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Prediction of Rowing Ergometer Performance from Functional Anaerobic, Aerobic and Muscle Power

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Abstract*—The purpose of this research is to find predictors of 2000 meters indoor rowing performance from the aspect of physical condition that is the ability of aerobic, anaerobic and muscle power. The samples used were twenty-six (26) rowers, consisting of 16 male rowers and 10 female rowers, aged 19 ± 29 years old, who joined the Program Indonesia Emas, participated in this study. Participants give written approval before participating in this research. All experimental procedures are approved by the Executive Board of the Indonesian Rowing and Canoeing Association. The test was performed with a physical test series developed by Danish Rowing, taking a standard of 21 Danish rowers. Rowing athletes participated a 3-day physical tests, showing all out performance for the type of time-determined test or distance specified using Concept2, type C rowing ergometer. The results of this study revealed that the relationship between rowing performance variables 2000 meters with free variables, sorted from the largest to the smallest shows: aerobic capacity = 0.976, muscle power = 0.950 and anaerobic capacity = 0.937. This shows a strong correlation between aerobic capacity, muscle power and anaerobic capacity (the correlation between variables was above 0.5). This indicates the presence of multicollinearity, or the correlation between the three independent variables. After passing through 2 stages of backward method, the independent variable that is included in regression model is Aerobic Capacity and Muscle Power. A 97.1% variation in rowing 2000 meter rowing performance can be explained by variable aerobic capacity and muscle power. While the rest (100% -97.1% = 2.9%) is explained by other factors. In conclusion, aerobic and muscle power capacity has a significant effect and can be a predictor of 2000 meters rowing performance. In addition, the research is also in line with other studies, which show that strength and endurance are important training objectives to optimize 2000 m rowing performance. However, the prediction variables identified in this study may be specific to the samples in this study. To use this predictor in more rowers, cross validation in larger samples is necessary. This research can be a source of information and references in the development of scholarship training especially in identifying talent of prospective rowing athletes. For coaches, the finding can be a source of information and references in in determining the priority scale aspects that must be fostered to improve the performance of rowing athletes.

Keywords—performance rowing; indoor rowing; ergometer

I. INTRODUCTION

Performa 2000 m indoor rowing performance depends largely on aerobic and anaerobic functional capacities, and the ability to maintain aerobic and anaerobic performance [1]. Aerobic metabolism shows a contribution of 67-88% [2] and, as rowing performance is highly associated with maximum oxygen uptake (VO2Max) [3,4], maximal oxygen uptake (VO2Max) is an important physiological parameter for a rower. VO2Max is the variable with the largest correlation (r = 0.71) with rowing performance compared to other parameters [5]. Cosgrove, Wilson, Watt and Grant examined the relationship between performance of 2000 m indoor rowing and physiological variables at club-level rowers and found that VO2Max showed the highest correlation [6].

Apart from the importance of VO2Max as a determinant of rowing indoor 2000 m rowing performance, rowing is a power endurance sport [7]. The production of large strengths and the contribution of higher anaerobic metabolism can be done in rowing compared to other endurance sports because rowing is relatively short (i.e. ± 6 ± 8 minutes) and requires only the speed and frequency of slow muscle contraction [8], so that it can improve the recovery of anaerobic energy systems. Furthermore, Russell, Rossignol, and Sparrow conducted a study using accumulated oxygen deficits as a measure of anaerobic capacity but apparently did not predict the performance of rowing indoor rowing 2000 m [9]. Although the accumulation of oxygen deficits consistently shows a high correlation with VO2max, this is not enough to predict exercise performance that depends on the measured level of anaerobic strength [2].

Although indoor rowing on an ergometer does not fully require the same skills as rowing on water, research shows that the ergometer simulates the same biomechanical and metabolic rowing as on water [10]. Therefore, ergometers are usually used to measure individual physiological performance variables and become one of the rowing training methods [1,11]. Riechman et al. conducted a study by predicting the performance of 2000 m indoor rowing using 30 s sprint and maximum oxygen uptake, this study suggested that the method used was able to accurately predict the performance of 2000 m ergometer rowing on female professional rowers, and the possibility of developing the method by testing more specific to aerobics and anaerobics [12]. The purpose of this study was

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to develop a method for predicting indoor rowing performance through muscle power, aerobic capacity and anaerobic capacity performance. This study hypothesizes that muscle power, aerobic capacity and anaerobic capacity performance will predict the performance of 2000 m indoor rowing.

