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I am submitting herewith a thesis written by Amy Jo Fletcher entitled "Predictors of Rowing Performance in Collegiate Female Rowers". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

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Predictors of Rowing Performance in Collegiate Female Rowers

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Amy J. Fletcher

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DEDICATION

This thesis is dedicated to my husband Jeremy. Without his support and encouragement, I could never have come this far.

I also dedicate this thesis to my Aunt Mary.

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ABSTRACT

Successful performance in rowing is dependent upon many factors. Physiological variables such as VO_2max, muscular strength, and lean body mass have been identified as being correlated with 2000 m ergometer time; however, the relationship between lactate concentrations and performance has not been thoroughly investigated. The purpose of this investigation was to examine the relationship between various physiological variables and performance in collegiate female rowers. Performance was evaluated by the time taken to row 2000 m on a Concept II rowing ergometer.

Nineteen collegiate female rowers served as subjects. Rowing experience varied from 3 years to 3 months. Subject's average age, height, weight and body fat percentage were 19.89 ($\pm$ 1.34) years, 167.11 ($\pm$ 6.65) cm, 67.11 ($\pm$ 5.82) kg, and 20.95 ($\pm$ 4.62) percent, respectively. A discontinuous incremental ergometer test was completed to determine oxygen consumption at the lactate threshold (VO_2@LT), VO_2 at 2.5 mM lactate (VO_2@2.5), VO_2@4.0 mM and VO_2peak. Subjects performed 1-RM lifts on the hip sled and seated rows to determine strength. Hydrostatic weighing was performed to determine percentage body fat and fat-free mass. Performance was evaluated by "all-out" 2000 m and 500 m distances on the rowing ergometer. The rowers had low VO_2peak values (2.87 $\pm$ 0.31 L/min or 42.91 ml/kg/min) in comparison with elite female competitors but were similar to other collegiate rowers. Pearson correlation coefficients reveal that 2000 m ergometer time was significantly correlated with: 500 m (r = 0.951), seated rows (r = -0.573), hip sled (r = -0.468), VO_2peak (r = -0.489), FFM (r = -0.774), height (r = -0.522), weight (r = -0.589) and VO_2@4.0 mM (r = -0.494). Ergometer times were not significantly

correlated with %VO_2peak at LT, 2.5 mM, or 4.0 mM. Multiple regression analysis found significant prediction equations from the combinations of VO_2peak and FFM ($p = 0.001$), FFM and hip sled ($p < 0.001$), FFM and rows ($p < 0.001$), FFM, rows and hip sled ($p < 0.001$), VO_2peak and rows ($p < 0.020$), VO_2peak and hip sled ($p < 0.025$) and VO_2peak, rows, and hip sled ($p < 0.045$). Combinations of VO_2peak and lactate variables did not result in R values that reached significance.

The implications of this study emphasize the importance of a high VO_2max (VO_2peak in this study) and increasing the ability to perform near this level. The results from this study strengthen support for the current training practices of rowers: training at a low intensity to optimize endurance while focusing on intermittent periods of high intensity workloads to increase anaerobic ability. Although there was a high correlation between performance and VO_2@4.0 mM lactate, the relationship between VO_2peak and VO_2@4.0 suggests that the high correlation may be a reflection of the significance of VO_2peak. Therefore, the importance of 4.0 mM lactate may be as a diagnostic tool and in prescribing training for high intensity, short duration workouts. It appears that increasing VO_2max and muscular strength (upper and lower body) would be advantageous to competitive female rowers.

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CHAPTER I

INTRODUCTION

The first collegiate rowing race took place in 1852 between Yale and Harvard (Churbuck, 1988). The teams rowed a distance of 1.5 miles and each boat consisted of six rowers with one oar each (sweep rowing) without a coxswain. Today a rowing competition may involve hundreds of athletes who compete in groups of two, four, or eight persons (with or without a coxswain) sweep rowing or one, two, or four persons sculling (using two oars with or without a coxswain). The last 150 years have brought great technological advances in boat and oar design which have had tremendous effects on rowing and performance. At the same time, there has also been much scientific research in the last 75 years to help better understand human athletic performance. Yet, the majority of research on the specific physiological requirements of rowing has only been conducted in the last thirty years and has been performed primarily using elite male rowers as subjects.

Present day rowing training programs include on-water rowing supplemented through the use of strength training, running and on-land equipment such as the Concept II cycle wheel ergometer (Concept II, Morrisville, VT). A typical rowing competition entails a 2000 meter (m) course which may be completed in 6-7 minutes for world class athletes (Steinacker, 1993). A comparable rowing ergometer test is the 2000 m sprint in which the time it takes to complete the distance is recorded. This test has become the standard for comparing individual rowers and is used nationally during rowing ergometer competitions (Ergo Update, 1995). The ergometer has an advantage over on-water training in that it is able to provide instant feedback on power,

stroke rate, and distance traveled to the rower from an electronic readout (Lamb,1989). The ergometer is also used frequently in scientific research because of the difficulty of taking measurements during on-water rowing. Although the kinematics of on-water and ergometer rowing are not identical and the ergometer does not require the same level of teamwork (Kramer et al., 1994), the rowing ergometer does simulate on-water rowing and is commonly used in scientific research (Lamb, 1989).

Rowing is a sport that is demanding physiologically and also requires high technical skill (Lamb, 1989). Rowers have demonstrated some of the highest absolute maximal aerobic power (VO_2max) values among athletes performing aerobic exercise (diPrampero et al., 1970; Hagerman et al., 1979) and a high VO_2max is an important predictor of success (Steinacker, 1993). Mahler and colleagues (1987) demonstrated training specific alterations in rowers in oxygen consumption (VO_2) and heart rate (HR) at the ventilatory threshold. Additionally, rowers have achieved very high venous lactate levels during a 6-min "all-out" test (17 mM for men and 16 mM for women) and apparently develop an ability to tolerate lactic acid (Hagerman et al., 1979). It has also been suggested that VO_2 values at a blood lactate concentration of 4.0 mM are correlated with rowing performance (Steinacker, 1993). Evaluations of strength such as the one repetition maximum (1 RM) leg press and bench pull are also highly correlated with 2500 meter (m) time (Kramer et al., 1994). The extent to which each contributes to successful rowing performance has not been thoroughly quantified, especially in the female rower.

In the past, the predominant factor in predicting running performance has been VO_2max, but today it is more widely accepted that success can be determined through the lactate threshold. The onset of plasma lactate

accumulation is found to be more highly correlated with long distance running performance than VO_2max (Farrell et al., 1979). It has also been shown that the lactate threshold is more highly correlated with 5 km and 10 km running performance than VO_2max (Kumagai et al., 1982; Tanaka et al., 1984).

PURPOSE

The purpose of this investigation was to examine the relationship between various physiological variables and performance in collegiate female rowers. Performance was evaluated by the time taken to row 2000 m on a Concept II rowing ergometer (Morrisville, VT). These relationships provide greater knowledge of factors affecting performance and may be useful in planning training programs.

HYPOTHESES

1. The power output at lactate threshold, VO_2max, fat-free mass, and maximal strength on the hip sled and seated rows will all correlate highly with rowing performance.
2. The power output at lactate threshold, 2.5 mM and/or 4.0 mM lactate levels will be more highly correlated with performance than VO_2max.

DEFINITION OF TERMS

Lactate Threshold (LT) - the point during a graded exercise test when the blood lactate concentration increases abruptly above resting levels.

VO_2max (maximal oxygen uptake) - greatest rate of oxygen uptake by the body measured during severe dynamic exercise. VO_2max criteria include 1) a leveling-off of oxygen uptake with an increase in work rate, 2) a heart rate that is

± 10 beats/min within the subject's predicted max heart rate, and 3) a respiratory exchange ratio (RER) > 1.15 (Powers and Howley, 1994).

VO_2peak (peak oxygen uptake) - highest value of oxygen consumption measured during an exercise test.

VO_2@LT - the oxygen consumption corresponding to LT during an incremental rowing ergometer test.

VO_2@2.5 mM - the oxygen consumption corresponding to a lactate concentration of 2.5 mM during an incremental rowing ergometer test.

VO_2@4.0 mM - the oxygen consumption corresponding to a lactate concentration of 4.0 mM during an incremental rowing ergometer test.

CHAPTER II

REVIEW OF LITERATURE

Successful performance in any sport, including rowing, is dependent on many different factors. Various physical fitness variables such as cardiorespiratory endurance, muscular strength and endurance, flexibility, and body composition may play a role in athletic performance. The degree to which each affects performance may help shape and improve training techniques which, in turn, leads to better performance and a more successful rower.

ROWING ERGOMETER

The rowing ergometer is a device which simulates the rowing motion. It is used by the majority of rowing teams as a training tool to supplement on-water rowing (Concept II, 1995). The rowing ergometer may also serve as a substitute for on-water training during times of inclement weather or injury. These machines have an advantage over on-water rowing in that they are stationary and are able to provide instantaneous feedback to the athlete (Lamb, 1989). Physiologic measurements from rowing ergometers are also used by the United States Rowing Association as a part of their selection process for national rowing teams (Lamb 1989).

Concept II and Gjessing Rowing Ergometers

The use of the rowing ergometer for measuring work capacity was first introduced in 1971 (Hagerman and Lee, 1971). The two major types of rowing ergometers used in scientific research are the Gjessing (MICROW, Halden, Norway) and Concept II (Concept II, Morrisville, VT). The Gjessing ergometer is a mechanical, friction braked ergometer in which the handle is guided straight

backwards and forwards by a bar attached to the "oar" handle (Martindale and Robertson, 1984). This type of rowing ergometer is commonly used in European rowing clubs and in research (Steinacker et al., 1986). The Concept II rowing ergometer is a variable resistance ergometer which incorporates a chain and pulley with an air-resistance flywheel. The ergometer provides variable resistance based on the number of revolutions of the flywheel. The Concept II is more commonly used in training and research in the United States. According to experienced oarsmen and oarswomen, the Concept II rowing ergometer provides a better simulation of actual rowing than the fixed resistance rowing ergometer (Hagerman,1984).

