ACCUMULATED OXYGEN DEFICIT AMONG HIGHLY CONDITIONED FEMALE ROWERS DURING A 2,000 METER RACE SIMULATION

by

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ABSTRACT

In the last twenty years there have been various studies that have examined physiologic demands of rowing for the competitive athlete, however most of the literature focuses on male rowers. Now with the growing popularity of women's rowing programs at both collegiate and national levels, there is a need for research that evaluates the physiological profiles of highly conditioned oarswomen. The significant contribution of aerobic work to a rower's performance has been substantiated in past research (Hagerman, F.C., 1984), however, fewer studies have specifically looked at anaerobic energy release during a simulated 2,000 meter rowing race in female rowers. This is partly due to the difficulty in quantifying anaerobic energy capacity in the laboratory. Studies by Medbo et al. (1988,1993) have validated the linear extrapolation method of accumulated oxygen deficit (AOD) to determine anaerobic energy release during exercise. Data on AOD suggest that 2 minutes of exercise to exhaustion is required to use anaerobic sources fully (Medbo et al., 1988). It has also been concluded by Gastin et al. (1995) that an "all-out" protocol provides a valid estimate of maximal AOD (mAOD). Therefore the objectives of the present study were to measure both the maximal anaerobic capacities of highly conditioned oarswomen by the AOD method and compare this to the AOD of each rower during a 2K race simulation (RS) on the Concept II rowing ergometer (RE).

Sixteen highly trained female rowers volunteered for the study. The protocol consisted of 4, four minute submaximal VO2 rowing bouts (20-80% max), a 2 minute all-out test, and a 2K RS. Each test was performed on the RE with VO2 and power output (PO) recorded every 15 sec. Positive linear

correlations between VO2 and PO for each subject were all greater than 0.99. The mAOD (2 minutes) averaged 3.40L± 0.68 which was not significantly different than the AOD for the 2K RS (3.50L±1.40). These results indicate that the subjects maximally taxed their anaerobic energy systems in the RS. Total time for 2K RS averaged 7.5 min±0.2 and the relative contribution of the anaerobic energy sources during RS equaled approximately 12% of total as determined via the AOD method.

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Most of all, I would like to dedicate this paper to my family (Mom, Dad, David and Jeremy), for instilling in me the confidence in myself to pursue the path of academia and for providing a model of achievement to strive towards.

CHAPTER 1

1.1 Introduction:

Although rowing is one of the world's more traditional sports, with regattas dating back to the late 1800's, the sport of rowing has been minimally researched in the exercise physiology laboratory (Kramer, et.al., 1994; Hagerman, 1984; Hagerman, et. al., 1979). In recent years, there has been a growing interest in the sport of rowing both at the collegiate level and at the national competitions. As the numbers of college rowing programs steadily increase in North America, so does the level of competition for oarsmen and women (Concept II, Inc., 1994; Secher, N.H., 1993). Now more and more coaches are looking to exercise science for a physiological assessment of rowers and an objective method for evaluating rowing ability.

In the last twenty years there have been various studies that have examined the physiologic demands of rowing for the competitive athlete (Hagerman, et. al., 1984, 1979, 1978; Kramer, et. al., 1994; Mahler, et.al., 1985, 1984; McKenzie, et.al., 1982; Mickleson, et.al., 1982; Rosiello, et. al., 1987; Secher, et. al., 1993, 1983, 1982; Steinacker, 1993; Vermulst,et. al., 1991; Williams, 1978; Young, et. al., 1991, 1988, 1986). Most of the literature focuses on male rowers, with only a limited number of studies evaluating the performance of oarswomen (Kramer, et.al., 1994; Hartmann, et.al., 1993; Young, et. al., 1991, 1988; Hagerman, et.al., 1984, 1979; Secher, et. al., 1982). This is partly due to the fact that women only began racing the standard 2,000 meter race distance as late as 1985 (Secher, 1993; Young, et. al., 1991, 1988). Now, over a decade later, women's rowing has grown tremendously and concomitantly their times for 2,000 meters races have become faster.

Because success in competitive rowing depends a great deal on a high level of aerobic and anaerobic ability we now see a growing need for research that evaluates the physiological profiles of elite female rowers (Secher, 1993; Young, et.al., 1991; Kramer, et.al., 1994; Hagerman, et.al., 1984, 1979; Vermulst, et.al., 1991). By estimating the relative contributions of aerobic and anaerobic energy sources during competitive rowing and calculating the maximum power and mechanical efficiency for each competitor, implications for training, competitive strategy, and possibly team selection criteria can be determined.

Due to the time of a 2,000 meter on-water rowing race averaging 6.5 minutes (ranging from 5.8 to 7.2 minutes) for elite male crews and approximately 6.6 minutes for elite women (ranging from 5.9 to 7.3 minutes), depending on conditions, a great deal of emphasis has been placed on the aerobic energy system's contribution during a rowing event (Secher, 1993; Hagerman, 1984). Therefore, most of the early research on the sport of rowing was directed towards evaluating the aerobic capacity of oarsmen. Unlike other sports, like running and cycling, that could use such sports specific equipment as the treadmill and the stationary bicycle ergometer, to test athletes in the physiology laboratory, rowing did not lend itself to easy standardization or quantification. Secher, N.H., 1983, recorded in his review article of the history of rowing some early research studies that attempted to measure the rowing physiology by setting up on-water testing. "A first attempt to describe the physiology of rowing was carried out when Liljestrand and Lindhard (1920) measured oxygen uptake, heart rate and cardiac output during rowing of an 'ordinary' boat."(Secher, N.H., 1983, p.23). Since then few other studies tried to evaluate on-water rowing (Jackson, et. al., 1976; Di Prampero, et. al., 1971) due the impractical nature of measuring physiological variables in a boat, on water, and during competition. Therefore, initially a rower's VO_2 max was often determined during cycling and running (Bouckaert, et. al., 1983; Carey, et. al, 1974; Cunningham, et. al., 1975) or in rowing tanks (Asami, et. al., 1978; Di Prampero, et. al., 1971). With the introduction, in 1971, of rowing ergometers simulating sweep rowing and sculling, aerobic capacity has later been determined through more sports specific performance tests (Hagerman, et. al., 1984, 1979, 1978, 1971; Kramer, et. al., 1994; Mahler,et. al., 1984; Secher, et. al., 1983). To date, stationary rowing ergometers have become the standard test, training, and research instrument for rowers (Kramer, et. al., 1994). In North America, the Concept II rowing ergometer is used in both national team selection (Rowing Canada Aviron, 1992-1993) and carding decisions for national athletes (Kramer, et. al., 1994; Hagerman, 1984).

Although rowing has not been researched as extensively as some other sports, there has been quite a substantial volume of data collected on the oarsman's physiological profile and responses to the 2,000 meter race, relative to information on their female counterpart. In addition, there are currently few published studies that evaluate the oarswoman's responses racing the 2,000 meter distance (6 to 8 minutes), as opposed to the 1,000 meter distance (3 to 4 minutes) (Kramer, et. al., 1994; Young, et. al., 1991). Therefore a combination of the 1,000 meter women's data and the 2,000 meter women's data, will be reviewed in this study.

1.2 Data with Oarswomen- Race Simulation

Although the significant contribution of aerobic work to a rower's performance has been substantiated in past research, fewer studies have specifically looked at anaerobic energy release during a simulated rowing race

(Hagerman, et. al.,1984, 1978, 1972, 1968; Kramer, et. al., 1994; Mahler, et.al., 1985, 1984; McKenzie, et.al., 1982; Mickleson, et.al., 1982; Rosiello, et.al., 1987; Secher, et.al., 1993, 1983, 1982; Vermulst,et.al., 1991; Williams, 1978;). Whereas oxygen consumption rate is commonly used to represent aerobic metabolism, the indirect assessment of anaerobic metabolism is much more difficult. The relative contribution of anaerobic metabolism to rowing has been estimated in a number of ways including the measurement of oxygen deficit, oxygen debt and the energy equivalent of post exercise lactate concentrations (Hagerman, 1984). It seems the majority of the studies that did quantify anaerobic capacity of rowers seemed to do so by calculating the oxygen debt incurred while performing a taxing 3-4 minute or 6-6.5 minute simulated rowing test either on the ergometer or in the rowing tanks (Hagerman, et. al., 1979).

Hagerman, et.al., (1974) first evaluated the metabolic responses of 12 female members of the 1973 US National Team, during and following 4 minutes of exhaustive rowing on an electrostatic rowing ergometer (Hagerman, et. al., 1974, abstract). Collecting lactates, oxygen deficit and oxygen debt measurements, Hagerman determined that approximately 70% of the rowing performance was contributed by the aerobic system and 30% the anaerobic system. These findings are comparable to the values of Astrand and Rodahl (1977) which list a 70%/30% ratio for the aerobic/anaerobic energy contribution for a 4 minute maximal exercise bout. In another study by Hagerman, et. al., 1979, they evaluated elite oarswomen (n=40) by testing their physiological responses to rowing a 3-minute race on a Stanford side pull rowing ergometer. The aerobic contribution was found to be 55%. Post exercise oxygen consumption data during a 30 minute recovery of this 3 minute test led to oxygen debt calculations which showed a 45% relative contribution of the anaerobic energy system (Hagerman, et. al., 1979).

In a 1982 study by Secher and his colleagues, through oxygen deficit calculations, a 23% anaerobic contribution to a 4 minute rowing ergometer test was determined. This 23% anaerobic value is somewhat less than the value of Hagerman, et. al., (1979, 1974) and Astrand and Rodahl (1977).

Fewer studies have evaluated the metabolic cost of rowing the standard 2,000 meter distance with oarswomen. Young and Rhodes measured the energy demands of a 7 minute race simulation on a Gjessing rowing ergometer with 5 collegiate oarswomen (Young, et. al., 1986, abstract). The oxygen debt data collected showed an 83%/17% aerobic/anaerobic contribution. Later, Young and Rhodes (1991) evaluated a 6.5 minute race simulation for six national level female rowers and determined, by oxygen debt collection, 80% of the total energy requirement to be aerobic and 20% anaerobic (Young et. al., 1991). These studies seem to show a slightly higher aerobic contribution than oxygen debt data collected with oarsmen performing similar distance race simulations (6 minutes), but compared more favorably with results from lactate and oxygen deficit studies done with male rowers.

1.3 Data with Oarsmen - Race Simulation

Hagerman, et. al., 1984, have reviewed some studies that have evaluated the anaerobic contribution to a 2,000 meter (6 minute) race simulation with highly conditioned male rowers. He makes reference to a doctoral dissertation by Connors (1974) who measured oarsmens' anaerobic energy contribution during a 6 minute race simulation by collecting the post-exercise blood lactate levels. Results showed the anaerobic system with 22.2%

of the energy supply for the 6 minute ergometer race (77.8% aerobic contribution). Another group of studies that evaluated the German Lightweight Rowing Team by measuring each rower's lactate performance curve during a 6 minute maximal rowing test showed anaerobic capacity contributing 10-20% of the performance in competition in trained rowers (Steinacker, 1993). These values are similar to the results measuring anaerobic contribution with female rowers during 6.5-7 minutes of ergometric race simulation. It should be noted that although anaerobic metabolism is often assessed by measurement of blood lactate concentrations despite difficulties in determining the distribution volume for lactate, oarsmen's maximum blood lactate concentration has been found to be 11 mmol/l after "maximal" running on a treadmill, 15 mmol/l obtained after national competition, and 17 mmol/l after an international championship regatta (Secher, 1983). Thus psychological factors may influence the results. The blood lactate concentration should be regarded as an indication of the extent to which the anaerobic processes are activated (Gollnick et. al., 1973).

