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Determinants of 2000 Meter Rowing Ergometer Performance

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Lean body weight and aerobic and anaerobic factors have long been recognized as important determinants of performance in the 2000 meter (M) race distance for rowing. Current research with noninvasive techniques has important implications for training and performance but is inconclusive. The purpose of this study was to investigate the relationship between a 2000 M rowing ergometer performance test (PT) and lean body weight (LBW), velocity at heart rate deflection (Vd), and anaerobic capacity (AC) in experienced rowers. Vd was used as an estimate of aerobic function. Thirteen trained male rowers (mean age 38.5 ± 8 years) were studied. Hydrostatic weighing at residual lung volume was used to estimate LBW. Each subject performed five exercise tests on a Concept II rowing ergometer: one 2000 M PT, two submaximal stepwise progressive tests to determine Vd (s/500 M), and two maximal 40-s anaerobic tests to determine AC. Intraclass correlation coefficients for the test/retest trials of Vd and AC were R = 0.740 and R = 0.863, respectively. Stepwise multiple linear regression analysis was used to explain variance in PT. The order of entry of each independent variable (and associated multiple R^2 at each step) in the analysis was (1) Vd, 0.589; (2) LBW, 0.709; (3) AC, 0.720. The regression equation was PT (s) = 375.66 + 1.093 (Vd) - 0.820 (LBW) - 0.0007 (AC); S.E.E. = 10.01. It was concluded that performance in a 2000 M rowing ergometer PT is primarily dependent on aerobic metabolism and available lean body weight with anaerobic factors contributing to a lesser degree. These results have implications for specific training and team selection.

DETERMINANTS OF 2000 METER ROWING ERGOMETER PERFORMANCE

by

JEFF C. YOUNG

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TO THE OFFICE OF GRADUATE STUDIES:

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DEDICATION

To my family, friends and the pursuit of excellence that is rowing for their continuing renewal of the process of life.

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CHAPTER I

INTRODUCTION

Human beings have been interested in the determinants of exercise performance since the beginning of sport. Over 3000 years ago, Homer wrote about maximum spear-throwing ability in his account of the funeral competition in honor of the Greek nobleman and war hero, Patroclus (Metheny, 1968). Such non-combative performances for excellence no doubt predate Homer's recording. Today, with science and efficient time-use emphases, physiology and individualized training have become major factors in sport performance. Aerobic, anaerobic and body composition factors are particularly relevant to the performance of the aerobic, or endurance sports. In cross-country skiing, for example, John Underwood has used individual blood lactate concentration measurements to guide the training and performance of athletes at Central Oregon Community College in Bend, Oregon. With this guidance, the school has won both nordic and alpine university championships and attracted many athletes interested in "scientific training" (Richard, 1988). The German Democratic Republic has also used physiological parameters to guide the training of athletes and predict performance. It has been reported that

East German oarsmen and oarswomen must attain a VO_2 max of at least 6 L/min and 4 L/min, respectively, to be considered for national rowing team selection (Hagerman, 1984).

Rowing is a team sport (four or eight members per team) and requires the use of both the lower and upper body musculature. The rower exerts force from a sliding seat to move a 18.6 M shell through the water with a 3.86 M oar. A good racing crew completes the standard 2000 M race course in about six minutes. In the past 16 years, "anaerobic threshold" ("AT"), or the point at which exercise is said to become primarily anaerobic, has emerged as an important physiological parameter of rowing performance (Gorman, 1987; Hagerman, Hagerman, & Mickelson, 1982). In simplified terms, "AT" is thought to be an important determinant of the maximal pace a rower can maintain for 2000 M. It was once thought that an athlete's maximal ability to take in, transport, and use oxygen (VO_2 max) was the primary determinant of success in stressful physical performance. However, the importance of VO_2 max has probably been overstated. An athlete's ability to perform work at a fast rate, without becoming "anaerobic" is hypothesized to be an important factor in performance (Jacobs, Schele, & Sjodin, 1985; Wasserman, Whipp, Koyal, & Beaver, 1973). For example, if the point at which "AT" occurs is different for two competing athletes with similar maximal aerobic capacities, the athlete with the higher "AT" will presumably be the better performer in an aerobic event.

Noninvasive, accurate and reliable field tests for measuring "AT" and other physiological variables are important for scientific training and team selection. Tests for "AT" and anaerobic capacity (AC) may provide important information for predicting rowing performance and directing the emphasis of training. For the individual rower, strengths and weaknesses may also be efficiently assessed, and personalized training programs developed. These data are easily obtained and monitored from tests on a stationary rowing ergometer (RE). Further data from "AT" and AC tests may also furnish nonrowers with important information for use in enhancing health and performance.

STATEMENT OF THE PROBLEM

There is currently no conclusive published research, using noninvasive techniques, which describes the relationship between 2000 M rowing ergometer performance and velocity at heart deflection (Vd), lean body weight (LBW) and anaerobic capacity (AC). The efficacy of a 40-s AC test performed on a rowing ergometer is unknown and the variance in PT accounted for by Vd, LBW and AC is also not known.

HYPOTHESES

The following hypotheses were proposed:

1. When modified for use with a rowing ergometer, the indirect, noninvasive "AT" test proposed by Conconi, Ferrari, Ziglio, Droghetti, and Codeca (1982) is reliable.

2. The 40-s maximal anaerobic capacity test performed on a stationary rowing ergometer is reliable.

3. There are high correlations between Vd, lean body weight, anaerobic capacity and 2000 M rowing ergometer performance.

4. Together, Vd, lean body weight, and anaerobic capacity account for a significant proportion of the variance in 2000 M rowing ergometer performance in experienced male rowers.

PURPOSE

The purpose of this research was to investigate the physiological determinants of 2000 M rowing performance for trained male rowers, aged 24-52 years. Specifically, "anaerobic threshold", lean body weight, anaerobic capacity, and 2000 M rowing ergometer performance were measured, and stepwise multiple linear regression was used to examine the relationship between 2000 M rowing ergometer performance and the independent variables.

SIGNIFICANCE OF THE STUDY

There is now no conclusive published research on the factors important for 2000 M rowing performance using noninvasive techniques. The research should contribute information concerning the importance of the velocity of deflection concept and lean body weight. It will also add original data on a 40-s anaerobic capacity test and provide estimates of the intercorrelations among the three independent variables in addition to exploring their relationship to 2000 M rowing performance. With repeatable, noninvasive measurement of the important determinants of rowing, focused individual training and physiological testing for team selection are feasible. Individual rowers, for example, could focus on aerobic training by working at heart rates and RE velocities below the velocity of deflection or they could train with short, high intensity intervals in an attempt to increase "AT". Easily administered noninvasive Vd and AC tests could provide documented evidence of important training changes.

