# PREDICTORS OF 2 KILOMETER ROWING ERGOMETER TIME TRIAL PERFORMANCE

by

**Jason William Metz**

BS, Exercise and Sport Science, Frostburg State University, 2002

MS, Exercise Science and Health Promotion, California University of Pennsylvania, 2006

Submitted to the Graduate Faculty of

The School of Education in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2017

UNIVERSITY OF PITTSBURGH

SCHOOL OF EDUCATION

This dissertation was presented

by

Jason William Metz

It was defended on

July 25, 2017

and approved by

Dr. Robert Robertson, Professor, Health and Physical Activity

Dr. Elizabeth Nagle, Assistant Professor, Health and Physical Activity

Dr. John Abt, Assistant Professor, Health and Rehabilitation Sciences

Dissertation Advisor: Dr. Fredric Goss, Associate Professor, Health and Physical Activity

`

## TABLE OF CONTENTS

## LIST OF TABLES

# 1.0 INTRODUCTION

The aim of this study was to develop a regression model to predict performance of a simulated 2 kilometer race. Several factors have been reported to predict rowing performance including body composition, fat free mass, oxygen uptake and maximum power (watts). (3,4,9,37) However, no research has collectively utilized these and other variables in an effort to predict 2km performance.

Predictors of performance aid coaches, strength coaches, and trainers in prescribing exercise programs for athletes and clients. To date, most of the prediction models have been developed using cyclists, runners and tri-athletes. Little research has been conducted on rowing performance and it is difficult to extrapolate findings from cycle or treadmill performance to rowing performance. (13,23) A few studies have shown that maximal oxygen uptake and maximum oxygen uptake steady state can be used to predict 2km rowing performance in both male and female rowers, of various competitive experience and relative to their age and competitive experience. (13,23,45) A higher maximal oxygen uptake is associated with faster times during a 2km race in rowers of varying competitive experience. (13,23) Because of the duration of the time trial and the fact that most competitive rowers can maintain an intensity equal to 96% of maximal oxygen uptake for the entire race, maximal oxygen uptake may be a strong predictor of race performance. (40) In addition, the higher the power output (watts) an individual can sustain in a steady state, the better the performance in a 2km race. (27) An experienced rower will have greater maximum steady state and a lower oxygen uptake at a specific workload than an inexperienced rower. In contrast, a comparatively inexperienced rower will have higher oxygen uptake levels at submaximal exercise intensities. (51)

Several different predictor variables were examined during pilot testing for the present investigation. These variables were used in an attempt to predict a 2km time trial and ultimately, 5 variables proved to have a high predictive value, power/stroke ratio at the second ventilatory breakpoint ($r^2$ = .868, $p<0.01$), oxygen uptake at the second ventilatory breakpoint ($r^2$ = .842, $p<0.05$), body fat percentage ($r^2$ = .929, $p<0.005$), fat free mass ($r^2$ = .681, $p<0.05$) and mechanical energy cost per stroke (power/stroke ratio) ($r^2$ = .854, $p<0.01$). Some additional variables that were considered in the present investigation are maximal oxygen uptake, maximal power output and physiological and mechanical energy cost per stroke (power/stroke ratio). Both mechanical and physiological energy cost per stroke are calculated values represented by power output (watts)/strokes per minute and $VO_2$/strokes per minute, respectively. These will be the variables that will be examined in the proposed investigation as potential predictors of performance. Previous research reports moderate to strong negative correlations between 2km rowing performance and peak power output, oxygen uptake, fat free mass and body fat percentage (6,10,14,23,24,30).

The ventilatory breakpoint, another potential predictor of performance, occurs as a result of an increased hydrogen ion concentration in blood and muscle. Hydrogen ions build up during exercise primarily as a result of a lack of available oxygen. These hydrogen ions and the resulting decrease in pH are powerful stimulators of ventilation. (41) The ventilatory breakpoint characterized by the point at which there is a non-linear rise in ventilation with an increase in exercise intensity signifies the transition from a predominantly aerobic metabolic state to a condition where the contribution of anaerobic metabolism increases significantly. Because the 2km race typically requires maximal effort, the aerobic energy system will likely not be able to satisfy the energy demands leading to an increased reliance on glycolysis. (13,14,38) This reliance on glycolysis will increase lactic acid, hydrogen ions, non-metabolic CO2 and ventilation. (41) The ventilatory breakpoint is a non-invasive correlate of the anaerobic threshold that has previously been validated through research. (1,41)

## 1.1 RATIONALE

The purpose of the present study was to develop a combined gender regression model to predict performance on a rowing ergometer during a simulated 2 kilometer race. 2km is a standard length of a race in competitive rowing. The distance is typically covered in 6-10 minutes depending on the performance level of the athlete. (5,10) Identifying variables that can be used to predict performance may lead to better training programs to optimize performance.

## 1.2 RESEARCH OBJECTIVE

Objective 1: Develop an equation to predict performance during a simulated 2km race for male and female competitive rowers

## 2.0 REVIEW OF LITERATURE

### 2.1 PREVIOUS PREDICTION MODEL ANALYSIS

Identifying predictors of performance can aid in the development of conditioning programs for a given athletic population. Some of the previously established predictors of rowing performance are maximal oxygen uptake, maximum heart rate, anaerobic threshold, movement efficiency, lean body mass, and peak power development. (5,28,30) Jensen (1996) determined peak rowing power output was significantly correlated to 2km rowing time ($r=-0.52$; $P< 0.05$)

#### 2.1.1 Anaerobic Threshold

Beneke (1995) identified an individual anaerobic threshold (IAT) during rowing that was also a predictor of 2km racing performance ($r=0.79$, $p<0.01$). The IAT is the highest workload in which lactate elimination and accumulation are in balance resulting in no increase in lactate (ie. a lactate steady state). Beneke also states that the IAT corresponds to the second lactate breakpoint identified by Rankinen(1995) and corresponds to a blood lactate concentration of 6.0 mmol/l. (4) A blood lactate concentration of 4.0 mmol/l (AT4), sometimes referred to as Onset of Blood Lactate Accumulation (OBLA), has also been used as a predictor of 2km rowing performance. (5,43)

The anaerobic threshold should signify the increase in hydrogen ion concentration in the blood resulting from anaerobic metabolism. The 2km rowing test lasts about 6-10 minutes based on the experience and fitness level of the athlete. (24,35,36) Experienced rowers typically finish 2km in about 6-8 minutes while inexperienced rowers can take upwards to 10 minutes. (48) In the present investigation subjects completed the 2km time trial in 447±47.34 seconds. Since the race is comparatively short and intense, and 30% of the energy metabolism for 2km rowing is derived from anaerobic pathways an anaerobic marker as a predictor of performance was shown to be valuable. (28,30,42).

The concentration of lactic acid and lactate in the blood is influenced by the production and removal. Lactic acid is the metabolic by-product of anaerobic metabolism. Lactic acid quickly dissociates a hydrogen molecule and the resulting product is lactate. Training can decrease lactate production at submaximal intensities resulting in an increase in the lactate threshold (41). During competition, the higher the intensity the rower can maintain without a significant increase in lactate the better the performance. Training can alter lactate dynamics via two mechanisms. Buffering capability can be enhanced leading to a decreased accumulation of lactic acid and the removal of lactate via the Cori Cycle can be facilitated. The Cori Cycle is the process by which lactate is shuttled to the liver to be converted back to glucose which is then returned to the blood stream or stored in the liver. (41) Lactate is also used by skeletal muscle and the heart and other systems as a substrate and training may also enhance the potential to convert lactate into glucose. (1,41)

The anaerobic threshold signifies an increase in anaerobic metabolism by-products, lactic acid, carbon dioxide, sulphuric acid, phosphoric acid, keytone bodies and carbonic acid. (8,41) This breakpoint typically occurs at about 78% of maximal oxygen uptake in trained individuals. (8,43) For this study, the anerobic threshold will be included as a potential predictor of 2km rowing performance. This breakpoint, will be identified as the point at which $Ve/VO_2$ increases without a concomitant increase in $Ve/VCO_2$.

### 2.1.2 Maximal Oxygen Uptake

Other strong predictors of 2km rowing performance cited in many research studies are maximal oxygen uptake ($r=0.9$, $p<0.001$), fat free mass ($r=-0.91$, $p<0.001$), and body mass ($r=-0.85$, $p<0.001$). (2,23,34,42). According to one research study, during a 2km race, collegiate rowers exercised at about 96% of their maximal oxygen uptake and at about 98% of their maximal heart rate. (40). However, additional factors may influence rowing performance. For example, elite rowers typically have a high anaerobic threshold and efficient mechanics(power/stroke ratio). Ingham et al.(2002), reported a correlation between 2km rowing performance and the anaerobic threshold of ($r=0.87$, $P=0.001$). Efficient mechanics decrease oxygen demand at submaximal workloads when compared to someone with less efficient mechanics. (1,41) This higher tolerance to work will allow a rower to achieve a higher workload before reaching the anaerobic threshold. Maximal oxygen uptake reveals more about potential and less about production. Therefore, the anaerobic threshold or maximal steady state may be a more accurate predictor of rowing performance than maximal oxygen uptake.

### 2.1.3 Movement Efficiency

One aspect of rowing that can impact all areas of performance is efficiency of movement. Poor movement economy causes higher energy requirements for a given workload. A rower with flawed mechanics will expend more energy per stroke than an efficient rower. (27,28) Fatigue patterns of the muscles involved in rowing also contribute to movement efficiency which ultimately affects performance. (33,48) In this investigation, movement efficiency will be referred to the amount of power created per stroke (power/stroke ratio).

