Date ....

APPENDIX B

Calibration of the Biokinetic Swim Bench Ergometer

CALIBRATION OF THE BIOKINETIC SWIM BENCH ERGOMETER

Accurate and meaningful results could only be obtained from the Biokinetic swim bench ergometer (Pacer 2A) after calibration. Calibration was achieved by standing the swim bench vertically so that known weights attached to a handle were free to fall. The weights were then allowed to fall while the tension developed was recorded by the computer software developed specifically for the Biokinetic swim bench ergometer. The procedure was repeated on setting one, two and three for a variety of weights including five, 10 and 15 kilograms. At least five recordings were taken for each weight on the three settings tested. The recorded output was then exported to an ASCII file. As the swim bench is isokinetic, the ASCII values were analysed for plateaus. A consecutive series of five plateauing values, representing the ASCII equivalent of the force produced by the falling weight, were noted for each drop.

Regression analysis was then performed using MINITAB which constructed a function depicting the ASCII values against the actual force values derived by Newton's third law of motion.

5 kg :	Force	= mass * acceleration
		= 5 * 9.8 (gravity)
		= 49 Newtons.
10 kg:	Force	= 98 Newtons.
15 kg:	Force	= 147 Newtons.

MINITAB analysis yielded the following equation:

Actual force = 0.14275 * ASCII force + 18.575 ($R^2 = 0.997$).

APPENDIX C

- **Analysis of Douglas bag**
- **Sample Calculation of Oxygen Deficit**

ANALYSIS OF DOUGLAS BAG

The Morgan metabolic system was used to determine fraction of expired oxygen (F_EO_2), fraction of expired carbon-dioxide (F_ECO_2), and volume of expired air ($\dot{V}_E$). Gas temperature within the Douglas bag (T) was determined at the time of analysis using a temperature probe (Yellow Springs, Series 400). Barometric pressure (Pb) and the pressure of water (Pw) for the bag at air temperature were recorded. It was assumed that fraction of inspired oxygen (F_EO_2) was 0.2093 and the fraction of inspired carbon-dioxide (F_ECO_2) was 0.0003. The oxygen uptake was assumed to equal the oxygen deficit of the air contained within the Douglas bag in comparison to room air. Thus, oxygen uptake was determined as follows:

Step 1 - Convert $\dot{V}_E$ (ATPS) to $\dot{V}_E$ (STPD)

$$\dot{V}_E\ (STPD) = \dot{V}_E\ (ATPS) * 273/(T+273) * (Pb-Pw)/760$$

Step 2 - Calculate $\dot{V}_I$ (STPD)

$$\dot{V}_I\ (STPD) = [\dot{V}_E\ (STPD) * (1-F_EO_2-F_ECO_2)]/0.7904$$

Step 3 - Calculate $\dot{V}O_2$ and $\dot{V}CO_2$

$$\dot{V}O_2 = (\dot{V}_I\ (STPD) * 0.2093) - (\dot{V}_E\ (STPD) * F_EO_2)$$

$$\dot{V}CO_2 = (\dot{V}_E\ (STPD) * FECO_2) - (\dot{V}_I\ (STPD) * 0.0003)$$

Step two, known as the Haldane transformation, is based on the valid assumption that the volume of nitrogen remains constant from inhalation to expiration.

SAMPLE CALCULATION OF OXYGEN DEFICIT

The oxygen deficit (OD) for the 60 s all-out test was calculated as the difference between the theoretical oxygen cost of the exercise and the actual oxygen uptake. The theoretical oxygen cost of the exercise was estimated by substituting the mean power of the test into the individually developed efficiency function. Actual oxygen uptake was determined through Douglas bag analysis. For example:

Mean power = 225.8 watts

Efficiency function: $\dot{V}O_2 = 0.017587 * MP + 0.564$

Actual oxygen uptake = 2.31 l

Step 1 - Calculate theoretical oxygen cost

Theoretical oxygen cost $= 0.017587 * (225.8) + 0.564$

$= 4.54\ l$

Step 2 - Calculate OD

OD = Theoretical oxygen cost - Actual oxygen uptake

= 4.54 - 2.31

= 2.23 l

The relative contributions of the energy systems were calculated by expressing the actual oxygen uptake and the OD as a percentage of the theoretical oxygen cost which represents the total energy release during the test as an oxygen equivalent.