Additionally, the weighing of performance factors would provide the physiological profiles for team selection. Further, there may be information obtained which would be useful to nonrowers interested in measuring fitness improvements.

LIMITATIONS AND ASSUMPTIONS

Limitations

1. Only 13 male rowers were recruited. The subjects were not randomly selected.

2. The CIC heart rate monitor did not work well on all subjects.

3. The study was limited in time and number of trials for each subject.

Assumptions

1. The revised oxygen dilution method is a reliable and valid assessment of residual lung volume and hydrodensitometry is a valid and reliable test for estimating body density.

2. All subjects performed maximally on AC and PT tests.

3. The power readouts displayed by the monitor resulting from the force applied through the drive portion of the stroke were accurate.

4. The Vd protocol for "AT" determination is valid.

DEFINITION OF TERMS

Crew The sport involving the movement of a 18.6 M racing shell over 2000 M by eight rowers and a coxswain. The shell is levered past the oarlock fulcrums by eight carbon-fiber oars held by crew members moving forward and backward on sliding seats. The duration of a typical 2000 M race is between 5.5 and 7.5 minutes.

Stroke One full cycle of pulling the oar through the water and bringing it up out of the water to prepare for the next entry.

Drive The portion of the stroke in which the legs push the sliding seat back and transfer power through the body to the oar. This occurs while the oar is in the water.

Recovery The portion of the stroke in which the oar is out of the water and the body is moving up the slide in preparation for the beginning of the next stroke.

Time/500 M Time used to describe the speed of the shell. It is roughly equivalent to the quarter-mile time in track. Velocity can be calculated from time/500 meters and this calculation provides the velocity data for the heart rate versus velocity graphs (see Figure 1).

Residual lung volume (RLV) The air volume remaining in the lungs after full exhalation (Lamb, 1984).

Rowing Ergometer (RE) An ergometer which simulates the crew rowing motion and power application (Hagerman, Connors, Gault, Hagerman, & Polinski, 1978).

Performance Test (PT) 2000 M maximal exercise test performed on the rowing ergometer.

Velocity of Deflection (Vd) The velocity at the point of departure from linearity on the graph of heart rate versus velocity. It has been argued that this point represents the "anaerobic threshold". This study uses Vd as a marker for aerobic metabolism and does not address the question of theoretical validity of the "anaerobic threshold".

Anaerobic Capacity (AC) The total power output (watts) from an all-out 40-s exercise test on the rowing ergometer.

Lean Body Weight (LBW) Fat-free weight estimated from hydrostatic weighing.

"Anaerobic Threshold" ("AT") The level of work or O_2 consumption at which metabolic acidosis and the associated changes in gas exchange occur (Wasserman et al., 1973).

"Conconi Test" The submaximal progressive exercise test in which the velocity of deflection (Vd) is measured (Conconi et al., 1982).

CHAPTER II

REVIEW OF THE LITERATURE

In 1920, two Scandinavian scientists attempted to measure oxygen consumption, heart rate, and cardiac output of exercising rowers (Liljestrand & Lindhard, 1920). In another early study, Henderson and Haggard (1925) estimated the energy expenditure and power output of the 1924 Olympic gold medal eight-oared crew team using weights and a water resistance rowing ergometer. Since the 1960's, much has been added to this early research with regard to the explanation of important physiological parameters of rowing performance (di Prampero, Cortili, Celentano, and Cerretelli, 1978; Williams, 1978; and Secher, 1983). Specific 6-minute exercise tests have been used by Hagerman and associates since 1971 (Hagerman, Hagerman, & Mickelson, 1979; and Hagerman, 1984). Hagerman's research includes a detailed description of the physiological profiles of 623 elite rowers (Hagerman, et al., 1979).

Hay (1968) and Williams (1978) performed studies on the 1968 Olympic team and the 1978 Colt level (less than 23 years old) oarsmen of New Zealand. Hagerman et al. (1979) profiled VO_2 max, single leg strength, total power, maximal heart rate, muscle fiber type, speed of movement, lactic acid, O_2 pulse, ventilation volume and O_2 deficit in elite rowers. Similarly, Hay (1968) and Williams (1978) examined 104 variables between their two studies. This "blanket" approach to exploring the physiological determinants of rowing performance has some utility, but requires a large sample size for valid conclusions to be made. In 1979, Hagerman commented that the "most impressive physiological attribute [of rowers] is their capacity to sustain an extremely high percentage of their VO_2 max." (Hagerman et al., p. 77, 1979). Other research on endurance training in men further supported the selection of "anaerobic threshold" ("AT") as the preferred indicator of training intensity (Davis, Frank, Whipp, & Wasserman, 1979; Gorman, 1987; Mickelson and Hagerman, 1982). These studies were among the first to reevaluate the importance of VO_2 max standards of performance used by the East Germans and others. As early as 1974, the Romanians had already studied the relationship of aerobic and anaerobic energy demands to time-specific, 6-minute cycle ergometer performance (Szogy and Cherebetiu, 1974). Their methods employed, however, were not easily applicable, and they did not always provide accurate performance prediction.

The work of Conconi and his associates (Conconi et al., 1982) concerning noninvasive "anaerobic threshold" determination appeared to offer a solution to the problem of application. Conconi's research with runners revealed that

"AT" could be measured using a plot of heart rate versus running velocity. Simply, the point at which the increase in heart rate deviates from linearity during incremental exercise (Vd) is identified as the "AT". This point could be determined fairly easily with the use of a noninvasive heart rate monitor and a stopwatch. This method of determining "AT" could be modified to fit a rowing ergometer, which is often used as an indoor training device for rowing clubs in the United States (Korzeniowski, 1987). Modifications of the "AT" test proposed by Conconi et al. (1982) have been used by a number of different groups, including the 1987 world champion American rowing team, the 1985 gold medal Italian cross-country ski team, the 1985 New York Marathon winner and the 1985 Italian cycling team (Korzeniowski, 1987). The original work of Conconi et al. (1982) has been extended to rowing (Droghetti, 1986) and other activities (Droghetti et al., 1985). In further support of the concept of "AT" determination by measurement of the heart rate deflection, Gaisl and Weisspeiner (1987), reported a Pearson correlation of .92 between heart rates at "AT" determined invasively and noninvasively in 72 eleven-year-old children. In their study, heart rate at an intensity corresponding to a blood lactate level of 4 mmol/L was compared with heart rate at the noninvasively-determined Vd. They used a cycle ergometer protocol which involved progressive 10 W/min increases in power output.