Muscle fatigue during exercise may be caused by multiple factors. Favero et al (1999) cites calcium delivery as having a profound effect on skeletal muscle fatigue. A decrease in calcium delivery impairs actin and myosin crossbridge formation. Disruption of the sarcoplasmic reticulum decreases the amount of calcium that is released from the lateral sac thus affecting the coupling of actin and myosin. The disruption of calcium release may originate with the decrease of potassium outside of the muscle cell membrane and a decrease in sodium inside the cell membrane. Potassium decrease causes a decreased action potential. (15,20) This action potential reduces the stimulation of the transverse tubule thus limiting the calcium release from the lateral sac. Calcium triggers the binding of myosin heads to the actin filament. (41)

Once cross-bridges are formed, actin and myosin filaments slide past one another thus causing the muscle to shorten. Once the myosin heads have completed a single stroke, ATP binds to the myosin head causing it to detach from the actin filament. Once the energy is released and a phosphate bond is broken, the myosin head re-attaches to the actin filament causing another power stroke. If calcium is not released from the lateral sac of the sarcoplasmic reticulum the muscle cannot contract. (1,41)

Adenosine Tri-Phosphate (ATP) must be present to break the bond between actin and myosin to allow the myosin heads to re-attach to another actin filament to continue the shortening. If ATP is not present the heads cannot re-attach and thisleads to cessation of contraction.

Favero et al (1999) identifies two types of fatigue patterns, high frequency fatigue (HFF) and low frequency fatigue (LFF). High frequency fatigue is a rapid loss of force but once muscle activation slows or stops, recovery is rapid. Low frequency fatigue is a loss of force and recovery can take several days. Favero et al (1999) speculates that the low frequency fatigue occurs as a result of metabolic acidosis, low mitochondrial density or from sarcoplasmic reticulum disruption. High frequency fatigue may occur as a result of a decrease in neurological drive to the muscle (20)

Metabolic fatigue typically occurs as a result of a build-up of lactic acid. Lactic acid accumulation, as a result of an increase in anaerobic metabolism leads to an increase in hydrogen ion concentration and a decrease in pH. A decrease in pH inhibits enzyme activity resulting in the reduced ability to generate ATP. (1,41)

Mitochondrial fatigue occurs as a result of the inability of the Krebs cycle to produce reduced NADH and $FADH_2$ for transport to the electron transport chain. NADH and FADH are reduced hydrogen carriers. The electron transport chain is the final step in oxidative phosphorylation. Oxidative phosphorylation is the aerobic production of ATP. If the intensity of exercise is too high sufficient oxygen will not be present at the final step to accept the hydrogen ions. The build-up of hydrogen ions results in the production of lactic acid and eventually muscle fatigue. (41)

So et al (2007) identifies mechanical deficiencies resulting from physiological mechanisms of fatigue. (48) Mechanical or movement deficiencies affect the ability of an athlete to perform sport skills. (26) So et al (2007) identified a phenomenon called biodynamic compensation. Biodynamic compensation is a sharing of the workload between muscles involved in a particular sport skill. In rowing there is a lot of sharing of load as many muscles throughout the body are activated. When rowing begins, dominant muscles, such as the trapezius, latissimus dorsi, and biceps brachii (primary arm flexor) are activated. As those muscles begin to fatigue, secondary muscles such as the brachialis and rhomboids, become more active and alleviate the stress on the muscles that were engaged early in the activity. As the secondary muscles begin to fatigue there is once again a shift of exertional load to other less fatigued muscles. This switching on and off of muscle activation allows certain muscles to rest while others perform work. The sharing of workload allows for increases in power output, torque, velocity of movement and oxygen uptake (48).This mechanism explains why trained rowers can sustain high levels of exertion for extended periods of time. Perkins et al (2003) showed rowers exercise at 96% of maximal oxygen uptake and 98% of their maximum heart rate during a 2 kilometer time trial. (40) Experienced rowers exhibit signs of biodynamic compensation due to great familiarity with the distance and equipment as well as optimal movement efficiency as a result of training and greater experience rowing. Biodynamic compensation should allow a rower to maintain a needed level of performance to complete a 2km race. Elite rowers exhibit not only the ability to produce high maximal workloads but also the ability to sustain those workloads due impart, to biodynamic compensation.

An alternate factor to consider is how biomechanical alignment affects various systems of the body. Rowers can produce higher maximal values ($VO_2$, power output, etc) with efficient biomechanical movements by increasing the tolerance towards that workload. (46,48) Inefficient mechanics will increase the oxygen demand at a submaximal level. This lowers the percentage of maximal oxygen uptake a rower can utilize for training and competition and thereby increases reliance on anaerobic pathways. (1,41)

### 2.1.4 Ventilatory Response

Ventilation increases during exercise primarily as a result of an increase in hydrogen ions and carbon dioxide as exercise intensity increases. There is a linear relation between PO and Ve during sub-maximal exercise. However, as intensity is progressively increased above the ventilatory threshold the ventilatory response becomes curvilinear. Increases in intensity result in an overcompensation of Ve after which Ve will stabilize. Ventilation will also be affected by body temperature, pH and the ability of the lactate shuttle to input lactic acid into the Cori Cycle in the liver. The Cori Cycle converts lactic acid into glucose to be either re-circulated in the blood or transported back to the muscles for storage. (1,38,40)

## 2.2 GRADED ROWING PROTOCOLS

Seven different rowing protocols were examined during pilot work, (Table 1). The tests ranged in aggressiveness and type of information being recorded such as 500m split times instead of power output. Some testing protocols involved discontinuous maximal testing procedures and therefore did not fit the objectives of this study. A 2 km race requires a continuous effort for the duration of the race. Ideally, testing protocols should mimic the race format in order to improve the reliability of prediction.

Guevel et al (2006) used 50 watt increases every stage to volitional exhaustion. Between each stage there is a 30 second break to enable blood samples to be obtained. (23) The concern with such an aggressive protocol is that subjects may terminate the test before reaching a true maximal oxygen uptake level. This would ultimately affect the accuracy of the prediction models.

Womack et al (1996) developed a protocol using 5 second decreases in the rowers 500m split time for every stage change. In order to decrease a 500m split time, rowers needed to row faster or pull with more force. Beneke et al (1995) utilized a protocol with 35 watt increases per stage to volitional exhaustion. Mahler et al (1991) and Rosiello et al (1987) utilized km/hr measurements with a 3 km/hr increases per stage until volitional exhaustion was achieved. Reichman et al (1997) and Celik et al (2005) utilized the same incremental increases in intensity but with different starting power outputs and stage lengths. Refer to Table 1 for all testing protocols examined.

**Table 1. Graded Rowing Protocols**

| Protocol | 1$^{st}$ stage | 2$^{nd}$ stage | 3$^{rd}$ stage | Stage (minutes) |
|---|---|---|---|---|
| Guevel2006 | 150 watts | 200 watts | 250 watts | 3 |

**Table 1** continued

| | | | | |
|---|---|---|---|---|
| Womack 1996 | 2:30 (500 m) | 2:25 (500 m) | 2:20 (500 m) | 3 |
| Beneke 1995 | 215 watts | 250 watts | 285 watts | 3 |
| Mahler 1991 | 22 km/hr | 25 km/hr | 28 km/hr | 1 |
| Rosiello 1987 | 26 km/hr | 29 km/hr | 32 km/hr | 1 |
| Reichman 1997 | 25 watts | 50 watts | 75 watts | 2 |
| Celik 2005 | 75 watts | 100 watts | 125 watts | 1 |
| Proposed* | 75 watts | 100 watts | 125 watts | 2 |

*Power output will be increased 25 watts/stage until test termination

Guevel (2006) and Beneke (1995) et al designed protocols for maximal exertion with little consideration for submaximal variables due to such intense starting power outputs. (5,23) Womack (1996), Mahler (1991) and Rosiello (1987) et al utilized primarily a speed sensitive testing protocol. (32,45,48) Power output can be increased by either speed increases or force applied to the ergometer with higher exertion on the pull. The protocol utilized by Reichman et al (1997) was built for examination of submaximal variables because of lower starting power outputs however; due to the short duration of the exercise stages, (1 minute), a true steady state may not have been reached. When the intensity of the stage is increased the body initially overcompensates by increasing the heart rate while oxygen consumption lags behind resulting in an oxygen deficit. Once the body reaches steady state, oxygen consumption and heart rate remain constant. (1) The proposed protocol for the current investigation utilizes the strengths of the Reichman and Celik studies. Celik (2005) utilized the same power outputs as the proposed protocol but the stage duration was too short to achieve steady state.

## 2.3 INSTRUMENTATION RELIABILITY

In a study completed by MacFarlane et al. (1997) it was determined the Concept II air braked ergometer calculates and displays accurate information relating to power output, 500m split times and distance. MacFarlane et al. (1997) utilized modified force plate technology to examine force and velocities at the handle and at the feet. (30)

Examining the velocity at the handle involved using an infrared emitter-receiver that senses the movement of the eight vanes on the flywheel. Force at the handle was determined by using a force transducer attached directly to the handle from the chain. To assure only the force was analyzed; a three-pole Bessel low-pass filter with a cut-off at 34 Hz was used. This low pass filter screens the data to only allow the force production to make it through without manipulation due to other noise sources. Forces at the feet were examined by placing 2 force plates (1 on each foot pad) on the ergometer. Because the force plates are closer to the air chamber, a lower pass filter of 10 Hz was used. After proper calibration procedures were used for all of the equipment using standard weighted mechanisms, the results of the study showed high reliability($r=0.96$) in the data displayed (power output, 500m split times and distance) on the Concept II rower when compared to actual measures from the force transducers and force plates. (26) In addition, Schabort et al. (1999) showed that the Concept II Rower exhibited a very high test-retest reliability ($r^2=0.96$).(47)

# 3.0 METHODS

## 3.1 SUBJECTS

All subjects were recruited from the University of Pittsburgh Crew Club, 3 Rivers Rowing Association and Row Fit. Attempts were made to recruit an equal sample of male and female participants for this investigation. A power analysis, using GPower, revealed a need for a combined male and female cohort of 29 rowers.