Step 3 - Calculate relative contribution of the aerobic and anaerobic energy systems

Aerobic contribution = Actual oxygen uptake/Theoretical oxygen uptake * 100

= 2.31/4.54 * 100

= 50.9 %

Anaerobic contribution = OD/Theoretical oxygen uptake * 100

= 2.23/4.54 * 100

= 49.1 %

Step 4 - Calculation of aerobic and anaerobic work

Aerobic Work = Aerobic contribution/100 * Total Work

Anaerobic Work = Anaerobic contribution/100 * Total Work

APPENDIX D

- Individual data

Individual data for characteristics of subjects before training

Subject	Age (yrs)	Mass (kg)	Height (cm)	$\dot{V}O2peak$ (l/min)
CL	19	82.8	171.5	2.43
DM	23	69.7	177.0	3.06
GD	23	77.2	184.5	3.00
JM	20	69.2	177.0	2.83
MT	23	69.9	178.5	2.59
SP	20	68.1	173.5	2.52
WB	22	70.8	172.0	3.04
Mean	21	72.5	176.3	2.78
SE	1	2.0	1.7	0.10

Individual data for characteristics of subjects following training

Subject	Age (yrs)	Mass (kg)	Height (cm)	$\dot{V}O2peak$ (l/min)
CL	19	84.4	171.0	2.44
DM	23	69.0	176.5	3.41
GD	23	76.8	184.5	3.33
JM	20	68.6	176.5	2.97
MT	23	70.3	179.0	3.01
SP	20	68.3	173.5	2.49
WB	22	72.0	172.0	2.90
Mean	21	72.8	176.1	2.94
SE	1	2.2	1.8	0.14

Individual data for 60 second all-out test 1 (Pre)

Subject	MP (W)	PP (W)	T. PP (s)	FP (W)	T. FP (s)	FI (%)	AD (m)	NS	HR (bpm)
CL	182.2	297.1	1.3	119.2	59.5	59.9	0.84	65	181
DM	230.6	460.0	2.3	219.7	57.6	52.2	0.93	69	170
GD	180.2	280.5	0.7	145.3	57.9	48.2	0.84	58	202
JM	197.0	300.8	4.8	178.0	59.5	40.8	0.88	60	161
MT	201.0	358.0	15.5	152.0	58.8	57.5	0.85	62	172
SP	138.2	213.6	5.3	143.3	58.1	32.9	0.71	47	175
WB	216.6	374.5	9.5	213.9	57.5	42.9	0.93	68	196
Mean	192.3	326.4	5.6	167.3	58.4	47.8	0.85	61	180
SE	11.3	29.9	2.0	14.3	0.3	3.6	0.03	3	6

Individual data for 60 second all-out test 2 (Mid1)

Subject	MP (W)	PP (W)	T. PP (s)	FP (W)	T. FP (s)	FI (%)	AD (m)	NS	HR (bpm)
CL	166.8	345.7	10.8	156.6	57.3	54.7	0.78	66	176
DM	224.4	460.4	1.4	190.5	57.1	58.6	1.02	64	165
GD	182.4	321.7	2.5	148.1	57.6	54.0	1.01	66	165
JM	187.9	340.8	1.7	163.9	59.5	51.9	0.95	61	158
MT	203.4	410.2	4.8	162.5	57.5	60.4	0.99	69	178
SP	196.3	438.5	7.6	187.9	58.1	57.2	0.94	73	177
WB	218.2	422.3	7.2	212.2	57.6	49.8	1.07	75	178
Mean	197.0	391.4	5.1	174.5	57.8	55.2	0.97	68	171
SE	7.6	20.6	1.3	8.6	0.3	1.4	0.04	2	3

Individual data for 60 second all-out test 3 (Mid2)

Subject	MP (W)	PP (W)	T. PP (s)	FP (W)	T. FP (s)	FI (%)	AD (m)	NS	HR (bpm)
CL	213.7	526.6	1.4	143.0	57.7	72.9	0.86	73	190
DM	223.6	463.3	2.5	97.1	56.8	79.0	0.95	68	170
GD	206.4	381.8	7.4	153.1	58.0	59.9	1.06	64	172
JM	213.0	376.2	10.5	159.6	58.2	57.6	0.92	62	168
MT	217.8	510.6	6.6	149.4	58.2	70.7	1.11	68	182
SP	203.5	409.7	0.7	130.3	57.6	68.2	0.85	65	184
WB	216.6	467.0	2.4	161.3	57.7	65.5	0.90	71	175
Mean	213.5	447.9	4.5	142.0	57.7	67.7	0.95	67	177
SE	2.6	22.7	1.4	8.5	0.2	2.8	0.04	1	3

Individual data for 60 second all-out test 4 (Mid3)