Several researchers have criticized the validity, reliability and precision of the Conconi method for "AT" determination. Leger and Tomakidis (1985) attributed the high validity coefficients reported by Conconi et al. (1982) to the methodological bias of the research. They argued that the lactate response to incremental exercise cannot be described with a linear equation because it demonstrates a curvilinear relationship with exercise intensity (Leger and Tomakidis, 1985). It was also stated that Conconi's methodology was not totally clear and the magnitude of testing variations due to equipment changes was not known. Other researchers, using a variety of instruments and procedures, have also stated that the methodology of Conconi et al. (1982) is not without problems (Tiberi, Bohle, Zimmerman, Heck, & Hollmann, 1988; Heck, Tiberi, Beckers, Lammerschmidt, Pruin, & Hollmann, 1988; Yeh, Gardner, Adams, Yanowitz, & Crapo, 1983). Heart rate deflection does not always occur for cycle ergometry and it does not coincide with the "AT" determined from lactate measurements when it does occur (Kuipers, Keizer, deVries, van Rijthoven, & Wijts, 1988). Coen, Urhausen, & Kinderman (1988) pointed out that subject-dependent variability problems further limited the accurate determination of deflection points. Graph interpretation has resulted in large reviewer error (Tiberi et al., 1988). In one report, 20 percent of the deflection points determined from cycle ergometer tests were equivocal and another 20 percent could not be found (Heck et al, 1988). The "AT" determined from blood lactate concentration has also been shown to be too low when compared with the heart rate deflection point (Chwilkowski, Volker, & Hollmann, 1988). The methods used in many of these studies are inconsistent and there has been too little field work with the test to allow conclusions to be made about its validity and reliability. Much more work must be done to determine whether the concept originally described by Conconi et al. (1982) is useful.

Even with the Conconi method for measuring the contribution of the aerobic system to 2000 M rowing performance, the explanation of determinants of rowing performance is incomplete. The anaerobic determinants of a race distance that is estimated to be 30 percent anaerobic must be considered (Hagerman et al., 1979). The measurement of anaerobic capacity, defined as the "ability to persist in the repetition of strenuous muscular contractions that rely substantially on anaerobic mechanism of energy supply" (Lamb, 1984, p.465) is needed. Anaerobic capacity is traditionally measured with the 30-s protocol of the Wingate cycle ergometer test (Lamb, 1984), but Katch and Weltman (1977) and Nebelsick-Gullett, Housh, Johnson, & Bauge (1988) proposed a 40-s protocol that is better suited to the measurement of the rower's anaerobic capacity. The 40-s AC test should provide additional performance data and may better assess the contribution of the anaerobic energy systems.

SUMMARY OF THE LITERATURE

Research on the physiological determinants of rowing performance has been reported since 1920. In the 1960's, many performance variables were investigated and maximal oxygen consumption was considered the most important. By the 1980's, "anaerobic threshold" assumed a more important role in both the science of training and the prediction of rowing performance. The research on a novel method for determining "AT" in runners (Conconi et al., 1982) brought about the possibility of a noninvasive field test for the measurement of rowing performance using the rowing ergometer. There is considerable debate with regard to the accuracy, reliability and validity of Conconi's test. More research is needed to determine the utility of the Conconi test and the role of AC in 2000 M rowing performance.

CHAPTER III

METHODS

This chapter presents the methods used to estimate lean body weight (LBW), velocity of deflection (Vd), anaerobic capacity (AC), 2000 M rowing ergometer performance (PT), and their relationships to one another.

SUBJECTS

Thirteen trained male oarsmen were recruited from the Portland, Oregon metropolitan area. All subjects were volunteers with two or more years rowing experience. All were familiar with the rowing ergometer used for the five tests (Concept II). Height, weight, age, resting heart rate and average training intensity were obtained from each subject. Subjects were fully informed of all risks and benefits of participation in the study and gave voluntary written consent in accordance with the Portland State University Human Subjects Research Review Committee. The characteristics of the subjects are presented in Table I.

TABLE I

SUBJECT CHARACTERISTICS

n 13	AGE (yrs)	HEIGHT (cm)	WEIGHT (kg)	BODY FAT (%)	LBW (kg)
MEAN	38.4	185.3	84.1	15.6	70.8
STANDARD DEV.	8.3	5.8	9.8	4.7	7.5
RANGE	24-52	173-197	61-96	6-21	56-82

EQUIPMENT

A Concept II rowing ergometer (Concept II, Inc., Morristown, VT.) with digital electronic performance monitor was used for all tests. This ergometer has two sprockets, a flywheel with built-in fan blades, a wind damper, and a sliding seat. It accurately simulates actual rowing (Hagerman et al., 1978).

The electronic performance monitor is a battery operated microprocessor which displays elapsed time, stroke rate, stroke output (time/500 M and watts/stroke) and total workout information (distance rowed and average watts/stroke for that distance). The power output (watts) is calculated from the "drive" portion of the stroke divided by the time of the full stroke cycle. The microprocessor uses the factory measured moment of inertia with precise measurements of flywheel speed and acceleration in this computation.

The heart rate monitor used (CIC model #8733) included a wireless electrode belt worn around the chest which transmitted signals to a nearby digital wrist watch which displayed the heart rate.

Lean body weight (LBW) was estimated with hydrodensitometry (Brozek, Grande, Anderson, & Keys, 1963), and residual lung volume was measured with the oxygen dilution method (Wilmore, Vodak, Parr, Girandola, & Billing, 1980). Oxygen and carbon dioxide concentrations were measured in duplicate with Beckman E2 and L1 analyzers, respectively. Residual lung volume measurements were performed with the subject in the seated position. The mean of two trials was used, with additional trials performed if the first two measurements differed by more than 200 ml. Ten trials of the hydrostatic weighing procedure were performed on each subject, with the mean of the three heaviest underwater weights used to calculate body density. Percent fat was estimated using the Siri (1956) equation, and lean body weight was defined as the difference between total body weight and fat weight.

PROCEDURES

A pilot study was performed to practice data collection for the Vd test, determine the optimal anaerobic capacity test, and review hydrostatic weighing and residual lung volume procedures. Four male and two female subjects were tested to determine that a 40-s protocol was suitable for the rowing ergometer AC test. The pilot study further resulted in the addition of an optional seat strap for the AC test, the standardization of the ergometer gearing for the Vd and AC tests, and the decision to study only trained male subjects. The selection of male subjects was necessary to avoid the bias caused by training and racing for different distances and was supported by the identification of greater anaerobic contribution for women than men (Hagerman et al., 1979).

After the pilot study, trained male rowers were recruited by telephone and personal contact, and meeting times at the Portland State University Exercise Physiology Laboratory were arranged for all the subjects. At this meeting the informed consent was obtained and the physical characteristics recorded. Hydrostatic weighing and LBW calculations were done at a separate time during the 10 day period.

