Journal of Sports Science 7 (2019) 81-87
doi: 10.17265/2332-7839/2019.03.002

Predictors of 2 Kilometer Rowing Ergometer Time Trial Performance

Jason W. Metz, Fredric L. Goss, Robert J. Robertson, Elizabeth F. Nagle and John P. Abt
Department of Health and Physical Activity, University of Pittsburgh, Pittsburgh, PA 15260, USA

Abstract: Predictors of performance can aid coaches and trainers in prescribing exercise programs for rowing athletes. To date, most of the prediction models have been developed for runners and cyclists. Purpose: The aim of this study was to develop a regression model to predict performance of a simulated 2 kilometer rowing ergometer time trial. Methods: A group of mixed gender rowing athletes (n = 12) completed in a counterbalanced order a 2 kilometer rowing time trial and a continuous progressively incremented graded exercise test on a rowing ergometer. Subjects were 23.91 ±4.99 years old, weighed 79.14 ±12.85 kg, were 187.38 ±12.60 cm, had a VO_2max of 55.48 ±10.32 mL/kg/min and had 3.17 ±2.79 years of rowing experience. Physiological measures were recorded during both testing protocols. Results: Maximum power/stroke ratio (r = -0.96, p < 0.001), power/stroke ratio at the ventilatory breakpoint (r = -0.90, p < 0.001), maximal oxygen uptake (r = -0.84, p < 0.001) and oxygen uptake at the ventilatory breakpoint (r = -0.82, p < 0.001) were found to be strong and significant predictors of 2 kilometer rowing performance. Conclusion: The four significant predictors of rowing performance suggest training should focus on improving both aerobic capacity and strength. Practical Application: Rowing training should focus on developing hip and leg aerobic and anaerobic capacities to improve performance. Developing strength improves mechanical efficiency as well as raising anaerobic thresholds allowing athletes to utilize a larger portion of their aerobic capacity.

Key words: Maximal oxygen uptake, ventilatory threshold, power/stroke ratio.

1. 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, 7, 20]. However, no research has collectively utilized these and other variables in an effort to predict 2 km 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 [9, 12]. A few studies have shown that maximal oxygen uptake and maximum oxygen uptake steady state can be used to predict 2 km rowing performance in both male and female rowers, of various competitive experiences and relative to their age and competitive experience [9, 12, 26]. A higher maximal oxygen uptake is associated with faster times during a 2 km race in rowers of varying competitive experience [9, 12]. Because of the duration of the time trial and the fact that most competitive rowers can maintain intensity equal to 96% of maximal oxygen uptake for the entire race, maximal oxygen uptake may be a strong predictor of race performance [23]. In addition, the higher the power output (watts) an individual can sustain in a steady state, the better the performance in a 2 km race [14]. 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 [29].

Corresponding author: Jason W. Metz, Ph.D, Assistant Professor, West Liberty University.

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) at the ventilatory breakpoint. 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 2 km rowing performance and peak power output, oxygen uptake, fat free mass and body fat percentage [5, 12, 13, 16].

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 [23, 24]. 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 2 km 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 [9, 10, 21, 24]. This reliance on glycolysis will increase lactic acid, hydrogen ions, non-metabolic CO_2 and ventilation [23, 24]. The ventilatory breakpoint is a non-invasive correlate of the anaerobic threshold that has previously been validated through research [1, 23].

2. Methods

2.1 Experimental Approach to the Problem

The aim of this study was to develop a regression model to predict performance of a simulated 2 kilometer race. A graded exercise protocol was utilized to generate a maximal oxygen uptake, maximal power output as well as oxygen uptake and power output at the ventilatory breakpoint. Ventilatory breakpoint was determined by graphing VE/VO_2 and VE/VCO_2 and determining a dissociation of the two lines. Variables tested during the graded exercise test were then used to generate prediction equations for 2 kilometer performance using SPSS v24. A stepwise linear regression analysis was used to generate the formulas.

2.2 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. Subject demographics are shown in Table 1. This study was approved by the University of Pittsburgh Institutional Review Board (IRB). Subjects were screened to determine eligibility utilizing a questionnaire and a PAR-Q. 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. Once eligibility was determined, subjects completed an informed consent prior to testing.

3. Procedures

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. A questionnaire specific to the proposed study 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 was used to determine if a medical contradiction to participation may exist. A written informed consent approved by the University of Pittsburgh IRB 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 rating of perceived exertion (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 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 [23]. 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

Table 1 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
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

Table 2 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

graded rowing protocol is presented in Table 2.

