Japan Society of Exercise and Sports Physiology

Anthropometric and Physiological Factors Predicting 2000 m Rowing Ergometer Performance Time

Chie YOSHIGA[1], Yasuo KAWAKAMI[2], Tetsuo FUKUNAGA[2], Kohji OKAMURA[3] and Mitsuru HIGUCHI[4]

[1]*Graduate School of Education, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0013, Japan*
[2]*Graduate School of Arts and Science, The University of Tokyo, Multi-Disciplinary Sciences, Life Science, 3-8-1, Komaba, Meguro-ku, Tokyo 153-8902, Japan*
[3]*Saga Research Inst., Otsuka Pharmaceutical Co., Higashiyama, Ohmagari, Higashisefuri-son, Kanzaki-gun, Saga 842-0195, Japan*
[4]*Laboratory for Health Evaluation, National Institute of Health and Nutrition, 1-23-1, Toyama, Shinjuku-ku, Tokyo 162-8636, Japan*

Abstract

YOSHIGA, C., KAWAKAMI, Y., FUKUNAGA, T., OKAMURA, K. and HIGUCHI, M., Anthropometric and Physiological Factors Predicting 2000 m Rowing Ergometer Performance Time. Adv. Exerc. Sports Physiol., Vol.6, No.2 pp.51-57, 2000. In attempt to predict 2000 m rowing ergometer performance time, we studied anthropometric and physiological limiting factors among 78 collegiate male rowers. Among variables that we measured, 2000 m rowing performance time was significantly and inversely related to lean body mass ($r = -0.68$), maximal oxygen uptake (-0.64), and leg extension power (-0.54) ($p < 0.001$), respectively. Furthermore, stepwise multiple regression analysis indicated that lean body mass, maximal oxygen uptake, and leg extension power were selected as the explanatory variables in the order of strength of a standardized partial regression coefficient. Subsequently, we developed single and multiple linear regression models to predict 2000 m rowing performance time applying Ridge regression analysis to the multiple regression analysis. The multiple model using three explanatory variables: 2000 m- rowing ergometer performance time (sec) $= 559.45 - 1.04 \times$ LBM (kg) $- 12.85 \times VO_{2max}$ ($l \cdot min^{-1}$) $- 0.0067 \times$ leg extension power (W) was the most accurate model in the present study. The findings of the present study suggest that the three most important factors predicting successful rowing are lean body mass, maximal oxygen uptake, and leg extension power. Our findings would help rowers and coaches to identify their potential talents and to construct highly focused training programs.

Key words: lean body mass, maximal oxygen uptake, leg extension power

Introduction

Elite rowers have shown to have the highest maximal aerobic capacities of all athletes (1, 3, 4, 7, 9), when they are expressed in absolute units. Among elite rowers higher maximal oxygen uptake in a variety of exercise manner is associated with the better rowing performance. Additionally, isokinetic knee extension strength as well as strength measured in a simulated rowing position have been correlated with rowing ergometer performance (20, 21, 23).

In recent years, the development of models based on laboratory data has gathered attention because it has practical importance for talent identification and for the development and assessment of activity-specific training programs. In addition, performance prediction modeling could help us understand the physiological characteristics of a sport activity. Performance prediction models have been successfully developed for road cycling (5, 16), track cycling (6), and distance running (19) using both anthropometric and physiological variables. However, so far only one multiple regression analysis was applied to develop prediction equations to predict 2000 m rowing ergometer performance time using anthropometric, metabolic and strength variables (21).

The present study, therefore, was conducted: 1) to identify the effects of anthropometric and physiological variables on the maximal rowing performance of rowers, 2) to develop single linear regression models to easily and feasibly predict a 2000 m rowing performance time on the rowing ergometer, and 3) to develop a multiple linear regression model that provides both rowers and coaches a more accurate prediction of a rowing performance time such that it allows them to assess their potential talents and to make training programs success.