Jensen et al. (1996), established that rowers of differing experience levels and recreational exercisers that have familiarity with a rowing ergometer will fit within the same prediction models but maximal oxygen uptake and maximal power output will be greater in the experienced population. (30,47)

Inclusion/Exclusion Criteria:

Subjects were screened to determine eligibility utilizing a questionnaire (appendix B) and a PAR-Q (appendix C). Subjects were qualified to participate in the study if they exercise at least 150 minutes per week, were not sick within the last 2 weeks, and were free of any medical contradictions to exercise. Rowers should be expected to minimally row at 20 strokes per minute.

Subjects were asked to wear comfortable appropriate workout attire. Subjects were not permitted to use specialized gear (eg: gloves, belts, etc) during testing.

## 3.2 EXPERIMENTAL DESIGN

This study employed a descriptive experimental group design. Descriptive studies provide relevant information directed at a problem but don't provide control groups. Subjects were randomly counterbalanced for testing sequence in order to account for training adaptations.

## 3.3 EXPERIMENTAL VARIABLES

Oxygen uptake (ml/kg/min), power output (watts), heart rate (bpm), $VCO_2$, RER, Ve, RPE, and strokes per minute were obtained during the last 30 seconds of each stage of a graded exercise test as well as the 2km time trial. Physiological energy cost per stroke was calculated using the following equation for each time period: mean $VO_2$/strokes per minute. Mechanical energy cost per stroke was calculated using the following equation for each time period: mean power output (watts)/strokes per minute. Power output was relativized to body weight and lean mass, where power output was expressed as watts/BW or watts/lean mass. Prior to the graded exercise test, height, weight and body composition were collected on each subject.

## 3.4 INSTRUMENTATION

A Concept II rowing ergometer was used for all tests (Morrisville, VT). A ParvoMedicsTrueMax 2400 Metabolic Measurement System (Salt Lake City, UT).open circuit spirometer was used for gas analysis (Sandy, UT). Polar heart rate monitors was used to measure heart rate (Lake Success, NY).

The reliability and validity of the Concept II Rowing Ergometer was examined by MacFarlane et al (1997). The instrumentation and output variables (strokes per minute, watts, 500m splits and distance have test-retest correlation coefficients of 0.9 ($p<0.05$) or higher indicating that the Concept II Ergometer is a reliable instrument to use for exercise testing. (31)

## 3.5 PILOT TESTING

Pilot testing was conducted to examine various rowing protocols and to determine proper set-up of the metabolic cart and rowing ergometer. Prior to testing, subjects were briefed about the protocols. Three male and three female subjects participated in pilot testing. Since there are a variety of graded testing protocols, pilot testing was conducted to determine the best protocol to administer in order to assure steady state for at least 3 workloads. Six of the seven protocols considered were discontinuous in nature however, since blood sampling is not part of the proposed experimental paradigm, a continuous protocol to volitional fatigue was considered more appropriate. The subjects that participated in the pilot work were all experienced exercisers and all had prior experience with a rowing ergometer. The subject descriptive data and results of the pilot work are shown in Table 2.

### 3.5.1 Pilot Testing Results

After administering maximal exercise tests using each of the 7 protocols it was determined that a modified Celik protocol will be used in the present investigation. (Table 3) This is a continuous progressively incremented protocol involving 2 minute stages. It was determined that a 2 minute stage is sufficient to achieve steady state at submaximal workloads. The use of 2 minute stages is consistent with the Reichman et al. (1997) study.

Starting an incremental test too aggressively may result in premature fatigue and not allow subjects to achieve maximal oxygen uptakes or heart rates. In addition, the 150 watt starting power output used by Guevel et al. resulted in many pilot subjects reaching the ventilatory breakpoint during the first stage. In contrast, Riechman et al (1997)used an initial power output of 25 watts, and that may have contributed to premature subject fatigue. For the purposes of the present investigation, it is essential to have subjects reach steady state in several stages. The testing protocol that was used in the proposed investigation is presented in the Table 1.

In reference to Table 2, the percent body fat was assessed using a Tanita Bioelectrical Impedence Analyzer and an average of athletic and normal settings was used. The ventilatory breakpoint was determined by graphing $Ve/VO_2$ against $Ve/VCO_2$.The ventilatory breakpoint was determined by the point where $Ve/VO_2$ rises without a concomitant rise in $Ve/VCO_2$. Once the ventilatory breakpoint was determined, the corresponding oxygen uptake level, power output and associated power/stroke ratio was determined.

**Table 2. Pilot Testing Subject Demographics**

| | N | Mean ± SD | Male ± SD | Female ± SD |
|---|---|---|---|---|
| Age (yrs) | 6 | 26.83 ± 4.75 | 24.33 ± 1.15 | 29.33 ± 6.03 |
| Percent Body Fat | 6 | 23.83 ± 7.06 | 17.4 ± 4.81 | 29.77 ± 5.17 |
| Height (cm) | 6 | 169.67 ± 13.6 | 182 ± 2 | 157.33 ± 1.53 |
| Weight (kg) | 6 | 78 ± 13.65 | 89.57 ± 5.58 | 66.43 ± 5.75 |
| 2k Time (s) | 6 | 553 ± 105.42 | 474.33 ± 53.8 | 631 ± 79.51 |
| Oxygen Uptake at VPt (L/min) | 6 | 2.29 ± 0.658 | 2.72 ± 0.61 | 1.87 ± 0.41 |
| Power Output at VPt (watts) | 6 | 183.33 ± 64.55 | 233.33 ± 52.04 | 133.33 ± 14.43 |
| Power/Stroke Ratio at VPt | 6 | 6.74 ± 3.1 | 9.16 ± 2.37 | 4.31 ± 0.91 |
| Maximal Oxygen Uptake (L/min) | 6 | 3.48 ± 1.08 | 4.24 ± 0.64 | 2.59 ± 0.29 |

## 3.6 TESTING PROCEDURES

### 3.6.1 Graded Exercise Testing

Prior to testing, subjects were encouraged to not engage in strenuous exercise for at least 24 hours. Subjects were asked to eat a small meal at least 3 hours prior to testing.

All subjects were briefed concerning the testing procedure (Appendix A). A questionnaire specific to the proposed study (appendix B) was used to determine if there are any pre-test behaviors that may affect the outcome of the study (recent physical activity behaviors, dietary concerns, etc). A PAR-Q (appendix C) was used to determine if a medical contradiction to participation may exist. A written informed consent approved by the University of Pittsburgh Institutional Review Board (appendix D) was collected from each subject. Next, subject body weight and body composition were determined using BIA (Tanita model TBF-410GS). An average of the standard and athletic setting values was used as the body composition value. Prior to exercise testing, subjects were oriented and anchored to the Borg RPE scale. Subjects were fitted with a polar heart rate telemetry strap (Model: FS2c)to track heart rate during the test. The wrist receiver for the polar heart rate monitor (Model: FS2c) was placed near the metabolic cart so the test administrator could record heart rate throughout the continuous test. Subjects were instructed to set the ergometer foot straps to their desired position. The metabolic cart, which was calibrated according to the manufacturer's recommendations prior to each test was placed next to the ergometer in a position that will not impede the rower's movements. Subjects were then fitted with the facemask. The ergometer monitor provides information on watts, exercise time as well as a performance work rates relative to drag factors. The display on Concept 2

Rowers recommends a low drag factor, between 2-5 be used to more accurately replicate a race environment. The drag was pre-set at 5 for consistency throughout all subjects. Subjects were asked to warm-up at a self-selected pace and power output for 5 minutes. They were instructed to set the pace and power at a level that would not cause fatigue. Subjects were given a 1 minute warning prior to the start of the first stage and then again at 15 seconds. Subjects started the graded exercise test immediately following the warm-up period with no break in between. During the graded exercise test heart rate, RER, $VCO_2$, Ve, strokes per minute (from ergometer display), power output (watts) and oxygen uptake were collected continuously throughout the test and RPE was collected during the last 30 seconds of each stage. Subjects were asked to point to a number on the RPE scale corresponding to their perceived level of exertion as it relates to their overall body. At the beginning of the first stage, subjects were instructed to increase power output to the desired watts. Each stage lasted 2 minutes and subjects were informed when 1 minute and again when 15 seconds remain in the stage. At that time subjects were reminded of the next power output level. In accordance with the protocol, subjects were asked to keep a stroke rate of 20-34/spm and instructed to use the ergometer display to self-regulate the cadence. To ensure compliance, stroke rate and power output were monitored by the test administrator. Subjects continued this protocol until volitional exhaustion, strokes per minute drop below 20 for 10 consecutive seconds, or the subject requested to stop testing. The criteria for determining maximal oxygen uptake were a respiratory exchange ratio of greater than 1.15, heart rate within 10 bpm of age predicted values and/or a plateau of oxygen uptake with an increase in workload. (41). At the completion of the test the respiratory mask was removed from the subject and he/she was encouraged to row at a self selected pace and power output to cool-down for up to 5 minutes. The complete proposed graded rowing protocol is presented in Table 3.

**Table 3 Graded Rowing Protocol**

| Stage | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-16 | 16-18 | 18-20 |
| Power (watts) | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 |

### 3.6.2 Time Trial Testing

After a minimum of a 48-96 hr rest period following the graded exercise test, subjects returned to the lab to undergo a 2km time trial. Subjects were instructed to complete this trial at race pace to achieve the best possible time. During the period between tests, subjects were asked to not engage in strenuous exercise.

Subjects were once again be given a brief overview of the experimental procedures. The aerobic metabolic system was calibrated and subjects were fitted with a polar heart rate monitor and facemask. Subjects completed a 5 minute warm up at a self selected pace and power output. After the warm up, there was a 30 second break to allow the ergometer flywheel to stop completely. For the 2km time trial, subjects started the ergometer from a stop as to simulate a real water situation which also occurs from a dead stop. Subjects began the test after the 30 second break and instructed to complete the 2km time trial as if it was a race. Every effort was taken to replicate race conditions on the water such as not having a coach or teammates cheering or providing feedback. Rowers employed a competition method where they started off at a sprint and gradually lowered the intensity to a sustainable pace. With approximately 200m remaining in the 2km time trial, the rowers once again sprinted to finish the race. Physiological and mechanical values (oxygen uptake, heart rate, RER, $VCO_2$, ventilation, power, strokes per minute) were obtained every 15 seconds during the test until the subject has completed the 2km distance. RPE corresponding to the overall body was collected once per minute and at the completion of the test. The time required to complete the 2km trial was recorded in seconds.