To investigate the test specificity of the rowing ergometer, comparisons were made between maximal oxygen uptake measurements taken while rowing the Gjessing and Concept II rowing ergometers and during on-water rowing (Chenier and Leger, 1991). Fourteen regional and national rowers underwent incremental testing on the two ergometers to determine VO_2max. On-water VO_2max was determined when sculling by the average of three 4-minute trials at maximal speed. The VO_2max values obtained for each test were not significantly different from each other. Correlation coefficients comparing VO_2max values were 0.92 (Concept II vs. Gjessing), 0.93 (Gjessing vs. scull) and 0.96 (Concept II vs. scull). It was concluded that the determination of VO_2max using rowing ergometers was a valid assessment of on-water maximal aerobic power.

Comparison of On-Water and Rowing Ergometry

A study by Lamb (1989) compared the kinematic variables between on-water and ergometer rowing. Thirty male subjects of potential National Heavyweight Rowing Team caliber were videotaped while rowing on a Stanford

Rowing Ergometer (Robert Austin Co.) and during on-water rowing in an eight person shell. This type of rowing ergometer is designed to simulate the technique and feel of on-water sweep rowing in an eight-oared shell. Comparison of the two films indicated that the kinematics were similar for both the trunk and leg components of the rowing movement; however, there were significant differences between the upper and lower arm components. The differences were possibly due to the fact that during simulated rowing there is no slippage of the oar in the water and also to the lack of "feathering" during simulated rowing which does occur on the water. Despite these differences, the author concludes that ergometer rowing simulates on-water rowing.

Urhausen and colleagues (1993) investigated the heart rate, blood lactate and catecholamine response during ergometer and on-water rowing. Seven subjects rowed in a single scull at a "low" intensity and "high" intensity (pre-determined) for a duration of 20 minutes each. Subsequently, they performed two ergometer rows of the same duration and at the same heart rate as during the on-water row. Within 60 seconds after all bouts of exercise, blood was drawn from the forearm and later analyzed for catecholamines and lactate. Heart rate, lactate and epinephrine were not significantly different for ergometer and on-water trials; however, plasma norepinephrine was slightly higher during ergometer rowing at both intensities. From the above studies, it appears that the physiological response to ergometer rowing is quite similar to that seen during on-water rowing.

Rowing Ergometer and Scientific Research

Because rowing is performed in a boat with up to eight rowers, it is difficult to perform scientific research on the water. Researchers have found it difficult to collect the needed data as well as isolate an individual's contribution

to the group effort (Kramer et al., 1994). Rowing ergometers incorporate the same basic movements as on-water rowing although they are not kinematically identical to on-water rowing (Lamb, 1989; Martindale and Robertson, 1984). The rowing ergometer is able to simulate the rowing motion and produce comparable physiological responses as on the water (Chenier and Leger, 1991; Urhausen et al., 1993). Mahler et al. (1983) concluded that "physiologic parameters during simulated rowing on the ergometer generally reflect rowing performance." Therefore, the rowing ergometer is the best available tool for simulating rowing in the laboratory and is valid for use in scientific research.

ROWING STRATEGY

Rowers have a unique style of pacing which is quite different from other endurance athletes. Rowers begin their race with a burst of effort and a sprint for the first 30-40 strokes with a stroke rate of 40-50 strokes/min (Hagerman et al., 1979; Mahler et al., 1984). They then reduce their stroke rate to approximately 30-40 strokes/min for the majority of the race until the last 300-400 m when they will begin their final sprint to the finish. The coxswain may also order intermittent bursts of power throughout the race to quickly pass other boats. Measurement during a 6-min "all-out" test has revealed that oarsmen and women work at 96-98% of their maximal aerobic power which is comparable to the physiological demands of on-water rowing. Many scientists consider rowing to be one of the most physiologically demanding endurance sports (Hagerman et al., 1979).

TESTING PROTOCOLS

The specific pacing and strategy of the rowing race has led some investigators to adapt the 6-min "all-out" (6M-AO) rowing ergometer test for physiological assessment in the laboratory (Hagerman et al., 1979). Another protocol used to measure physiological parameters during simulated rowing is a progressive incremental (PI) exercise test to exhaustion (Mickelson and Hagerman, 1982). During this test, a subject begins rowing at a low intensity (35 km/hr) for a 5 min warm-up. After the warm-up, the subjects increase the intensity by 3 km/hr every 3 min until exhaustion . A study by Mahler et al. (1994) investigated the physiological differences between the two tests. A 6M-AO test and a PI were performed by 12 lightweight men from the 1983 United States National Team. Measurements of peak power and ventilatory components were recorded during both tests. The results from both tests were nearly identical for peak measurements of power, oxygen consumption, minute ventilation, carbon dioxide production and heart rate; however, the time at which these values were reached were different for the two tests. Peak values were achieved during the first 1-2 min of the 6M-AO test and during the last 2 min of the PI test. The researchers conclude that either test may be used for evaluation of rowing performance; however, the PI protocol allows for the determination of when specific changes in metabolism take place (i.e., anaerobic threshold). Researchers are therefore able to compare results obtained from either of these testing protocols.

A discontinuous incremental rowing ergometer test has also been used successfully in assessing the physiological response to rowing (Weltman et al., 1994). The protocol consists of 3 min of exercise and 1 min of rest in-between each stage. The initial rowing pace is set so that 500 m can be completed in 2.5

min. Thereafter the intensity is increased by completing the 500 m in 5 fewer seconds. The period of rest allows for the sampling of blood for determination of lactate concentrations. This discontinuous protocol has advantages over the continuous test in that it allows for the determination of the lactate curve; however, the major disadvantage is that a true "max" may not be achieved due to the duration of the exercise test (>30 min).

Investigators have found the contribution of aerobic metabolism to account for 70% and anaerobic metabolism to account for 30% of the total energy required during the 6M-AO rowing test (Hagerman et al., 1978; Hagerman et al., 1979; Secher, 1993). The contribution of aerobic and anaerobic metabolism to rowing has been addressed during the 6M-AO test which may be a shorter time limit than actual 2000 m rowing time for some smaller boats (7.3 min) (Secher, 1993). This may overestimate the contribution of anaerobic metabolism. However, the anaerobic energy contribution is very important for the initial sprint at the start of the race, the intermittent bursts of power required throughout the race, and the final sprint at the end of the race.

TRAINING

The main focus of training for the rower is on improving technique and aerobic fitness (Mahler et al., 1985). This is done mainly by on-water workouts supplemented with on-land training on the rowing ergometer, running, and weight lifting. The competitive season for rowing consists of long endurance races of up to 5000 m during the fall months and the 2000 m sprint during the late spring and early summer. Highly competitive rowers train throughout the year with a concentration on aerobic conditioning and weight lifting during the fall and winter months and increasing anaerobic workouts during the spring and

summer. Due to the differences in seasonal training foci, rowers have demonstrated seasonal variability in rowing technique and fitness level (Mahler et al., 1984; Mahler et al., 1985).

Seasonal Changes

Mahler et al. (1984) studied the physiological changes due to training that occurred during seven months prior to competition. The subjects were eight male candidates (average age = 26 $\pm$ 3 years) for the 1983 US Men's National Sculling Team. Testing was performed in December 1982, March 1983 and June 1983 and the final competition taking place in August, 1983. Physiological variables were measured during progressive, incremental exercise tests to exhaustion performed on the Concept II rowing ergometer. The results indicated progressive significant increases in absolute VO_2max which is reflective of the improvements in aerobic power due to training. The anaerobic threshold (AT), as a percentage of VO_2max, was significantly changed from December to June; however, AT did not significantly increase from December to March but did significantly increase from March to June. The results are indicative of the seasonal changes of training with more intense exercise shifting the AT to a higher percentage of VO_2max. It may be important to note that these subjects trained in the northeastern section of the United States in which outdoor training was impossible during the late fall and winter months. These rowers follow the traditional training pattern of aerobic training in the winter and more anaerobic workouts during the warmer weather in spring.

A similar study by Mahler et al. (1985) looked at physiological changes that occurred due to training in female collegiate rowers. Seven female varsity rowers completed the same testing as the males (Mahler et al., 1984), but the testing was conducted in November, February and May because the season for

collegiate rowers traditionally ends in mid to late May. The results indicate a significant increase in absolute VO_2max from February to May and November to May; but the increase was not significant from November to February The greatest increase in VO_2max in these athletes occurred during a training period when the rowers trained at high intensity and short duration. The %VO_2max at the anaerobic threshold decreased significantly from November to February and significantly increased from February to May; but the slight increase from November to May was not significant. The female rowers' AT as a percentage of VO_2max did not increase as significantly over the six month time period as was evident in the males of Mahler's prior study (Mahler et al., 1984). However, the absolute value of VO_2 at the anaerobic threshold did increase significantly from November to May in the female rowers, which paralleled the increase in VO_2max. Even though the percentage of max at the AT did not change significantly, the absolute VO_2 at the AT was higher after training which is evidence of adaptation. Peak power production was also significantly increased from November to May. For both the male and female rowers studied, the changes in VO_2max and anaerobic threshold are indicative of the switch from aerobic to anaerobic training emphasized over a six month time period.

Vermulst et al. (1991) studied the seasonal changes in training volume and working capacity variables in elite female rowers. The rowers were tested over a 9 month period from December to August at intervals of approximately 5 weeks. The testing, conducted on the Gjessing rowing ergometer, involved a 3 minute warm-up, 5 minutes of rowing at a rate which approximated a lactate response of 4.0 mM, and a final two minutes of maximal exertion. Blood lactate values were taken at rest, after the 5 minute 4.0 mM pace, and after the maximal bout. Two performance variables were analyzed from this test: the power at 4.0

mM lactate (P4) and the power achieved during the last two minutes of testing (PM). Also investigated was daily training time, including rowing and on-land training. There was a significant increase in training volume and rowing training volume by the third test date, which continued to the end of testing. P4 and PM also significantly increased when comparing initial and final values; however, the increase in P4 was more profound than the increase in PM. The authors found that the increase in P4 was related to the increase in training volume, but PM did not reflect the same increase. These findings reflect the seasonal changes in training that occur in elite oarswomen even though the changes in maximal values were less than the 18% increase in peak power observed by Mahler et al. (1985) who tested female college rowers. Vermulst et al. (1991) speculate that the evaluation of training volume in elite female rowers is better done through a lactate response of 4.0 mM than maximal aerobic power.