A total of five rowing ergometer tests were required of each subject. Tests included two trials of a submaximal. 10-14 min Vd test, two trials of a 40-s AC test and one trial of a 2000 M PT. All five tests were completed in a 10 day period. The subject first began the adapted Conconi Vd test (Korzeniowski, 1987). In this test, the subject completed a steady-state, 5 min warmup at a heart rate greater than 130 beats/min. The subject then increased the velocity by approximately 3-s/500 M for the next minute by increasing stroke rate and/or leg drive. (See Definition of Terms) This submaximal exercise progression continued for a maximum of 7 min or until the subject could not continue increasing the velocity. The investigator recorded velocity and heart rate several times throughout each minute. The mean heart rate was obtained from the digital watch display of the CIC heart rate monitor in the last 30-s of each minute. Heart rate and velocity scores were graphed for each trial of each subject. Three independent investigators individually determined linearity and departure from linearity of each graph. The two closest scores of the three independent, subjective determinations of this deflection point from the heart rate versus velocity graph were averaged to obtain the Vd for that trial. Figure 1. graphically illustrates the subjective determination by one reviewer of the Vd points for two trials.

After a 15-min active recovery, the subject performed an all-out 40-s AC test on the rowing ergometer. Throughout the AC test the power output of each stroke was displayed on the electronic performance monitor, and the total power output was recorded as the anaerobic capacity of the subject for the trial.

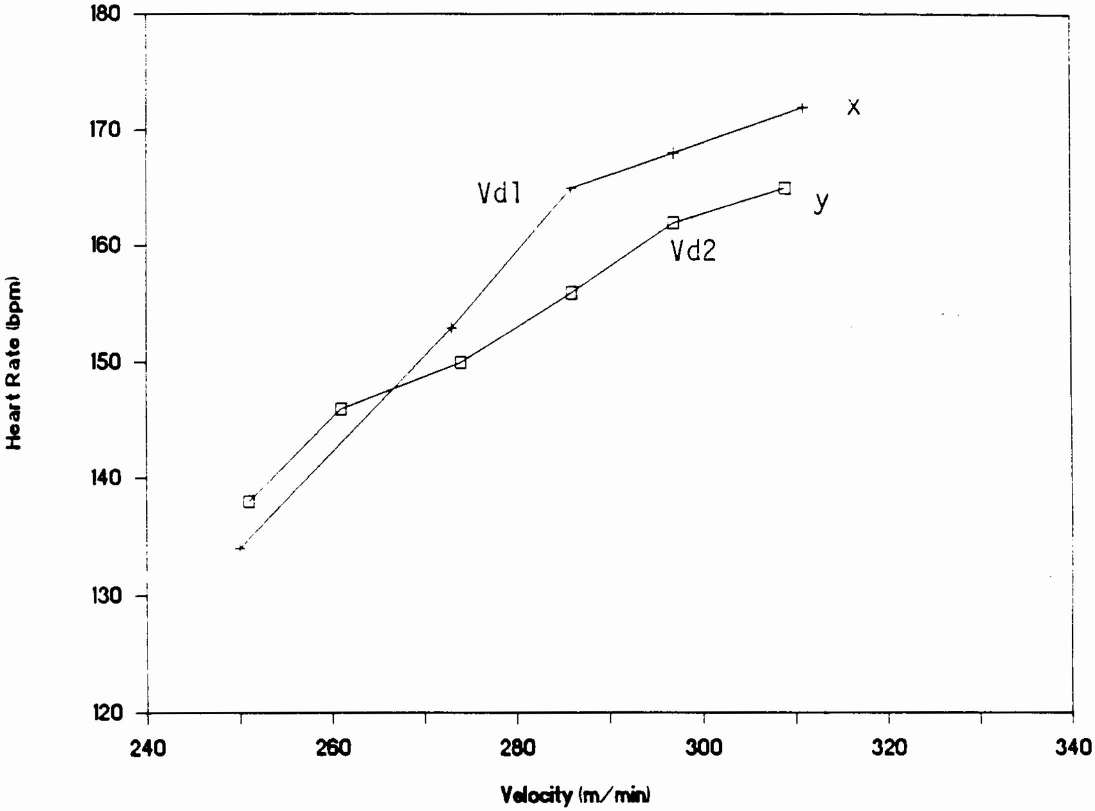

Figure 1. - Heart rate vs. velocity for subject 7.
x = trial 1; y = trial 2

The AC test was followed by another full active recovery. During the second visit to the laboratory the Vd and AC testing procedures were repeated. The subjects performed the 2000 M PT during the third laboratory visit. This final test was preceded by a warmup and followed by an active recovery. The subjects chose their own ergometer settings and were verbally encouraged throughout the 2000 M performance.

At the completion of the testing, all subjects received feedback concerning their test performance, including training guidelines calculated from test results. They also received the anonymous, summarized results of all subjects on the performance tests.

STATISTICAL ANALYSIS

There were four primary statistical steps used in the analyses of the five rowing ergometer tests and LBW results. First, a simple analysis of variance (ANOVA) with repeated measures was used on the two Vd and two AC tests to determine whether significant differences existed between the first and second tests. The BMDP2V statistical package was used for this determination (Dixon & Brown, 1981). Second, intraclass correlation (R) was used to determine reliability between first and second tests of Vd (Baumgartner & Jackson, 1982). Third, Pearson's r was used to determine the interclass correlations of mean AC to PT and mean AC to mean Vd. In this determination, mean AC was the average of the two AC tests for each subject and mean VD was the average of the two Vd scores. Fourth, stepwise multiple linear regression analysis was used to explain variance in PT using three independent variables: Vd, LBW, and AC. The BMDP2R statistical software package was used for this analysis (Dixon & Brown, 1981). The multiple R^2 (amount of variance explained by one, two and three variable models) was reported at each step, as were the regression equations for the prediction of PT.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS

The mean data for each of the rowing ergometer tests for the 13 subjects are listed in Table II. Individual data are reported in Table III.

TABLE II

SUMMARY RESULTS

n 13	Vd m/min	AC watts	PT s
MEAN	284.6	16679.5	420.2
STANDARD DEV.	44.9	3754.0	16.4
RANGE	98-121	8723-23451	395-448

The scatter plots of figures 2, 3, and 4 graphically illustrate the mean Vd, LBW, and mean AC data vs. the 2000 M performance time of Table III, for the 13 subjects. Table IV presents the interclass and intraclass correlational results of the study.