Upon completion of the 2km time trial, subjects then had the facemask removed and were given sufficient cool-down time in which they rowed at a self selected pace and power output.

## 3.7 DATA ANALYSIS

Data were entered into the Statistical Package for the Social Sciences (SPSS) v. 23. Means and standard deviations were calculated for all subject descriptive characteristics and experimental variables. Pearson correlations were performed between the experimental variables and 2 km time. A combined gender model with a total of 12 subjects was used to generate the mixed gender prediction model. An attempt was made to have an equal distribution of males and females in the 2 groups. Subjects were randomly counterbalanced, to testing sequence (GXT or Time Trial first) to eliminate the impact of testing order on the dependent variables.

A stepwise regression utilizing oxygen uptake at the ventilatory breakpoint, power/stroke ratio at the ventilatory breakpoint (determined using the second non-linear rise in ventilation), power output at the ventilatory breakpoint, percent body fat, fat free mass, maximal oxygen uptake, and maximal power/stroke ratio were used to create the prediction model. The ventilatory breakpoint was determined by graphing $Ve/VO_2$ against $Ve/VCO_2$ and determined by the point where $Ve/VO_2$ increased without a concomitant rise in $Ve/VCO_2$. A dependent T-test was used to determine if there is a significant difference between predicted performance and actual performance time. Pearson correlations were conducted on the predicted performance and actual performance times. The level of significance was set at $\alpha \leq 0.05$.

# 4.0 RESULTS

## 4.1 SUBJECT DEMOGRAPHICS

The aim of this study was to develop a regression model to predict rowing time of a simulated 2 kilometer race. Subjects (n=12) 8 male and 4 female completed 2 exercise trials separated by at least 48 hours. Subjects were recruited from the University Pittsburgh Crew Team as well as Three Rivers Rowing Association, local health clubs and training facilities. A stepwise linear regression analysis was used to examine the relation between performance variables and 2km rowing time. Statistical significance was set *a priori* at the $p \leq 0.05$ level. Subject demographics are presented in Table 4.

**Table 4. Subject Demographics (N=12)**

| Variable | Mean±SD |
| --- | --- |
| Height (cm) | 187.38±12.60 |
| Weight (kg) | 79.14±12.85 |
| Age (yrs) | 23.91±4.99 |
| Body Fat (%) | 13.77±6.51 |
| Rowing Experience (yrs) | 3.17±2.79 |

**Table 4** continued

| | |
|---|---|
| Maximum Heart Rate (GXT) (beats/min) | 185.92±8.13 |
| Heart Rate at Vpt (beats/min) | 160.75±11.41 |
| Maximum RPE (GXT) | 18.08±1.62 |
| RPE at Vpt | 11.08±3.0 |

## 4.2 PERFORMANCE DATA

Subject performance data are presented in Table 5. Power/stroke ratio (watts/stroke per minute) is an index of rowing efficiency and was determined by dividing power (watts) by strokes per minute. This variable was assessed during the GXT. The ventilatory breakpoint (Vpt) was determined by graphing VE as a function of $VO_2$ ($VE/VO_2$) and the point at which $VE/VO_2$ increased without a concomitant rise in $VE/VCO_2$ was determined to be the ventilatory breakpoint. In order to develop the 2km prediction model, stepwise linear analyses were conducted. Because of high correlations, only one variable was represented in the various models. The individual predictor variables, correlations, and associated prediction equations are shown in Table 6. The stepwise linear regression analysis revealed a strong negative relation between 2km rowing time and maximal power/stroke ratio (r= -0.96), power/stroke ratio at the Vpt (r= -0.90), maximal oxygen uptake (r= -0.84) and oxygen uptake at the Vpt (r= -0.82).

**Table 5. Subject Performance Data (N=12)**

| Performance Variable | Mean±SD |
|---|---|
| Maximal Oxygen Uptake (l/min) | 4.42±1.28 |
| Maximal Oxygen Uptake (ml/kg/min) | 55.48±10.32 |
| Maximum Power/stroke GXT (watts/stroke per min) | 9.64±2.40 |
| Power/stroke 2km (watts/stroke per min) | 9.59±2.79 |
| Average Power 2km (watts) | 271.98±84.07 |
| Average 2km time (sec) | 447.00±47.34 |
| Predicted 2km time (sec) from Maximum Power/stroke | 447.00±45.27 |
| Oxygen Uptake at Vpt (l/min) | 3.38±1.14 |
| Oxygen Uptake at Vpt (ml/kg/min) | 42.17±9.05 |
| Vpt (% $VO_2$ max) | 75.27±8.27 |

**Table 6. Regression Models**

| Variable | Correlation (r) | Coefficient of Determination ($r^2$) | Formula | Standard Error of the Estimate |
|---|---|---|---|---|
| Maximum Power/Stroke (watts/stroke) | -0.96* | 0.92 | Time (sec) = -18.790x + 628.183 | 0.74 sec |
| Power/Stroke at Vpt (watts/stroke) | -0.90* | 0.81 | Time (sec) = -14.714x + 562.909 | 1.34 sec |
| Maximal Oxygen Uptake (L/min) | -0.84* | 0.71 | Time (sec) = -30.948x +583.712 | 0.73 sec |
| Oxygen Uptake (Vpt) (L/min) | -0.82* | 0.67 | Time (sec) = -34.026x + 562.208 | 0.68 sec |

*$p \leq 0.001$

Vpt = ventilatory breakpoint

# 5.0 DISCUSSION

## 5.1 RESEARCH FINDINGS

The primary purpose of this study was to develop a combined gender model to predict simulated 2km rowing time. This study was conducted by administering 2 counterbalanced trials separated by at least 48 hours. One protocol was a simulated 2km race performed at competition pace. In competitive rowing this distance is usually covered in 6-10 minutes. (5,10) The second protocol was a maximal graded exercise test. A stepwise linear regression analysis was conducted to generate the prediction models. This study identified the following 4 variables as having a high predictive value: maximum power/stroke ratio ($r = -0.956$, $p<0.001$), power/stroke ratio at the ventilatory threshold ($r = -0.896$, $p<0.001$), maximal oxygen uptake ($r = -0.838$, $p<0.001$), and oxygen uptake at the ventilatory threshold ($r = -0.818$, $p<0.001$). Because the pearson correlation coefficients were so high (0.82-0.96), only 1 variable was entered into each prediction equation. Individual equations were created for each predictor variable, see Table 6.

## 5.2 MAXIMUM POWER/STROKE RATIO

Although this variable (power/stroke ratio) was created in the present study, the potential importance of this variable on rowing performance was supported by So et. al (2007) and this ratio may be related to mechanical efficiency. So et. al (2007), realized mechanical efficiency can positively affect rowing performance. In that study, a phenomenon termed biodynamic compensation was discussed as a reason to consider the impact of mechanical efficiency on rowing performance. (41,48) Biodynamic compensation was described as a phenomena that occurs in elite athletes, especially rowers where there is a sharing of workload between muscles. So et. al (2007) identified this phenomena by using EMG analysis which revealed a "switching on and off" of muscles from being a primary to a secondary contributor. This was achieved by an alternating of neural drive to muscles. This allowed motor units to recover while maintaining high levels of rowing performance, which translated into faster times. (48)

Jensen et. al (1996) and Firat et al (2014), identified peak power ($r = -0.52$; $p<0.05$) and ($r= -0.756$, $p<0.05$), respectively, to be a significant predictor of 2km rowing performance (21,30) In a study completed by Costill et al (1979), it was found that a main contributor to the development of maximum power output in the legs was strength. Power is a function of both strength and speed and the increase of either variable improves power. Collectively, these findings suggest that strength is an important contributor to rowing performance (1,12,41) Reichman et al (2002), determined that 75.7% of the variability in the 2km rowing time was attributed to maximum power development and maximum power was significantly ($r= -0.847$, $p<0.001$) correlated to 2km time. (42) Firat et al. also determined 1 RM Leg Press was a significant predictor of 2km time ($r = -0.755$). The scientific literature is consistent across studies from other exercise modalities on the importance of leg strength to performance. Storen et. al (2008), for example, found the inclusion of strength training with aerobic training in runners not only improved running economy by 5% but also improved time to exhaustion by 21.3%. (49) The inclusion of resistance training for rowing athletes can improve power development and movement efficiency that will contribute to improved performance. (2,34,49)

Maximum Power/Stroke Ratio was examined presently as a means to assess mechanical efficiency during the 2km time trial. Maximum Power/Stroke Ratio was calculated by dividing the Power (watts) by the Stroke rate (Strokes per minute) during the last stage of the graded exercise test. So et al., found rowers with more experience and better training practices achieved higher power and faster times (48). Performance in other exercise modalities has also been shown to be influenced by factors related to mechanical efficiency. For example, running economy has been shown to be highly predictive ($r = -0.812$, $p<0.05$ and $r = -0.91$, $P<0.001$) of 16k and 20k running time trial performance, respectively. (25,34) From a study completed by Storen et al. (2008), strength training in runners was shown to improve running economy. Mclaughlin et. al (2010), examined the relation between velocity at $VO_2max$ ($vVO_2max$) which is a prediction of running velocity at $VO_2max$ and 16km running performance. The $vVO_2max$ was shown to be strongly correlated ($r = -0.972$, $p<0.05$) with 16km run performance while $VO_2max$ alone was less strongly related ($r = -0.902$, $p<0.05$) to performance. (34) More efficient economy of movement decreases the energy cost of that mode of movement leading to an improvement in performance. (1,35) In rowing athletes, this improved efficiency and lower energy cost is due to improved strength development in the legs and hips as well as biodynamic compensation. (12,21,48)