Seat Position Variations

It is interesting to note that physiological changes due to training may be somewhat dependent upon the position one holds in the boat. Roth et al. (1993) investigated 16 highly trained rowers on the stroke biomechanics in a coxless pair and physiological data from a multistage lactate threshold test. Additionally, morphological data from muscle biopsies from the left deltoideus and pars medialis were analyzed from 10 of the 16 rowers. During low intensity rowing, the power was the same for both seat positions but lactate was higher and blood pH was lower in the stroke position (port). During high intensity rowing, the differences remained with significantly higher power and stroke velocities generated by the stroke rowers. The lactate threshold occurred at a lower intensity in the stroke rowers compared with the bow rowers. Morphological data showed that there were lower percentages of slow-twitch fibers and fast twitch

oxidative fibers and higher percentages of fast twitch glycolytic fibers in the stroke rowers. The biomechanical data showed that the stroke rowers had a faster increase in force and a faster velocity in the first half of the stroke which may lead to increased activation of fast twitch fibers or to higher activation of the glycolytic metabolism of the fibers. However, specific alterations in fast-twitch fiber differences could be dictated by the arm and grip positions which are different for stroke and bow rowers and in this investigation, all subjects were analyzed from the left arm. The results indicate a possible self-selection for the boat positions in athletes rowing a coxless pair and training modifications that have taken place over years of training

PHYSIOLOGICAL ASPECTS OF ROWING

A typical rowing distance is the 2000 m sprint which takes approximately 6.5 minutes (ranges from 5.8 min for eights to 7.2 min for a pair) for world class men and 6.6 minutes (range from 5.9 to 7.3 min) for elite women to complete (Secher, 1993) . Rowers work at their near maximal capacities for the entire duration of the race. The majority of research investigating the physiological aspects of rowing has been conducted through the use of a rowing ergometer on a 6 min "all-out" test or an incremental exercise test on elite oarsmen (Mahler et al., 1984). Research on oarswomen has also been conducted, but prior to the mid 1980's, women were tested for 3 min and competed at a distance of 1000 m (Hagerman et al., 1979; Mahler et al., 1984). Today both men and women rowers compete at a distance of 2000 m (Ergo Update, 1995).

Physical Characteristics of Rowers

The age range for international rowers is typically between 18-36 years (Hagerman et al., 1984). Rowers tend to be tall, lean and have relatively low

body fat percentages. The physical characteristics of elite oarsmen have often been compared with those of elite runners (diPrampero et al., 1970; Larsson and Forsberg, 1980); however, rowers do tend to have higher body fat percentages and weigh more. Data collected from the late 1970s demonstrated that the average height, weight, and body fat percentage for elite heavyweight oarsmen was 193 cm, 88 kg, and 11.0% respectively and elite oarswomen averaged 173 cm in height, 70 kg in weight and ranged between 12-25% body fat (Hagerman et al., 1979), which appears to still be the norm today (Beneke, 1996; Secher, 1993). Research on the muscle characteristics of female elite rowers have demonstrated 61% slow-twitch fibers in the vastus lateralis and 54.4% in the biceps brachii (Clarkson et al., 1983). Muscle biopsies of highly competitive male rowers indicate a very high percentage of type I muscle fibers (70-74%) with large mean fiber areas and high capillary densities (Larsson and Forsberg, 1980). This high percentage of slow-twitch fiber composition in elite rowers suggests self-selection by these athletes for endurance events. In the same study (Larsson and Forsberg, 1980), it was discovered that of the 26-30% fast twitch fibers, almost all were type IIa indicative of an adaptive response to endurance training.

Aerobic Capacity

Male rowers have demonstrated some of the highest absolute maximal aerobic energy expenditure values among Olympic athletes of all sports (diPrampero et al., 1970), with VO_2max values among the highest recorded (Hagerman et al., 1978; Jackson and Secher, 1976; McKenzie and Rhodes 1982; Secher et al., 1983; Steinacker, 1993). Hagerman (1979) found VO_2max levels of 6.1 L/min for heavyweight men and 4.1 L/min for women. Although the absolute values are quite high, when maximal oxygen uptake is measured in

relation to body weight (ml/kg/min), the values are well below that attained for other endurance athletes (Hagerman, 1984). The higher body weight of rowers allows for gains in strength which compensate for the extra energy cost of rowing caused by greater water resistance due to the boat sitting lower in the water (Larsson and Forsberg, 1980).

Rowers perform at a high percentage of their VO_2max during competition, which suggests that the cardiovascular and respiratory systems are working at near maximal levels. Pulmonary ventilation has been found to be a linear function of VO_2 during rowing ergometry in Olympic male rowers (diPrampero et al., 1971) and in non-trained male and female subjects (Hagerman et al., 1988) up to a certain point at which hyperventilation occurs (ventilatory threshold) (Secher, 1993). The mean pulmonary ventilation in a group of 8 male members of the national team was 200 L/min with one athlete reaching as high as 223 L/min during the final minutes of work (McKenzie and Rhodes, 1982). Such high pulmonary ventilation values found in rowers is in dispute with researchers that have found decreased pulmonary ventilation during rowing when comparing rowing ergometry with cycle ergometry (Cunningham et al., 1975; Mahler et al., 1987) and suggest that the cramped position of the body during rowing may limit pulmonary ventilation (Cunningham et al., 1975). Other researchers have not found differences between pulmonary ventilation between cycle and rowing ergometry (Bouckaert et al., 1983; Hagerman et al., 1988)

The cardiovascular response to rowing has been thoroughly described in a paper by Rosiello et al. (1987). Eleven males and 10 females varying in rowing experience from none to competitive underwent a maximal incremental test and testing at three sub-maximal levels of exercise on the Concept II rowing ergometer. There was a linear relationship between cardiac output and oxygen

consumption for both men and women. This same relationship is seen in other modes of exercise (Powers and Howley, 1994). Stroke volume (SV) increased initially and then leveled off, again like other types of exercise in the male subjects. However, the SV decreased significantly in the female subjects after reaching a plateau. The authors suggest that this may be due to working at a higher percent of VO_2max than the male subjects at this given stage, or that a steady state of exercise was not achieved; the latter is necessary for accurate measurements of cardiac output.

Comparison Studies of Rowing with Other Exercise Modes

Oxygen consumption has been found to be higher during rowing ergometry than other forms of exercise at the same submaximal power output (kgm/min) due possibly to the larger muscle mass involved of the upper and lower extremities (Hagerman et al., 1988; Bouckaert et al., 1983). However, two comparison studies have found the same maximal oxygen consumption during rowing and treadmill exercise in a group of five male collegiate rowers (Carey et al., 1974) and in a group of ten competitive male rowers (Weltman et al., 1994).

Comparisons have also been made between rowing and cycle ergometry, both non-weight bearing activities. Rowers achieved the same VO_2max values during rowing and cycling (Bouckaert et al., 1983; Cunningham et al., 1975) but control subjects achieved higher VO_2max values while cycling (Bouckaert et al., 1983). Another researcher found higher VO_2max values during cycling than rowing in competitive oarswomen and oarsmen (Mahler et al., 1987). However, Mahler's study on oarswomen found higher VO_2 at the ventilatory threshold which may be indicative of metabolic adaptation not evident by VO_2max (Mahler et al., 1987). Another investigation by Steinacker et al. (1986) found that rowers had slightly higher VO_2max values on the rowing ergometer than on the cycle

ergometer but the differences were not significant. It appears that oarsmen and women adapt to training which is evident while rowing but not necessarily during other forms of exercise.

Heart rates have been found to be higher during rowing at the same submaximal power output and/or oxygen consumption when comparing rowing and cycle ergometry in non-rowers (Hagerman et al., 1988), rowers with varying ability (Rosiello et al., 1987) and in both experienced rowers and inexperienced controls (Mahler et al., 1987). Rosiello et al. (1987) also found that heart rate was significantly higher and stroke volume significantly lower on the rowing ergometer at the same submaximal exercise intensities (up to 83% VO_2max) when comparing cycle and rowing ergometry. This suggests that there is a greater reliance upon the increase in heart rate than the stroke volume response during rowing.

Lactate Response to Rowing

The lactate response to a graded exercise rowing ergometer test appears to be the same as during other modes of exercise (Weltman et al., 1994; Beneke, 1996); lactate levels remain constant at lower work intensities and then begin to increase exponentially. The power output at the point where this transition takes place is called the lactate threshold. Weltman et al. (1994) studied the lactate and catecholamine response of ten male collegiate rowers to a discontinuous incremental exercise test on the rowing ergometer and treadmill. Peak VO_2 levels did not differ between the two modes of exercise; however, the lactate threshold occurred at a lower VO_2 during rowing than running. This is unusual because typically, one's LT occurs at a higher VO_2 in the mode on which one is trained.

Lactate formation

Glycolysis, which occurs in the cytoplasm of the cell, produces NADH (reduced form of nicotinamide adenine dinucleotide - NAD^+), ATP, and pyruvate. NADH may enter the electron transport system in the mitochondria where oxygen is the final electron acceptor. The generated ATP is used directly by the muscle cell. Pyruvate is converted into Acetyl-CoA to begin aerobic metabolism through the Krebs Cycle. Pyruvate may also react with the enzyme lactate dehydrogenase (LDH) and with the coupling of the conversion of NADH to NAD^+, lactate is formed. Lactate production increases when the cells need for ATP is elevated and aerobic sources do not fully meet this requirement. NADH begins to accumulate in the cytoplasm and in order for glycolysis to continue, NAD^+ must be resythesized by the conversion of pyruvate to lactate (Stainsby et al., 1991; Powers and Howley, 1994). Lactate is also produced by glycolytic fast twitch cells in which the enzymatic activity of LDH leads to the production of lactate (Powers and Howley, 1994).

At rest, lactate is produced by all cells undergoing glycolysis. However, lactate does not accumulate in the blood because the body is able to metabolize the lactate that is produced (converted into glycogen in the liver, or used as a source for ATP resynthesis) so that the rate of removal equals the rate of production (McArdle et al., 1991). During strenuous exercise, the energy demands may not be completely met by aerobic means; therefore the rate of glycolysis is increased and subsequently more lactate is produced. At these higher exercise intensities, the rate of appearance of lactate is greater than the rate of clearance and lactate begins to accumulate in the blood (Powers and Howley, 1994).