After a minimum of a 48-96 h rest period following the graded exercise test, subjects returned to the lab to undergo a 2 km 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 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 2 km 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 breaks and were instructed to complete the 2 km 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 200 m remaining in the 2 km time trial, the rowers once again sprinted to finish the race. Physiological and mechanical values (oxygen uptake, heart rate, Respiratory Exchange Ratio, VCO_2, ventilation, power, strokes per minute) were obtained every 15 seconds during the test until the subject has completed the 2 km 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 2 km trial was recorded in seconds.

Upon completion of the 2 km 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.

4. Statistical Analyses

A stepwise linear regression analysis was used to examine the relation between performance variables and 2 km rowing time. Statistical significance was set a priori at the $p \leq 0.05$ level. With $n = 12$, the statistical power achieved was between 0.998-1.00 for each of the 4 formulas created.

5. Results

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 (graded exercise test and 2 km time trial) 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. Subject demographics are presented in Table 1. Performance data are presented in Table 3. Created regression models are presented in Table 4. All regression models achieved $p < 0.001$ level of significance. Due to strong correlations, only 1 variable was able to be entered into the model for creating prediction formulas.

6. Discussion

Maximum power/stroke ratio was examined presently as a means to assess mechanical efficiency during the 2 km 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 [28]. Jensen et al. [16] and Firat et al. [11], identified peak power ($r = -0.52$; $p < 0.05$) and ($r = -0.756$, $p < 0.05$), respectively, to be a

Table 3 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 2 km (watts/stroke per min)	9.59 ± 2.79
Average power 2 km (watts)	271.98 ± 84.07
Average 2 km time (sec)	447.00 ± 47.34
Predicted 2 km 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 4 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.

significant predictor of 2 km rowing performance. In a study completed by Costill et al., 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 improve power. Collectively, these findings suggest that strength is an important contributor to rowing performance [1, 8, 23]. The inclusion of resistance training for rowing athletes can improve power development and movement efficiency that will contribute to improved performance [2, 17, 28].

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 [15]. In a study completed by Ingham et al. (2002), maximal oxygen uptake was determined to be significantly correlated with 2 km rowing time (r = -0.88, p < 0.001) and this finding is consistent with the current study (r = -0.84, p < 0.001) [29]. 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 only increased cardiac output but also improved gas exchange in the lungs and a greater a-VO_2 difference [2, 18]. Basset et al. [2], 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_2max. Muscle characteristics such as fiber type and mitochondrial density are identified as peripheral limiting factors [2].

Power/stroke ratio at the ventilatory threshold was shown presently to be another highly predictive variable with regard to rowing performance. Power/stroke ratio is simply the power (watts) shown as a function of strokes per minute. The ventilatory breakpoint is frequently used as a surrogate measure of the anaerobic/lactate threshold [22]. Ingham et al.

determined power output at the lactate threshold (r = -0.88, $p < 0.001$) was strongly predictive of 2 km rowing performance [16]. The current study showed power/stroke ratio at the ventilatory breakpoint (r = -0.896, $p < 0.001$) to be strongly predictive of 2 km rowing performance.

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 IAT (individual anaerobic threshold), defined as the workload corresponding to the maximal lactate steady state that an individual can achieve, was a predictor of 2 km rowing racing performance (r = 0.79, $p < 0.01$). [5] This was consistent with an investigation conducted by Ingham et al. [15] in which a correlation between 2 km 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 2 km rowing performance (r = -0.818, $p < 0.001$).

7. Practical Application

This study identified 4 separate predictors of 2 km 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 2 km rowing test lasts about 6-10 minutes based on the experience and fitness level of the athlete [13, 18, 19]. Experienced rowers typically finish 2 km in about 6-8 minutes while inexperienced rowers can take upwards to 10 minutes [13]. In the present investigation subjects completed the 2 km 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 2 km rowing is derived from anaerobic pathways an anaerobic marker as a predictor of performance was shown to be valuable [15, 16, 25]. Since 30% of the energy metabolism for 2 km rowing is derived from anaerobic pathways, which means there is a 70% contribution from aerobic pathways. For this reason, both anaerobic and aerobic measures should be considered when developing conditioning programs.

Acknowledgements

This study was completed with the help of dissertation committee members, Fredric Goss, Ph.D., Robert Robertson, Ph.D., Elizabeth Nagle, Ph.D. and Jonathan Abt, Ph.D. and the help of the Center for Health and Fitness Research at the University of Pittsburgh, University of Pittsburgh Crew Team and Row Fit Rowing Club. The study completed was not done with financial or professional interest from manufactures or companies that could potentially benefit from the results. This study did not receive grant support. The results of this present study do not constitute endorsement of the product by the authors of the NSCA.

References

[1] Baechle, T. R., and Earle, R. W. 2000. *Essentials of Strength Training and Conditioning*. 2nd ed., editted by Kinetics, H. Champaign, IL: National Strength and Conditioning Association.