Szoby and Cherebetiu (1974) investigated the physical work capacity of 32 male rowers during a 6 minute progressive intensity test on a cycle ergometer. Using oxygen deficit calculations, a percentage ratio between exercise VO2 and oxygen deficit was determined to represent the aerobic and anaerobic ratio of the exercise. Mean percentage ratios for the rowers were found to be 68.4% aerobic and 31.6% anaerobic (Szoby, et. al., 1974). The fact that this testing was not sports specific to rowing, may explain the discrepancy between this data and other findings of oarsmens' anaerobic contribution during race simulation.

In another study using oxygen deficit to calculate anaerobic energy metabolism, Secher, et. al. (1982) measured oxygen deficit of elite oarsmen during a 6 minute rowing ergometer race simulation. He determined a 14% anaerobic contribution for men rowing a 6 minute "all-out" race. These values are somewhat less than those generally expected for other types of "all-out" exercise of 4 to 6 minutes (Astrand, et. al., 1977) and less than values determined by other means of assessing anaerobic capacity during rowing a 2,000 meter race simulation (Hagerman, et. al., 1979, 1978).

The majority of the studies that evaluate metabolic cost of rowing have used the oxygen-debt collection method (Hagerman, et. al, 1979, 1978; Secher, et. al., 1982). In 1978, Hagerman, et. al., determined energy expenditure of oarsmen during simulated rowing for 6 minutes. Calculating the aerobic cost of the exercise from the total net VO2 of the work period, it was concluded that 70% of the relative energy contribution was supplied by aerobic metabolism. Oxygen consumption values collected during a 30-minute recovery period were used to calculate an oxygen debt. This value is believed to represent the anaerobic contribution during the 6 minute race simulation and was determined to be 30%.

Although in the past a majority of researchers have used oxygen debt to represent the anaerobic component of rowing, the unique style of pacing for the 2,000 meter rowing races where there is a high series of strokes taken at the start causing a significant initial anaerobic contribution, it has been hypothesized that oxygen deficit may more accurately represent this component during exercise (Secher, 1993, 1983, 1982; Hagerman, et. al., 1984, 1979). In addition, Hagerman, et. al., 1979, reports "Oxygen deficit and debt have frequently been used to estimate the anaerobic component for a given level of exercise. Submaximal, steady-state exercise generally produces equality between these variables, but they become disproportionate if the exercise lasts between two and three minutes and a steady state is never attained. A recent study has reported that oxygen debt was always larger than oxygen deficit, and this difference increased significantly with increasing severity of exercise. In our study, oxygen debt for all three groups following ergometer rowing was approximately 40% higher than the respective oxygen deficit values....Although we have used oxygen debt to represent the anaerobic energy component, we believe that because of the nature of rowing, oxygen deficit may more accurately represent this component during exercise."(Hagerman, et. al., 1979, p.82).

1.4 Anaerobic Metabolism

Research by Fletcher and Hopkins, dating back to as early as 1907, established that energy required for muscular contraction comes from the breakdown of glycogen to lactic acid under anaerobic conditions (Hermansen, 1969). Further analysis showed that phosphocreatine disappeared with a concomitant build up of creatine and phosphates during muscular work, and during recovery, phosphocreatine stores are regenerated. Later it was discovered that when the break down of CP was inhibited, ATP would disappear instead of CP, and the formation of ADP would result (Hermansen, 1969). From these experiments studying the pathways of energy metabolism, it can be concluded that when human muscles contract, ATP is hydrolyzed to ADP and inorganic phosphate. In order to maintain muscle contraction, ATP can be resynthesized through aerobic processes:

$$\mathbf{NADH + H+ \ + 3ADP + 3P + 1/2\ O2 \ \Rightarrow NAD + \ H2O + 3ATP}$$

It is the primary role of oxygen to resynthesize ATP, yet not all energy can be provided aerobically during work. For example, performances of short duration and high intensity require immediate and rapid supply of energy and, even during work that is submaximal in intensity, oxygen consumption does not increase instantaneously to steady state at the onset of exercise (McArdle, et. al., 1991). This lag in oxygen uptake is compensated by the immediate and non-oxygen consuming breakdown of ATP in the muscle - anaerobic metabolism, and is referred to as the oxygen deficit.

1.5 Oxygen Debt:

Numerous methods are used to measure anaerobic metabolism due to the fact that the accurate estimation of the anaerobic energy reserves has little standardization (Lawson, 1981; Young, 1985). One of the more popular methods of examining anaerobic metabolism and total anaerobic capacity has been through measurement of the oxygen debt (Lawson, 1981). In addition to the lag in oxygen consumption at the onset of exercise, at the cessation of work, there is a delayed return of oxygen uptake to the resting value. The amount of oxygen taken up in excess of the resting value during the recovery period is referred to, in classical concept, as the oxygen debt (Hermansen, 1969) **(See Figure 1, p.10).**

Investigating the relationship between oxygen debt and deficit, Whipp, et. al. (1970), found evidence for the equality of oxygen debt and oxygen deficit in exercise of 4 to 6 minutes duration. The equations used to calculate oxygen deficit and oxygen debt were as follows:

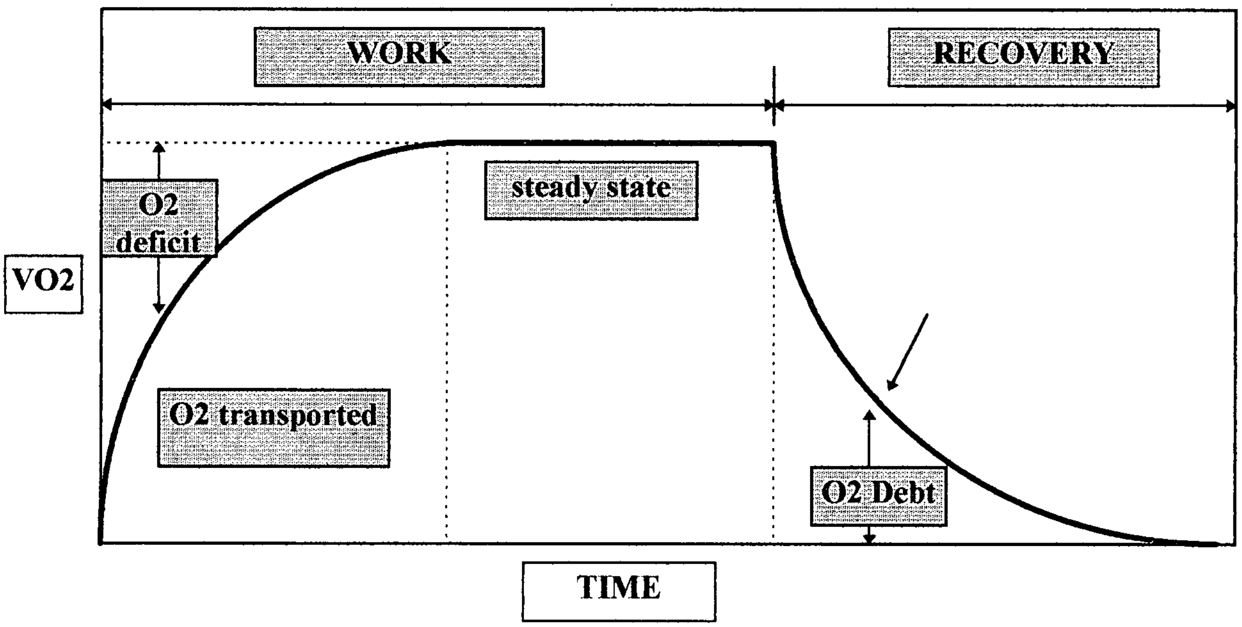
$$\text{oxygen deficit} = VO_{2ss} - VO_2 \text{ actual (dt)}$$

$$\text{oxygen debt} = VO_2 \text{ recovery} - VO_2 \text{ unloaded cycling (dt)}$$

(ss = steady state; dt = derivative of time)

FIGURE I. (Hermansen, L., 1969)

Oxygen uptake during and after submaximal work load in relation to time.



The intensity of the exercise used was such that a steady state in VO_2 was achieved. Therefore, the results may be interpreted to suggest that O_2 deficit and O_2 debt are equivalent in steady state (Young, 1988). However, there are several limitations when quantifying this relationship between oxygen deficit and oxygen debt to determine the efficiency of anaerobic work (Stainsby, et. al., 1970; Hermansen, 1969). There have been a number of studies that have shown a direct relationship existing between oxygen debt and the energy of work contributed by aerobic sources *only after light exercise* (Lawson, 1981; Stainsby, et.al., 1970). It has also been widely hypothesized that elevated oxygen uptake following maximal work may be due to different metabolic factors in addition to the "pay back" of the oxygen deficit incurred at the start of exercise (Hermansen, 1969; Medbo, et.al., 1988; Stainsby, et.al., 1970). Some of these factors include: restoring myoglobin concentration in the muscles, replenishing dissolved oxygen in tissue fluids, regenerating venous oxyhemoglobin to the resting values, the increase in body temperature and the output of adrenaline that occur during exercise. Increased ventilation and elevated heart rates may also require some extra oxygen uptake during the recovery period (Hermansen, 1969). Hagermen, et. al., 1979, reported that upon testing elite rowers in a 6-minute race simulation that mean oxygen debt values were approximately 40% larger than the respective oxygen deficits. This data is consistent with literature testing O_2 deficit-debt relationships (Hermansen, 1969; Stainsby, et. al., 1970). This inequality suggests that a substantial portion of the O_2 debt is being used for activities not directly related to skeletal muscle metabolism.

In addition to these confounding factors contributing to the oxygen debt, another possible problem with measuring anaerobic energy release during a 2,000 meter rowing event via post exercise oxygen consumption is that it may not give an accurate picture of the total anaerobic contributions that occurred at the start of the race. As mentioned earlier, due to the peculiar pacing of a 2,000 meter race, where the rower begins the race with an intense burst of activity at maximal effort lasting anywhere up to 45 seconds before settling into the body of the race, a large oxygen deficit occurs initially (Hagerman, et.al.,1984, 1979, 1972; McKenzie, et.al., 1982) . If during the body of the race, some of this deficit is restored via the aerobic energy system, the "oxygen debt" collected post exercise would not account for the anaerobic energy at the start. Thus, by measuring the accumulated oxygen deficit over a 2,000 meter race, a more accurate picture of the total anaerobic energy contributions for conditioned rowers may be obtained (Hagerman, et.al., 1979).

1.6 Accumulated Oxygen Deficit (AOD):

The concept of oxygen deficit was first introduced by Krogh and Lindhard in 1920 as the difference between the curve of the actual oxygen uptake at the beginning of exercise and the final steady-state level of the oxygen uptake (Graham, 1996; Medbo, et.al., 1988). Hermansen reintroduced the principle in 1969 and calculated the accumulated oxygen deficit as the area between the curve of the oxygen demand and the curve of the actual oxygen uptake **(See Figure 1, p.10).** This supposedly represents anaerobic metabolism and should be equivalent to the use of high energy phosphate stores and to lactate formation from glucose to glycogen (Graham, 1996).

In one particular study by Medbo, et. al., 1988, he explains the basis behind AOD : The rate of energy release is probably constant from the beginning of exercise at constant intensity. At submaximal intensities the steady-state oxygen uptake is assumed to reflect the total rate of energy release during exercise. For supramaximal intensities (intensities exceeding the maximal oxygen uptake), the rate of energy release of oxygen demand can be estimated by extrapolating the linear relationship between exercise intensity and the steady-state oxygen uptake at submaximal intensities (Medbo, et.al., 1988) **(see Figure 2, p.14)**. The AOD for a given exercise bout at a constant intensity is then equal to the calculated accumulated oxygen demand minus the measured accumulated oxygen uptake (Lawson, 1981; Medbo, et.al., 1988).