The energy for rowing comes from the aerobic and anaerobic systems (most of the research is done on male elite rowers). It was stated that rowing for 6:43 minutes requires an 84% aerobic energy system and 16% anaerobic energy [13]. This is also in line Droghetti, Jensen, and Nilsen who found an aerobic contribution of 80% to 82%, on a 6-minute ergometer test [13]. Fiskerstrand and Seiler explained about VO2Max in elite athletes which increased by 12% during the training period and conversely the volume of exercises that prioritized anerobics decreased from 23 hours to 7 hours in one month. This shows that the training program and fitness capacity have an impact on aerobic and anaerobic energy production when rowing for 2 km. A good level of fitness with a high capacity of VO2max allows athletes to row during the race without relying heavily on anaerobic systems [14]. The anaerobic system (anaerobic allactate and anaerobic glycolytic system) contribute greatly at start and towards the finish of a race. When developed properly, the anaerobic system can contribute about 2 minutes of primary energy. Because rowing 1 km lasts an average of 4 minutes, we can illustrate that the anaerobic contribution to 1 km races is 50% to 60% of total energy. Understanding the physiological profile in a race provides some general information on the importance of the rower's physiological profile when searching for talent. Some physiological characteristics that need to be considered for rowing athletes are as follows

As explained earlier, the anaerobic contribution to energy production in rowing reaches 50% in 1000 m and a 20% to 30% in the 2000 m category. Anaerobic fitness plays an important role at the start and 250 m towards the finish during the race. The two anaerobic fitness aspects in the spotlight are peak power and average strength. In recent years' peak power has begun to emerge as a strong predictor of rowing performance. Analysis of data collected from Canadian heavyweight elite athletes showed that although strength in VO2max was the best predictor of rowing ergonomic performance, peak power on the ergometer was higher correlated with rowing performance on water compared to aerobic threshold / V˙O2max on paddle ergometers ($r = 0.82$, $r = 0.72$, and $r = 0.70$, respectively) [13]. The same results were seen in university female rowers where peak power had a correlation $r = 0.875$ with an ergometer time of 2000 m, and changes in peak power significantly correlated with changes in performance on the 2000 m ergometer.

Average anaerobic power was also found to be strongly associated with rowing performance, Riechman et al. found that the average power of the 30-second ergometer sprint test explained 75.7% of the variance in the 2000 m ergometer performance while VO2max only explained 12.1% [12]. It might seem contradictory that anaerobic variables are predictors of rowing performance that are better than aerobic fitness variables seeing paddles as a sport dominated by aerobic abilities. However, the fact that every coach realizes the importance of aerobic fitness in rowing is the most likely explanation for this phenomenon. Because every coach knows that aerobic fitness is very important, there is a greater emphasis on training in developing aerobic systems compared to anaerobic.

II. METHODS

A. Participants

Twenty-six (26) rowers, consisting of 16 male and 10 female athletes, aged 19 ± 29 years, who joined the Indonesia Golden Program Indonesia Emas Cabang Olahraga Dayung Rowing, participated in this study. Participants gave written approval before participating in this study. All experimental procedures were approved by the Executive Board of the Indonesian Rowing Association (PB. PODSI).

1) 60-second test

a) Tets preparation: To do this test you need a Concept2 ergometer and a video camera. Video cameras must be installed to record monitors on the ergometer. Performance monitors on ergometers can be connected to a computer, and you can download data using the program from the manufacturer's website. The ergometer monitor needs to display power per stroke and average power in watts. The ergometer fan should be set at 10 and note the drag factor; the higher the drag factor is, the better it will get. Warm up with steady-state rowing for about 10 minutes. Then stop, drink a little water, and start training yourself. Set up the monitor for 1 minute of work and take a 1 minute break and turn on the video camera. The test can be done without a video camera, but someone needs to record the power output for each hit. The video camera allows you to review this test as much as needed to ensure that you record the right wattage for each stroke.

b) Test application: Start rowing lightly; the monitor must calculate the 1 minute working period. Continues to row when the monitor switches to the rest period. For the last 3 to 5 seconds of the rest period, start some hard strokes by increasing the stroke speed and pulling harder. Once the monitor switches back to the 1 minute work period, the test will turn on and your goal is to draw as many watts as possible for each stroke for the next 60 seconds. You can use the tempo you want as long as you continue rowing with the full slide. Don't row with the rhythm of the race yourself; this is an all-out test.

c) Recording results: To get your test results, you need to analyze the video footage. Replay the 1 minute test section of the video. Record the wattage for each test stroke in the spreadsheet and graph the power for all strokes (watts of all stroke performed) for the 60-second working period.