## 5.3 MAXIMAL OXYGEN UPTAKE

Maximal oxygen uptake is a measure of oxygen utilization during maximal exercise and has been used as a fundamental test to determine, categorize and predict athletic performance in a variety of sports. (28) In a study completed by Ingham et al. (2002), maximal oxygen uptake was determined to be significantly correlated with 2km rowing time ($r = -0.88$, $p<0.001$) and this finding is consistent with the current study ($r = -0.84$, $p<0.001$). Maximal oxygen uptake impacts the rate of aerobic oxygen production during exercise. Numerous studies have shown the higher the $VO_{2max}$ the better the aerobic performance. This is especially true in a group of athletes with a wide range of maximal oxygen uptakes. However, $VO_{2max}$ does not ultimately set the upper limit of performance in endurance activities. Other factors found to be strongly correlated to rowing performance according to Ingham et. al (2002) were maximum power ($r =-0.95$, $p<0.001$) and oxygen uptake at the anaerobic threshold ($r =-0.87$, $p<0.001$). Ingham et al., also determined that 98% of the variability in 2km rowing performance was attributed to the combination of power output at $VO_{2max}$, oxygen uptake at the anaerobic threshold, maximum power output, and power output at the anaerobic threshold. (28) Maximal oxygen uptake is, in part, a function of the delivery of oxygen to working muscles that can be a result of increases in cardiac output. (2). The amount of oxygen delivered to exercising muscle has a significant impact on maximal oxygen uptake but the ability to deliver oxygen is not the only component. Acute increases in oxygen uptake occur as a result of not just increased cardiac output but also improved gas exchange in the lungs and a greater a-$VO_2$ difference. (2,35) Basset et al. (1999), identified pulmonary diffusion, cardiac output and oxygen carrying capability of the blood as central limiting factors of $VO_{2max}$. Cardiac output was determined to be about 70-85% of the limitation of $VO_{2\ max}$. (2) Muscle characteristics such as fiber type and mitochondrial density are identified as peripheral limiting factors. (2)

When compared to rowing, running appears to have similar predictors of performance. It was determined by McLaughlin et. al (2008) that high $vVO_2max$ values were dependent on either high $VO_2max$ and/or very economical running styles. (34) $VO_2max$ and running economy, defined as oxygen cost associated with running at submaximal intensities, explains more of the variability in running performance than the inclusion of $VO_2$ at the lactate threshold. (34,49) According to Basset et. al (2000), high $VO_2max$ is a prerequisite for success in middle to long distance runners.

Storen determined the running economy, $vVO_2max$, and increased time to exhaustion improved without concurrent increases in $VO_2max$. In this study, a resistance training program was implemented in conjunction with endurance training and it was determined improvement in strength led to improved $vVO_2max$ and delayed exhaustion. With increased running speed at specific submaximal $VO_2$ values an improvement in economy and an increase in performance was observed. (49)

Unlike the current study that found a significant correlation between maximal oxygen uptake (L/min) and 2km time (seconds) ($r= -0.84$, $p<0.001$), Reichman et al. (2002) did not find a strong relationship ($r= -0.502$). Reichman et al. (2002), used 12 female rowers between the ages of 19-29 years old. The current investigation utilized 8 male and 4 female subjects between the ages of 18-35 years old. However, both studies tested rowers at about the same time of year, the weeks surrounding the indoor competitive season. Had testing been done at different times of the competitive year, results could have been affected due to different training and practice regimens.

### 5.4 POWER/STROKE RATIO AT THE VENTILATORY BREAKPOINT

Power/stroke ratio at the ventilatory threshold was shown presently to be another highly predictive variable with regard to rowing performance. Ingham et al. determined power output at the lactate threshold ($r = -0.88$, $p<0.001$) was strongly predictive of 2km rowing performance. (28) The current study showed power/stroke ratio at the ventilatory breakpoint ($r = -0.896$, $p<0.001$) to be strongly predictive of 2km rowing performance. Power/stroke ratio is simply the power (watts) shown as a function of strokes per minute. The ventilatory breakpoint is frequenly used as a surrogate measure of the anaerobic/lactate threshold. (39) The lactate threshold has been widely shown to influence aerobic performance. (5) Rowers can produce high submaximal values ($VO_2$, power output, etc) with efficient biomechanical movements compared to inexperienced rowers by increasing the tolerance to higher workloads. (46,48) Inefficient mechanics increase the oxygen demand at submaximal levels and lowers the percentage of maximal oxygen uptake a rower can utilize for training and competition. This lowers the anaerobic threshold and causes early fatigue (1,41)

Another predictor variable is the running velocity at lactate threshold. The LT velocity had a high correlation ($r^2 = 0.79$, $p<0.01$) to 5km running performance. (49) Like Reichman et al. (2002), Storen et al. (2008), determined an increase in strength would improve economy of movement and it was determined that running economy along with increased time to exhaustion increases endurance performance without any increases in $VO_2max$. Economy is a primary factor in both rowing and running performance. (2,34,44,49) Running velocity at the lactate threshold was highly predictive of 16km performance ($r = -0.907$, $p<0.05$). (34)

The concentration of lactic acid/lactate in the blood is influenced by production and removal. Lactic acid is the metabolic by-product of anaerobic metabolism. Lactic acid quickly dissociates a hydrogen molecule and the resulting product is lactate. Ventilation increases during exercise primarily as a result of an increase in hydrogen ions and carbon dioxide as exercise intensity increases. (1,32,34) During competition, the higher the intensity the rower can maintain without a significant increase in lactate the better the performance. Lactate is also used by skeletal muscle and the heart and other systems as a substrate and training may also enhance the potential to convert lactate into glucose. (1,35,38)

## 5.5 OXYGEN UPTAKE AT THE VENTILATORY BREAKPOINT

Oxygen uptake at various indicies of the lactate threshold has been shown to be a predictor of performance across exercise modalities. Beneke (1995) identified the individual anaerobic threshold (IAT), defined as the workload corresponding to the maximal lactate steady state that an individual can achieve, was a predictor of 2km rowing racing performance ($r=0.79$, $p<0.01$). This was consistent with an investigation conducted by Ingham et. al. (2002) in which a correlation between 2km rowing performance and the oxygen uptake at the anaerobic threshold ($r=0.87$, $P=0.001$) was reported. The current study found a similar association between oxygen uptake at the ventilatory threshold and 2km rowing performance ($r= -0.818$, $p<0.001$). Previous work determined that approximately 70% of the energy metabolism for 2km rowing is derived from aerobic pathways. (24,25,36) McLaughlin et al. (2010) determined runners also do not run at 100% of their $VO_{2max}$ during races and instead the runner that is able to compete at a higher percentage of their respective $VO_{2max}$ will out perform others. (34) In a study completed by Evans et al. (1995), there was a strong relationship between $VO_2$ at the lactate threshold and running performance ($r = -0.87$, $p<0.05$). (18) Impellizzeri et al. (2005) found a strong determinant ($r = -0.63$, $p<0.05$) of cycling performance was oxygen uptake at the respiratory compensation threshold (RCT). RCT is defined as the intensity associated with the second slope rise in $VCO_2$. The RCT is consistent with the IAT identified by Beneke et al. (1995) and further supported by Rankinen et al. (1995) and corresponds to the second lactate breakpoint, also called the anaerobic threshold. (5,29,43) The running and cycling data from their investigation are consistent with the rowing data from the current investigation as $VO_2$ at the ventilatory breakpoint was found to be strongly associated ($r = -0.818$, $p<0.001$) with 2km rowing performance.

The ventilatory threshold is a measure of physiological functioning that can determine how much of a person's aerobic capacity is usable. Trained individuals typically have a ventilatory threshold of 70-80% of their maximal oxygen uptake. (1,38) As with studies from other modalities, oxygen uptake at the ventilatory breakpoint was shown in the present investigation to highly correlate with performance. Being able to maintain high oxygen uptake without exceeding the ventilatory threshold/lactate threshold allows the athlete to balance aerobic and anaerobic ATP usage and generation thereby increasing performance. (2,49)

## 5.6 IMPLICATIONS FOR PRACTICE

The current study found four significant predictors of rowing performance: maximum power/stroke ratio ($r= -0.956$, $p<0.001$), power/stroke ratio at the ventilatory threshold ($r= -0.896$, $p<0.001$), maximal oxygen uptake ($r= -0.838$, $p<0.001$), and oxygen uptake at the ventilatory threshold ($r= -0.818$, $p<0.001$).

Several studies identified power as a significant contributor to 2km rowing performance. (12,21,29,44) The current study identified power/stroke ratio as a significant contributor to rowing performance. The average strokes per minute between the graded exercise test and the 2km time trial were, 27.58±2.87 and 28.25±2.26 respectively. This suggests power output may play a bigger role in rowing performance. Rowing training should include resistance exercise since it is associated with improved movement efficiency and with inefficient movement there is a higher oxygen cost/usage per unit of work. (2,34,49)

The current study also identified maximal oxygen uptake as a significant predictor ($r = -0.838$, $p<0.001$) of 2km rowing performance. This finding along with strong support from previous studies, show maximal oxygen uptake is a main factor in endurance performance. Increases in maximal oxygen uptake are the result of endurance training and an improved oxygen delivery to working muscles by way of an increase in cardiac output not a-vO2 difference. (2) Improved oxygen delivery allows for a lower heart rate at a given workload and may contribute to the amount of power an exerciser may produce. Many studies have shown increases in performance following a plateau in $VO_2max$. The explanation for this observation is an increase in ventilatory/lactate threshold.