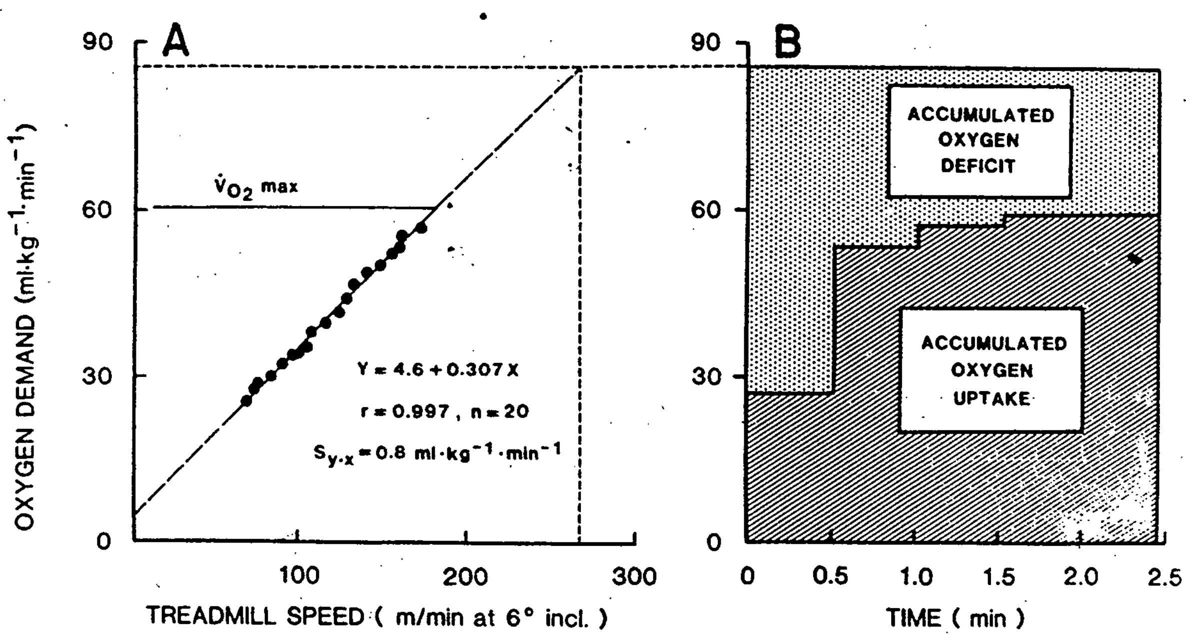
Although a "gold-star" standard test for anaerobic energy release still has not been designed, researchers have done studies to validate the method of AOD as an accurate means of determining this energy source (Gastin, et.al., 1994; Lawson, 1981; Medbo, et.al., 1996, 1993, 1988; Scott, et.al., 1991). It is the conclusion of these studies that the AOD method, under appropriate exercise conditions, seems to provide an accurate estimate of the anaerobic capacity (Gastin, et.al., 1995; Lawson, 1981; Medbo, et.al., 1996, 1993, 1988; Scott, et.al., 1991). In a study by Medbo, et.al., 1988, a method for quantifying the anaerobic capacity based on the determination of the maximal AOD was researched. The AOD was calculated for eleven men during five bouts of treadmill running to elicit exhaustion after 15s, 30s, and 1, 2, and 4 minutes. The method is based on estimation of the oxygen demand by extrapolating the linear relationship between treadmill speed and oxygen uptake at submaximal intensities. According to Medbo, for the AOD to provide a good estimate of anaerobic capacity the following criteria should be met:

1. ***A leveling off with exercise duration..*** Arguments have been made that the amount of ATP formed anaerobically during short, exhaustive exercise is independent of the duration of the interval (Medbo,1988). If there are

FIGURE II. (Medbo, J.I., et.al., 1988, Figure 1., p.52)

The linearity of the power out-put vs. oxygen consumption relationship.

"VO2 maximum oxygen uptake. Slope of the regression of the steady state oxygen uptake on treadmill speed at 6 degrees inclination. n=3."



"Principles for determining oxygen deficit. A: relationship between exercise intensity (treadmill speed) and oxygen demand. B: aod is calculated as difference between accumulated oxygen demand and accumulated oxygen uptake of exercise. Subject RB ran for 2.45 min. at 267 m/min. corresponding to an oxygen demand of 86 ml/kg/min VO2max, maximal oxygen uptake."

limitations on both the amount of ATP formed by anaerobic processes and the rate of these processes, the AOD would be expected to increase with the duration of the exhausting exercise until a leveling off is observed. In order to test this hypothesis, Medbo et al designed his study to cause exhaustion after different timed intervals ranging from 15 s - > 4 minutes.

Results from Medbo's study show that exercise bouts lasting less than 2 minutes, had a decrease in AOD with each decrease in duration ($p<0.001$). For durations exceeding 2 minutes, the AOD leveled off. No statistically significant differences in AOD between exhaustive exercise bouts lasting 2 minutes, 4 or > 5 minutes ($p > 0.2$) were found. Medbo et al., concluded that 2 minutes is the duration needed to quantify maximal anaerobic energy stores.

2. ***Independence from maximal oxygen uptake.*** Although the glycolytic enzymes are shared by the aerobic and anaerobic ATP-forming pathways, due to the maximal rate of aerobic glycogen oxidation being much lower than the capacity of the glycolytic enzymes, the anaerobic capacity and the maximal oxygen uptake are two independent variables. Medbo measured oxygen uptake in both hypoxic and normoxic conditions to see whether the maximal oxygen uptake could be lowered independently of the AOD.

Results from this same study showed that after reducing the oxygen fraction in the inspired gas for the subjects running on the treadmill, the maximal oxygen uptake was reduced significantly ($p < 0.001$). The AOD, however, did not significantly change ($p = 0.60$). Therefore, Medbo concludes the aerobic power was unrelated to maximal AOD (Medbo, et.al., 1988).

3. ***Agreement with existing methods.*** One approach, as stated in Medbo's study, has been to measure the changes in the metabolites linked to anaerobic

ATP formation, i.e. changes in phosphocreatine and lactate concentrations measured both in muscle and blood. Although the assumptions of the distribution volumes must be done, hence making for imprecise methods, a rough picture can be estimated.

Results from Medbo's study show that peak blood lactate for exercise bouts lasting <2 minutes decreased with decreasing exercise duration ($p<0.02$). For tests lasting >2 minutes, no further increases in peak blood lactate concentration were observed ($p > 0.3$) (Medbo, et.al., 1988).

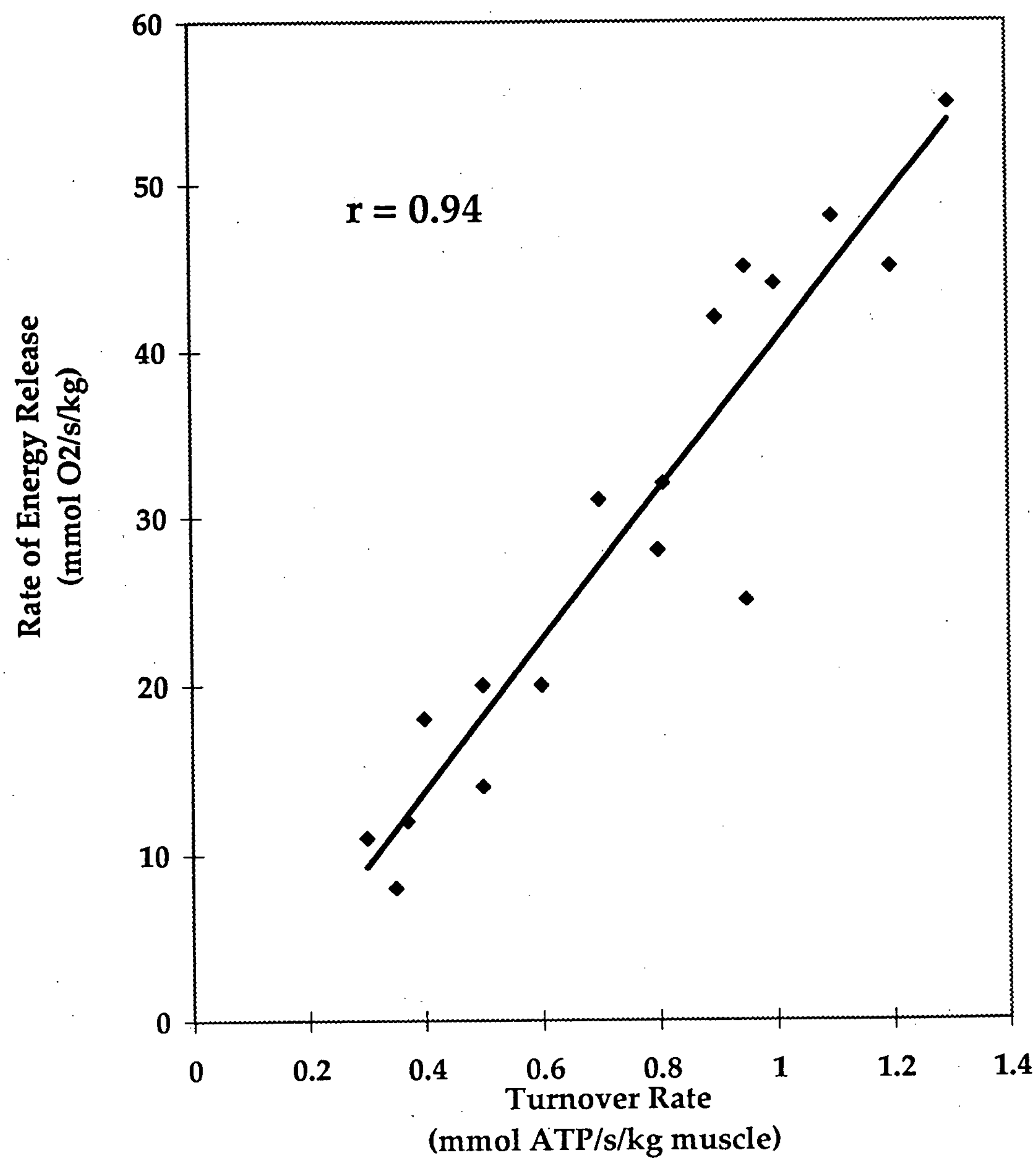
In a later study, Medbo et.al., 1993, further validated the linear extrapolation for determining AOD by determining the anaerobic energy release by two independent methods during high-intensity exhausting bicycling. They compared the direct determination of anaerobic energy release calculated from changes in muscle metabolites with the previously explained non-invasive linear extrapolation for AOD measurement. They found a close linear relationship between the rates of anaerobic ATP production in muscle and the value estimated for the whole body by the oxygen deficit ($r=0.94$). This gives further credence to the validity of AOD as a measure of the anaerobic energy release during exercise **(See Figure 3, p.17).**

1.7 Summary of AOD Method :

The measure of accumulated oxygen deficit has been proposed as a quantification of anaerobic capacity. The AOD method relies on an extrapolation procedure using the linear power output-oxygen uptake relationship based on several submaximal exercise tests. From these data points a regression line is drawn so that supramaximal oxygen uptake can be predicted. AOD is calculated as the difference between predicted oxygen uptake at the supramaximal intensities and actual oxygen uptake collected.