2) The 100-meter test

a) Test preparation: To do this test you need a Concept2 ergometer and a video camera. Video cameras must be installed to record monitors on the ergometer. Performance monitors on ergometers can be connected to a computer, and you can download data using the program from the manufacturer's website. The ergometer monitor needs to

display power per stroke and average power in watts. Set the ergometer fan at 10 and note the drag factor; the higher the drag factor is, the better it will get. Warm up with steady-state rowing for about 10 minutes. Then stop, drink a little water, and start training yourself. Set the monitor to 100 meters and turn on the video camera. The test can be done without a video camera, but someone needs to record the power output for each hit. The video camera allows you to review this test as much as needed to ensure that you record the right wattage for each stroke.

b) Test application: Start a few hard strokes by increasing the stroke speed and pulling harder; your goal is to draw as many watts as possible on each stroke of 100 meters. You can use the tempo you want as long as you continue rowing with the full slide. Don't row with the rhythm of the race yourself; this is an all-out test.

c) Recording the result: To get your test results, you need to analyze the video footage. Replay the test section 100 meters from the video. Record the wattage for each test stroke in the spreadsheet and graph the power for all stroke strokes (watts of all stroke performed) for the 100 meter working period.

3) The 6000-meter test

a) Test preparation: To do this test you need a Concept2 ergometer and a video camera. Video cameras must be installed to record monitors on the ergometer. Performance monitors on ergometers can be connected to a computer, and you can download data using the program from the manufacturer's website. The ergometer monitor needs to display power per stroke and average power in watts. Set the ergometer fan at 10 and note the drag factor; the higher the drag factor is, the better it will get. Warm up with steady-state rowing for about 10 minutes. Then stop, drink a little water, and start training yourself. Set the monitor to 6000 meters and turn on the video camera. The test can be done without a video camera, but someone needs to record the power output for each hit. The video camera allows you to review this test as much as needed to ensure that you record the right wattage for each stroke.

b) Test application: Start a few hard strokes by increasing the stroke speed and pulling harder; your goal is to draw as many watts as possible on each stroke of 6000 meters. You can use the tempo you want as long as you continue rowing with the full slide.

c) Recording the result: To get your test results, you need to analyze the video footage. Replay the 6000 meter test section from the video. Record the wattage for each stroke test in the spreadsheet and graph the power for all stroke strokes (watts of all stroke performed) for 6000 meters of work period.

B. Statistical Analysis

Variables that are highly correlated with performance are chosen for the development of regression models. Arropometric data are not included in the analysis because they are highly correlated with physiological variables of interest and, therefore, interfere with ensuring the independent association of these parameters with performance. The 100 meter test (maximum power), the 60 second test (anaerobic ability) and the 6000 meter test (aerobic ability) were hypothesized as predictor variables and submitted to stepwise multiple regression analysis (SPSS 7.0, Chicago, IL, USA). The criteria variable is the performance time of the participants in the 2000 m race recorded during the indoor championship

III. RESULTS

The average performance of rowing 2000 meters (with a total data of 26 people) is 325.3077 with a standard deviation of 72.82240. The average aerobic capacity (with a total data of 26 people) is 251.8077 with a standard deviation of 51.58373. The average anaerobic capacity (with a total data of 26 people) is 599.1154 with a standard deviation of 154.90470. Average aerobic capacity (with a total data of 26 people) is 502.9615 with standard deviation 113.47228.

TABLE I. DESCRIPTIVE STATISTICS

	Mean	Std. Deviation	N
Y	325.3077	72.82240	26
X1	251.8077	51.58373	26
X2	599.1154	154.90470	26
X3	502.9615	113.47228	26

Whereas the relationship or correlation between rowing performance of 2000 meters rowing with independent variables, sorted from the largest to the smallest: Aerobic capacity = 0.976, Muscle Power = 0.950 and Anaerobic Capacity = 0.937. This shows; 1) there is a fairly strong correlation between the aerobic capacity and muscle power and anaerobic capacity (the correlation between variables is above 0.5). This indicates the existence of multicollinearity, or the correlation between the three independent variables. 2) The level of significance of the one-sided correlation coefficient of output (measured by probability) produces the same number.

TABLE II. CORRELATIONS

		Y	X1	X2	X3
Pearson Correlation	***Y***	1.000	.976	.937	.950
	X1	.976	1.000	.897	.915
	X2	.937	.897	1.000	.967
	X3	.950	.915	.967	1.000
Sig. (1-tailed)	***Y***	.	.000	.000	.000
	X1	.000	.	.000	.000
	X2	.000	.000	.	.000
	X3	.000	.000	.000	.
N	***Y***	26	26	26	26
	X1	26	26	26	26
	X2	26	26	26	26
	X3	26	26	26	26

The backward method starts with entering all variables (see Model 1 which has ENTER information). Then the analysis is done and variables that are not feasible to enter in the regression are eliminated one by one.