Effects of lactate on performance

Lactic acid, which dissociates into lactate and hydrogen ions, accumulates in the blood during strenuous exercise and contributes significantly to the challenge in maintaining pH during exercise. Hydrogen (H^+) ions attach to molecules altering their size and shape and thus changing the normal function of enzymes. The increase in H^+ concentration (decrease in pH) can impair exercise performance in two significant ways: 1) H^+ ions reduce the muscle cell's ability to produce ATP by inhibiting key enzymes involved in anaerobic and aerobic metabolism and 2) H^+ ions compete with calcium ions for binding sites on troponin hindering the contractile process (Powers and Howley, 1994).

Lactate and training

Lactate concentrations have been used to define and monitor training. Hartmann et al. (1990) studied a group of 40 elite male rowers during training. For every training exercise, blood samples were taken, heart rates were monitored and the length of the session was recorded. These results were used to divide the different training exercises into four categories of lactate accumulation: 1) > 8 mM; 2) 4 mM - 8 mM; 3) 2 mM - 4 mM; and 4) < 2 mM. This system was used to evaluate the training load over the year. The majority of training (70- 90% depending on the time of year) was done at a lactate concentration less than 2 mM. Only about 2-8 % of the training was done at a lactate concentration above 4 mM. The authors state that the results found are in conflict with other theories that conclude that endurance training is only effective at a lactate concentration between 2.5 - 3.5 mM and 4.0 mM. They further state that for rowing, long distance endurance training at an intensity corresponding to 4.0 mM lactate can not be justified. This conclusion is in conflict with other researchers who suggest that high intensity training is vital in

the seasonal changes observed in rowers (Mahler et al., 1984; Mahler et al., 1985; Vermulst et al., 1991).

Anaerobic threshold

The lactate response has become an important tool for monitoring and prescribing training protocols for rowing. Several investigations have utilized the anaerobic threshold as an estimate of the onset of lactic acid accumulation. Anaerobic threshold (AT), which is sometimes linked with the ventilatory threshold (the disproportionate increase in ventilation during incremental exercise), is a non-invasive method of estimating the point at which there is a "rapid and systematic increase in blood lactate concentration" (Powers and Howley, 1994). The AT is identified by specific alterations in gas exchange (point at which a nonlinear increase in ventilation and CO_2 production occurs as well as an increase in end-tital O_2 without a corresponding decrease in end-tital CO_2) (Wasserman et al., 1973). However, some researchers also define AT as 4.0 mM blood lactate (Beneke, 1995). The AT is not well defined and researchers use the term "anaerobic threshold" to represent different physiological events. Also, the term "anaerobic" implies that there is a lack of oxygen in the working muscles which is disputed (Stainsby, 1986; Powers and Howley, 1994). Nonetheless, in the sport of rowing anaerobic threshold tests have been recommended for use in evaluating fitness levels and as a method of determining the effectiveness of various training programs (Mickelson and Hagerman, 1982).

Mickelson and Hagerman (1982) measured the ventilatory changes during a progressive incremental ergometer test of 25 nationally competitive oarsmen. AT was determined by the gas exchanged variables defined by Wasserman et al. (1973). They found that the oarsmen had an average AT of

83% VO_2max. The authors suggest that this high percentage of VO_2max may be attributed to the specific training regimens used by rowers to increase endurance capacity of muscle fibers and the cardiorespiratory system.

LACTATE THRESHOLD AND OTHER BLOOD LACTATE CONCENTRATIONS AS PREDICTORS OF RUNNING PERFORMANCE

The sport of distance running, like rowing, is based on endurance. Investigators have found that VO_2max is an important predictor for middle and long distance running performance (Costill, 1967); however, the focus has recently switched away from VO_2max toward the lactate response. Farrell et al. (1979) investigated laboratory and field assessments on eighteen male distance runners for distances of 3.2, 9.7, 15, 19.3, and 42.2 km. They reported higher correlations between the treadmill velocity corresponding to the onset of plasma lactic acid (OPLA) and performance than VO_2max and performance at all distances. The investigators conclude that "runners appear to set a race pace which allows the utilization of the largest possible VO_2 which just avoids the exponential rise in plasma lactate". Another investigation by LaFontaine et al. (1981) compared the relationship between the maximal steady state (MSS-oxygen uptake, heart rate and/or treadmill velocity at which plasma lactate concentration is 2.2 mM) and various running distances in seven male runners. Significant correlations were found between MSS and all distances greater than 402.3 m. An investigation of 19 untrained female subjects compared lactate parameters of LT (VO_2 at which blood lactate begins to increase above the resting level), LT1 (VO_2 at which blood lactate increases 1 mM above resting values), LT2 (VO_2 at which blood lactate increased 2 mM above resting values), and OBLA (VO_2 at which blood lactate reached 4.0 mM) with 12 minute run

performance (Yoshida et al., 1987). All lactate parameters were more highly correlated with performance than VO_2max. The researchers concluded that "the lactate threshold is the best index for aerobic capacity and endurance running performance".

Training At the Lactate Threshold

Training at and above the lactate threshold resulted in significant improvements in VO_2max (Yoshida et al., 1982) and in the VO_2 at the lactate threshold (Henritze et al., 1985). Yoshida et al. (1982) investigated the changes that took place over an eight week training program in seven healthy male college students exercising at an intensity corresponding to a lactate concentration of 4.0 mM on a Monark cycle ergometer. The subjects trained for 15 minutes, 3 days per week. The subjects significantly improved in VO_2max and the VO_2 at 4.0 mM increased significantly. Henritze et al. (1985) performed a similar study on college women. The subjects exercised at LT (n=12) or above LT (n=11) 5 days a week for 12 weeks on a Monark cycle ergometer. No significant improvements in VO_2max were found in either group but the VO_2 at LT increased significantly by 48% in the group training above the LT. The improvements at LT may be more closely linked to performance than improvements in VO_2max. In running, improved performance may come from the ability to work at a higher percentage of VO_2max. Thus, the shifting of the lactate breakpoint to a higher intensity may reflect improved performance due to the ability to sustain a higher work rate during competition (Farrell et al., 1979).

ROWING PERFORMANCE

There is limited research available on predicting rowing performance from physiological variables. This may be due to the fact that many variables may

contribute to rowing performance, including psychological factors such as "self-awareness, self-motivation, mental strength and team membership which are necessary to withstand training and to be successful in competition" (Steinacker, 1993).

Physiological and Psychological Variables

Williams (1978) investigated various physiological as well as psychological variables associated with rowing ability. Thirty-three male trialists for the 1973 New Zealand Colts Rowing Team (mean age = 20.3 years) were evaluated on a 6-min maximal ergometer test which measured heart rate, work output, and stroke rate. A strain gauge apparatus was used to measure leg and back strength and anthropometric data of height, weight, skinfolds, bone diameters, and muscle girth measurements were also recorded. Additionally, subjects completed a psychological test which produced 16 psychological variables. The criterion for rowing ability was determined by 5 experienced judges who ranked each oarsman on the basis of rowing ability independent of boat position. This method was found statistically valid.

A stepwise regression analysis using combinations of the variables produced the following equation:

Y = 186.5 + 1.66(PFI) -1.36(PFC) - 1.19(PFQ2) - 1.16(PFM) - 0.98(PFL) - 0.36 (HR6) - .20 (REV12) - 0.01 (TOT.STR)

Where: HR6 = heart rate for the last minute of ergometer exercise
REV12 = number of flywheel revolutions during the last 30 sec. period of ergometer exercise
TOT.STR = total strength
PFI = tough-minded vs. tender-minded
PFC = emotionally less stable vs. emotionally stable
PFQ2 = group dependent vs. self-sufficient
PFM = practical vs. imaginative
PFL = trusting vs. suspicious
*(PF variables correspond to factors from the psychological test)

The equation was examined for validity by comparison with actual selection of the 1973, 1974 and 1975 Colts teams. The average success of the equation in predicting selection was 59.7 % and predicting rejection 72.7 %. This research supports the combined use of physiological and psychological variables for prediction of top-level athletic ability.

Strength

Williams' investigation (1978) found leg and back strength to be a factor in predicting success. Yet, another study revealed that strength tests on a variety of muscle groups were not statistically significant factors associated with outstanding rowing performance in a group of Olympic trial rowers; however, it was stated that the chosen Olympic rowers were stronger than the nonselected and that the slight strength difference may have aided in their selection (Hagerman et al., 1972). An investigation by Kramer et al. (1991) studied the relationship between isokinetic knee extensor strength at two angular velocities (160 and 200 deg/sec) and performance on 15 male lightweight rowers. The correlations were low and non-significant ($r = -0.26$ to -0.43, $p>0.05$). Rodriguez et al. (1990) analyzed the rowing stroke of five male rowers and found "the strength of an individual muscle is most likely not as important to the rowing stroke as the combined activity of two or more groups of muscles". Kramer et al. (1994) demonstrated that 1-RM leg press and bench pull correlated highly ($r = 0.57$ and 0.52, $p<0.05$) with 2500 m ergometer rowing time. It appears that isotonic strength may play a role in rowing performance but this has not been fully quantified.

VO_2max

Secher et al. (1982) studied the relationship between on-water rowing performance and the maximal aerobic power of 37 international oarsmen.

VO_2max was determined during uphill running or on a bicycle ergometer. Two performance criteria were used as indicators of rowing performance: the final placing in the European championship regatta and the time difference at the finish line between the crews in a 2000 m race. The relationship between the final placing and absolute VO_2max values was significant (r = 0.87). An average time delay of 6 seconds was associated with a VO_2max value that was 0.54 L/min less than the winning team. The researchers conclude that oarsmen should have considerable VO_2max values (> 6.1 L/min) to meet the metabolic demands of international competition.