TABLE III

INDIVIDUAL DATA

	LBW(kg)	Vd(m/min)			AC(W)			PT(s)
Subj.		Trial 1	2	Mean	1	2	Mean	
1.	72.3	*	302.1	302.1	22408	24494	23451	398.2
2.	70.5	287.9	300.6	294.3	17869	22991	20430	409.1
3.	75.2	259.1	274.0	266.6	15978	12849	14414	429.3
4.	75.9	*	302.1	302.1	18792	18344	18568	408.2
5.	63.6	273.0	291.5	282.3	14859	13126	13993	448.0
6.	70.6	270.0	273.0	271.5	16592	16249	16421	428.8
7.	77.5	297.0	286.0	291.0	17026	18613	17820	407.8
8.	82.0	316.1	300.0	308.1	16713	16144	16429	395.1
9.	67.2	287.1	299.1	293.1	15155	13206	14181	424.2
10.	75.3	274.0	294.1	284.1	18257	18225	18241	412.2
11.	58.8	*	283.0	283.0	14328	13589	13959	430.0
12.	56.4	233.0	266.0	249.5	7544	9901	8723	443.5
13.	75.0	275.2	297.0	286.1	16832	23582	20207	428.0

LBW = Lean body weight; Vd = Velocity of deflection
AC = Anaerobic capacity
PT = Performance time for one 2000 M rowing ergometer trial
* = Vd trial 1 scores not included because of equipment failure

TABLE IV

CORRELATIONAL RESULTS

	Vd_1/Vd_2	AC_1/AC_2	
Intraclass R	0.740*	0.863	
	$\overline{AC}/PT$	$\overline{AC}/\overline{Vd}$	$\overline{AC}/LBW$
Interclass r	-0.714	0.700	0.625

$\overline{AC}$ = Mean of two 40-s all-out trials

$\overline{Vd}$ = Mean of all velocity of deflection trials

* = No trial 1 scores for subjects 1,4 and 11 (n = 13)

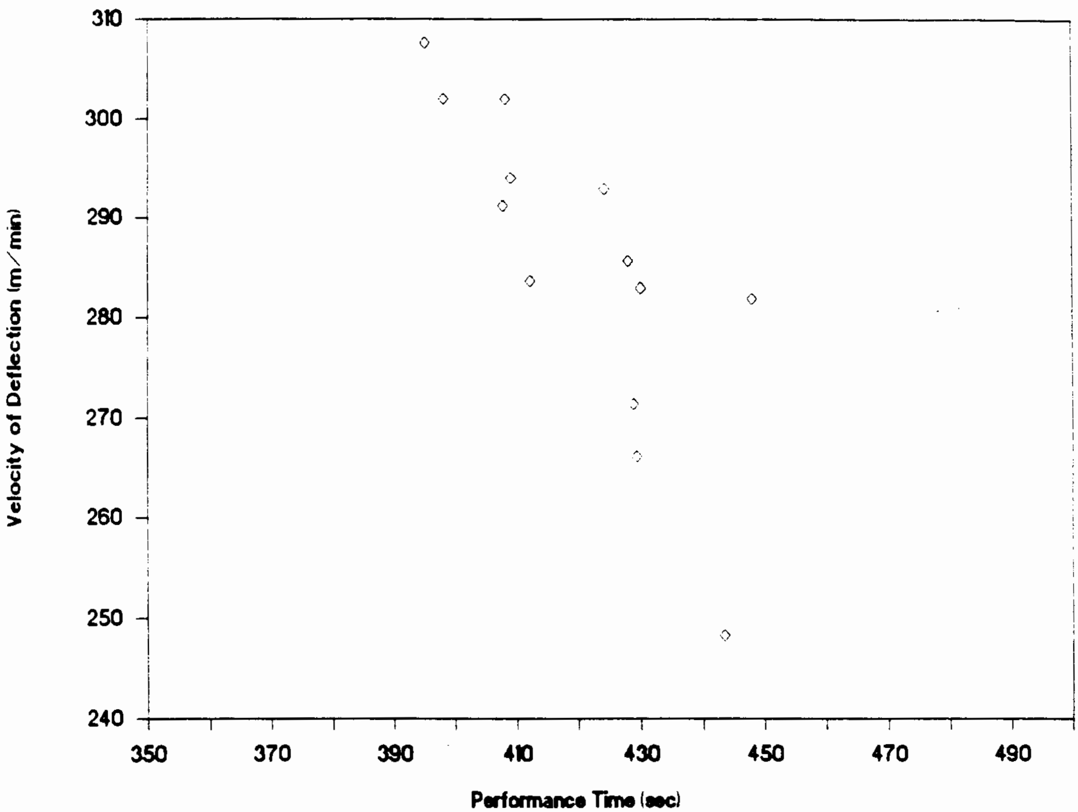

Figure 2. - Velocity of deflection vs. 2000 M rowing ergometer performance time for all subjects. (n = 13)