[2] Bassett, D., and Howley, E. 2000. "Limiting Factors for Maximum Oxygen Uptake and Determinants of Endurance Performance." *Medicine and Science in Sports and Exercise*.

[3] Baudouin, A. H. 2004. "Investigation of Biomechanical Factors Affecting Rowing Performance." *Journal of Biomechanics* 37: 969-76.

[4] Baudouin, A., and 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., and LaJambe, C. M. 2008. "Collegiate Rowing Crew Performance Varies by Morningness-Eveningness." *Journal of Strength and Conditioning Research* 22 (6): 1894-900.

[7] Celik, O., Kosar, S. N., Korkusuz, F., and Bozkurt, M. 2005. "Reliability and Validity of the Modified Conconi Test on Concept II Rowing Ergometers." *Journal of*

Strength and Conditioning Research 19 (4): 871-7.

[8] Costill, D., and Witzmann, F. 1979. “Adaptations in Skeletal Muscle Following Strength Training.” *Journal of Applied Physiology*.

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

[10] Di Prampero, P. C. 1971. “Physiological Aspects of Rowing.” *Journal of Applied Physiology* 31 (6): 853-7.

[11] Firat, A. 2014. “Prediction of Rowing Ergometer Performance from Functional Anaerobic Power, Strength and Anthropometric Components.” *Journal of Human Kinetics* 41: 133-42.

[12] Guevel, A., Zimmerman, M., and 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.” Presented at 4th International Sport Sciences Days, Paris, France.

[13] Hagerman, F. C. 1988. “A Comparison of Energy Expenditure during Rowing and Cycling Ergometry.” *Medicine and Science in Sport and Exercise* 20 (5): 479-88.

[14] Hofmijster, M. J. 2008. “Rowing Skill Affects Power Loss on a Modified Rowing Ergometer.” *Medicine and Science in Sport and Exercise*, 1101-9.

[15] Ingham, S., Whyte, G., Jones, K., and Nevil, A. 2002. “Determinants of 2000 m Rowing Ergometer Performance in Elite Rowers.” *European Journal of Applied Physiology* 88: 243-6.

[16] Jensen, R. L. 1996. “The Prediction of Power and Efficiency during Near-Maximal Rowing.” *European Journal of Applied Physiology* 73: 98-104.

[17] Mc Laughlin, J. E., Howley, E. T., Bassett, D. R., Thompson, D. L., and Fitzhugh, E. C. 2010. “Test of the Classic Model for Predicting Endurance Running Performance.” *Medicine and Science in Sports and Exercise* 42 (5): 991-7.

[18] Mohrman, D., and Heller, L. 2013. *Cardiovascular Physiology*. 8th ed., McGraw Hill Publishing.

[19] Nakamura, F. Y., Okuno, N. M., Perandini, L. A. B., Caldeira, L. F. S., Simoes, H. G., Cardoso, J. R., and Bishop, D. J. 2008. “Critical Power Can Be Estimated from Nonexhaustive Tests Based on Rating of Perceived Exertion Responses.” *Journal of Strength and Conditioning Research* 22: 937-43.

[20] Nelson, W. N. 1983. “Kinematic Analysis and Efficiency Estimate of Intercollegiate Female Rowers.” *Medicine and Science in Sport and Exercise* 15 (6): 535-41.

[21] Ozkan, A., and Kin-Isler, A. 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.

[22] Peltonen, J. E. 1995. “Effects of Oxygen Fraction in Inspired Air on Rowing Performance.” *Medicine and Science in Sport and Exercise*, 573-9.

[23] Perkins, C. D., and Pivarnik, J. M. 2003. “Physiolgical Profiles and Performance Predictors of a Women’s NCAA Rowing Team.” *Journal of Strength and Conditioning Research* 17 (1): 173-6.

[24] Powers, S. K., and Howley, E. T. 2007. *Exercise Physiology: Theory and Application to Fitness and Performance*. 6th ed. New York, NY: McGraw-Hill.

[25] Psycharakis, S. 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): 420-6.

[26] Rosiello, R. A. 1987. “Cardiovascular Responses to Rowing.” *Medicine and Science in Sport and Exercise* 19 (3): 239-45.

[27] So, R. C., Tse, M. A., and 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): 724-30.

[28] Storen, O., Helgerud, J., Stoa, E., and Hoff, J. 2008. “Maximal Strength Training Improves Running Economy in Distance Runners.” *Medicine and Science in Sports and Exercise* 40 (6): 1089-94.

[29] Yoshiga, C. H. 2003. “Rowing Performance of Female and Male Rowers.” *Scandinavian Journal of Medicine and Science in Sports* 13: 317-21.