Subject	MP (W)	PP (W)	T. PP (s)	FP (W)	T. FP (s)	FI (%)	AD (m)	NS	HR (bpm)
CL	213.1	548.7	1.7	165.2	58.5	69.9	0.83	76	185
DM	243.1	537.1	2.4	250.7	58.5	53.3	1.02	72	170
GD	210.1	446.7	2.2	122.1	58.3	72.7	0.97	67	205
JM	210.6	476.2	1.7	195.6	58.2	58.9	1.06	71	176
MT	216.2	473.6	2.1	159.5	58.6	66.3	1.07	72	173
SP	206.3	525.2	2.1	173.3	57.0	67.0	0.87	75	174
WB	241.4	519.2	2.7	185.6	59.4	64.2	0.94	73	178
Mean	220.1	503.8	2.1	178.9	58.4	64.6	0.97	72	180
SE	5.8	14.4	0.1	14.9	0.3	2.5	0.03	1	5

Individual data for 60 second all-out test 5 (Post)

Subject	MP (W)	PP (W)	T. PP (s)	FP (W)	T. FP (s)	FI (%)	AD (m)	NS	HR (bpm)
CL	218.0	481.2	4.2	161.7	58.9	66.4	0.96	81	190
DM	247.9	542.3	1.7	259.7	58.1	52.1	1.01	75	168
GD	205.6	465.3	2.3	144.3	57.7	69.0	1.00	65	168
JM	219.3	517.2	0.7	240.0	58.4	53.6	0.99	72	168
MT	220.1	520.3	4.7	136.5	57.6	73.8	1.03	72	173
SP	217.5	476.7	6.7	154.3	58.1	67.6	0.90	72	180
WB	219.9	494.2	5.4	122.6	59.1	75.2	1.04	69	178
Mean	221.2	499.6	3.7	174.1	58.3	65.4	0.99	72	175
SE	4.9	10.5	0.8	20.2	0.2	3.5	0.02	2	3

MP: Mean Power, PP: Peak Power, T. PP: Time to Peak Power: FP: Final Power, T. FP: Time to Final Power, FI: Fatigue Index, AD: Average Distance per Stroke, NS: Number of Strokes, HR: Heartrate

Individual data for pre-training time trials

Subject	75 metre (s)	140 metre (s)	250 metre (s)
CL	51	89	189
DM	37	70	127
GD	52	92	162
JM	39	80	132
MT	44	77	142
SP	47	101	176
WB	43	74	136
Mean	44.7	83.3	152.0
SE	2.1	4.2	9.0

Individual data for mid-training time trials

Subject	75 metre (s)	140 metre (s)	250 metre (s)
CL	42	87	163
DM	36	67	127
GD	40	74	138
JM	38	71	130
MT	40	74	135
SP	42	84	164
WB	40	71	134
Mean	39.7	75.4	141.6
SE	0.8	2.8	5.8

Individual data for post-training time trials

Subject	75 metre (s)	140 metre (s)	250 metre (s)
CL	42	89	167
DM	37	71	128
GD	40	74	138
JM	38	74	134
MT	38	73	135
SP	41	81	159
WB	40	74	137
Mean	39.4	76.6	142.6
SE	0.7	2.4	5.5

Individual data for pre-training efficiency tests

Subject	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	Slope	Intercept	R-sq
CL	36.25	1.1009	39.88	1.1672	42.18	1.2047	49.31	1.3662	54.20	NSS	0.020429	0.35367	99.6
DM	41.90	1.1227	51.40	1.2906	59.86	1.5006	66.41	1.6716	74.50	NSS	0.022505	0.16101	99.6
GD	42.75	1.1258	49.61	1.3361	57.46	1.5232	65.46	1.6514	72.47	1.8362	0.023006	0.17052	99.5
JM	39.97	1.0337	47.63	1.1742	53.84	1.2640	62.31	1.3951	71.06	1.6406	0.018836	0.26076	98.7
MT	41.77	1.1560	51.33	1.3071	56.98	1.3844	64.67	1.5839	72.09	1.7502	0.019768	0.30230	99.2
SP	40.85	1.0789	45.76	1.2110	49.81	1.4508	53.18	1.5568	56.86	NSS	0.040588	-0.59947	98.8
WB	44.40	1.1594	51.59	1.3354	55.23	1.4331	57.99	1.5298	62.13	1.5934	0.025297	0.03738	99.5