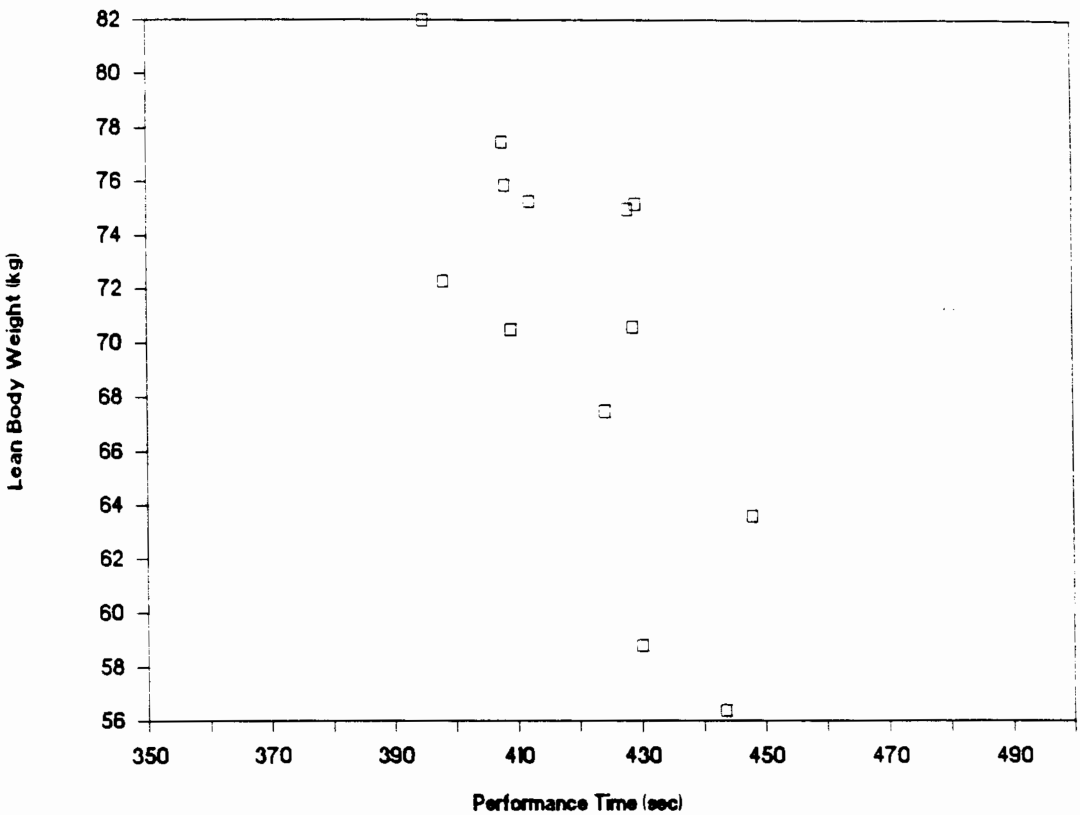

Figure 3. - Lean body weight vs. 2000 M rowing ergometer performance time for all subjects. (n = 13)

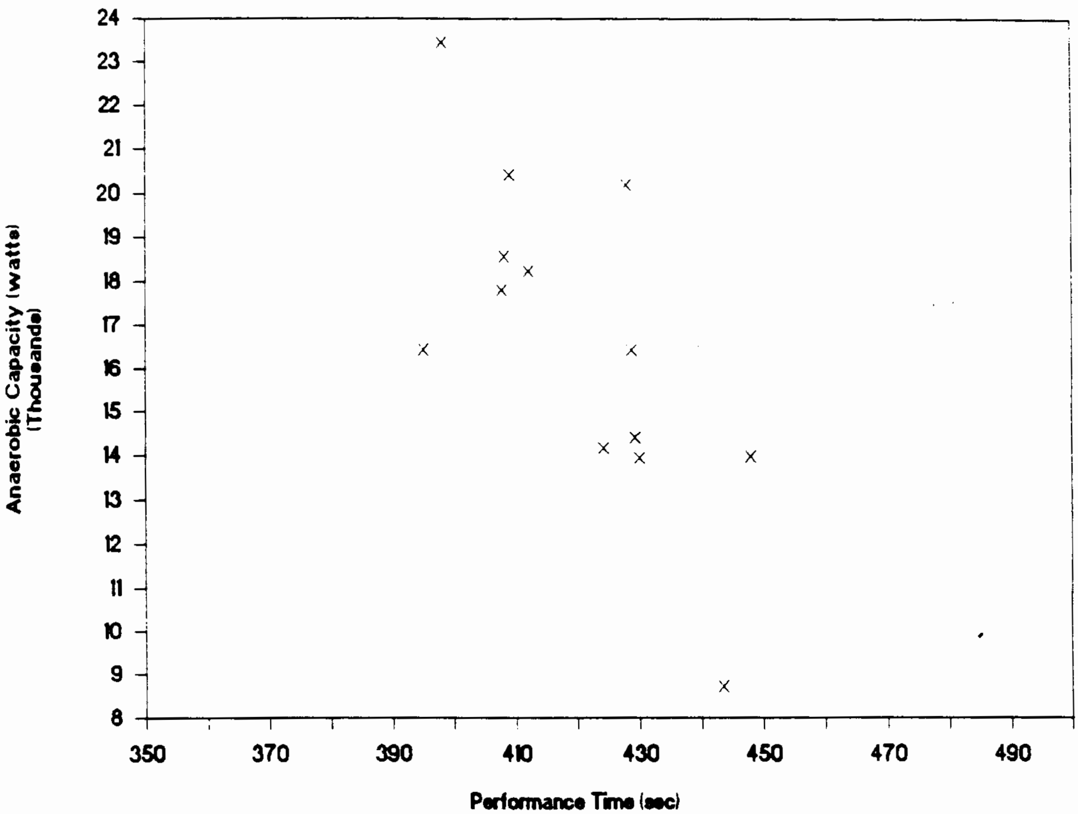

Figure 4. - Anaerobic capacity vs. 2000 M rowing ergometer performance time for all subjects. (n = 13)

ANOVA with repeated measures for the two Vd and two AC tests showed no statistically significant differences between trials for either test at the .05 level of significance. Intraclass correlations showed the tests to be reliable, with R(Vd1 versus Vd2) = 0.740 and R(AC1 versus AC2) = 0.863. Interclass correlations for mean AC versus PT and mean AC versus mean Vd were r = -0.714 and r = 0.700, respectively. Stepwise multiple linear regression resulted in multiple R^2 at three steps of 0.589, 0.709 and 0.720, using independent variables Vd, LBW, and AC. Appendix C, graphically illustrates the contributions of Vd, LBW, and AC to PT variance at the final step of the regression. The regression equation for PT prediction was PT(s) = 375.7 + 1.093(Vd) - 0.820(LBW) - 0.0007(AC) with a standard error of estimate(S.E.E.) of 10.0 s when AC was forced into the regression and PT(s) = 346.2 + 1.33(Vd) - 0.94(LBW) with S.E.E. = 9.7 s when it was not.

DISCUSSION

Statistical analysis of the data obtained from both the Conconi test and the 40-s AC test revealed that the Vd and AC tests are reliable. There were, however, some difficulties with the subjective determination of the Vd points by the three independent reviewers. All reviewers were in agreement (within 10 m/min) in only two determinations, and two reviewers reached this level of agreement in only four cases. These unclear subjective determinations point to potential difficulties in applying the test as a criterion in the selection of elite athletes for national teams. Problems with the heart rate monitor (subjects 1,4, and 11) add further difficulty to Vd determination. Despite the selection of only experienced male rowers, there may have been a learning effect in the research trials, as eight of the second Vd trials resulted in significantly higher scores. The analysis of training regimens and relative individual progress may be the best application of this test. In this application, the Conconi test could give indications of heart rate/velocity changes important to evaluating training changes.

The AC tests also resulted in some second test score variations. Subjects 2,12, and 13 recorded inordinate second test improvements. These improvements can be attributed to an increase in stroke rates (subjects 2 and 13) and competitive attitude (subject 12). The relationship of mean AC to PT is illustrated by a relatively high negative correlation coefficient (-0.714). The moderately high correlation between AC and Vd (0.700) may also have tended to "mask" the importance of AC in explaining variance in PT. A comparison of the graphs of figures 2,3, and 4 illustrates this correlation of high AC scores to better performance times and implies that AC is more important to 2000 M performance than the 0.0007 contribution to the multiple R^2 indicated in the final forced step of the multiple linear regression. The three variable stepwise regression results indicate in the first step, that Vd explained 59.0% of the variance in PT. This study does not test the validity of the Vd as an anaerobic threshold point, but it does show the variable to be an important predictor of 2000 M PT. The study further results in new AC data and mean AC correlations to PT and Vd. This information can be added to the existing research, but it is limited in generalizability to the 13 trained rowing subjects of the study.