Model 2 states that the variable removed is X2 (Anaerobic Capacity). Thus, after passing 2 stages, the independent

variables that are feasible to be included in the regression model are Aerobic and Muscle Power Capacity.

TABLE III. VARIABLES ENTERED/REMOVED[A]

Model	Variables Entered	Variables Removed	Method
1	X3, X1, X2[b]	.	Enter
2	.	X2	Backward (criterion: Probability of F-to-remove >= .100).
a. Dependent Variable: Y			
b. All requested variables entered.			

As mentioned before, there are 2 stages of analysis, where at each stage there are variables that must be excluded from the regression model. In the table above, in Model 1, it appears Adjusted R Square is 0.971. For regression with more than two independent variables, adjusted R2 is used as the coefficient of determination. Then in Model 2, by eliminating an anaerobic capacity variable (see description b. Predictor below the table where the variable anaerobic capacity is lost), then adjusted R2 is 0.971, or there is no increase. However, it should be noted that the number 0.971 is only for two variables. The higher adjusted R2 will be better for the regression model, because the independent variable can explain the dependent variable is greater. This means that 97.1% of the variation in performance of rowing 2000 meters can be explained by aerobics and muscle power capacity. While the rest (100% - 97.1% = 2.9%) is explained by other reasons.

TABLE IV. MODEL SUMMARY

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	*F Change*	*df1*	*df2*	*Sig. F Change*	
1	.987a	.975	.971	12.32018	.975	283.815	3	22	.000	
2	.986b	.973	.971	12.46288	-.002	1.536	1	22	.228	2.203
a. Predictors: (Constant), X3, X1, X2										
b. Predictors: (Constant), X3, X1										
c. Dependent Variable: Y										

It can be seen from the above model, there is an increase in the Standard Error of Estimate, from 12.32018 in model 1, to 12.46288 in model 2. However, because it is smaller than the standard deviation of rowing 2000 meters (72.82240), the regression model is a better predictor of the performance of rowing 2000 meters compared to the average rowing performance itself.

From the ANOVA test or F test, The F observed value for model 2 or the model used is 415,279 with a significance level of 0.0000. Because the probability (0,000) is far less than 0.05, the regression model can be used to predict the performance of rowing 2000 meters. In other word, the aerobic capacity and muscle power together influence the performance of rowing 2000 meters. The level of significance of one-sided correlation coefficients of output (measured by probability) produces a variable number, with a note that the anaerobic capacity variable does not correlate significantly (has a significance value above 0.05) with other variables.

VIF or Variance Inflation factor has the same equation: VIF = 1 / TOLERANCE. For example, in model 1 for the aerobic capacity variable, the tolerance size is 0.161. Then the size of the VIF is: VIF = 1 / 0.161 = 6.21. In general, if VIF is greater than 5, then the variable has a multicollinearity problem with other independent variables. If seen in the table above, then the competitor's independent variable and Promotion have a VIF of more than 5, so that it can be expected that there is a problem with multicollinearity (a large correlation between independent variables).

TABLE V. ANOVA[A]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	*Regression*	129238.229	3	43079.410	283.815	.000[b]
	Residual	3339.309	22	151.787		
	Total	132577.538	25			
2	*Regression*	129005.100	2	64502.550	415.279	.000[c]
	Residual	3572.438	23	155.323		
	Total	132577.538	25			
a. Dependent Variable: Y						
b. Predictors: (Constant), X3, X1, X2						
c. Predictors: (Constant), X3, X1						

Pay attention to the TOLERANCE or tolerance column. For example, in model 1, for the aerobic capacity variable, the tolerance size is 0.161. This means R2 is 1 - 0.161 or 0.839. This means that only 83.9% of the variability in aerobic capacity can be explained by other predictors (independent variables). The default for SPSS for tolerance numbers is 0,0001. All variables to be included in the calculation of the regression model must have tolerance above 0,0001. It appears that all variables have met the tolerance threshold requirements.

In model 4, in the table above, in the Unstandardized Coefficient column, a regression equation is obtained: Y = -

21.018 + 0.932 X1 + 0.222 X3. Where: Y = 2000 meters performance, X1 = Aerobic capacity and X2 = Muscle Power. The equation is the same as the multiple regression equation in the previous case, where there are only aerobic and muscle power variables.