FIGURE III. (Medbo, J.I., 1993, Figure 2., p. 1658)

"Mean rate of anaerobic energy release determined for whole body vs. mean ATP turnover rate in muscle. Whole body rate was calculated from oxygen deficit as explained in SUBJECTS AND METHODS, whereas rate in muscle was calculated from measured changes in muscle lactate, phosphocreatine, and ATP concentrations. Solid line, line of identity provided biopsy data were representative of all working muscle and that working muscle mass was 25% of body mass."



Maximal AOD (total anaerobic capacity) is measured as the difference between predicted oxygen uptake and actual oxygen uptake collected during a 2 minute exhaustive exercise bout to fatigue (Scott, et.al., 1991).

1.8 AOD "Controversy":

Although the concept and theory behind AOD are relatively simple, it should be noted that the assumptions underlying the concepts are very complex and difficult to prove (Graham, 1996). The validity of AOD as a measure of anaerobic capacity has been an on-going controversy since the concept was first introduced in 1920. Graham (1996) summarizes the points of controversy very clearly in his review article, "Oxygen Deficit: Introduction to the Assumptions and Skepticism":

- Are there changes in the metabolism of tissues other than active muscle such that the events occurring at the pulmonary level are not a direct reflection of what is occurring in the active muscles?
- What is the mass of the active muscle?
- Is the relationship between energy cost and power output linear throughout the exercise duration?
- What is the energy cost of the exercise? Does it change during the continuous exercise?

If the pulmonary measure of oxygen deficit is an accurate reflection of the active muscle, then the measure of total VO2 for the exercise combined with the energy cost of the activity would allow one to evaluate anaerobic metabolism in the muscle (Graham, 1996). It is recognized that the controversy regarding this method of testing surrounds the assumptions involved and that future work in this area is necessary.

CHAPTER 2

2.1 Purpose:

The level of competition for women's rowing has dramatically increased since the implementation of the 2,000 meter race in 1985 (which was previously only performed by their male counterpart) (Kramer, et.al., 1994; Secher, 1993). To this day, most of the literature on the sport of rowing focuses on oarsmen (Hagerman, 1984; Kramer, 1994; Young, 1991, 1988). Because success in competitive rowing depends a great deal on a high level of aerobic and anaerobic ability, there is a growing need for research that evaluates physiological profiles of elite female rowers. This study is an attempt to fill this need.

Studies by Medbo et al. (1993, 1989, 1988) have attempted to validate the linear extrapolation method of accumulated oxygen deficit (AOD) to determine anaerobic energy release during exercise. Data on AOD suggest that 2 minutes of exercise to exhaustion is required to use anaerobic sources fully (Gastin, et.al., 1995; Lawson, 1981; Medbo, et.al., 1988; Scott, et.al., 1991). It has also been concluded by Gastin et.al., 1995, that an "all-out" protocol provides a valid estimate of the maximal AOD. Therefore the purposes of the present study are the following:

- To determine individual oxygen cost versus power output relationships for use in the estimation of supramaximal oxygen cost by administering four bouts of 4 minute submaximal VO_2 stages on the rowing ergometer with continuing progression to maximal VO2.

- To determine aerobic/anaerobic energy systems' contributions to a 2,000 meter simulated rowing race on the Concept II rowing ergometer of highly trained female rowers.

- To measure the maximal AOD of highly trained female rowers while performing an "all-out" 2 minute ergometer test.

- To compare AOD of "all-out" ergometer test with AOD during a 2,000 meter race simulation in order to determine the extent each rower taxes her anaerobic energy stores in competition. These results can then be analyzed to see if there is a statistically significant correlation between rowing performance and indices of anaerobic energy contribution.

- By estimating the relative contributions of aerobic and anaerobic energy sources during competitive rowing in elite oarswomen, implications for training, competitive strategy, and possibly team selection criteria can be determined.

2.2 Delimitations:

This study was delimited by:

1) The sample size (N</= 16)
2) The testing period relative to the rower's competitive training/racing schedule.
3) Between subject variability (i.e. some rowers may be selected for the Canadian National Team while others will still be competing for a lower level team).
4) The race simulation on the Concept II as opposed to on-water.

2.3 Possible Limitations:

Accumulated Oxygen Deficit

- **The linearity of the power out-put vs. oxygen consumption relationship**

The calculation of the AOD is based on a linear extrapolation of the relationship between power and oxygen demand (Medbo, et.al., 1988). It has been hypothesized that the lactic acidosis developing during exercise may reduce the mechanical efficiency by 20% near exhaustion (cited in Medbo, et.al., 1993, 1988). A possibly reduced efficiency would require a higher turnover rate of ATP to maintain the exercise intensity. If this were the case, a curved relationship between power output and energy production with a y-intercept different from zero would be expected. In the study by Medbo, et.al., 1993, which looked at the relationship between mean rate of anaerobic energy release for whole body vs. mean ATP turnover rate in muscle, this appeared not to be the case. Thus an impaired efficiency near exhaustion is not supported by this data.

- **Confirmation of AOD by Medbo**

The study by Medbo, et.al., 1993, validating the method of AOD by comparing the whole body anaerobic energy release vs. ATP turnover rate in muscle, assumed the following :

1) That 1 mol oxygen is equivalent to 6.5 mol ATP, as for oxidation of glycogen.
2) That the muscle biopsy data obtained from a small part of only one muscle represents the whole working muscle mass. The two measurements are equal provided the working muscle mass amounts

to 25% of the body mass. This estimate of the working muscle mass during bicycling is similar to values obtained from other studies.

3) That phosphocreatine concentration was measured correctly. Data of Soderlund and Hultman (1986) (cited in Medbo, et.al., 1993), suggest that only 2-3 mmol phosphocreatine/kg is lost during biopsy sampling.

2.4 Testing Protocol Assumptions:

- 2 minutes "all-out" on the rowing ergometer will elicit a maximal anaerobic energy production. It should be noted that Gastin, et.al., 1995, determined that an "all-out" protocol provides a valid estimate of the maximal AOD. In addition, there appears to be a degree of test specificity such that endurance trained subjects may be better suited to a supramaximal, constant intensity test that is slightly longer than a test of 60-90 seconds. This study uses 2 minutes due to the higher ratio of aerobic vs. anaerobic contributions for rowing to assure a complete taxing of anaerobic system.

2.5 Justification of the Study:

As stated previously, the justification of this study is based on a combination of the growing level of competition among oarswomen, and the paucity of research evaluating the physiology of female rowers.

2.6 Hypotheses:

1. During the 2,000 meter race simulation test, the AOD will be greater than or equal to the AOD during the 2 minute "all-out" test.

Rationale:

The rationale for this predicted supramaximal effort during race situation, is partially based on the nature of the competitive strategy in rowing and previous studies done by Hagerman, et. al., 1984 and Mahler, et.al., 1984. The rowing strategy for a 2,000 meter race is to start with successive high-powered, fast strokes for the first 40-45 seconds before settling into the body of the race. Also, each crew usually takes 10-20 stroke bursts (called "power-10's or power 20's") in the middle 1,000 meters before preparing for their sprint in the last 500 meters. Due to the intensity of the start and finish, and high aerobic demands during the body of the race, it seems plausible that elite oarswomen may completely tax their anaerobic energy stores in the first 500 meters of the race and then "pay-back" some of this AOD during the body of the race to allow for a sprint finish. Mahler, et.al., 1984, showed when testing elite oarsmen during a 6 minute "all-out" race simulation, that peak power production and near maximal aerobic uptake was achieved at the first minute and then gradually decreased until the last minute of exercise when there was a slight rise in power. These results are in agreement with those taken by Hagerman, et. al., 1978 .

2. Between 20-30% of the energy required for a 2,000 meter rowing race will be anaerobic.

Rationale:

The rationale for this predicted energy contribution is based on the previously reported findings of Hagermen, et.al., 1979, 1978,1974; Secher, et.al., 1982; and Young, et.al., 1991, 1986. In these studies examining energy expenditure of elite oarsmen and women using oxygen debt-deficit relationships, estimated contributions of anaerobic energy were between 20-30%.

CHAPTER 3

3.1 Methodology:

Subjects: 16 highly conditioned female rowers (either on the University of British Columbia's Varsity Women's team or training for the Canadian National Team in Victoria, British Columbia) served as subjects for this study. Subject characteristics are displayed in **Table 1.**

Table 1. Physical Characteristics:

Subjects (N=16)	Age (yrs.)	Wt. (kg.)	Ht. (cm.)	# Years Rowing
Average	20.94	74.07	174.86	3.5
St. Dev. (±)	2.57	7.85	4.37	1.8

Each subject performed 3 tests in the Allan McGavin Sports Medicine Center:

1. Four, 4 minute submaximal exercise stages on a Concept II rowing ergometer with continuing progression to maximal oxygen consumption.
2. A 2 minute "all-out" test on the rowing ergometer (oxygen consumption was collected to determine AOD).
3. A 2,000 meter race simulation on the Concept II rowing ergometer. Oxygen consumption was also collected during 2K test in order to establish the different energy contributions and AOD.

Each rower completed an approved informed consent form and a one-page personal background questionnaire prior to testing.

3.2 Maximal AOD Test:

Apparatus: During each test the subject breathed through a non-rebreathing valve (Hans-Rudolph, #2700B). Expired air volume was directed into a 5 Liter mixing chamber and gas samples were analyzed for oxygen and carbon dioxide using calibrated equipment (S-3A oxygen analyzer and CD-3A carbon dioxide analyzer, Applied Electrochemistry). These analyzer outputs and inspired ventilatory volumes (Vacumetries # 17150 meter) were processed by an automated system to provide VE (L,L/min), VO_2 (L/min, ml/kg), VCO_2, and RER, at the end of each 15 second interval of exercise.

All tests were performed on the Concept-II Plus rowing ergometer. The average power output (watts) and heart rate (bpm) (Accurex II Polar Heart Rate Monitor) were recorded every 15 seconds.

Protocol: Following a self-determined warm-up on the rowing ergometer, the subject was instructed to row at maximal intensity for 2 minutes. Average power was measured in watts. Total accumulated oxygen was measured in liters.

3.3 Submaximal Stages - Maximal VO2

Apparatus: Same as in Total Maximal AOD Test.

Protocol: Oxygen uptake was assessed during four, 4 minute submaximal rowing bouts ranging from 30-80% of VO_2 max. Individual relationships were determined from the regression of steady state oxygen uptake and power outputs at the submaximal exercise intensities. The duration and relative intensity of submaximal bouts used to establish oxygen uptake and power relationships has been tested in studies by Medbo et.al., 1993, 1988, and Gastin, et.al, 1995. A duration of 4 minutes is justified by Gastin, et. al., 1995, provided exercise intensities are not severe. Steady state values are usually achieved within 3 minutes of light to moderate exercise intensities. In a pilot study done prior to this study, oxygen consumption and power output relationships were established with 6 varsity female rowers on a Blade Power Model 200 Rowing Simulator using four submaximal stages of 4 minute rowing bouts and individual linear correlations were all greater than 0.90. (Pripstein, et.al., 1996).

In order to establish appropriate power outputs for the 4 stages of submaximal rowing, percentages were taken from each rower's power average for the 2 minute all-out test done 20-30 minutes earlier. Percentages equalled approximately 20-30%max for the first stage, 40-50% for second, 60-70% for third, and between 75-85% max for the final stage. Due to the anaerobic nature of the 2 minute test, subject's VO2, heart rate, and perceived exertion were monitored on last two stages to make sure they were not exceeding these ranges.