Investigations on Oarswomen

Kramer et al. (1994) determined the relationships between measures of rowing performance and various descriptive, field and laboratory variables in collegiate oarswomen. Twenty female rowers ranging in experience from international to novice were evaluated. Rowing performance was determined by three criteria: the time to complete a 2500 m rowing ergometer test, years of competitive experience and coach's ranking. Various anthropometric variable such as height, weight, arm length and sitting height were taken as descriptive variables. Field variables included strength and endurance tests of the leg press and bench pull, and a 90 s ergometer distance. Isokinetic knee extension tests and a progressive stepwise test on a Concept II rowing ergometer, measured VO_2max and maximum heart rate, were analyzed as laboratory variables. Correlation coefficients between the rowing performance criterion and the descriptive, field, and laboratory variables were determined. Descriptive variables (age, height, mass, years rowing experience, arm length, and sitting height) and laboratory variables (HRmax, concentric and eccentric peak torque, and concentric and eccentric work) correlated poorly (r <0.40) with rowing

performance. The exception was VO_2max which correlated highly ($r = -0.77$) with 2500 m time and was found to be statistically significant ($p<0.01$). Strength tests correlated modestly with rowing performance ($0.41 < r < 0.69$) and were found to be statistically significant ($p<0.05$). Correlations between the variables and rowing performance criterion (2500 m time, coach's ranking, and rowing experience) were quite similar because they are all interrelated and may predict the other. Multiple linear regression was used to determine the two variables that could best predict 2500 m ergometer time. The results indicate that the combination of experience and VO_2max accounted for 75% of the variance in 2500 m time which was statistically significant ($p<0.01$). This research again supports VO_2max as an important factor in predicting rowing performance in female oarswomen of varying degrees of experience.

CHAPTER III

METHODS

This investigation was approved by the Institutional Review Board of the University of Tennessee prior to any research. Each subject completed an informed consent (Appendix A) and health history questionnaire (Appendix B) prior to participation.

SUBJECTS

Nineteen female subjects, ages 18 to 22, from the University of Tennessee Women's Crew volunteered to participate in this study. The rowers consisted of both varsity and novice rowers with at least 3 months of rowing experience. The subjects were tested in the spring, during the mid to late competitive season of the first year as a varsity sport. The subjects' weekly training regimen consisted of approximately nine hours on-water rowing, three hours strength training, and an additional fours hours of running, stair climbing or swimming. Each subject was tested for VO_2peak, lactate threshold, 2000 m and 500 m time, strength, and body composition.

METHODS

Testing was performed on three separate days and the order of testing was randomly assigned. All tests were completed within four weeks. On the three test days, one of the following was performed: (1) incremental test for lactate threshold and VO_2peak; (2) strength testing and 2000 m time; and (3) body composition and 500 m time. Each subject reported to testing in a rested state and having refrained from exercise for the previous 12 hours. Strength

testing was conducted in the Lady Vol's Strength and Conditioning room in Stokely Athletic Center and all other testing was conducted in the University of Tennessee Exercise Science Laboratory.

Lactate Threshold and VO_2peak

A discontinuous incremental protocol was performed on the Concept II (Morrisville, VT) Model C rowing ergometer to measure power output at LT, 2.5 mM, 4.0 mM, and VO_2peak. Each stage consisted of 3 min of rowing followed by 1 min of rest to allow for blood sampling. Three min stages allowed for a steady state to be achieved (Weltman et al., 1990). Subjects started at an initial rowing pace so that 500 m could be completed in 2 min 35 seconds (sec) with the intensity increasing at each stage so that 500 m could be completed in 5 fewer seconds (monitored electronically on the ergometer) (Weltman et al, 1994). Subjects monitored their own intensity through the use of the electronic readout and were informed by the researchers when to increase or decrease intensity. The damper setting on the flywheel was maintained at level 4 for all subjects. One hundred-fifty µl of blood were sampled by the fingerstick method at rest, in-between each stage, and immediately after completion of the test.

During the test, the subject breathed through a Hans-Rudolph facemask attached to a two-way Daniel's valve connected to flexible tubing to allow for gas sampling. Expired gases were sampled during the entire test and analyzed using an Apple computer with Rayfield REP-200C software interfaced with a Rayfield Equipment dry gas meter, S-3A/I oxygen analyzer (Applied Electrochemistry, Inc., Sunnyvale, CA), and CD-3A carbon dioxide analyzer (Applied Electrochemistry, Inc., Sunnyvale, CA) to determine ventilation, fraction of expired O_2 and CO_2 , VO_2, VCO_2, and respiratory exchange ratio. Analyzers were calibrated with known gases (Scholander, 1947) prior to each test. Heart

rate was monitored during the last 15 seconds of each stage by a Polar Heart Rate monitor (Polar Favor, Oy, Finland). Subjects were also asked to rate their perceived exertion from the Borg 6-20 rating of perceived exertion (RPE) scale (Borg, 1982) after each stage. The test was terminated when the intensity was not maintained at a given stage or at the subject's request.

Blood sampling and determination of LT and BLC

The whole blood samples were preserved using the YSI 2315 Blood Lactate Preservative Kit (Yellow Springs Instrument Co., Inc., Yellow Springs, OH). Blood samples were analyzed for lactic acid using the YSI 2300 STAT + lactate analyzer. The analyzer self-calibrated and was also standardized with a 5.0 mM solution and linearity monitored using a 15.0 mM calibration solution prior to lactate analysis. The analyzer self-calibrated every fifth sample. Blood samples were analyzed within 3 hours of sampling.

LT was determined by visual inspection of the blood lactate-rowing pace and rowing pace-VO_2 relationships observed during the VO_2peak tests. LT was characterized as the "VO_2 associated with the highest rowing pace before the curvilinear increase in blood lactate observed with further increases in exercise intensity" (Weltman et al., 1994). The VO_2 associated with blood lactate concentrations (BLC) of 2.5 mM and 4.0 mM lactate was also determined from the blood lactate-rowing pace and rowing pace-VO_2 relationships. Figure 1 is an example of one subject's response to the rowing protocol.

Strength

Subjects performed 1 repetition maximum (1-RM) lifts for the hip sled and seated rows. Subjects stretched and rowed approximately 500 m slowly as a warm up prior to lifting. Each subject's initial lift was at the weight at which she normally trained. After one lift was completed at a given weight, the subject

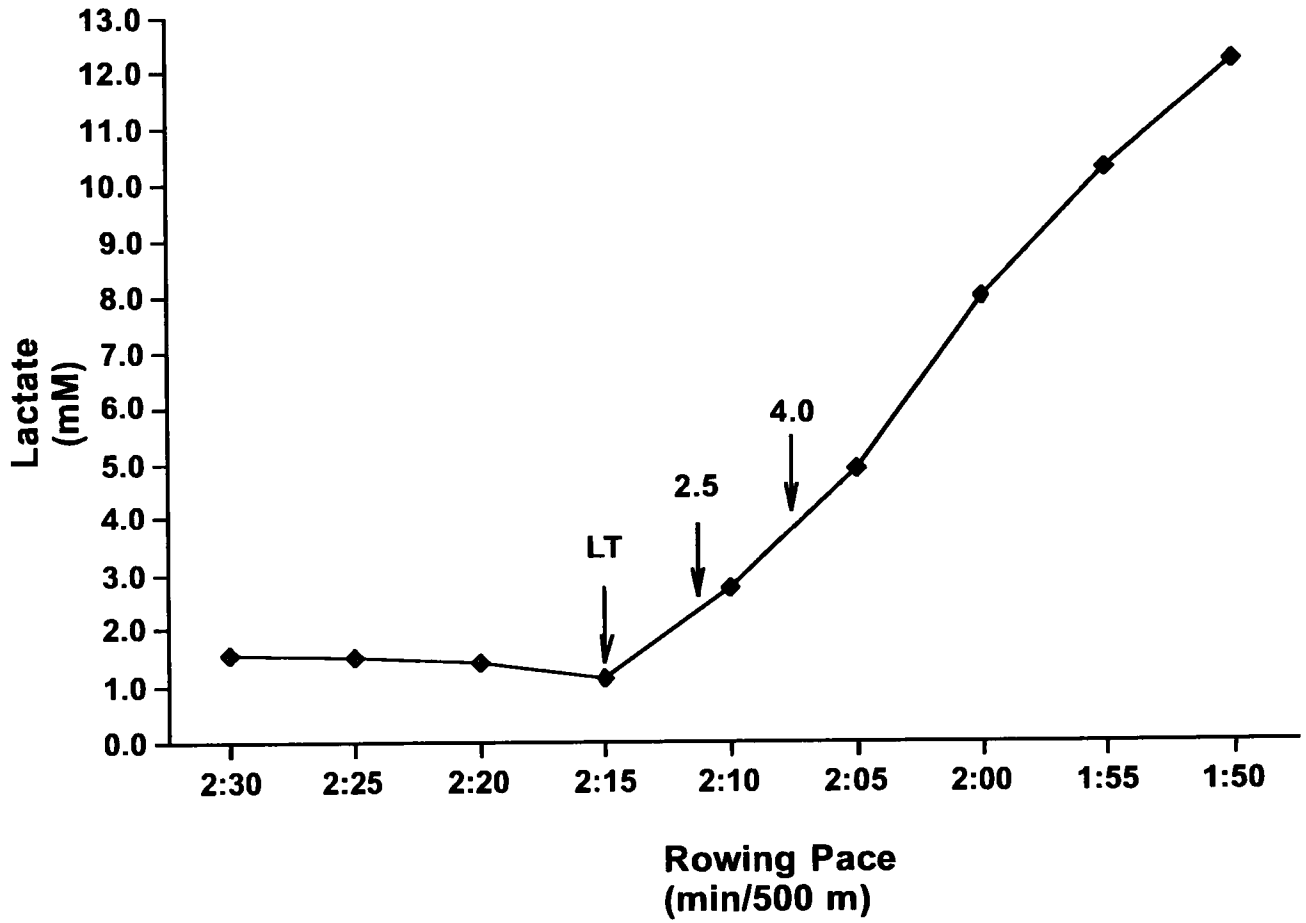


Figure 1. Lactate Curve for an Individual Subject.

rested for approximately 1-2 minutes and then resistance was increased by approximately 10-20% of the initial lift. This process was repeated until the subject reached a maximum weight which was indicated by an inability to lift a higher resistance.

During the hip sled movement, subjects were in a supine position with their hips and legs slightly flexed along a 45° incline. The weight support was released and subjects completely extended their legs. The movement begins by slowly lowering the weight until approximately 120° hip and 100° knee flexion was achieved and then extending the legs to the starting position. Seated rows were completed while seated with the legs extended and the chest pressed against a cushioned support. Subjects pulled on a bar attached to the weight by a chain and pulley system. Subjects began the movement with arms fully extended and pulled the bar using the arms, upper back and shoulders until the bar touched the chest support. The arms were then allowed to return to the starting position to complete the repetition.