Oxygen uptake at the ventilatory breakpoint ($r = -0.818$, $p<0.001$), was shown to be another strong predictor of 2km rowing performance. Like maximal oxygen uptake, oxygen uptake at the ventilatory breakpoint also is affected by both delivery and uptake of oxygen by skeletal muscles. (2) It has been determined that the oxygen uptake at the anaerobic threshold is determined by the body's ability to generate high rates of ATP regeneration through oxidative pathways. This ATP generation through oxidative pathways determines the percent of maximal $VO_2$ that can be maintained. (2) In addition, other studies have determined that economy of movement can have a positive impact on affect the anaerobic threshold by decreasing oxygen cost secondary to improvements in the efficiency of movement. (34,49) This collectively suggests rowing training should also focus on increasing the ventilatory breakpoint. Improvements in the ventilatory breakpoint may come about by improved buffering of lactic acid. This can occur as a result of an improved efficiency of the cori cycle to convert lactate into glucose via gluconeogenesis. (1,36) Another way lactate accumulation can be controlled is through the myocardium's ability to utilize lactate as a fuel source. (35) The myocardium can use phosphocreatine, glucose, free fatty acids and lactate as primary fuel sources. (35)

Coaches and rowers have access to rowing ergometers with appropriate displays of data. Maximum power/stroke ratio would be the easiest formula for coaches to track athlete progress since they would only need the rowing ergometer. The other prediction equations generated presently would require access to a metabolic cart.

## 5.7 RECOMMENDATIONS FOR FURTHER RESEARCH

Further investigation into predictors of rowing performance is warranted and tests such as 500m sprint, rowing ergometer wingate or a 6 pull test for maximum power may also have high predictive value. A 6 pull test is an anaerobic power test that involves a rower attempting to generate maximum power within 6 strokes. A 500m sprint uses anaerobic pathways as the primary energy source. Further investigations should determine if 500m sprint time, peak power and/or average power/stroke ratio in a 500m sprint could be used to predict performance in a 2km time trial. The rowing ergometer wingate involves a 30 second sprint and provides information on anaerobic power and anaerobic capacity. Previous work determined that approximately 30% of the energy metabolism for 2km rowing is derived from anaerobic pathways. (28,30,42) Some additional directions for further study could be to generate gender specific prediction equations, design a training program based upon the current results and determine the effectiveness of this training program, and validate the current study prediction models. In addition models to predict 2km performance during an actual race could be developed. This approach would have greater ecological validity than the present study, however, when conducting field-based rowing research, water currents and environmental variables such as wind, weather, temperature, humidity and barometric changes could be problematic.

## 5.8 LIMITATIONS

Testing was conducted in a controlled environment and the present results therefore may not translate to water performance.

All rowing ergometers have a drag adjuster but it is unknown if that drag setting accurately replicates water currents. This limitation would reduce the ability to generalize the results of this study to water performance.

A small number of subjects were used therefore gender specific equations could not be generated.

Measures of strength, anaerobic power and anthropometrics were not obtained.

## 5.9 CONCLUSIONS

This study identified 4 separate predictors of 2km rowing performance: 1) Maximal power/stroke ratio during a graded exercise test, 2) power/stroke ratio at the ventilatory breakpoint, 3) maximal oxygen uptake, and 4) oxygen uptake at the ventilatory breakpoint. Maximum power/stroke ratio was the single strongest predictor ($r = -0.96$, $p < 0.001$). The 2km rowing test lasts about 6-10 minutes based on the experience and fitness level of the athlete. (24,35,36) Experienced rowers typically finish 2km in about 6-8 minutes while inexperienced rowers can take upwards to 10 minutes. (48) In the present investigation subjects completed the 2km time trial in 447±47.34 seconds which equates to 7 minutes and 27 seconds. Since the race is comparatively short and intense, and 30% of the energy metabolism for 2km rowing is derived from anaerobic pathways an anaerobic marker as a predictor of performance was shown to be valuable. (28,30,42). Since 30% of the energy metabolism for 2km rowing is derived from anaerobic pathways, that means there is a 70% contribution from aerobic pathways. For this reason, both anaerobic and aerobic measures should be considered when developing conditioning programs.

## APPENDIX A

## TESTING FORMS

Rowing Maximal Graded Exercise Test Assessment Form ID#_______

Participant Code:________ Age:______ Weight (kg):_____

Height (cm):_____

Years Experience:________ Body Fat %:________ Resting HR:________ Resting BP:________

Calculated Ventilatory Breakpoint:________________

Maximal Power achieved:_______________

Maximal Oxygen Uptake (l/min):_______________

Maximal HR:_______________

Avg Stroke rate:_______________

Maximal RPE achieved:_______________

Stage 1: 75 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:________ RPE:__________

Stage 2: 100 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 3: 125 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 4: 150 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 5: 175 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 6: 200 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 7: 225 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 8: 250 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 9: 275 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

Stage 10: 300 watts – 2 minutes

VO2 (l/min):_________HR:______Stroke rate:_______ RPE:__________

2km Rowing Time Trial ID#_______

Participant Code:________ Age:______ Weight (kg):_____ Height (cm):_____ BF%_________ Years Experience:________ Avg: # of races per year:________

Resting HR:________ Resting BP:________2k time:_______________

Minute Readings

1: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

2: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

3: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

4: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

5: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

6: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

7: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

8: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

9: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

10: VO2 (l/min)_______________ HR:__________ RPE:__________

Stroke rate:__________ Avg Power:__________

Maximal VO2 (l/min)_______________ Maximal HR__________

Maximal RPE__________

## APPENDIX B

### A.1 INTAKE QUESTIONNAIRE ID#_______

Name: ____________________________________________________

DOB:_______________Height:_____________ Weight_______________

When was your last use of a rowing ergometer?_______________________

How many minutes per week do you spend on a rowing ergometer?_________________

Do you have any low back injuries/considerations?____________________

If so, explain:_________________________________________________

Do you have any bone or joint disorders than may impact your ability to perform these tests?______________

If so, explain:_________________________________________________

Do you have any medical conditions such as low/high blood pressure or low/high blood sugar?___________________________________________

Have you ever sustained an injury while rowing either on water or on an ergometer?_______

If so, explain:_________________________________________________

## APPENDIX C

ID # _____

University of Pittsburgh

Center for Exercise and Health-Fitness Research

Physical Activity Readiness Questionnaire (PAR-Q)

Now I am going to ask you a few questions to determine if you are eligible to complete the stationary cycle exercise …

**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**

No ___ Yes ___ If yes, specify: ______________________________

**Do you feel pain in your chest when you do physical activity?**

No ___ Yes ___ If yes, specify: ______________________________

**In the past month, have you had chest pain when you were not doing physical activity?**

No ___ Yes ___ If yes, specify: ______________________________

**Do you lose your balance because of dizziness or do you ever lose consciousness?**

No ___ Yes ___ If yes, specify: ______________________________

**Do you have a bone or joint problem that could be made worse by a change in your physical activity?**

No ___ Yes ___ If yes, specify: ______________________________

**Is your doctor currently prescribing drugs (for example, water pills) for a blood pressure or heart condition?**

No ___ Yes ___ If yes, specify: ______________________________

**Do you know of any other reason why you should not do physical activity?**

No ___ Yes ___ If yes, specify: ______________________________

## APPENDIX D

School of Education
Health, Physical and Recreation Education
Center for Exercise and Health-Fitness Research

A149B Trees Hall
Pittsburgh, Pennsylvania 15261
412-648-8251
Fax: 412-648-7092

**INFORMED CONSENT**

**TITLE: PREDICTORS OF PERFORMANCE DURING A 2 KILOMETER ROWING ERGOMETER TIME TRIAL**


**PRINCIPAL INVESTIGATOR**: Jason Metz, M.S.
Doctoral Student
149 Trees Hall
Pittsburgh, PA 15261
(570) 854-2242
Email: jmetz_cscs@yahoo.com
Department of Health and Physical Activity
School of Education

**CO-INVESTIGATOR:** Fredric L. Goss, Ph.D.
Associate Professor, Academic Program Coordinator
113 Trees Hall
Pittsburgh, PA 15261
Phone: (412) 648-8259 Fax: (412) 648-7092
Email: goss@pitt.edu
Department of Health and Physical Activity
School of Education



**SOURCE OF SUPPORT:** None

***Why is this research being done?***

Affect is defined as the emotion or mood that is experienced during exercise. An individual may feel that exercise is pleasant or unpleasant, and these feelings may change during exercise. Affect has been compared during different self-selected exercise intensities (that are the subjects choice) and imposed exercise intensities (chosen by the investigators). However, it is unknown whether there is an independent effect of exercise intensity. Therefore, the purpose of this investigation is to examine the independent effect of self-selected versus imposed exercise intensity on affect, specifically during cycle exercise.

***Who is being asked to take part in this research study?***

Twenty-two male and female adults (at least 18yrs old) will be recruited as subjects in this research. The research study will last approximately 5 to 8 days. You are being invited to take part in this research study because you are healthy and undertake at least 150 minutes of recreational aerobic activity per week. To minimize risks associated with maximal aerobic exercise testing, you will be asked to complete the Medical History Form and a Physical Activity Readiness Questionnaire (PAR-Q) that contains questions about your current health status. If you have an orthopedic (muscle or bone), cardiovascular (heart), and/or metabolic disease (i.e. coronary artery disease/heart disease), prior myocardial infarction (heart attack), peripheral vascular disease (blockages in legs), chronic obstructive pulmonary disease (lung disease), and diabetes mellitus (high/low blood sugar) and/or if you are knowingly pregnant or you are a current smoker, you will not be eligible to participate in this research study.

***What procedures will be performed for research purposes?***

If you decide to take part in this research study, you will be required to complete 2 separate visits, 2-3 days apart. Each visit will involve a rowing ergometer exercise test. The first visit will be a Graded Exercise Test (GXT). The second visit will involve rowing for 2 kilometers at self-selected intensity.

If an abnormal response occurs during exercise, such as chest pain, the test will be immediately stopped and you will be given proper medical attention. Emergency equipment will be available on site for all testing procedures and research staff are certified in CPR and First Aid by the American Red Cross. If you have an abnormal response to the cycle test, you will be told of the findings and will be encouraged to contact your primary care physician.