When the fourth minute of the fourth stage was completed, the rower was instructed to increase rowing intensity every minute until volitional exhaustion, in order to elicit a maximal VO2 value. At the beginning of this phase in the test, the clock interface on the rowing ergometer was switched from watts to 500 meter split times (which is the display each rower is accustomed to use in training) and the rower then gauged their intensity by the time it takes to row 500 meters. Each minute the rower increased intensity by dropping their split times by 5 seconds/500 meters and holding it for the full minute:

SPLIT TIME (TIME/500 METERS)	TIME INTERVAL
2:00	1 MIN
1:55	1 MIN
1:50	1 MIN
Continued until volitional exhaustion	" "

The test was ended when the subjects could no longer hold a constant split.

3.4 2,000 Meter Race Simulation:

The 2,000 meter ergometer test is a standard criterion for making national team selection camps in most countries (Kramer, et.al., 1994). The Concept II rowing ergometer has a clock that determines the time it takes to row 2,000 meters. The highly conditioned rowers in this study have performed numerous 2,000 meter tests during the course of their training. The test is designed to simulate the duration, intensity and stroke rating of an actual 2,000 meter race on the water. Each rower was instructed to use their normal race strategy. Total time to complete 2,000 meters, oxygen uptake, and average power at each 15 second interval were recorded. Heart rates were recorded every minute. The AOD for each 15 second interval was calculated as the difference between the oxygen demand estimated from the power output values and the measured oxygen uptake. The total 2K AOD was the sum over all intervals. An example of one subject's oxygen demand and uptake values are plotted in **Figure 4, p. 30**.

3.5 Data Analysis:

Calculations and Statistics:

- Individual regression lines and equations to determine supramaximal oxygen uptake/power out-put relationships (standard protocol, Medbo, et., al., 1993, 1988)

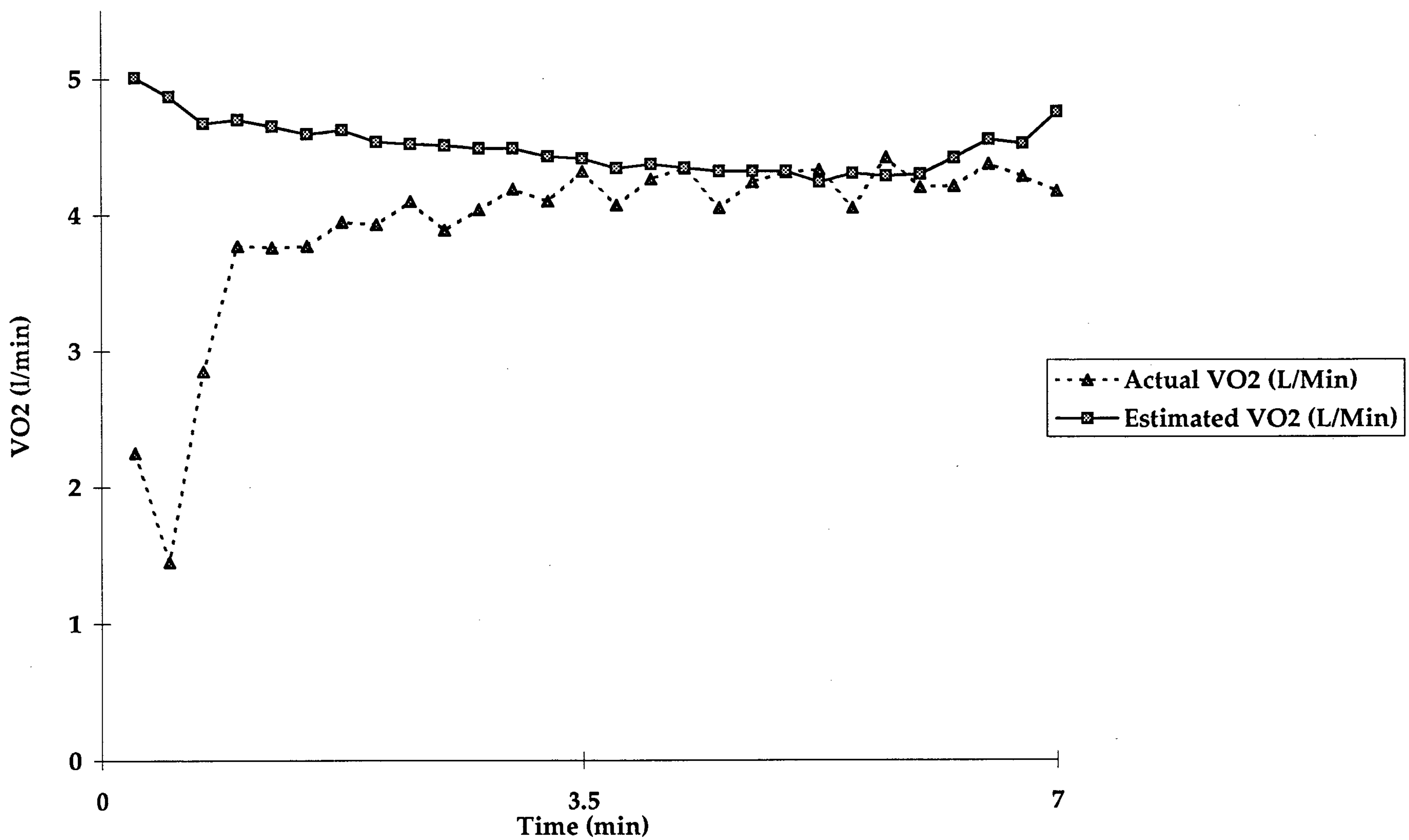
- Student's matched t-tests comparing:

  1. Total AOD of 2 minute "all-out" test and total AOD of 2,000 meter race simulation.

  2. The 95% confidence limit for the per cent energy contribution from aerobic sources was determined to see if it overlaps the hypothesized 70-80% range.

- Correlations of dependent variables with performance time during 2,000 meter race simulation were explored to aid with data interpretation.

Figure 4. Single Subject Data:
Race Simulation - VO2 vs Time



CHAPTER 4

4.1 Results

4.1.1. 2 minute "all-out" test

The mean AOD measured during the 2 minute "all-out" test was 3.40 L ± 0.681. Heart rate values were also recorded every 15 seconds during the 2 minutes, and maximal heart rate values averaged 178 bpmin for 14 out of the 16 rowers (due to equipment failure not all heart rates were recorded for every subject). Peak power outputs recorded over a 15 second interval were 330.2 watts. When averaged over the 2 minutes, mean power values equaled 318.0 watts (see **Table 2**).

Table 2. 2 Minute "All-Out" Test:

Subjects (16)	AOD (L)	Peak Power (Watts)	Average Power (Watts)
Average	3.40	330.16	317.98
St. Dev. (±)	0.68	43.42	39.84

4.1.2. Submaximal rowing (30-80% max)

The relationship between oxygen consumption and power output for each subject was determined from measurements during 4 stages of submaximal rowing ranging an estimated 20% to 80% of max. Positive linear correlations between VO2 and power outputs for each subject were all greater than 0.995, and the standard error of estimate averaged 0.046 ± 0.036 (L/min). When calculated as a % of VO2max, submaximal oxygen uptake values averaged 34% ± 3.2, 52% ± 4.7, 69% ± 3.2, 83% ± 3.8%, respectively over the 4 stages.

4.1.3. 2,000 meter race simulation

The average time it took the subjects to row 2,000 meters on the Concept II rowing ergometer equaled 7.5 min ± 0.22 (see **Table 4**). The mean AOD measured during the 2K race simulation was 3.50 L ± 1.40. Heart rate values were recorded every minute during the test, and peak heart rates for the 2K averaged 188 bpm ± 9. Power and VO2 values were recorded every 15 seconds during the race. Peak power values were attained during the first minute of exercise and averaged 276.8 watts ± 32.4 (see **Table 3**).

Table 3. 2K Race Simulation / Anaerobic Values:

Subjects (16)	AOD (L) Total	AOD (L) First 2 min. of 2K	Peak Power (Watts)	2K-%anaerobic
Average	3.50	2.43	276.80	12.31
St. Dev. (±)	1.40	0.47	32.39	4.36

Maximal oxygen consumption values during the 2K averaged 3.58 L/min and were usually attained during the final "sprint" of the race (last minute of exercise). When averaging the VO2 after 1 minute of exercise, the subjects sustained oxygen consumption levels of 3.31 L/min which represented 91.2% of max VO2 (see **Table 4**).

Table 4. 2K Race Simulation / Aerobic Values:

Subjects (N=16)	VO2max (l/min)	2K-mVO2 (l/min)	2K-avg VO2 (l/min)	2K-%max	2K-Time (min)
Average	3.55	3.58	3.31	91.16%	7.50
SD (±)	0.35	0.36	0.34	3.72%	0.22

4.2 Accumulated oxygen deficit during 2,000 meter race simulation vs. 2 minute "all-out" test AOD

There was no significant difference (p=0.37) between the AOD during the 2,000m race simulation (3.50L ±1.40) and the 2 minute "all-out" AOD (3.40 L± 0.681). The hypothesis that the AOD during the 2,000m race simulation would be equal to or greater than the 2 minute "all-out" AOD, is therefore supported by this data (see **Figure 5**).

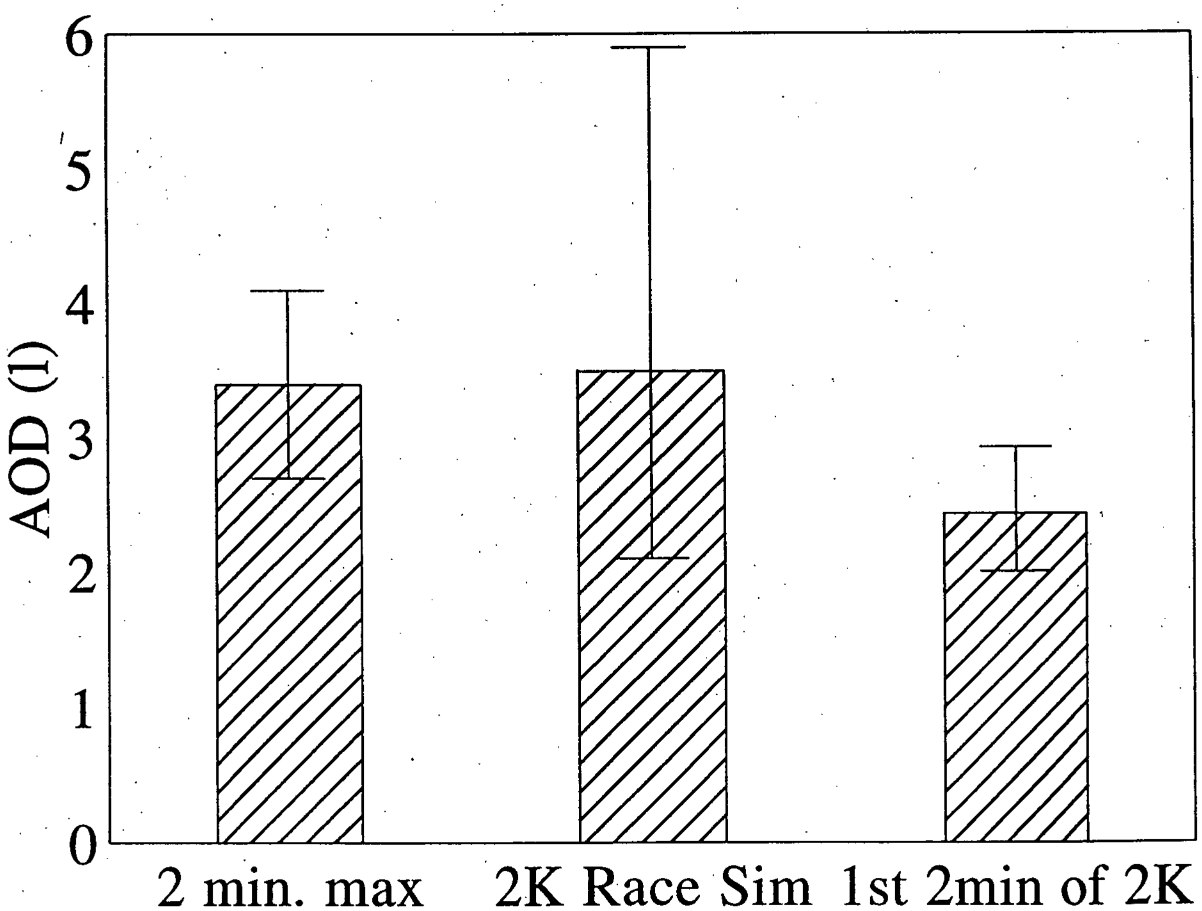


Figure 5. Maximal and 2K Race AOD

4.3 Anaerobic energy system contribution during 2,000 meter race simulation

The results indicate that anaerobic contribution during the 2,000 meter race simulation averaged 12.3%, with a 95% confidence interval of 10.1 - 14.4% (see **Table 3**). This did not support the hypothesis that anaerobic contribution would be between 20 and 30% of total energy required for the 2,000 meter race simulation.