Individual data for mid-training efficiency tests

Subject	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	Slope	Intercept	R-sq
CL	35.85	1.0452	39.40	1.1486	43.28	1.1853	47.18	1.2990	51.97	1.3712	0.019985	0.33981	99.0
DM	45.23	1.1987	51.39	1.2623	57.60	1.3105	64.41	1.3745	73.97	1.5306	0.011176	0.68132	98.7
GD	39.15	1.0712	50.64	1.3168	57.94	1.4198	63.49	1.5584	61.97	1.4986	0.019096	0.32955	99.6
JM	42.26	1.0523	53.28	1.2637	58.29	1.3782	65.73	1.5225	73.74	1.6605	0.019529	0.22993	99.9
MT	41.48	1.1689	47.15	1.3117	55.89	1.5757	61.04	1.6269	66.76	1.7488	0.023117	0.22731	99.1
SP	40.65	1.1705	46.37	1.3258	50.77	1.4266	57.72	1.5818	58.66	1.6624	0.025708	0.12657	99.5
WB	35.01	1.0533	47.23	1.3040	53.17	1.3761	61.25	1.4873	63.13	1.4942	0.015637	0.53052	99.0

Individual data for post-training efficiency tests

Subject	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	MP (W)	$\dot{V}O2$ (l/min)	Slope	Intercept	R-sq
CL	29.90	1.0913	36.95	1.1789	41.71	1.2455	46.02	1.3348	50.57	1.3632	0.013841	0.67487	99.2
DM	40.36	1.0446	48.87	1.1343	55.00	1.2456	63.43	1.3341	70.19	1.4361	0.013191	0.50592	99.7
GD	41.61	1.1261	46.42	1.2525	51.44	1.3066	59.17	1.4085	62.20	1.4591	0.015136	0.52091	98.8
JM	36.94	0.9684	47.37	1.1350	55.84	1.2589	60.96	1.3378	66.22	1.3501	0.013346	0.50218	98.2
MT	43.18	1.1753	51.30	1.2860	57.74	1.4686	61.45	1.5231	70.55	1.7372	0.020951	0.24713	99.4
SP	36.89	1.0404	39.56	1.0697	42.99	1.1489	49.91	1.3751	55.60	1.4711	0.024757	0.10718	99.1
WB	39.37	1.1236	44.10	1.2175	53.26	1.3436	58.30	1.4415	68.54	1.5734	0.015360	0.53026	99.8

MP: Mean Power, $\dot{V}O2$: Steady state oxygen consumption, NSS: Not steady state.

Analysis of the oxygen deficit related data using the efficiency function established with the pooled data from the pre-, mid- and post-efficiency testing sessions

Individual efficiency functions constructed from pooled efficiency testing data

Subject	Slope	Intercept	R-sq	SEE
CL	0.016083	0.54328	92.9	0.04222
DM	0.014390	0.50630	95.8	0.08911
GD	0.020719	0.25759	97.1	0.05125
JM	0.018722	0.26317	98.8	0.05113
MT	0.020505	0.29149	97.5	0.06141
SP	0.028729	-0.04587	97.2	0.06215
WB	0.017093	0.45881	96.9	0.06831
Mean	0.019463	0.32497	96.6	0.060797
SE	0.001772	0.07645	0.7	0.005753

Calculation of OD related data for 60 second all-out test 1 (Pre) using pooled efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	182.21	3.47	2.11	1.36	39.26	60.74	4292.03	6640.57
DM	230.59	3.82	2.81	1.01	26.53	73.47	3670.61	10164.79
GD	180.19	3.99	2.39	1.60	40.11	59.89	4336.93	6474.47
JM	197.03	3.95	2.33	1.62	41.04	58.96	4851.90	6969.90
MT	200.97	4.41	2.40	2.01	45.61	54.39	5499.45	6558.75
SP	138.21	3.92	2.38	1.54	39.36	60.64	3263.92	5028.68
WB	216.64	4.16	2.28	1.88	45.22	54.78	5877.42	7120.98
Mean	192.26	3.96	2.39	1.58	39.59	60.41	4541.75	6994.02
SE	11.27	0.11	0.08	0.12	2.40	2.40	355.01	587.92

Calculation of OD related data for 60 second all-out test 2 (Mid1) using pooled efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	166.82	3.23	2.33	0.90	27.78	72.22	2780.54	7228.66
DM	224.39	3.32	2.29	1.03	31.07	68.93	4183.30	9280.10
GD	182.43	4.04	2.25	1.79	44.27	55.73	4845.76	6100.04
JM	187.87	3.78	2.07	1.71	45.24	54.76	5100.10	6172.10
MT	203.36	4.46	2.41	2.05	45.98	54.02	5610.41	6591.19
SP	196.29	5.59	2.14	3.45	61.74	38.26	7271.40	4506.00
WB	218.19	4.19	2.16	2.03	48.43	51.57	6339.92	6751.48
Mean	197.05	4.09	2.24	1.85	43.50	56.50	5161.63	6661.37
SE	7.63	0.30	0.04	0.32	4.28	4.28	551.43	543.20