The results of this study do not validate the Vd concept as a noninvasive measurement of the "anaerobic threshold" for male rowers. They do show, however, that the point at which the heart rate increase departs from linearity on a heart rate versus velocity graph is an important indicator of 2000 M rowing ergometer performance. There were problems with the heart rate monitors and the subjective detection of the deflection points, but Vd was the most important variable explaining rowing ergometer performance for these 13 subjects. With the addition of LBW the results indicated that over 70% of the variance in PT could be explained. This could be a powerful tool for both individual training and team selection. In these situations Vd can be translated to time/500 M on the rowing ergometer for easy and frequent measurement of training progress and, although not as accurate, LBW can be estimated outside the laboratory with appropriate anthropometric techniques.

The correlation of AC with PT (-0.714) and its correlation with Vd (0.700), indicated that this variable may be an important determinant of 2000 M rowing performance. However, more research is needed to explore the degree to which anaerobic factors contribute to rowing performance--especially in shorter races. It can be concluded then from this study of 13 trained male rowers that anaerobic factors were important to their 2000 M performance and that PT is primarily dependent on factors of aerobic metabolism and available lean body weight. These results have implications for elite rower physiological profiles but are better applied to the analysis and determination of the training of individual rowers.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

1. Aerobic and LBW factors explained approximately 71% of the variance in 2000 M rowing ergometer performance for the 13 male subjects in this study.

2. These noninvasive rowing field tests are specifically applicable to individual training programs and team selection criterion. These tests are best used in the analysis and determination of individual training regimens.

3. Further research is indicated. Short- and long-range clarifications of Conconi's Vd concept and a more complete investigation of anaerobic capacity are needed. This investigation should involve factors in 1000 M PT for both men and women.

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APPENDIX A

EVALUATION AND RECRUITMENT

ROWING PERFORMANCE RESEARCH - SUBJECTS NEEDED

Purpose: To investigate the physiological determinants of 2000 M rowing performance.

Qualifications: Trained, male rowers, 18-50 years of age, with no health problems and with Concept II ergometer experience.

Benefits: The measurements of Anaerobic Threshold (AT) and Anaerobic Capacity (AC) with the CIC Heart Rate Monitor and the Concept II computer will provide the information for a focused and efficient personalized training plan. Body composition will also be measured with hydrostatic weighing and residual lung volume techniques. More generally, this study evaluates the applicability of noninvasive AT and AC field tests to the selection and training of crew teams.

Commitments: What - Three 30 min. sessions in 7-10 days.
Where - Portland State University Exercise Physiology Laboratory or Station "L" Rowing Club.

Sample Format -	1st day AT & AC	Sat.
	2nd day AT & AC	Wed.
	3rd day Weighing & 2000	Sat.

Contact: Jeff Young, 236-0224, for application or further information. Also available by appointment: Rm. 230, PSU.

PORTLAND STATE UNIVERSITY ROWING PERFORMANCE RESEARCH PROJECT:

INFORMED CONSENT

Explanation - You will be performing a series of tests on the Concept II Rowing Ergometer (RE) that will be used to investigate the determinants of 2000 M rowing performance. This study seeks to provide personal training guidelines and noninvasive field tests of Anaerobic Threshold (AT) and Anaerobic Capacity (AC) for crew team selection and training. Additionally, this study will estimate the feasibility of AT and AC testing for non-rowers. The measurements to be obtained and the tests to be performed are listed below:

1. Age, Height, and Weight.
2. Heart Rate - at rest and during exercise.
3. Percent Body Fat - Hydrostatic Weighing includes Residual Lung Volume determination.
4. AT tests - 2.
5. AC Tests - 2.
6. PT Test - 2000 M Performance Test.

Risks and Discomforts - The primary risks with participation in this study are physical. Specifically, the rower could experience muscular distress or injury as a result of improper rowing technique or inadequate training. There is also a small possibility that light-headedness may occur during/after the residual lung volume determination and immediately following the 2000 M PT and AC tests. Every effort will be made to minimize these risks. The principal investigator will be present to monitor the signs/symptoms of light-headedness and over-exertion. Adequate warm-up and cool-down periods are required for all tests. Finally, no subject will leave the testing area until fully recovery is attained.

Benefits - The subject will obtain training information from the AT test. Power, anaerobic capacity, and body composition information will also be given to the subject. Personal, efficient training programs can be established from this information. More generally, this study could provide information on noninvasive field tests of AT and AC which could be used for team selection and training.

Freedom of Consent - Permission for you to perform these tests is voluntary and you may choose to withdraw from participation in the study at any time.

I have read this form and the description of the tests and further verify that I am suitably trained for these tests. I consent to participate in these tests. Questions on this informed consent form may be directed to the Office of Grants and Contracts of Portland State University, at 464-3417.

__________________________ _______________

Signature of Participant Date

HEALTH STATUS (check areas which relate to you)

______ ALLERGY
______ ANEMIA
______ BRONCHITIS (EMPHYSEMA)
______ CANCER
______ CIRRHOSIS
______ DIABETES
______ DRUG PROBLEM
______ GOUT
______ HEART DISEASE
______ HIGH BLOOD PRESSURE
______ HIGH CHOLESTEROL
______ NERVOUS BREAKDOWN
______ KIDNEY DISEASE
______ NEURAL DYSFUNCTION

______ RHEUMATISM
______ SEIZURES
______ SKIN RASHES
______ STROKE
______ SURGERY
______ THYROID
______ ULCERS
______ HERNIAS
______ EDEMA
______ INSOMNIA
______ OVERWEIGHT
______ LUNG DISEASE
______ PNEUMONIA
______ OTHERS
____

INDICATE MEDICATIONS

______ BIRTH CONTROL PILLS
______ HORMONES/STEROIDS
______ SLEEPING PILLS
______ BLOOD PRESSURE MED.
______ HEART MEDICATION
______ LAXATIVES

______ CORTISONE
______ ASPIRIN
______ VITAMINS
______ TRANQUILIZERS
______ SEDATIVES
______ OTHER
____

FAMILY HISTORY (check if any blood relatives, parents, sisters, aunts, grandparents, etc. have had the following)

LIST RELATIONSHIP

______ HEART DISEASE ____________________
______ HEART ATTACKS OR STROKE,
PRIOR TO AGE 50 ____________________
______ AFTER AGE 50 ____________________
______ HIGH BLOOD PRESSURE ____________________
______ HIGH CHOLESTEROL ____________________
______ DIABETES ____________________

APPENDIX B

TESTS

EXPLANATION OF TESTING PROCEDURES

Age, Height, and Weight - Self-explanatory.