2000 m and 500 m Ergometer Time

Subjects rowed one "all-out" 2000 m and one "all-out" 500 m on the Concept II rowing ergometer. Subjects were given verbal encouragement to perform at their best. Elapsed time to complete each distance was recorded to the tenth of a second.

Body Composition

The body density of each subject will be determined using hydrostatic weighing (Katch et al., 1967) with residual volume estimated using an equation described by Goldman and Becklake (1959). Each subject performed ten trials and underwater weight was determined using an average of the three heaviest trials. Body density was converted to percent body fat using the Siri equation

(Siri, 1961). The Schutte equation (Schutte et al., 1984) was used to calculate percent body fat in the one African-American subject. Fat-free mass was calculated by subtracting fat mass from total body weight. Measurements of weight, height, and waist and gluteal circumferences were taken using the Health-o-meter scale (Continental Scale Corporation, Bridgeview, IL), metric wall ruler, and metric tape measure, respectively. Skinfold thickness of the subscapula, triceps, chest, axilla, abdomen, suprailium and thigh were taken in triplicate using a Lange caliper.

STATISTICAL ANALYSIS

The Statstar program was used for all statistical analysis. Pearson correlation coefficients (r) were determined from all variables. A significance level of $p \leq 0.05$ was chosen for all comparisons. Additionally, multiple regression analysis was used to examine the ability of a combination of variables to describe 2000 m performance.

CHAPTER IV

RESULTS

The mean and standard deviation of the nineteen subjects' physical characteristics are listed in Table 1. The highest VO_2peak was 3.88 L/min and the lowest, 2.64 L/min. Average 2000 m and 500 m times as well as the strength test results are shown in Table 2. Table 3 reports the average VO_2 (L/min and ml/kg/min), % of VO_2peak and RPE values at LT, 2.5 mM, 4.0 mM lactate, and maximal exercise. Pearson's correlation coefficients are listed in Tables 4 and 5. 2000 m ergometer time was significantly correlated ($p \leq 0.05$) with 500 m time ($r = 0.951$), seated rows ($r = -0.573$), hip sled ($r = -0.468$), VO_2peak ($r = -0.489$), fat-free mass (FFM) ($r = -0.774$), height ($r = -0.522$), weight ($r = -0.589$), and VO_2 at 4.0 mM lactate ($r = -0.494$) (Table 4). The highest correlation was found between 2000 m time and FFM. The correlation between 4.0 mM lactate and 2000 m time ($r = -0.494$) was quite similar to the correlation between VO_2peak and 2000 m time ($r = -0.489$). Ergometer times were not significantly correlated with %VO_2peak at LT, 2.5 mM or 4.0 mM lactate (Table 5). Neither 2000 m or 500 m ergometer times were significantly correlated with RPE scores at LT, 2.5 mM or 4.0 mM lactate (Table 5).

Table 6 reports the relationship between various combinations of predictor variables and 2000 m time. Significant multiple correlations were observed for the combination of FFM and VO_2peak ($p = 0.001$), FFM and hip sled ($p < 0.001$), FFM and rows ($p = 0.001$), and FFM, rows and hip sled ($p = 0.001$) as well as VO_2peak and rows ($p = 0.02$), VO_2peak and hip sled

($p = 0.025$), and VO_2peak, rows and hip sled ($p = 0.045$). The combinations of VO_2peak and VO_2@LT, VO_2peak and VO_2@2.5 mM, and VO_2peak and VO_2@4.0 mM did not result in R values that reached significance.

Table 1. Physical Characteristics of the Subjects

	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Body Fat (%)	FFM (kg)
Mean	19.89	67.11	167.11	24.01	20.95	52.93
S.D.	1.34	6.65	5.82	1.69	4.62	4.76

S.D. = standard deviation
BMI = Body Mass Index
FFM = Fat-free mass

Table 2. Rowing Times and Maximal Strength

	2000 m Time (min:sec)	500 m Time (min:sec)	Max Rows (lbs.)	Max Hip Sled (lbs.)
Mean	8:06.5	1:49.3	46.29	135.17
S.D.	0:25.1	0:06.6	6.04	31.08

S.D. = standard deviation

Table 3. VO_2, % of VO_2peak, and RPE at the lactate threshold (LT), 2.5 mM lactate (2.5), 4.0 mM lactate (4.0) and maximal exercise.

	LT	2.5	4.0	peak
VO2 (L/min)	2.1 (0.16)	2.29 (0.12)	2.5 (0.13)	2.87 (0.31)
VO2 (mg/kg/min)	31.61 (3.65)	34.47 (3.45)	37.49 (3.32)	42.91 (4.48)
% of peak	74.42 (8.24)	81.03 (6.08)	88.11 (5.09)	100
RPE	11.42 (1.31)	12.8 (1.46)	14.63 (1.22)	18.31 (1.34)

Values are mean ± (standard deviation)

Table 4. Correlation Matrix

	500 m	Height	Weight	FFM	%BF	Rows	Hip Sled	VO2pk	VO2 at LT	VO2 at 2.5mM	VO2 at 4.0mM
2000 m	0.951*	-0.522*	-0.589*	-0.774*	0.221	-0.573*	-0.468*	-0.489*	-0.030	-0.396	-0.494*
500 m		-0.390*	-0.450	-0.666*	0.285	-0.626*	-0.475*	-0.459*	-0.032	-0.353	-0.445
Height			-0.692*	-0.648*	0.175	0.057	-0.137	0.398	-0.205	0.231	0.408
Weight				0.817*	0.430	0.370	0.121	0.456	-0.042	0.172	0.383
FFM					-0.168	0.626*	0.368	0.543*	0.091	0.340	0.565*
%BF						-0.349	-0.385	-0.064	-0.183	-0.243	-0.188
Rows							0.689*	0.481*	0.186	0.346	0.479*
Hip Sled								0.240	0.271	0.441	0.375
VO2 pk									0.117	0.595*	0.888*
VO2 at LT										0.367	0.229
VO2 at 2.5mM											0.844*

* = $p \leq 0.05$
FFM = fat-free mass
LT = lactate threshold
VO_2pk = highest oxygen uptake observed during testing expressing in L/min
%BF = percent body fat

Table 5. Correlation Coefficients for 2000 m and 500 m with % of VO_2peak and RPE at LT, 2.5 mM lactate, and 4.0 mM lactate.

	% VO2peak at LT	% VO2peak at 2.5mM	% VO2peak at 4.0mM	RPE at LT	RPE at 2.5 mM	RPE at 4.0 mM
2000 m Time	0.322	0.265	0.307	-0.235	-0.213	-0.002
500 m Time	0.305	0.267	0.306	-0.143	-0.132	-0.108

Table 6. Multiple Regression Equations for Prediction of 2000 m Time

Variables	Regression Equation	R	p-value
VO2peak, VO2@LT	Y = 9.830 - 0.655(X1) + 0.074(X2)	0.489	0.112
VO2peak, VO2@2.5	Y = 10.923 - 0.521(X1) - 0.576(X3)	0.506	0.094
VO2peak, VO2@4.0	Y = 11.306 - 0.317(X1) - 0.916(X4)	0.506	0.094
VO2peak, FFM	Y = 11.829 - 0.129(X1) - 0.063(X5)	0.778	0.001
VO2peak, rows	Y = 10.572 - 0.369(X1) - 0.014(X6)	0.622	0.020
VO2peak, hip sled	Y = 10.308 - 0.531(X1) - 0.002(X7)	0.608	0.025
VO2peak, rows, hip sled	Y = 10.547 - 0.400(X1) - 0.009(X6) - 0.001(X7)	0.637	0.045
FFM, rows	Y = 11.746 - 0.060(X5) - 0.005(X6)	0.782	0.001
FFM, hip sled	Y = 11.726 - 0.061(X5) - 0.001(X7)	0.799	< 0.001
FFM, rows, hip sled	Y = 11.719 - 0.062(X5) + 0.001(X6) - 0.001(X7)	0.799	0.001

X1 = VO_2peak
X2 = VO_2@LT
X3 = VO_2@2.5 mM
X4 = VO_2@4.0 mM
X5 = Fat-free mass (FFM)
X6 = Rows
X7 = Hip Sled

CHAPTER V

DISCUSSION

This study was designed to determine which physiological variables are most closely related to 2000 m rowing ergometer performance. The major findings of this study are that fat-free mass, seated row and hip sled strength, VO_2peak, and VO_2 at 4.0 mM are the most significant variables related to performance.

Kramer et al. (1994) found significant correlations between 2500 m ergometer time and VO_2max, 1-RM leg press, and 1-RM bench pull in a group of collegiate female rowers. The correlation between 2500 m time and VO_2max was the highest ($r = -0.77$, $p < 0.01$). The present study found similar variables to be significantly correlated with 2000 m time (VO_2peak, 1-RM rows and 1-RM hip sled). VO_2max has also been highly correlated with placement in a international regatta ($r = 0.87$) in an investigation on male rowers (Secher et al., 1983). The average VO_2max of successful (winners of international rowing championships) rowers was significantly higher than that of unsuccessful rowers (Secher et al., 1983). The present investigation further supports the importance of VO_2max and/or VO_2peak in rowing which has been elucidated in numerous other investigations (Hagerman et al., 1978; Jackson and Secher, 1976; McKenzie and Rhodes, 1982; Secher et al.,1983; Steinacker, 1993).