Calculation of OD related data for 60 second all-out test 3 (Mid2) using pooled efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	213.72	3.98	2.00	1.98	49.76	50.24	6380.25	6442.95
DM	223.64	3.31	1.98	1.33	40.24	59.76	5399.44	8018.96
GD	206.36	4.53	2.53	2.00	44.19	55.81	5471.31	6910.29
JM	213.04	4.25	2.15	2.10	49.43	50.57	6318.60	6463.80
MT	217.81	4.76	2.38	2.38	49.98	50.02	6531.12	6537.48
SP	203.49	5.80	1.92	3.88	66.90	33.10	8167.80	4041.60
WB	216.64	4.16	2.32	1.84	44.26	55.74	5752.49	7245.91
Mean	213.53	4.40	2.18	2.22	49.25	50.75	6288.72	6523.00
SE	2.59	0.29	0.09	0.30	3.25	3.25	356.75	464.91

Calculation of OD related data for 60 second all-out test 4 (Mid3) using pooled efficiency function

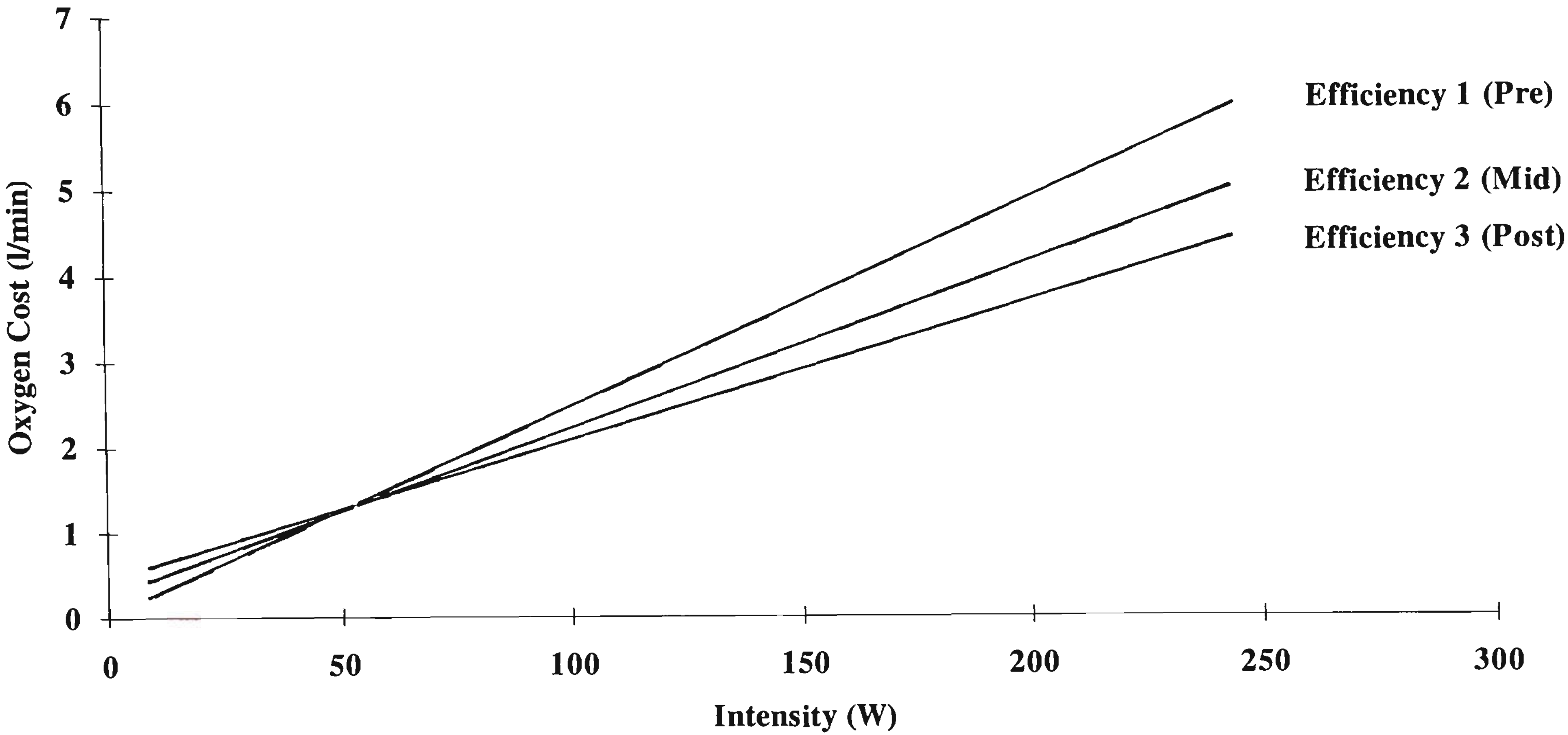
Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	213.09	3.97	2.36	1.61	40.56	59.44	5185.79	7599.61
DM	243.06	3.55	2.81	0.74	20.81	79.19	3035.38	11548.22
GD	210.09	4.61	2.72	1.89	41.00	59.00	5168.66	7436.74
JM	210.64	4.21	2.49	1.72	40.81	59.19	5157.70	7480.70
MT	216.15	4.72	2.52	2.20	46.65	53.35	6050.22	6918.78
SP	206.28	5.88	2.10	3.78	64.29	35.71	7956.78	4420.02
WB	241.41	4.59	2.32	2.27	49.40	50.60	7155.79	7328.81
Mean	220.10	4.50	2.47	2.03	43.36	56.64	5672.90	7533.27
SE	5.83	0.28	0.09	0.35	4.91	4.91	602.99	790.54