All procedures will take place in the Center for Exercise and Health-Fitness Research (CEHFR) located in Trees Hall at the University of Pittsburgh. All testing sessions will be administered by trained staff members from the CEHFR.

**Pre-Exercise Procedures:**

1. Before starting the study protocol, you will complete the Medical History Form, a Physical Activity Readiness Questionnaire (PAR-Q) and an Intake Questionnaire. All forms will take less than ten minutes to complete.

2. Prior to each exercise trial, a heart rate monitor will be positioned around your chest and secured in place with an elastic strap. Immediately prior to exercise, a rubber mouthpiece, connected to a headset, will be placed in your mouth to determine the amount of oxygen that you use during exercise. A rubber padded clip will be attached to your nose to insure that all the air that you breathe goes in and out through your mouth. Some individuals become anxious when fitted with the nose clip and mouthpiece. If this occurs to you, please inform the individual performing the test and the test will be stopped. Your heart rate and the amount of oxygen that your body uses will be measured during cycle exercise.

3. Prior to the exercise trials, you will receive standard instructions on how each test is to be completed.

**Trial 1: Fitness Assessment and Baseline GXT on a Rowing Ergometer**

4. Your body height and weight will be measured using a standard physicians' scale.

5. Body composition will be assessed using a Tanita bioelectrical impedance analyzer (BIA). The BIA is a non-invasive pain-free procedure for measuring your body fat and muscle that transmits a low-grade electrical impulse through the body. You will remove your shoes and socks and stand on the Tanita scale for approximately 10 seconds to obtain body fat assessment. During the body composition measurement there may be a potential for the hair on your arms and legs to stand up.

6. Based on the information you provide on the Medical History Form and PAR-Q, if you do not have any conditions that would limit your ability to exercise, you will complete the first testing session in order to determine your fitness level. You will perform the GXT on a rowing ergometer while maintaining a stroke per minute rate of 20-34 strokes per minute. The exercise protocol will begin at a low resistance and the resistance will increase every2 minutes. You will be encouraged to continue until fatigued. However, you may stop the test at any time for any reason.

**Trial 2: 2 kilometer Time Trial**

7. 2 to 3 days after you have completed the baseline GXT, you will return to the laboratory to perform the self-selected exercise intensity trial on a stationary cycle.

8. Following a 5-minute warm-up, the exercise trial will consist of 2 kilometers of continuous rowing exercise at an intensity that you choose. At any point during the test, you can choose a different stroke rate or power output based on your ability to perform.

***What are the possible risks, side effects, and discomforts of this research study?***

**Risks of the Graded Exercise Test**

Abnormal responses, such as excessive rises in blood pressure, mental confusion, shortness of breath, chest pain, heart attack, and death, to maximal aerobic exercise tests in young healthy adults are rare, occurring in less than 1% of people (less than 1 out of 100 people tested). However, some common risks, occurring in 1% to 25% of people (1 to 25 out of 100 people tested), of maximal exercise testing include: heavy breathing, dizziness, muscle fatigue, headache, and overall fatigue.

**Risks of the Study Monitors**

Risk associated with study monitors (e.g. heart rate monitor and mouthpiece) include skin redness, irritation, and chafing.

***What are possible benefits from taking part in this study?***

You will likely receive no direct benefit from taking part in this research study. However, you will receive information regarding your aerobic fitness level, percent body fat, and the importance of promoting your cardiovascular health.

***If I agree to take part in this research study, will I be told of any new risks that may be found during the course of the study?***

You will be promptly notified if, during the conduct of this research study, any new information develops which may cause you to change your mind about continuing to participate.

***Will my insurance provider or I be charged for the costs of any procedures performed as part of this research study?***

Neither you, nor your insurance provider, will be charged for the costs of any procedures performed for the purpose of this research study.

***Will I be paid if I take part in this research study?***

There will not be covered compensation for this study due to the short time commitment.

***Who will pay if I am injured as a result of taking part in this study?***

University of Pittsburgh researchers and their associates who provide services at UPMC recognize the importance of your voluntary participation in their research studies. These individuals and their staff will make reasonable efforts to minimize, control, and treat any injuries that may arise as a result of this research. If you believe that you are injured as a result of the research procedures being performed, please contact immediately the Principal Investigator or one of the Co-Investigators listed on the first page of this form.

Emergency medical treatment for injuries solely and directly related to your participation in this research study will be provided to you by the hospitals of the UMPC.

It is possible that the UPMC may bill your insurance provider for the costs of this emergency treatment, but none of these costs will be charged directly to you. If your research-related injury requires medical care beyond this emergency treatment, you will be responsible for the cost of this follow-up unless otherwise specifically stated below. There is no plan for monetary compensation. You do not, however, waive any legal rights by signing this form.

***Who will know about my participation in this research study?***

Any information about you obtained from this research will be kept as confidential (private) as possible. All records related to your involvement in this research study will be stored in a locked file cabinet. Your identity on these records will be indicated by a case number rather than by your name, and the information linking these case numbers with your identity will be kept separate from the research records. You will not be identified by name in any publication of the research results unless you sign a separate consent form giving your permission (release).

***Will this research study involve the use or disclosure of my identifiable medical information?***

This research study will not involve the use or disclosure of any identifiable medical information.

***Who will have access to identifiable information related to my participation in this research study?***

In addition to the investigators listed on the first page of this authorization (consent) form and their research staff, the following individuals will or may have access to identifiable information related to your participation in this research study:

- Authorized representatives of the University of Pittsburgh Research Conduct and Compliance Office may review your identifiable research information for the purpose of monitoring the appropriate conduct of this research study.

- In unusual cases, the investigators may be required to release identifiable information related to your participation in this research study in response to an order from a court of law. If the investigators learn that you or someone with whom you are involved is in serious danger or potential harm, they will need to inform, as required by Pennsylvania law, the appropriate agencies.

- Authorized people sponsoring this research study, because they need to make sure that the information collected is correct, accurate, and complete, and to determine the results of this research study.

***For how long will the investigators be permitted to use and disclose identifiable information related to my participation in this research study?***

The investigators may continue to use and disclose, for the purposes described above, identifiable information related to your participation in this research study for a minimum of six years after final reporting or publication of a project.

***Is my participation in this research study voluntary?***

Your participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above, is completely voluntary. (Note, however, that if you do not provide your consent for the use and disclosure of your identifiable information for the purposes described above, you will not be allowed, in general, to participate in this research study.) Whether or not you provide your consent for participation in this research study will have no affect on your current or future relationship with the University of Pittsburgh. Whether or not you provide your consent for participation in this research study will have no effect on your current or future medical care at a UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider. If you are a student, the decision to participate or not participate in this study will have no influence on class standing or grades.

***May I withdraw, at a future date, my consent for participation in this research study?***

You may withdraw, at any time, your consent for participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above. Any identifiable research information recorded for, or resulting from, your participation in this research study prior to the date that you formally withdrew your consent may continue to be used and disclosed by the investigators for the purposes described above.

To formally withdraw your consent for participation in this research study you should provide a written and dated notice of this decision to the principal investigator of this research study at the address listed on the first page of this form.

Your decision to withdraw your consent for participation in this research study will have no effect on your current of future relationship with the University of Pittsburgh. Your decision to withdraw your consent for participation in this research study will have no effect on your current of future medical care at a UPMC hospital or affiliated health care provider or your current or your future relationship with a health care insurance provider.

***If I agree to take part in this research study, can I be removed from the study without my consent?***

It is possible that you may be removed from the research study by the researchers to protect your safety or if you are unable or unwilling to complete the research protocol.

## VOLUNTARY CONSENT

All of the above has been explained to me and all of my questions have been answered. I understand that any future questions I have about this research study during the course of this study, and that such future questions will be answered by the investigators listed on the first page of this consent document at the telephone numbers given. Any questions I have about my rights as a research subject will be answered by the Human Subject Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668). By signing this form, I agree to participate in this research study.

______________________
Participant's Name (Print)

______________________ ______________________
Participant's Signature Date

----------------------------------------------------------------------------------------------------

## CERTIFICATION OF INFORMED CONSENT

I certify that I have explained the nature and purpose of this research study to the above-named individual, and I have discussed the potential benefits, and possible risks associated with participation. Any questions the individual has about this study have been answered, and we will always be available to address future questions as they arise. I further certify that no research component of this protocol was begun until after this consent form was signed.

______________________ ______________________
Printed Name of Person Obtaining Consent Role in Research Study

______________________ ______________________
Signature of Person Obtaining Consent Date

## APPENDIX E

### Borg Scale of Perceived Exertion

| rating | description |
|---|---|
| 6 | NO EXERTION AT ALL |
| 7 | EXTREMELY LIGHT |
| 8 | |
| 9 | VERY LIGHT |
| 10 | |
| 11 | LIGHT |
| 12 | |
| 13 | SOMEWHAT HARD |
| 14 | |
| 15 | HARD (HEAVY) |
| 16 | |
| 17 | VERY HARD |
| 18 | |
| 19 | EXTREMELY HARD |
| 20 | MAXIMAL EXERTION |

## BIBLIOGRAPHY


1. Baechle, T. R., & Earle, R. W. (2000). *Essentials of Strength Training and Conditioning* (Second ed.). (H. Kinetics, Ed.) Champaign, IL: National Strength and Conditioning Association.

2. Bassett, D., Howley, E. (2000) Limiting Factors for Maximum Oxygen Uptake and Determinants of Endurance Perfomance. *Medicine and Science in Sports and Exercise*.

3. Baudouin, A. H. (2004). Investigation of Biomechanical Factors Affecting Rowing Performance. *Journal of Biomechanics, 37*, 969-976.

4.Baudouin, A., & Hawkins, D. (2002). A Biomechanical Review of Factors Affecting Rowing Performance. *British Journal of Sports Medicine, 36*, 396-402.