CHAPTER 5

5.1 Discussion

5.1.1. Accumulated Oxygen Deficit

Anaerobic capacity is defined as the maximum amount of ATP that can be supplied by glycolysis (Scott, et. al., 1991). Ways of measuring this energy system range from direct quantification of ATP-CP breakdown and muscle lactate concentration through muscle biopsy and blood samples, to non-invasive collection of mechanical work completed during a short duration, high intensity exercise (Scott, et. al., 1991). Currently there is no gold-star standard for measuring anaerobic capacity due to the difficulties with measurements and inaccuracies with both the direct and indirect methods. For example, the direct measurement of anaerobic energy from muscle biopsies is an invasive procedure that provides information on relative concentrations of anaerobic indices, not total amounts. (Scott, et. al., 1991). Since the exact active muscle mass has not been quantified, only estimations can be made based on this information. The validity of the non-invasive short duration, high intensity tests where work is measured over time (e.g. Wingate test), is based on the assumption that the activity is of high enough intensity and long enough duration, that the capacity of the anaerobic energy system will be reached. Research has shown that in the case of the Wingate test, for example, which is 30 s in duration, as much as 9-19% energy contribution comes from aerobic sources depending on mechanical efficiency (cited in Scott, et. al., 1991).

Accumulated oxygen deficit as a measure of maximal anaerobic capacity has been proposed as a more clear method of separating and defining anaerobic and aerobic energy production (Lawson, 1981; Medbo, et.al., 1996).

The AOD relies on the extrapolation of the submaximal linear workload-oxygen consumption relationship. The relationship between work and VO2 is established by several submaximal exercise tests at various intensities and from this data a regression line is drawn. From this regression equation, then supramaximal oxygen uptake (energy expenditure) can be estimated. MAOD is determined as the difference between the predicted supramaximal VO2 and the actual oxygen uptake collected over a 2 minute, "all-out" exercise bout to fatigue. Previous research by Linnarsson, et. al., 1974, (cited in Scott, et.al., 1991) which looked at muscle metabolites and oxygen deficit with exercise in hypoxia and hyperoxia, determined that MAOD remains unchanged in hypoxic conditions. This supports the notion that AOD has an independence from the aerobic energy system. In addition, studies by Medbo, et.al., (1993, 1988) indicate that MAOD remains unchanged when high intensity exercise is extended beyond 2 minutes. This would support the concept of a limited anaerobic energy production.

Based on past research that have validated AOD as a measurement of anaerobic energy capacity, the AOD method was used in this study to determine maximal anaerobic capacity of highly conditioned female rowers. In addition, it has been speculated by past researchers that have attempted to measure anaerobic contributions during rowing, that due to the unique style of pacing of a 2,000 meter rowing race where there is a significant anaerobic response at the start of the race, AOD would be a more accurate representation of the anaerobic component (Hagerman, et.al., 1979; Secher, et.al., 1983).

5.1.2. 2 Minute AOD

One of the assumptions of this study was that a 2 minute "all-out" test on the rowing ergometer would elicit a maximal anaerobic energy production while aerobic contribution to the total energy supply would be minimal. As stated in the results, the mean AOD measured during the 2 minute test for the 16 subjects was 3.4L ± 0.681. Due to the lack of research analyzing the physiology of female rowers, there is little with which to compare these results. One study by Hagerman, et. al., 1979, looked at various physiological variables in 40 elite female rowers and over a 3 minute high intensity rowing bout reported an oxygen deficit of 6.4L ± 3.6. Hagerman noted in his discussion that the energy-cost data for those 40 elite rowers exceeded the values determined for other maximal exercise studies. Maximal power generated during the 2 minute test in this study (330.2 watts) exceeded the max power reported in Hagerman's study over the 3 minute rowing interval (284 watts) and heart rates in this study were lower than in Hagerman's research (178 bpm vs. 190 bpm). The AOD results of our study do compare favorably with a study by Lawson, 1981, that measured maximal oxygen deficit in 20 subjects performing a 1 minute bicycle ergometer ride (AOD averaged 3.39 L ± 0.63). Unfortunately this article does not specify whether the subjects were male or female.

5.1.3. Submaximal Rowing Intervals

In order to extrapolate the linear relationship between oxygen uptake and power output on the rowing ergometer and thus determine the accumulated oxygen deficit, a battery of submaximal steady state VO2 tests were performed by each subject. The relationship between oxygen consumption and power output were determined from 4 stages of submaximal rowing with positive linear correlations between VO2 and work output all greater than 0.99. In a pilot study examining 6 highly conditioned female rowers from the University of Michigan, done prior to this research, positive linear correlations were made between power output on a rowing simulator and oxygen consumption for the same protocol of submaximal rowing. In the pilot study, positive linear correlations between VO2 and work output on the rowing simulator were all greater than 0.90 (Pripstein, et.al., 1996). In this current study, when calculating the fourth stage as a percentage of the subjects maximal power output (taken from the 2 minute all-out test) the % max averaged approximately 60%. We noticed during testing that when starting the fourth interval at 80% of max power out-puts, the VO2 values and heart rates of the subjects were elevated past 80% of maximal VO2; therefore the work intensity of the final stage was reduced so that the power outputs equaled 60% of max power but the oxygen uptake averaged 83% of maxVO2. One possible reason for this discrepancy is that the maximal power outputs were taken from the 2 minute all-out test which is primarily utilizing anaerobic energy sources. This in turn would over estimate power outputs for eliciting submaximal oxygen uptakes.

5.2 2,000 meter race simulation

There have been some research studies designed to analyze various physiological responses to simulated rowing races, both in the boat and on a rowing ergometer (Di Prampero, et.al., 1971; Hagerman, et.al., 1979, 1978; Jackson, et.al., 1976; Kramer, et.al., 1994; Mahler, et.al., 1984; McKenzie, et.al., 1982; Rosiello, et.al., 1987; Secher, et.al., 1983; Young, et.al., 1991, 1986). Because there are only few studies that specifically looked at oarswomen's responses to rowing, some comparisons can be made with studies using male rowers when looking at the variables as percentages of maximal values. Unlike other studies that tested rowers in a race simulation which used a set time for the subjects to complete there race (estimated from what times a

2,000 meter race takes highly conditioned eight-oared crews to complete on the water), this study used the set distance of 2,000 meters on the Concept II Rowing Ergometer and calculated the time for each subject to row that distance. Each rower in this study was very familiar to this way of testing, as it is the standard protocol for collegiate programs and national team testing.

The average time it took the subjects to row 2,000 meters on the Concept II Ergometer averaged 7.5 minutes ± 0.22. It should be noted that rowing ability for this subject pool ranged from junior varsity all the way to women in competition for the Canadian National Team, including one woman who has medalled in the past two Olympics for Canada. The subject criteria also did not distinguish between lightweight and heavyweight rowers, thus creating a larger range of scores in this study. The mean VO2 max measured in the race simulation was 3.58 L/min ± 0.36. There was no significant difference when comparing the average max VO2 value of the 2K, 3.58 L/min ± 0.36, to a max VO2 value of 3.55 L/min ± 0.36, from the progressive intensity to max VO2 test performed by the same subjects within 2 weeks of the 2,000m, ($p>0.05$). Our VO2max findings are similar to values reported in another study by Young, et. al. (1986) who found a mean VO2 max of 3.51 L/min ± 0.2 when testing collegiate oarswomen. Our results fall a little lower than values by those of Hagerman, et. al. (1979), who reported a mean peak VO2 for elite female rowers of 4.1 L/min ± 0.4 in a 3 minute rowing ergometer test and Young, et. al. (1991) who looked at 6 female rowers and determined VO2 max values of 3.81 L/min 0.24 when performing a 6.5 minute race simulation on a rowing ergometer. However, the more elite rowers that participated in this study had VO2 values that would compare favorably to these past studies.

When examining the physiological profiles of elite rowers, it has been argued that far too much emphasis is placed on relative VO2max (Hagerman, 1984) and what is really the most impressive physiological attribute of conditioned rowers is the ability to sustain extremely high percentages of their absolute VO2max, even after they have exceeded their anaerobic threshold levels. Therefore, we have included the average VO2 the rowers maintained during the 2,000m race simulation. This average excludes the first minute of exercise when there is a time lag in the aerobic response and when a substantial amount of the energy requirement is supported by anaerobic means (Hagerman, 1984; Mahler, et.al., 1984). This average sustained oxygen consumption during the race simulation equaled 3.31 L/min ± 0.34, which is approximately 91.2% ± 3.7 of max. With individual values ranging from 80-95%. When correlating this average VO2 and time for the 2,000 meter race (performance variable) r = -0.82, which ended up being slightly higher than correlations between the peak VO2 during the 2,000m and the 2,000m time (r = -0.78). This data is comparable to studies done with both elite male and female rowers in the past. Young, et. al., 1991, reported that over a 6.5 minute rowing race simulation on the ergometer, 6 elite female rowers averaged an intensity equivalent to 94.6% ± 1.26% of their maximum (evaluated from start of 3rd minute to end of 6.5 minutes of test). In addition, Hagerman, 1984, reported anaerobic threshold measurements for the 1980 US Olympic Men's Rowing Team during race simulation to be approximately between 85% and 95% of VO2max.