An investigation on male, club rowers found significant correlations between 2000 m ergometer performance and lean body mass (LBM) ($r = -0.669$) and VO_2max ($r = -0.748$) (Gayer, 1994) which was similar to that found in the present study. Gayer did not find LT to be significantly correlated with 2000 m time but did find that LT was a factor in predicting performance in combination

with other variables (peak power, LT, and LBM). Based on their equation, 63.1% of variance was accounted for by these variables with peak power, LT, and LBM accounting for 24.4, 19.6 and 17.3% of the variance in 2000 m time, respectively. However, this was not found in the present study. In the present study, the addition of VO_2@LT, VO_2@2.5 mM, or VO_2@4.0 mM with VO_2peak did not significantly add to the 2000 m multiple regression equation. The combination of VO_2peak and VO_2at LT ($r = 0.489$, $p = 0.112$), 2.5 mM ($r = 0.506$, $p = 0.094$) or 4.0 mM ($r = 0.506$, $p = 0.094$) did not produce multiple R values which reached significance. During the 2000 m ergometer test, rowers perform at a high percentage of their VO_2max (96-98%) (Hagerman et al., 1979). This percentage is well above the percent of VO_2peak (74.4%) at which LT was observed in the present study. This difference may be a reason for the low correlation between VO_2@LT and 2000 m time. The low correlation between performance and VO_2@LT is quite different from other endurance athletes, such as runners. Kumagai et al. (1982) and Tanaka et al. (1984) found significant and high correlations ($r = -0.945$ and $r = -0.84$, respectively) between VO_2@LT and 5 km performance. Weltman et al. (1987) developed equations that accurately predicted VO_2 and velocity at LT, 2.0, 2.5, and 4.0 mM and peak from 3200 m time in a group of male runners. Farrell et al. (1979) suggest that distance runners appear to perform at speeds which allow for the highest VO_2 that just avoids the rise in lactate. Also, the longer the running event, the higher the correlation between race pace and treadmill velocity at LT ($r = 0.98$ and $r = 0.91$ for 42.2 km and 3.2 km, respectively) (Farrell et al.,1979). End of competition lactate values during running [e.g., 10 mM (Farrell et al., 1979) and 7.12 mM (Kumagai et al., 1982)] appear to be much lower than after rowing (17.5

mM) (Hagerman et al., 1979). During competition, rowers perform at an intensity which is much higher than that achieved at the LT.

The VO_2@4.0 mM was found to be correlated with performance in this study; however VO_2@LT and VO_2@2.5 lactate were not. This is also in agreement with a review by Steinacker (1993) which stated that "endurance capacity measured as the power which elicits a blood lactate concentration of 4.0 mM is the most predictive parameter for competition performance in trained rowers". The present study is the only known investigation to examine the relationship between lactate concentrations and rowing performance in collegiate female rowers. The VO_2@4.0 mM lactate was highly correlated with VO_2peak ($r = 0.888$). VO_2peak was also significantly correlated with 2000 m time. Therefore, the significant correlation between VO_2@4.0 mM lactate and 2000 m time may actually be reflective of the relationship between VO_2peak and performance. It can also be seen from Table 5 that the correlation between %VO_2peak at 4.0 mM was not significantly correlated with 2000 m time. This is an additional indication that VO_2peak rather than VO_2@4.0 mM is the most significant factor in determining 2000 m time.

Several combinations of variables resulted in a significant multiple correlation (R) with 2000 m time: VO_2peak and rows, VO_2peak and hip sled, VO_2peak, rows, and hip sled, VO_2peak and FFM, FFM and rows, and FFM and hip sled as well as FFM, hip sled and rows. FFM includes all non-fat components of the body. It is interesting that in the present study, the combination of strength measures and FFM produced a stronger relationship than either did alone. Strength is generated by muscle which is a component of FFM. These finding demonstrate the importance of both strength measures and FFM to rowing ergometer performance.

Isotonic strength measures of 1-RM rows and 1-RM hip sled were found to be statistically correlated with 2000 m ergometer time in this study which is in agreement with Kramer et al. (1994). It is interesting that rows were more highly correlated with performance than the hip sled because the muscles of the thigh represent the major component of the drive of the rowing stroke (Mahler et al.,1984) Additionally, Kramer et al. (1994) found a higher correlation between 2500 m time and leg strength than 2500 m time and upper body strength. It is important to remember that this testing was completed during a time of high endurance training but there was still a significant relationship between strength and performance. Subjects may not have been at their absolute peak in strength; however, Bell et al. (1993) demonstrated that strength measures were maintained while performing endurance training in female rowers. Another investigation comparing isokinetic knee extensor strength measures and performance found low and non-significant correlations (Kramer et al., 1991). However, isokinetic knee extensor strength isolates only one major muscle group involved in the drive phase of the rowing stroke while the leg press, a combination of muscle groups, better represents the total drive action (Kramer et al., 1991). The research suggests that isotonic strength measurements appear to be a better predictor of performance than isokinetic strength.

Since high correlations were found for FFM and strength but not body fat percentage, it appears that rowers may be able to improve their performance through strength training which would improve strength and increase muscle mass. An investigation by Secher and Vaage (1983) produced an equation for on-water rowing performance based on body weight. This idea developed due to the fact that heavyweight rowers have consistently faster times than the lightweights even when adjustments are made in shell dimensions and weight.

An investigation on running performance found LBM as a discriminate factor between good and elite middle and long distance runners (Pollock et al., 1983); however, LBM was a suppresser variable not directly related to performance. The findings of the present study reveal that body weight and more specifically, fat-free mass are important factors correlating with rowing ergometer performance in collegiate female rowers.

RPE values were not significantly correlated with any other variables of performance. The low standard deviation of RPE at the various lactate concentrations (approximately 1.4 units) indicate that RPE was similar for all subjects. Hetzler et al. (1991) found a stable relationship between blood lactate concentrations and RPE at LT, 2.5 mM and 4.0 mM in untrained males during cycling and running, and a similar relationship was found between lactate and RPE in untrained female subjects during treadmill running, and cycle and rowing ergometry (Zeni et al., 1996). It appears that RPE is reflective of physiological stress during rowing. This relationship is unaffected by training state or gender.

The subjects in this study included rowers of varying experience, from 3 months to 3 years. The average height, weight, and body fat percentage of the subjects were similar to the average elite oarswomen described by Hagerman (1984) and Vermulst et al. (1991). The subjects had a wide range of body fat percentages (12.6 - 29.7%) which was also demonstrated in an investigation of elite heavyweight oarswomen (Pacy et al., 1995). Absolute and relative VO_2peak values were quite low in comparison to other elite rowers. The average for the present study of 2.87 L/min was much lower than 4.1 L/min found by Hagerman and colleagues (1979) in an investigation of elite oarswomen. The VO_2peak as a measurement of body weight was on average slightly above that of the general college population and much lower than the

VO_2max of other female endurance athletes such as runners (McArdle et al., 1991). However, Mahler et al. (1985) found VO_2max values of 46.2 $\pm$ 4.4 ml/kg/min (3.2 L/min) and 39.0 $\pm$ 2.2 ml/kg/min (Mahler et al.,1983) in two groups of collegiate female rowers. These values are quite similar to the values measured in the present study. Additionally, the present investigation measured VO_2peak during an extended incremental rowing test. Using a similar incremental running protocol, VO_2peak values are approximately 5% less than VO_2max during an inclined maximal treadmill test (Weltman et al., 1990). Additionally, this suggests that the "true" VO_2max of the present subjects is slightly higher than the measured VO_2peak. The subjects in the present investigation are members of a women's crew team which became a varsity sport the same year in which the testing was conducted. Therefore, this sample of oarswomen may not be representative of the average collegiate population of female rowers but does reflect crews making the change from a club sport to the more competitive varsity level.

Researchers have suggested that the individual lactate threshold be used to determine training workloads (Urhausen et al, 1993); however, in the present investigation, LT was not related to 2000 m time. A significant correlation was found between 2000 m time and the VO_2@4.0 mM lactate, and rowing endurance training has previously been prescribed at intensities corresponding to 4.0 mM lactate. This has led to overstrain due to substrate depletion and incomplete recovery (Steinacker, 1993). In athletes with high training loads (1000 hours per year), it has been suggested that the intensity be reduced for adequate preparation for competition (Steinacker, 1993). Beneke (1995) found that the intensity corresponding to the individual lactate threshold was not the same as the maximal lactate steady state (MLSS) which is defined as the

"highest BLC increasing by no more than 1.0 mM within the last 20 min of constant workload". Additionally the MLSS was significantly lower than a blood lactate concentration of 4.0 mM. The optimal training point may be the MLSS which would optimize the rowers' endurance capacities yet prevent premature fatigue due to lactate accumulation.

The training implications from the information provided in this study appear to reemphasize the importance of a high VO_2max and increasing the ability to perform near this level. Monitoring training at a concentration which would increase the ability to perform at high lactate levels (competition-like conditions) without overtraining appears optimal. This also strengthens support for the current training practices of rowers: training at a low intensity optimizing rowing endurance, while focusing on intermittent periods of high intensity workloads to increase anaerobic ability (Mahler et al., 1985; Hartmann et al.,1990). 4.0 mM lactate was significantly correlated with performance but this relationship may be a reflection of the significance of VO_2peak. Therefore, the importance of 4.0 mM lactate may be as a diagnostic tool and in prescribing training for high intensity, short-duration workouts (Weltman, 1995). Improvements in fat-free mass and strength may be achieved by resistance training to increase the size and neural adaptations of muscle fibers, specifically type IIa. Primary consideration for body composition should be to increase fat-free mass rather than altering body fat percentage. In conclusion, it appears that increasing VO_2max and muscular strength (upper and lower body) would be advantageous to competitive female rowers.

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APPENDICES

APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

TITLE OF THE STUDY: Predictors of Rowing Performance in Collegiate Female Rowers

PURPOSE

You are invited to participate in a study, the purpose of which is to determine the physiological parameters associated with peak performance of collegiate female rowers on a rowing ergometer and evaluate the best predictors of successful performance.

PROCEDURES

If you choose to participate in this study, you will complete a health and personal history questionnaire prior to any testing. This is to ensure that the testing is safe for you as well as allow you to contribute information on your training status and rowing experience. Your participation in this project will consist of strength tests (hip sled, seated rows, and rows on an isokinetic lifting machine), an incremental rowing test for lactate threshold and peak aerobic power (VO_2peak), body composition analysis by underwater weighing and skinfolds, and timed 2000 meter (m) and 500 m ergometer tests. The testing will be supervised by Amy Fletcher and Dr. Dixie Thompson as well as graduate students (Karen Townsend, Kelly Johnson, or Tina Smeallie) from the Exercise Science Unit of the University of Tennessee, Knoxville. The testing will take place in the Exercise Physiology Laboratory in the HPER Building and the Lady Vol's Strength and Conditioning Center and will be completed on three different days at your convenience. Each testing day will require about one hour of your time. Before each test you will be required to report to the lab in a rested condition not having consumed food for 3-4 hours prior to testing. You will also be asked to refrain from alcohol consumption for 24 hours and strenuous exercise 12 hours prior to testing. Also, you should have consumed at least 2 meals since your last exercise session.