Calculation of OD related data for 60 second all-out test 5 (Post) using pooled efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	218.02	4.05	2.54	1.51	37.28	62.72	4876.57	8204.63
DM	247.93	3.61	2.48	1.13	31.26	68.74	4649.67	10226.13
GD	205.56	4.52	2.69	1.83	40.44	59.56	4987.93	7345.67
JM	219.30	4.37	2.55	1.82	41.63	58.37	5478.07	7679.93
MT	220.14	4.81	2.29	2.52	52.35	47.65	6914.05	6294.35
SP	217.49	6.20	2.33	3.87	62.43	37.57	8147.25	4902.15
WB	219.94	4.22	2.36	1.86	44.05	55.95	5813.35	7383.05
Mean	221.20	4.54	2.46	2.08	44.21	55.79	5838.13	7433.70
SE	4.85	0.31	0.05	0.34	3.89	3.89	480.07	620.48

MP: Mean Power, Theor. $\dot{V}O2$: Theortical oxygen cost, Actual $\dot{V}O2$: Actual oxygen uptake,
OD: Oxygen deficit, % Anaer.: Percent anaerobic, % Aer.: Percent aerobic,
An. Wk.: Anaerobic Work, Aer. Wk.: Aerobic work.

Analysis of the oxygen deficit related data using the pre-, mid- and post-efficiency functions established from the pre-, mid- and post-efficiency testing sessions



Mean pre-, mid- and post- efficiency functions established from pre-, mid- and post- efficiency testing sessions.

Note:

Efficiency 1 (Pre) -	Oxygen Cost = 0.024347 * Intensity + 0.098024	R-sq = 99.3
Efficiency 2 (Mid) -	Oxygen Cost = 0.019283 * Intensity + 0.352144	R-sq = 99.3
Efficiency 3 (Post) -	Oxygen Cost = 0.016655 * Intensity + 0.441207	R-sq = 99.2

Calculation of OD related data for 60 second all-out test 1 (Pre) using pre-efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	182.21	4.08	2.11	1.97	48.23	51.77	5273.24	5659.36
DM	230.59	5.35	2.81	2.54	47.48	52.52	6569.18	7266.22
GD	180.19	4.32	2.39	1.93	44.62	55.38	4824.51	5986.89
JM	197.03	3.97	2.33	1.64	41.34	58.66	4887.09	6934.71
MT	200.97	4.28	2.40	1.88	43.86	56.14	5288.80	6769.40
SP	138.21	5.01	2.38	2.63	52.50	47.50	4353.36	3939.24
WB	216.64	5.52	2.28	3.24	58.68	41.32	7627.28	5371.12
Mean	192.26	4.65	2.39	2.26	48.10	51.90	5546.21	5989.56
SE	11.27	0.24	0.08	0.21	2.22	2.22	433.60	431.68

Calculation of OD related data for 60 second all-out test 2 (Mid1) using pre-efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	166.82	3.76	2.33	1.43	38.06	61.94	3809.39	6199.81
DM	224.39	5.21	2.29	2.92	56.05	43.95	7546.74	5916.66
GD	182.43	4.37	2.25	2.12	48.48	51.52	5306.87	5638.93
JM	187.87	3.80	2.07	1.73	45.52	54.48	5130.98	6141.22
MT	203.36	4.32	2.41	1.91	44.24	55.76	5398.34	6803.26
SP	196.29	7.37	2.14	5.23	70.95	29.05	8356.50	3420.90
WB	218.19	5.56	2.16	3.40	61.13	38.87	8002.73	5088.67
Mean	197.05	4.91	2.24	2.68	52.06	47.94	6221.65	5601.35
SE	7.63	0.48	0.04	0.50	4.28	4.28	654.82	414.39