5.3 Anaerobic Energy Contribution

The anaerobic energy system's contribution to a 2,000 meter race simulation for highly conditioned female rowers as measured by the accumulated oxygen deficit method, was 12.3% of the total energy requirement. This % indicates the tremendous aerobic demand of the 2,000m race simulation. While this value is comparable to oxygen deficit measurements reported by Secher, et. al., (1982) who reported 14% anaerobic contribution for men during all-out rowing for 6 minutes, it is somewhat lower than past studies that have measured the anaerobic energy system's contributions in oarswomen during a race simulation (Hagerman, et.al., 1979, 1974; Secher, 1982; Young, et.al., 1991, 1986). This is due in part to the previous shorter race distance for women (1,000 m) where the relative anaerobic contribution is most likely higher due to the shorter duration. In the studies that tried to simulate the 2,000 meter distance, a set time was used for each rower (ranging from 6.5-7 minutes) which is also shorter than the average time our subjects completed the 2,000 meter race simulation (7.5 minutes). Hagerman, et. al., 1974, measured 12 oarswomen's metabolic responses during 4 minutes of ergometric rowing. The anaerobic energy system contributed approximately 30% with an oxygen deficit of 4.4 L (lactic portion of the deficit 3.0 L and alactic portion 1.4 L). Calculating the effect of duration, if anaerobic processes generated 4.4 L and that is 30% of total, then 14.66L is the total for the 4 minutes of rowing. Subtracting anaerobic contribution from total leaves 12.26 L/4min of aerobic contribution or 3.065 L/min. Multiplying this 1 minute aerobic value by 7.5 minutes (the average race time for our subjects), the anaerobic contribution is lowered to 16% of total which is closer to our findings. Young, et. al., 1991, also reported a 20% contribution of the anaerobic energy system when testing rowers over a 6.5 minute distance. Again, the shorter duration of time can also be a factor in this higher % of anaerobic contribution. When calculating the effects of duration on anaerobic contribution to race simulation, Young, et. al.s' value of 20% anaerobic contribution for 6.5 minutes of rowing lowers to 17.8% for 7.5 minutes of race simulation. Finally, Secher, et.al., (1982), measured the oxygen deficit in 4 female rowers during a 4 minute race simulation. With oxygen deficit values measuring 4.2 L for 4 minutes, he determined anaerobic contribution to be 23%. When adjusting for our 7.5 minute duration, anaerobic contribution equals 13.8% of total, which is closely related to our findings.

In addition, many of these past studies used the oxygen debt method to measure anaerobic contribution. As stated previously, the oxygen debt method is also controversial due to several limitations found when quantifying the relationship between oxygen deficit and oxygen debt to determine the amount of anaerobic work. One such limitation is that the elevated oxygen uptake following maximal work may be due to different metabolic factors in addition to the "pay back" of the oxygen deficit incurred at the start of exercise (Gaesser, et.al., 1984; Hermansen, 1969; Stainsby, et.al., 1970). Therefore, it is feasible that this higher anaerobic contribution reported in earlier studies may be in part due to this post exercise elevation of oxygen consumption after the race is completed.

Finally, another rationale for our findings of relatively low anaerobic contribution during rowing can be explained by the limitations of the AOD method. It is an assumption that oxygen demand increases linearly with intensity of exercise at supramaximal power outputs (Bangsbo, 1996; Graham, 1996; Medbo, et.al., 1996, 1993, 1988). If mechanical efficiency of rowing decreases at these supramaximal intensities and oxygen uptake needs to be, in fact, higher than what is predicted by the submaximal linear regression slope, AOD and anaerobic energy contributions would be underestimated. This is still a point of great controversy, as can be seen in the pointcounterpoint papers by Bangsbo and Medbo (1996), "Oxygen Deficit: Introduction to the Assumptions and Skepticism". Bangsbo argues that his study, which has found that a group of well trained runners "had a higher oxygen uptake at high submaximal running speeds than that estimated from extrapolating the linear relationship between oxygen uptake and power at lower running speeds, indicates that the relationship is not linear from low to high submaximal speeds." (Bangsbo, et.al., 1993, p.211). Medbo, on the other hand, reports that "Bangsbo's ...nonlinear effects at high treadmill speed... has not been a problem in our studies on the treadmill, not even for well trained subjects." (Medbo, 1996, p.365). It is quite evident that more research needs to be done with the AOD method in order to elucidate some of these unresolved issues.

The 2,000 meter AOD for this subject pool averaged 3.50 L $\pm$ 1.40. Although this value is not significantly higher than the 2 minute "all-out" average AOD of 3.40 L $\pm$ 0.681, this does agree with the hypothesis that stated: during the 2,000 meter race simulation test, the AOD will be greater than or equal to the AOD during the 2 minute "all-out" test. Due to the intensity of the 2,000 meter rowing race, this data indicates that, averaged over the subjects, during the first 2 minutes of exercise (a little over 500 meters) these oarswomen utilized 72% of their maximal anaerobic energy stores, which is significantly less than the 2 minute "all-out" AOD ($p<0.001$), (see **Figure 5, p. 33**).

The AOD for the first 2 minutes of the 2,000m race simulation was positively related to the 2 minute all-out AOD data, $r = 0.60$ ($p<0.05$), and the correlation between the AOD of the first 2 minutes of the race simulation with performance (2,000m race time) was significant $r = -0.57$ ($p = 0.02$). It seems, from these correlations, that a higher absolute value for the use of the anaerobic energy at the start of the 2,000 meter race, is positively correlated with better rowing performance. In addition, the correlation between the 2 minute "all-out" AOD and the performance variable, 2,000m race time, showed a r value of -0.77, which was statistically significant ($p=0.0004$). It is not surprising that rowers with a higher anaerobic capacity will have greater success at the 2,000 meter race.

5.4 Implications for Rowing Performance

In order to make some inferences regarding rowing performance and certain anaerobic and aerobic variables, we looked at a correlation matrix, using 2,000 meter time as the performance variable, the 2 minute "all out" AOD test as the anaerobic variable, and max VO2 and average sustained VO2 for the 2,000m race simulation as the aerobic indices. The following correlations were found: The anaerobic capacity test (2 minutes "all-out") correlated $r= -0.77$, ($p<0.001$); max VO2, $r =-0.825$, ($p< 0.001$); sustained race VO2, $r = -0.817$, ($p<0.001$), to 2,000m race time. We can conclude that although anaerobic energy sources only contributed 12% to the total energy required to row the 2,000 meter race, in this group of oarswomen, those with high anaerobic capacities *or* high aerobic capacities performed better during the race simulation. The correlation matrix also showed that the 2 minute test AOD correlated significantly to the aerobic variables (max VO2, $r = 0.72$, $p = 0.002$; and average VO2, $r = 0.66$, $p = 0.005$). This is not a surprising finding since the sport of rowing is very much interdisciplinary in terms of aerobic and anaerobic training. It has been well documented that high aerobic capacities correlate strongly to rowing performance (Bouckaert, et.al., 1983; Carey, et.al., 1974; Cunningham, et.al., 1975; DiPrampero, et.al., 1971; Hagerman, et.al., 1972, 1968; Ishiko, et.al., 1967; Williams, 1978) but more recently they have researched the importance of anaerobic threshold training (short duration, high intensity pieces at 85% to 95% max) for rowing (Mickleson, et.al., 1982; Hagerman, 1984; Steinacker, 1993). Hagerman reports in his paper "Applied Physiology of Rowing" that, "although rowers have achieved outstanding VO2max values, their most impressive physiological attribute seems to be their ability to sustain an extremely high percentage of their absolute VO2max even after they have exceeded their anaerobic threshold levels" (Hagerman, 1984, p.308). Although there still is some controversy regarding the validity of anaerobic threshold measurements, due to what we know regarding the high intensity of the 2,000 meter race distance coupled with the research showing trained oarsmen and women having high anaerobic capacities and the ability to sustain extremely high percentages of max aerobic capacities while racing, it can be concluded that training the anaerobic system is an important factor to improve rowing performance.

5.5 Summary

In conclusion, this study determined that anaerobic / aerobic contribution in a 2,000 meter race simulation for highly conditioned female rowers is 12.3% and 87.7% respectively when measured via the AOD method. The level of intensity at which these oarswomen rowed the 2,000 meter race simulation is equivalent to approximately 91.2% of their maximal aerobic capacities (or 3.31 L/min VO2). When comparing the AOD during the 2,000 meter race simulation with the AOD of the 2 minute "all out" test, these oarswomen completely taxed their anaerobic energy stores during the 2,000 meter race.

In terms of predicting rowing performance based on various physiological variables, we found that max VO2 and average sustained VO2 (after 1 minute of exercise) are the variables that correlate highest to rowing performance. However, the 2 minute "all out" test (representing the rower's maximal anaerobic capacity) also correlated significantly to 2,000 meter test time (performance). It is the conclusion of this study that due to the intensity of the rowing race simulation, a high aerobic capacity complemented with a high anaerobic capacity would be most beneficial in racing 2,000 meters. It is the intention that findings from this study will provide both athletes and coaches with a clearer understanding of the metabolic demands of the 2,000 meter rowing race and, in addition, add to the paucity of studies examining physiological variables of highly conditioned female rowers. Future research correlating anaerobic and aerobic variables to rowing performance, using various methods of determining anaerobic capacity, would be beneficial to the oarswomen's training regime and racing performance.

BIBLIOGRAPHY

Asami, T., Adachi, N., Yamamoto, K., Ikuta, K., and Takahashi, K. (1978) Biomechanical analysis of rowing skill. Biomechanics VI - B (edited by E. Asmussen and K. Jorgensen), pp.109-14, Baltimore: University Park Press.

Astrand, P.O. and Rodahl, K. (1977) Textbook of Work Physiology. McGraw-Hill Inc. (2nd edition).

Bangsbo, J., Michalsik, L., Petersen, A. (1993) Accumulated oxygen deficit during intense exercise and muscle characteristics of elite athletes. International Journal of Sports Medicine. 14(4): 207-213.

Bangsbo, J. (1996) Oxygen deficit: Measure of the anaerobic energy production during intense exercise? Canadian Journal of Applied Physiology. 21(5): 350-363.

Bouckaert, J., Pannier, J.L., Vrijens, J. (1983) Cardiorespiratory response to bicycle and rowing ergometer exercise in oarsmen. European Journal of Applied Physiology. 51: 51-59.

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

Concept II, Inc. (1994) Ergo Update. 22(Fall): 1-15.

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

Di Prampero, P.E., Cortill, G., Celentano, F., Cerretelli, P. (1971) Physiological aspects of rowing. Journal of Applied Physiology. 31(6): 853-857.

Gastin, P.B., et. al. (1995) Accumulated oxygen deficit during supramaximal all-out and constant intensity exercise. Medicine and Science in Sports and Exercise. 27(2): 255-263.

Gaesser, G.A., Brooks, G.A. (1984) Metabolic basis of excess post-exercise oxygen consumption: a review. Medicine and Science in Sports and Exercise. 16(1): 29-43.

Gollnick, P.D. and Hermansen, L. (1973) Biochemical Adaptations to Exercise: Anaerobic Metabolism. In Wilmore, J.H. Exercise and Sport Sciences Reviews . Volume 1, pp.1-43. New York, Academic Press Inc.

Graham, T. E. (1996) Oxygen deficit: Introduction to the assumptions and skepticism. Canadian Journal Applied Physiology. 21(5): 347-349.

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

Hagerman, F.C., Hagerman, G.R., Mickelson, T.C. (1979) Physiological profiles of elite rowers. Physician and Sportsmedicine. 7(7): 74-83.

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

Hagerman, F.C., Fox, E.L., Connor, M., Pompei, J. (1974) Metabolic responses of women rowers during ergometric rowing. Medicine Science Sports and Exercise. 6(1): p.87, (abstract).

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

Hagerman, F.C., Lee, W.D. (1971) Measurment of oxygen consumption, heart rate, and work output during rowing. Medicine and Science in Sports and Exercise. 3(4): 155-160.

Hagerman, F.C., Howie, G.A. (1968) Use of certain physiological variables in the selection of the 1967 New Zealand crew. Research Quaterly. 42(3): 264-274.

Hartmann, U., Mader, A., Wasser, K., Klauer, I. (1993) Peak force, velocity, and power during five and ten maximal rowing ergometer strokes by world class female and male rowers. International Journal of Sports Medicine. 14(1): S42-45.

Hermansen, L. (1969) Anaerobic energy release. Medicine and Science in Sports and Exercise. 1(1): 32-38.