This equation means:

- The constant of -21,018 states that if there is no aerobic capacity and muscle power, the rowing performance of 2000 meters is -21,018.
- Regression coefficient X1 is 0.932, stating that every addition (due to a sign +) 1 watt of aerobic capacity will increase the performance of rowing 2000 meters by 0.932 watts.
- The regression coefficient of X2 of 0.222 states that every addition (due to the + 1 sign) of 1 watt muscle power will increase the performance of rowing 2000 meters by 0.222 watts.

TABLE VI. COEFFICIENTS[A]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
	B	*Std. Error*	*Beta*			*Zero-order*	*Partial*	*Part*	*Tolerance*	*VIF*
(Constant)	-15.186	13.142		-1.156	.260					
X1	.914	.119	.647	7.678	.000	.976	.853	.260	.161	6.208
X2	.078	.063	.166	1.239	.228	.937	.255	.042	.064	15.587
X3	.127	.094	.197	1.354	.189	.950	.277	.046	.054	18.572
(Constant)	-21.018	12.412		-1.693	.104					
X1	.932	.119	.661	7.807	.000	.976	.852	.267	.164	6.110
X3	.222	.054	.346	4.084	.000	.950	.648	.140	.164	6.110

T test to test the significance of constants and dependent variables (aerobic capacity). Based on probability, if the probability is> 0.05, then H is accepted and if the probability is <0.05, then H is rejected.

It can be seen that the Sig / significance column is 0,000, or the probability is far below 0.05, so Ho is rejected, or the regression coefficient is significant, or the aerobic capacity really has a significant effect on the performance of rowing 2000 meters. Likewise, for the analysis of constants and outlets, the two methods produced constant numbers and significant muscle power.

This section discusses the presence or absence of multicollinearity or the occurrence of correlations among independent variables. A good regression model certainly does not have multicollinearity or the correlation between independent variables. Look at the columns in the table above:

- Eigen value, Multicollinearity will occur if the value of Eugen is close to 0.
- Condition Index, Multicollinearity will occur if the index exceeds 15, and the problem is really serious if the index exceeds 30.

TABLE VII. COLLINEARITY DIAGNOSTICS[A]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	*X1*	*X2*	*X3*
1	1	3.957	1.000	.00	.00	.00	.00
	2	.036	10.414	.66	.00	.02	.01
	3	.005	28.498	.25	.91	.17	.02
	4	.002	49.245	.09	.08	.81	.97
2	1	2.969	1.000	.00	.00		.00
	2	.028	10.348	.93	.03		.06
	3	.004	28.720	.07	.97		.94
a. Dependent Variable: Y							

In the last model (model 1), it can be seen that the values of aerobic capacity and muscle power (code 2 and 3) have Eugen values that are close to 0, and there are indices of independent variables that exceed 15. This means there is a problem with multicollinearity; there is a correlation between variable aerobics and muscle power.

TABLE VIII. EXCLUDED VARIABLES[A]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
						Tolerance	*VIF*	*Minimum Tolerance*
2	X2	.166[b]	1.239	.228	.255	.064	15.587	.054
a. Dependent Variable: Y								
b. Predictors in the Model: (Constant), X3, X1								

This section discusses the process of eliminating independent variables that are not feasible to be included in the regression model. Elimination is based on the amount t observed. In model 1, the independent variable with the smallest t observed is sought, the anaerobic capacity is obtained (, then the anaerobic is excluded. And so on until two independent variables are obtained (model 2) which are excluded from the regression model.

IV. CONCLUSIONS

- The relationship between performance rowing 2000 meters with independent variables, sorted from the largest to the smallest shows: aerobic capacity = 0.976, muscle Power = 0.950 and anaerobic capacity = 0.937. This shows that there is a strong correlation between aerobic capacity, muscle power and anaerobic capacity (the correlation between variables is above 0.5). This indicates the existence of multicollinearity, or the correlation between the three independent variables.
- The backward method starts with entering all variables (see Model 1 which has ENTER information). Then the analysis is done and variables that are not feasible to enter in the regression are eliminated one by one. Model 2 states that the variable removed is X2 (Anaerobic Capacity). Thus, after passing 2 stages, the independent variables that are feasible to be included in the regression model are the Aerobic capacity and Muscle Power.
- As much as 97.1% of the variation in performance rowing 2000 meters can be explained by the aerobics capacity and muscle power. While the rest (100% - 97.1% = 2.9%) is explained by other reasons.
- The Sig / significance is 0,000, or the probability is far below 0.05, so Ho is rejected, or the regression coefficient is significant, or the capacity of aerobics and muscle power really has a significant effect and can be a predictor of 200-meter rowing.

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