Calculation of OD related data for 60 second all-out test 3 (Mid2) using mid-efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	213.72	4.61	2.00	2.61	56.63	43.37	7261.20	5562.00
DM	223.64	3.18	1.98	1.20	37.75	62.25	5065.44	8352.96
GD	206.36	4.27	2.53	1.74	40.75	59.25	5045.77	7335.83
JM	213.04	4.39	2.15	2.24	51.03	48.97	6522.78	6259.62
MT	217.81	5.26	2.38	2.88	54.77	45.23	7158.15	5910.45
SP	203.49	5.36	1.92	3.44	64.17	35.83	7834.16	4375.24
WB	216.64	3.92	2.32	1.60	40.79	59.21	5301.78	7696.62
Mean	213.53	4.43	2.18	2.24	49.41	50.59	6312.76	6498.96
SE	2.59	0.29	0.09	0.30	3.74	3.74	440.67	520.16

Calculation of OD related data for 60 second all-out test 4 (Mid3) using post-efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	213.09	3.62	2.36	1.26	34.88	65.12	4459.94	8325.46
DM	243.06	3.69	2.81	0.88	23.94	76.06	3490.92	11092.68
GD	210.09	3.70	2.72	0.98	26.50	73.50	3340.81	9264.59
JM	210.64	3.31	2.49	0.82	24.85	75.15	3140.67	9497.73
MT	216.15	4.78	2.52	2.26	47.23	52.77	6125.61	6843.39
SP	206.28	5.21	2.10	3.11	59.72	40.28	7391.95	4984.85
WB	241.41	4.24	2.32	1.92	45.26	54.74	6555.92	7928.68
Mean	220.10	4.08	2.47	1.61	37.48	62.52	4929.40	8276.77
SE	5.83	0.26	0.09	0.32	5.17	5.17	657.44	746.59

Calculation of OD related data for 60 second all-out test 5 (Post) using post-efficiency function

Subject	MP	Theor. $\dot{V}O2$	Act. $\dot{V}O2$	OD	% Anaer.	% Aer.	An. Wk.	Aer. Wk.
CL	218.02	3.69	2.54	1.15	31.21	68.79	4082.86	8998.34
DM	247.93	3.76	2.48	1.28	34.01	65.99	5059.43	9816.37
GD	205.56	3.63	2.69	0.94	25.94	74.06	3199.53	9134.07
JM	219.30	3.43	2.55	0.88	25.63	74.37	3372.84	9785.16
MT	220.14	4.86	2.29	2.57	52.87	47.13	6983.77	6224.63
SP	217.49	5.49	2.33	3.16	57.57	42.43	7512.72	5536.68
WB	219.94	3.91	2.36	1.55	39.62	60.38	5228.33	7968.07
Mean	221.20	4.11	2.46	1.65	38.12	61.88	5062.78	8209.05
SE	4.85	0.29	0.05	0.33	4.80	4.80	636.35	648.88

MP: Mean Power, Theor. $\dot{V}O2$: Theortical oxygen cost, Actual $\dot{V}O2$: Actual oxygen uptake, OD: Oxygen deficit, % Anaer.: Percent anaerobic, % Aer.: Percent aerobic, An. Wk.: Anaerobic work, Aer. Wk.: Aerobic work.

APPENDIX E

- Analysis

Mean Power

Source	df	SS	MS	F-Ratio	P-Value
Name	6	6752.199	1125.366	7.255	0.0002
Mean Power	4	5006.407	1251.602	8.069	0.0003
Residual	24	3722.907	155.121		

	Vs.	Diff.	Crit. diff.	
Pre	Mid1	4.8	13.7	
	Mid2	21.3	16.6	S
	Mid3	27.9	18.6	S
	Post	28.9	19.6	S
Mid1	Mid2	16.5	13.7	S
	Mid3	23.1	16.6	S
	Post	24.1	18.4	S
Mid2	Mid3	6.6	13.7	
	Post	7.7	16.6	
Mid3	Post	1.1	13.7	

Peak Power

Source	df	SS	MS	F-Ratio	P-Value
Name	6	44078.351	7346.392	3.808	0.0083
Peak Power	4	159419.39	39854.848	20.658	0.0001
Residual	24	46302.538	1929.272		