Ishiko, T. (1967) Aerobic capacity and external criteria of performance. Canadian Medical Association Journal. 96: 746-749.

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

Kramer, J.F., Leger, A., Paterson, D.H., Morrow, A. (1994) Rowing performance and selected descriptive, field, and laboratory variables. Canadian Journal of Applied Physiology. 19(2): 174-184.

Lawson, D.L. (1981) Maximal oxygen deficit as an indicator of anaerobic potential. Australian Journal of Sports Medicine. 13(3): 50-54.

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

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

McArdle, W.D., Katch, F.I., Katch, V.L. (1991) Exercise Physiology - Energy, Nutrition, and Human Performance. Lea and Febiger (3rd edition), pp. 128-137.

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

Medbo, J.I., Mohn, A.C., Tabata, J.I., Bahr, R., Vaage, O., Sejersted, O.M. (1988) Anaerobic capacity determined by maximal accumulated oxygen deficit. Journal of Applied Physiology. 64(1): 50-60.

Medbo, J.I., Tabata, I. (1993) Anaerobic energy release in working muscle during 30s to 3 min of exhausting bicycling. Journal of Applied Physiology. 75(4): 1654-1660.

Medbo, J.I., and Tabata, I. (1989) Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. Journal of Applied Physiology. 65(5): 1881-1886.

Medbo, J.I. (1996) Medbo responds to Bangsbo's paper. Canadian Journal Applied Physiology. 21(5): 364-369.

Medbo, J.I. (1996) Is the maximal accumulated oxygen deficit an adequate measure of the anaerobic capacity? Canadian Journal Applied Physiology. 21(5): 370-383.

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

Pripstein, L.P., Coutts, K. (1996) Power - oxygen uptake relationships on a rowing simulator among collegiate female rowers. Medicine and Science in Sports and Exercise 28(5): p.S68, (abstract).

Rosiello, R.A., Mahler, D.A., Ward, J.L. (1987) Cardiovascular responses to rowing. Medicine and Science in Sports and Exercise. 19(3): 239-245.

Scott, C.B., Roby, F.B., Lohman, T.G., Bunt, J.C. (1991) The maximally accumulated oxygen deficit as an indicator of anaerobic capacity. Medicine and Science in Sports and Exercise. 23(5): 618-624.

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

Secher, N.H., Vaage, O., Jensen, K., Jackson, R.C. (1983) Maximal Aerobic Power in Oarsmen. European Journal of Applied Physiology. 51: 155-162.

Secher, N.H. (1983) The Physiology of Rowing. Journal of Sports Sciences. 1: 23-53.

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

Stainsby, W.N., Barclay, J.K. (1970) Exercise Metabolism: Oxygen deficit, steady level oxygen uptake and oxygen uptake for recovery. Medicine and Science in Sports and Exercise. 2(4): 177-181.

Szogy, A., Cherebetiu, G. (1974) Physical work capacity testing in male performance rowers with practical conclusions for their training process. Journal of Sports Medicine. 14: 218-223.

Vermulst, L.J.M., Vervoorn, C., Boelens-Quist, A.M., Koppeschaar, H.P.F., Erich, W.B.M., Thijssen, J.H.H., de Vries, W.R. (1991) Analysis of seasonal training volume and working capacity in elite female rowers. International Journal of Sports Medicine. 12(6): 567-572.

Wenger, H.A., Reed, A.T. (1976) Metabolic factors associated with muscular fatigue during aerobic and anaerobic work. Canadian Journal of Applied Sport Sciences. 1:43-48.

Whipp, B.J., Snead, C., Wasserman, K. (1970) Oxygen deficit-oxygen debt relationship and efficiency of anaerobic work. Journal of Applied Physiology. 28(4): 452-456.

Williams, L.R.T. (1978) Prediction of high-level rowing ability. Journal of Sports Medicine. 18: 11-17.

Williams, L.R.T. (1976) Work output and heart rate response of top level New Zealand Oarsmen. Research Quarterly. 47(3): 506-512.

Young, I.V., Rhodes, E.C. (1991) Energy demands of a 2000 meter race simulation for national level oarswomen. Sports Training, Medicine and Rehabilitation. 2: 155-170.

Young, I.V. (1988) Energy demands of a 2000 meter race simulation for national level oarswomen. Master's thesis (University of British Columbia, Vancouver, British Columbia).

Young, I.V., Rhodes, E.C. (1986) Energy demands of a 2,000 meter rowing race for collegiate oarswomen. Medicine and Science in Sports and Exercise. 11(4), (abstract).

APPENDIX

1. Individual Characteristics of Subjects

Subjects	Age (yrs)	Wt(kg)	Ht (cm)	#years rowing
1	20.00	67.95	175.70	3.00
2	19.00	68.22	173.70	0.67
3	19.00	78.70	174.20	1.00
4	24.00	61.65	170.00	7.00
5	18.00	87.40	183.00	3.50
6	22.00	66.85	165.40	2.00
7	21.00	75.25	174.10	4.00
8	22.00	87.70	173.20	
9	19.00	74.45	178.80	4.00
10	21.00	66.80	175.90	3.50
11	21.00	80.80	178.10	3.00
12	18.00	80.40	173.15	3.00
13	19.00	72.60	179.40	3.00
14	21.00	63.95	170.00	7.00
15	23.00	74.30	173.40	4.00
16	28.00	77.75	179.70	
average	**20.94**	**74.07**	**174.86**	**3.48**
standard dev	**2.57**	**7.85**	**4.36**	**1.81**

2. 2 Minute "All-out" Test

Subjects	AOD (L)	peak pwr (watts)	avg pwr (watts)	peak heart rate (bpmin)
1	2.57	273.30	269.40	173
2	3.20	341.80	334.60	173
3	3.34	340.00	324.00	172
4	3.36	312.20	296.40	173
5	3.08	306.20	298.20	183
6	3.63	353.10	317.70	181
7	4.47	414.10	386.90	
8	4.02	340.10	332.20	162
9	2.46	291.50	283.54	208
10	2.79	322.20	309.00	182
11	2.84	307.40	299.98	159
12	3.27	360.40	341.40	
13	4.00	338.30	326.30	172
14	2.85	270.30	265.75	184
15	3.54	291.40	287.20	174
16	4.91	420.20	415.14	197
Average	**3.40**	**330.16**	**317.98**	**178**
Standard Deviation	**0.68**	**43.42**	**39.84**	**13**

3. Individual Data - Submaximal VO2 Stages

Subjects	max VO2- (highest of 2 values)	Stage 1-VO2 (L/Min)	Stage 2- VO2 (L/Min)	Stage 3-VO2 (L/Min)	Stage 4-VO2 (L/Min)
1	3.20	1.01	1.62	2.22	2.56
2	3.55	1.09	1.66	2.29	2.73
3	3.55	1.13	1.72	2.24	2.63
4	3.61	1.33	1.93	2.56	3.03
5	3.62	1.19	1.95	2.55	3.05
6	3.14	1.21	2.04	2.30	2.54
7	3.72	1.24	2.06	2.65	3.21
8	4.22	1.22	2.01	2.88	3.24
9	3.64	1.36	1.94	2.67	3.09
10	3.42	1.15	1.76	2.37	2.76
11	3.48	1.28	1.76	2.34	2.88
12	3.59	1.33	2.03	2.45	3.04
13	3.92	1.34	2.10	2.88	3.12
14	3.48	1.25	1.81	2.42	2.77
15	3.67	1.15	1.94	2.46	3.05
16	4.42	1.24	2.03	2.88	3.53
Average	**3.64**	**1.22**	**1.90**	**2.51**	**2.95**
St. Dev	**0.33**	**0.10**	**0.15**	**0.23**	**0.27**

Subjects	% of max-1	%max-2	%max-3	%max-4
1	31%	51%	69%	80%
2	31%	47%	65%	77%
3	32%	48%	63%	86%
4	37%	53%	71%	84%
5	33%	54%	70%	88%
6	39%	65%	73%	81%
7	33%	55%	71%	88%
8	29%	48%	68%	77%
9	37%	53%	73%	90%
10	34%	51%	69%	83%
11	37%	51%	67%	83%
12	37%	57%	68%	85%
13	34%	54%	73%	82%
14	36%	52%	70%	83%
15	31%	53%	67%	83%
16	28%	46%	65%	81%
Average	**34%**	**52%**	**69%**	**83%**
St. Dev	**3%**	**5%**	**3%**	**4%**

4. Individual Data- Submaximal Power Stages

Subjects	Peak Power- 2 min test (watts)	Stage 1- Power (watts)	Stage 2- Power (watts)	Stage 3- Power (watts)	Stage 4- Power (watts)
1	273.30	51.50	99.30	147.60	181.00
2	341.80	60.00	108.60	157.80	198.70
3	340.00	67.60	113.50	153.60	184.40
4	312.20	62.00	112.30	163.20	205.50
5	306.20	59.10	105.50	154.00	199.60
6	353.10	65.20	122.30	151.10	169.20
7	414.10	53.00	105.50	158.60	204.20
8	340.10	59.80	120.40	180.80	214.60
9	291.50	54.50	98.60	148.40	203.50
10	322.20	55.50	99.30	149.60	179.90
11	307.40	64.30	106.20	150.60	195.00
12	360.40	45.10	96.10	145.00	198.30
13	338.30	60.80	118.80	172.60	204.10
14	270.30	54.50	102.80	149.50	178.90
15	291.40	61.10	116.90	155.30	195.90
16	420.20	63.00	120.30	182.80	231.10
Average	**330.16**	**58.56**	**109.15**	**157.53**	**196.49**
St. Dev	**43.42**	**5.83**	**8.78**	**11.63**	**15.30**

5. Individual Data - 2,000 meter Race Simulation

Subjects	2K Time (min)	AOD (L)	Peak Power (watts)	max Heart Rate (bpmin)	max VO2 (L/min)	avg VO2 (L/min)	avg VO2 %max	2K Energy Source %aerobic	%anaerobic
1	7.77	2.45	262.50	177	3.03	2.88	95%	90.00	10.00
2	7.53	1.55	244.40	188	3.55	3.24	91%	94.00	6.00
3	7.58	1.71	240.00	186	3.55	3.28	92%	93.00	7.00
4	7.40	3.99	270.90	184	3.56	3.28	91%	85.00	15.00
5	7.47	3.85	272.90	190	3.62	3.41	94%	86.00	14.00
6	7.57	5.46	319.40	193	3.11	2.93	93%	79.00	21.00
7	7.50	4.53	297.00		3.72	3.33	90%	84.00	16.00
8	7.17	4.03	315.60	174	4.13	3.81	90%	86.00	14.00
9	7.77	1.23	266.00	209	3.64	3.36	92%	95.00	5.00
10	7.58	3.26	263.80	192	3.42	3.24	95%	88.00	12.00
11	7.40	4.92	302.90	180	3.45	3.07	88%	81.00	19.00
12	7.62	2.54	236.50		3.59	3.29	92%	90.00	10.00
13	7.25	3.77	304.20	182	3.92	3.69	94%	87.00	13.00
14	7.82	2.62	236.90	197	3.48	3.05	88%	90.00	10.00
15	7.60	6.01	255.30	187	3.15	2.93	80%	88.00	12.00
16	7.00	4.06	339.70	198	4.42	4.14	94%	87.00	13.00
Average	**7.50**	**3.50**	**276.75**	**188**	**3.58**	**3.31**	**91%**	**87.69**	**12.31**
Standard Dev.	**0.22**	**1.40**	**32.39**	**9**	**0.36**	**0.34**	**4%**	**4.36**	**4.36**