5. Beneke, R. (1995). Anaerobic Threshold, Individual Anaerobic Threshold, and Maximal Lactate Steady State in Rowing. *Medicine and Science in Sport and Exericse* , 863-867.

6. Brown, F. M., Neft, E. E., & LaJambe, C. M. (2008). Collegiate Rowing Crew Performance Varies by Morningness-Eveningness. *Journal of Strength and Conditioning Research, 22* (6), 1894-1900.

7. Caldwell, J. S. (2003). The Effects of Repetitive Motion on Lumbar Flexion and Erector Spinae Muscle Activity in Rowers. *Clinical Biomechanics, 18*, 704-711.

8. Carey, D. G. (2010). The Ventilatory Response to Incremetal Exercise: Is it One or Two Breakpoints? *Journal of Strength and Conditioning Research, 24* (10), 2840-2845.

9. Celik, O., Kosar, S. N., Korkusuz, F., & Bozkurt, M. (2005). Reliability and Validity of the Modified Conconi Test on Concept II Rowing Ergometers. *Journal of Strength and Conditioning Research, 19* (4), 871-877.

10. Chin, M.-K., So, R. C., Perry, C. C., & Wong, A. S. (1994). Maximal Aerobic Power of Hong Kong Elite Lightweight Rowers. *Journal of Strength and Conditioning Research, 8* (2), 86-90.

11. Clifford, P. S. (1994). Arterial Blood Pressure Response to Rowing. *Medicine and Science in Sport and Exercise* , 715-719.

12. Costill, D., Witzmann, F. (1979) Adaptations in Skeletal Muscle Following Strength Training. *Journal of Applied Physiology*.

13. Cunningham, D. G. (1975). Cardiorespiratory Response to Exercise on a Rowing and Bicycle Ergometer. *Medicine and Science in Sports, 7* (1), 37-43.

14. DiPrampero, P. C. (1971). Physiological Aspects of Rowing. *Journal of Applied Physiology, 31* (6), 853-857.

15. Dunbar, C. R. (1992). The Validity of Regulating Exercise Intensity by Ratings of Perceived Exertion. *Medicine and Science in Sport and Exercise, 24* (1), 94-99.

16. Enoka, R. M. (1992). Neurobiology of Muscle Fatigue. *American Physiological Society* , 1631-1648.

17. Eston, Roger G., Faulkner, James A., Mason, Elizabeth A., Parfitt, Gaynor (2006). The Validity of Predicting Maximal Oxygen Uptake From Perceptually Regulated Graded Exercise Tests of Different Durations. *European Journal of Applied Physiology,* 97: 535-541

18. Evans, S., Davy, K., Stevenson, E., Seals, D. (1995) Physiological Determinants of 10km Performance in Highly Trained Female Runners of Different Ages. *Journal of Applied Physiology*

19. Faulkner, J., Parfitt, G., Eston, R. (2007). Prediction of Maximal Oxygen Uptake From the Ratings of Perceived Exertion and Heart Rate During a Perceptually-regulated Sub-maximal Exercise Test in Active and Sedentary Participants. *European Journal of Applied Physiology,* 101: 397-407

20. Favero, T. G. (1999). Sarcoplasmic Reticulum Ca2+ Release and Muscle Fatigue. *Journal of Applied Physiology, 87*, 471-483.

21. Firat, Akca (2014) Prediction of Rowing Ergometer Performance From Functional Anaerobic Power, Strength and Anthropometric Components. *Journal of Human Kinetics*, 41, 133-142

22. Gorelick, M. B. (2003). Short-duration Fatigue Alters Neuromuscular Coordination of Trunk Musculature: Implications for Injury. *Applied Ergonomics, 34*, 317-325.

23. Guevel, A., Zimmerman, M., & Guihard, V. (2006). A Physiological Comparison of On-Water and Ergometer Rowing: Relationship Between Heart Rate and Oxygen Uptake During an Incremental Graded Maximal Exercise Test. *4th International Sport Sciences Days* (pp. 61-62). Paris, France: National Institute for Sport and Physical Education.

24. Hagerman, F. C. (1988). A Comparison of Energy Expenditure During Rowing and Cycling Ergometry. *Medicine and Science in Sport and Exercise, 20* (5), 479-488.

25. Hawley, J., Noakes, D. (1992) Peak Power Output Predicts Maximal Oxygen Uptake and Performance in Trained Cyclists. *European Journal of Applied Physiology,* 65-79

26. Hill, D. W. (2003). Modeling the Relationship Between Velocity and Time to Fatigue in Rowing. *Medicine and Science in Sport and Exercise* , 2098-2104.

27. Hofmijster, M. J. (2008). Rowing Skill Affects Power Loss on a Modified Rowing Ergometer. *Medicine and Science in Sport and Exercise* , 1101-1109.

28. Ingham, S., Whyte, G., Jones, K., & Nevil, A. (2002). Determinants of 2000m Rowing Ergometer Performance in Elite Rowers. *European Journal of Applied Physiology, 88*, 243-246.

29. Impellizzeri, F., Marcora, S., Rampinini, E., Mognoni, P., Sasi, A. (2005) Correlations Between Physiological Variables and Performance in High Level Cross Country Off Road Cyclists. *British Journal of Sports Medicine.* 39, 747-751

30. Jensen, R. L. (1996). The Prediction of Power and Efficiency During Near-Maximal Rowing. *European Journal of Applied Physiology, 73*, 98-104.

31. MacFarlane, D., Edmond, I., & Walmsley, A. (1997). Instrumentation of an Ergometer to Monitor the Reliability of Rowing Performance. *Journal of Sport Sciences, 15*, 167-173.

32. Mahler, D. A. (1991). Ventilatory Responses and Entrainment of Breathing During Rowing. *Medicine and Science in Sport and Exercise, 23* (2), 186-192.

33. Marriott, Hellen E., Lamb, Kevin L. (1996). The Use of Ratings of Perceived Exertion for Regulating Exercise Levels in Rowing Ergometry. European Journal of Applied Physiology, 72, 267-271

34. McLaughlin, J.E., Howley, E.T., Bassett, D.R., Thompson, D.L., Fitzhugh, E.C. (2010) Test of the Classic Model for Predicting Endurance Running Performance. *Medicine and Science in Sports and Exercise.* 42(5), 991-997

35. Mohrman, D., Heller, L. (2013) Cardiovascular Physiology (eighth edition). McGraw Hill Publishing

36. Nakamura, Fabio Y, Okuno, Nilo M., Perandini, Luiz A.B., Caldeira, Lucio F.S., Simoes, Herbert G., Cardoso, Jefferson R., Bishop, David J. (2008). Critical Power Can Be Estimated From Nonexhaustive Tests Based on Rating of Perceived Exertion Responses. Journal of Strength and Conditioning Research. 22, 937-943

37. Nelson, W. N. (1983). Kinematic Analysis and Efficiency Estimate of Intercollegiate Female Rowers. *Medicine and Science in Sport and Exercise, 15* (6), 535-541.

38. Ozkan, Ali., Kin-Isler, Ayse (2007). The Reliability and Validity of Regulating Exercise Intensity by Ratings of Perceived Exertion in Step Dance Sessions. *Journal of Strength and Conditioning Research*, 21 (1), 296-300

39. Peltonen, J. E. (1995). Effects of Oxygen Fraction in Inspired Air on Rowing Performance. *Medicine and Science in Sport and Exercise* , 573-579.

40. Perkins, C. D., & Pivarnik, J. M. (2003). Physiolgical Profiles and Performance Predictors of a Women's NCAA Rowing Team. *Journal of Strength and Conditioning Research, 17* (1), 173-176.

41. Powers, S. K., & Howley, E. T. (2007). *Exercise Physiology: Theory and Application to Fitness and Performance* (Sixth ed.). New York, NY: McGraw-Hill.

42. Psycharakis, Stelios G. (2011). A Longitudinal Analysis on the Validity and Reliability of Ratings of Perceived Exertion for Elite Swimmers. *Journal of Strength and Conditioning Research,* 25 (2), 420-426

43. Rankinen, T., Vaisanen, S., Penttila, I., Rauramaa, R. (1995). Acute Dynamic Exercise Increases Fibrinolytic Activity. *Thrombosis and Haemostasis,* 73 (2): 281-286

44. Reichman, S., Zoeller, R., Balasekaran, G., Goss, F. F., & Robertson, R. F. (1997). Prediction of 2000m Rowing Performance in Females Using Indices of Anaerobic and Aerobic Power. *Medicine and Science in Sport and Exercise* .

45. Rosiello, R. A. (1987). Cardiovascular Responses to Rowing. *Medicine and Science in Sport and Exercise, 19* (3), 239-245.

46. Roy, S. H.-M. (1990). Fatigue, Recovery, and Low Back Pain in Varsity Rowers. *Medicine and Science in Sport and Exercise, 22* (4), 463-469.

47. Schabort, E., Hawley, J., Hopkins, W., & Blum, H. (1999). High Reliability of Performance of Well-Trained Rowers on a Rowing Ergometer. *Journal of Sport Sciences, 17*, 627-632.

48. So, R. C., Tse, M. A., & Wong, S. C. (2007). Application of Surface Electromyography in Assessing Muscle Recruitment Patterns in a Six-Minute Continuous Rowing Effort. *Journal of Strength and Conditioning Research, 21* (3), 724-730.

49. Storen, O., Helgerud, J., Stoa, E., Hoff, J. (2008) Maximal Strength Training Improves Running Economy in Distance Runners. *Medicine and Science in Sports and Exercise.* 40(6), 1089-1094

50. Womack, C. J., Davis, S. E., Wood, C. M., Sauer, K., Alvarez, J., Weltman, A., et al. (1996). Effects of Training on Physiological Correlates of Rowing Ergometry Performance. *Journal of Strength and Conditioning Research, 10* (4), 234-238.

51. Yoshiga, C. H. (2003). Rowing Performance of Female and Male Rowers. *Scandinavian Journal of Medicine and Science in Sports, 13*, 317-321.