	Vs.	Diff.	Crit. diff.	
Pre	Mid1	65.0	48.5	S
	Mid2	121.5	58.6	S
	Mid3	173.2	64.7	S
	Post	177.5	69.2	S
Mid1	Mid2	56.5	48.5	S
	Mid3	108.2	58.6	S
	Post	112.4	64.7	S
Mid2	Mid3	51.7	48.5	S
	Post	55.9	58.6	
Mid3	Post	4.2	48.5	

Fatigue Index

Source	df	SS	MS	F-Ratio	P-Value
Name	6	572.866	95.478	1.971	0.1099
Fatigue Index	4	1971.047	492.762	10.174	0.0001
Residual	24	1162.389	48.433		

	Vs.	Diff.	Crit. diff.	
Pre	Mid1	7.5	7.7	
	Mid2	19.9	11.0	S
	Mid3	16.8	9.3	S
	Post	17.6	10.3	S
Mid1	Mid2	12.5	10.3	S
	Mid3	9.4	7.7	S
	Post	10.2	9.3	S
Mid2	Mid3	3.1	9.3	
	Post	2.3	7.7	
Mid3	Post	0.8	7.7	

Oxygen Deficit

Source	df	SS	MS	F-Ratio	P-Value
Name	6	14.982	2.497	16.431	0.0001
Oxygen Deficit	4	1.708	0.427	2.81	0.048
Residual	24	3.647	0.152		

	Vs.	Diff.	Crit. diff.	
Pre	Mid1	0.3	0.4	
	Mid2	0.6	0.6	S
	Mid3	0.5	0.5	
	Post	0.5	0.6	
Mid1	Mid2	0.4	0.6	
	Mid3	0.2	0.4	
	Post	0.2	0.5	
Mid2	Mid3	0.2	0.5	
	Post	0.1	0.4	
Mid3	Post	0.0	0.4	

Percent Anaerobic

Source	df	SS	MS	F-Ratio	P-Value
Name	6	2358.824	393.137	12.694	0.0001
% Anaerobic	4	334.061	83.515	2.697	0.0449
Residual	24	743.31	30.971		

	Vs.	Diff.	Crit. diff.	
Pre	Mid1	3.9	7.4	
	Mid2	9.7	8.8	S
	Mid3	3.8	6.1	
	Post	4.6	8.2	
Mid1	Mid2	5.7	7.4	
	Mid3	0.1	6.1	
	Post	0.7	6.1	
Mid2	Mid3	5.9	8.2	
	Post	5.0	6.1	
Mid3	Post	0.8	7.4	

Anaerobic Work

Source	df	SS	MS	F-Ratio	P-Value
Name	6	28274535.37	4712422.562	5.632	0.0009
Anaer. Work	4	12593393.71	3148348.429	3.763	0.0163
Residual	24	20080365.49	836681.895		

	Vs.	Diff.	Crit. diff.	
Pre	Mid1	620.0	1009.5	
	Mid2	1746.9	1441.7	S
	Mid3	1131.6	1220.4	
	Post	1296.6	1348.3	
Mid1	Mid2	1126.9	1348.3	
	Mid3	511.6	1009.5	
	Post	676.6	1220.4	
Mid2	Mid3	615.3	1220.4	
	Post	676.6	1220.4	
Mid3	Post	165.0	1009.5	

75 metre Time Trial

Source	df	SS	MS	F-Ratio	P-Value
Name	6	167.619	27.937	4.595	0.012
75 metre	2	123.714	61.857	10.175	0.0026
Residual	12	72.952	6.079		

	Vs.	Diff.	Crit. diff.	
Pre	Mid	5.0	2.9	S
	Post	5.3	3.5	S
Mid	Post	0.3	2.9	

140 metre Time Trial

Source	df	SS	MS	F-Ratio	P-Value
Name	6	1030.476	171.746	7.795	0.0014
140 metre	2	252.286	126.143	5.726	0.018
Residual	12	264.381	22.032		

	Vs.	Diff.	Crit. diff.	
Pre	Mid	7.9	6.7	S
	Post	6.7	5.5	S
Mid	Post	1.1	5.5	

250 metre Time Trial

Source	df	SS	MS	F-Ratio	P-Value
Name	6	5598.286	933.048	21.905	0.0001
250 metre	2	463.524	231.762	5.441	0.0208
Residual	12	511.143	42.595		

	Vs.	Diff.	Crit. diff.	
Pre	Mid	10.4	9.3	S
	Post	9.4	7.6	S
Mid	Post	1.0	7.6	

Note: Significance levels calculated according to the Student-Newman-Keuls method.
S denotes significant difference at the 0.05 level.