Heart Rate - The CIC transmitting heart rate monitor will be used. This belt-like transmitter encircles the chest and transmits signals to a nearby wristwatch during both resting and exercising conditions.

Hydrostatic Weighing - Underwater weighing is used to estimate body composition. The protocol is:

1. Pretest shower. A swimsuit is needed.
2. At least ten complete submersions, each performed after maximal exhalation. The investigator will tap the side of the tank when each submersion is completed.
3. Maximal exhalation into a spirometer and rebreathing pure oxygen five to seven times from the spirometer. This test precedes the 2000 M PT performed the same day.

AT Test - The Concept II Rowing Ergometer (RE) is used to determine the point of transition from primarily aerobic work to the combination of aerobic and anaerobic work. You will be asked to wear a CIC Heart Rate chest belt. The submaximal test lasts 10-12 min. and follows the protocol below:

1. A 5 min. warm-up with heart rate below 130 bpm.
2. Incremental velocity and stroke rate adjustments until AT is reached. In rowing terms this means that 500 M times are decreased 3 sec./min. and the stroke rate goes up about 2 strokes/min. This test will take 5-7 min. to complete.
3. Active recovery of 15 min.

AC Test - This test measures peak, average, and total power for a 40 sec. period. You will perform a full power, all-out test for 40 sec. on the RE. The two AC tests will follow the AT tests and will conclude with a full, active recovery.

PT Test - This is a 2000 M racing trial on the RE. Best results are generally obtained with consistent 500 M pacing. The protocol is as follows:

1. 10 min. warm-up.
2. 2000 M at the intensity of your choice. Encouragement will be provided and the CIC Heart Rate monitor will be used.
3. Active cool-down and remain in testing area until the heart rate returns to within 15 beats of the resting heart rate.

PHYSIOLOGICAL DETERMINANT OF ROWING PERFORMANCE DATA

Subject__________________ Date______ Ht.______ Wt.______ Age_____

Workouts/Wk._________ Rowing Experience (yrs.)________________

Condition Today__________ RHR______ Other Sports_____________

Test Location______________ Phone_____________ Next Test______

Anaerobic Threshold Test Total Time_________________

Ergometer Adjustment (outside gear, windows closed)__________

Min.	500 M times	Strokes/min.	Heart Rates	Other
5				
6				
7				
8				
9				
10				
11				
12				

Active 15 min. recovery_________________.

Anaerobic Capacity Test

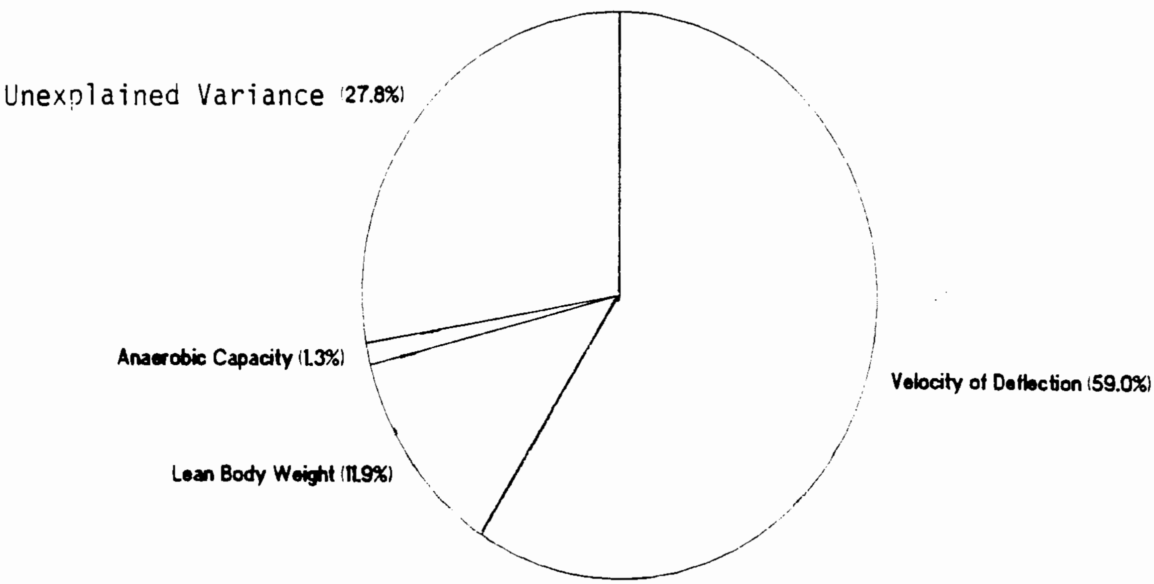
Erg' set @ outside gear, 1 window open__________________.
Avg. Watts from digital_____________ Total Watts_____________.
Total # strokes_____________ Avg. calculated Watts/str______.
Peak Power of________ in________ sec. Strop used?___________
Comments____.
Finishing HR______ Recovery HR's___________________________.

	Time (sec.)	Power spm	Time - Power spm	Time - Power spm

Data:

APPENDIX C

STATISTICS



Stepwise Regression of PT Variance includes velocity of deflection, lean body weight, and anaerobic capacity. (n = 13)

APPENDIX D

INDIVIDUAL DATA

INDIVIDUAL SUBJECT DATA

Subj.	LBW(kg)	Power(W) Avg.W/ Stroke *	Peak Power	AC(W)* 1	2	Mean	PT(s)
1.	72.3	687.0	819	22408	24494	23451	398.2
2.	70.5	678.3	780	17869	22991	20430	409.1
3.	75.2	692.0	673	15978	12849	14414	429.3
4.	75.9	724.5	774	18792	18344	18568	408.2
5.	63.6	562.0	567	14859	13126	13993	448.0
6.	70.6	538.5	605	16592	16249	16421	428.8
7.	77.5	639.8	709	17026	18613	17820	407.8
8.	82.0	686.1	703	16713	16144	16429	395.1
9.	67.2	529.8	598	15155	13206	14181	424.2
10.	75.3	647.8	717	18257	18225	18241	412.2
11.	58.8	534.3	567	14328	13589	13959	430.0
12.	56.4	426.3	489	7544	9901	8723	443.5
13.	75.0	692.0	737	16832	23582	20207	428.0

LBW = Lean body weight
AC = Anaerobic capacity
PT = Performance time for one 2000 M rowing ergometer trial
* = Two trials