On one day of testing an incremental rowing test for lactate threshold and VO_2peak will be performed. During the incremental rowing test, you will be required to breath through a rubber mouthpiece attached to headgear so that expired gases may be analyzed. You will also wear a heart rate monitor to observe your heart rate. The monitor consists of two parts: an elasticized band that contains a transmitter is worn around your chest where it picks up electrical activity of your heart and a wrist band device that displays this activity in the form of a heart rate. An initial blood sample of 100-150 microliters

Initials_____

(approximately 4 drops of blood) will be sampled from your fingertip using a sterile lancet. A gauze pad with Heparin will be placed over the puncture to decrease blood clotting and a latex covering will be placed over the tip of your finger to prevent blood from getting on the oar handle. This blood will be analyzed for the amount of lactic acid in your blood. This incremental exercise test involves stages of 3 minutes (min) of rowing followed by 1 min of rest which will allow for the sampling of 150 microliters of blood. In all, approximately 10 fingertip blood samples will be taken (a total of 1.5 ml or 4 teaspoons of blood). The intensity will begin at the power necessary to complete 500 m in 2 min 40 seconds and increase with each stage by decreasing the power output 5seconds/500m. You will row until you reach your maximal capacity and feel that you can no longer continue. We will stop the test at that point.

On another day of testing we will assess your 2000 m rowing time and strength. No blood will be sampled on this day. The strength tests require the measurement of your 1 repetition maximum (1-RM) on the hip sled and seated rows. For this procedure, you will begin lifting at a weight you typically train at and gradually increase resistance until you are able to complete the lift only once. You will also perform the row lift on a Cybex isokinetic machine. This machine controls the speed and resistance of your movement and thus force will be measured throughout your complete range of motion. During the 2000 m test, you will complete the distance as quickly as possible. The amount of time it takes you to row 2000 m will be recorded.

On another day of testing, we will assess your 500 m rowing time and body composition. No blood will be sampled on this day. During the 500 m test you will row 500 m as quickly as possible and time to completion will be recorded. Body composition analysis will involve measurements of height, weight, skinfolds, hip circumference and underwater weighing. The measurement of skinfolds requires that the researcher measure how thick your skin and fat are on your triceps, abdomen, hip and thigh. Your residual lung volume will be measured as you breathe into a spirometer, a machine that measures volumes of air. While performing this procedure you will inhale a small amount (less than 6 liters) of pure oxygen. You will also be weighed underwater which requires that you (while wearing a bathing suit) submerge yourself into a tank of warm water and exhale while you are underwater. As you are sitting in the tank of warm water (the water will come up to approximately shoulder level), you will be asked to lean forward and put your face and head just under the surface of the water. You will stay underwater for only a few seconds. You will be allowed to raise your head above water when you feel the need to breathe.

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BENEFITS OF PARTICIPATION

The findings of this study will provide vital information to exercise physiologists, as well as others, about the various physiological factors associated with rowing.

The benefits to you include results on your strength tests, percent body fat, peak aerobic power, and the power at lactate threshold. These tests are good overall indicators of physical fitness and may directly impact your training.

RISK OF PARTICIPATION

The risks involved in the exercise tests in this study are those normally associated with any exercise: injury to muscles and/or joints, dizziness, headaches, irregular heart beats, and in rare cases, heart attack. Every effort will be made to minimize these risks. Personnel trained in CPR will be present at every session. Warm-up and cool-down exercises consisting of static stretches for the quadriceps, hamstrings, calves, deltoids, upper back, triceps, biceps and forearms as well as light aerobic activity will be performed prior to and after each testing session to minimize the risks of sore or pulled muscles. The correct form for the strength tests will be demonstrated and the lower back will be stabilized or supported during each lift. There is also the slight chance you could incur bruising and/or infection in the area where blood is sampled. Sterile techniques will be utilized when sampling blood, so the risk of infection is minimal.

There are no known risks for the body composition procedures. To ensure your comfort, these procedures will be performed in private with only Amy, Dr. Thompson and another female graduate student present (either Karen Townsend, Kelly Johnson, or Tina Smeallie).

RIGHT TO ASK QUESTIONS AND/OR TO WITHDRAW FROM THIS INVESTIGATION

If you have questions or concerns at any time during the course or after this study, you may contact Amy J. Fletcher or Dixie L. Thompson, Ph.D. at (423)974-5111. Amy's office is number 144 and Dr. Thompson' s office is number 347, both located in the HPER Building. If at any time during this study events occur that will impact your ability to participate (i.e., you become injured, you become sick, etc.), you should inform Amy or Dr. Thompson immediately.

As a volunteer in this study, it is your right to withdraw from this investigation at any time. If you decide to withdraw from this study, you will in no way be penalized.

Initials_____

PRIVACY OF RECORDS

Only you, Amy and Dr. Thompson will have access to your results. All data collected will be kept on file by Dr. Thompson and will be coded by subject number rather than name. The results of the study will be published; however, no publication will contain information which will allow you to be identified. Neither Amy nor Dr. Thompson will release your results to your coaches; however, you may share your results with them if you so choose.

AUTHORIZATION

By signing this form, I am indicating that I have read this form, understand its contents, and have received a copy of this form for my files. I have also been given the opportunity to ask questions to clarify my role in the study. I understand the risks associated with this study and may withdraw at any time without penalty. My signature indicates that I agree to serve as a subject in this research study.

_____ _____

Participant's Signature Date

_____ _____

Investigator Date

APPENDIX B

HEALTH AND PERSONAL HISTORY FORM

HEALTH AND PERSONAL HISTORY FORM

Name:_____ Address:_____
Date:_____ Date of Birth:_____
Subject Number:_____

Past History:
Check appropriate box for the following:

	YES	NO	Don't Know
Free or easy bleeding (hemophilia)	( )	( )	( )
Rheumatic fever	( )	( )	( )
Heart murmur	( )	( )	( )
High blood pressure	( )	( )	( )
Any heart problem	( )	( )	( )
Varicose veins	( )	( )	( )
Lung Disease	( )	( )	( )
Seizures	( )	( )	( )
Irregular heart beat	( )	( )	( )
Bronchitis	( )	( )	( )
Emphysema	( )	( )	( )
Diabetes	( )	( )	( )
Asthma	( )	( )	( )
Kidney Disease	( )	( )	( )
Liver Disease	( )	( )	( )
Hay Fever	( )	( )	( )
Orthopedic problems	( )	( )	( )
Hyper or Hypothyroidism	( )	( )	( )
Hepatitis	( )	( )	( )
AIDS	( )	( )	( )

Present Symptoms Review:
Have you recently had any of the following symptoms (check all that apply)?

Chest Pain	( )	Frequent urination	( )
Shortness of breath	( )	Blood in urine	( )
Heart palpation's	( )	Burning sensation	( )
Leg or ankle swelling	( )	Severe headaches	( )
Coughing of blood	( )	Blurred vision	( )
Low blood sugar	( )	Difficulty walking	( )
Fainting feeling or dizziness	( )	Weakness in arms	( )
Leg numbness	( )	Back pain	( )
Significant emotional problems	( )		

Do you smoke?_____ If yes, how many per day?_____
Are you taking any medication?_____ If yes, please describe:_____
_____

Health and Personal History Form

Initials:_____
Subject Number:_____

Activity Level

How many minutes/meters a day do you train?_____
Other activities and time spent besides rowing:_____
_____
_____

Years of rowing experience and at what level?_____
Which side and seat number do you usually row?_____
In which weight class do you normally compete?_____

Emergency Information

In case of an unexpected emergency, please provide us with a person with whom to contact:

Name:_____
Address:_____
Phone #:_____
Physician's Name and Office Location:_____
_____

APPENDIX C

APPENDIX C1

ROWING ERGOMETER INCREMENTAL TEST WORKSHEET

Rowing Ergometer Incremental Test Worksheet

Name: _____ Date: _____
P_{BAR} _____ RH _____ Temp. _____
Weight _____ Age _____ Height _____
Resting Lactate _____
Resting HR _____

Time	Actual Time	Power Output	Lactate	VO2	HR	RPE
0-3						
4-7						
8-11						
12-15						
16-19						
20-23						
24-27						
28-31						
32-35						
36-39						
40-43						
44-47						
48-51						

APPENDIX C2

STRENGTH TESTS AND 2000 m WORKSHEET

Strength Tests and 2000 m Worksheet

Name: _____ Date: _____

P_{BAR} _____ RH _____ Temp. _____

Strength

Weight (lbs) x Reps

1. Seated Rows _____
   _____
   _____
   _____
   _____

2. Hip Sled _____
   _____
   _____
   _____
   _____

2000 m

1st 500 time: _____ Average Stroke Rate: _____
2nd 500 time: _____ Average Stroke Rate: _____
3rd 500 time: _____ Average Stroke Rate: _____
4th 500 time: _____ Average Stroke Rate: _____

2000 m time: _____

APPENDIX C3

BODY COMPOSITION AND 500 m WORKSHEET

Body Composition and 500 m Worksheet

Name: _____ Date: _____

P_{BAR} _____ RH _____ Temp. _____

Weight _____ Age _____ Height _____

Skinfolds

	1	2	3	Average
Subscapula				
Triceps				
Chest				
Axilla				
Suprailium				
Abdomen				
Thigh				
			Total =	
Waist Circumference				
Hip Circumference				

Underwater Weight

Water Temp.: _____

Water Density: _____

Trial 1: _____ Trial 6: _____

Trial 2: _____ Trial 7: _____

Trial 3: _____ Trial 8: _____

Trial 4: _____ Trial 9: _____

Trial 5: _____ Trial 10: _____

Average of Trials 8-10: _____

500 m

500 m Time: _____ Stroke Rate: _____

VITA

Amy Jo Fletcher was born in Wayne, Nebraska. She attended elementary and high school in Plainview, Nebraska, where she graduated from Plainview High School in May, 1989. She then attended the University of Nebraska-Lincoln and graduated in August of 1993 with a Bachelor of Science in Biology, with minors in chemistry and math. Amy worked as a laboratory assistant for Harris Laboratories Inc., in Lincoln, Nebraska for 7 months after graduation. She then entered the University of Tennessee in the fall of 1994 to study Exercise Physiology and received her Master of Science degree in August of 1996.