Address for correspondence: Mitsuru HIGUCHI
Laboratory for Health Evaluation, National Institute of Health and Nutrition, 1-23-1, Toyama, Shinjuku-ku, Tokyo, 162-8636, Japan.
e-mail: mhiguchi@nih.go.jp

Subjects and Methods

Subjects.

Seventy-eight collegiate male rowers participated in the present study [age 20±1 yrs,

NII-Electronic Library Service

Japan Society of Exercise and Sports Physiology

height 176±5 cm, body weight (BW) 69±6 kg]. All subjects were informed of the design and possible risks of the study before providing written informed consent to participate in the experiments as approved by the Ethical Committee of the National Institute of Health and Nutrition. None of the subjects had any diseases or injury in the three weeks prior to the experiment, nor were taking any medication. No vigorous exercise was allowed on the experimental day prior to the testing.

Body composition.

Height was measured to the nearest milimeter. BW (kg) was measured to the nearest 0.01 kg on the calibrated electronic scale. Body density was calculated as $D_{b(BP)} = BW/V_{b(BP)}$ where $D_{b(BP)}$ is body density and $V_{b(BP)}$ is body volume determined by the BOD POD system (Life Measurement Instruments, Concord, CA) (8, 18), and percent body fat (%) was derived using the Brozek formula (2). And then lean body mass (kg; LBM) was calculated.

Maximal oxygen uptake.

All subjects completed a progressive running test (22) on a treadmill to determine their VO_{2max}. The test was terminated when the subjects were unable to continue because of exhaustion. The following criteria for obtaining VO_{2max} were used: (1) a plateau in VO_2 against work load, or (2) respiratory exchange ratio (R) exceeding 1.0, (3) an age-predicted maximal heart rate (HR), and (4) the rating of perceived exertion (RPE) of 19 or 20.

The initial speed was set at 160 $m \cdot min^{-1}$ or 180 $m \cdot min^{-1}$ for 2 min and then increased by 20 $m \cdot min^{-1}$ every 2 min. The incline was set at 3.0 degrees (13). The expired gases were collected in Douglas bags during the last 1 min of each stage. The volume of the expired gases was measured with a dry gas meter (Shinagawa Seiki Co., Tokyo, JAPAN). The oxygen (O_2) and carbon dioxide (CO_2) content of the collected gases was analyzed using the Respiromonitor RM-300*i* (Minato medical science Co., Tokyo, JAPAN).

The HR was monitored continuously by an electrocardiogram (Nihon Kohden Co., Tokyo, JAPAN) as a safety and check. The RPE was also recorded every 2 min.

Leg extension power.

As a measure of muscular power in the lower limbs, the maximal bilateral leg extension power was determined by an isokinetic dynamometer Anaeropress 3500 (Combi Co., Tokyo, JAPAN). The apparatus is developed for measuring the explosive power of the leg in extension and was found to be reliable and validity (14) in subjects of both sexes. Briefly, the subjects sit on the seat and press their feet on the plate as hard as they can in a horizontal direction until the legs are fully extended. The body weight of each subject is used as a resistance.

Rowing performance.

On a separated day, a 2000 m rowing all out test was performed on a wind resistance braked rowing ergometer (Concept II model C, Morrisville, VT, USA). After a 5-min warm-up period, subjects rested for 3 min. From a "standing start", each rower began to row the first 10 strokes with maximal effort at a cadence of 40 strokes$\cdot min^{-1}$. The stroke count was then reduced to approximately 34 to 36 stroke$\cdot min^{-1}$ until the last 250 m of the test. Each rower increased the stroke rating to 40 to 42 stroke$\cdot min^{-1}$ for the final sprint. All rowers simulated competitive rowing on Concept II rowing machine and did their best in order to elicit their best time.

Analyses.

Pearson product-moment correlation coefficients were generated between each of the explanatory variables and criterion variable 2000 m rowing ergometer performance time (sec). The explanatory variables included height (cm), BW (kg), body fat (%), LBM (kg), VO_{2max} ($l \cdot min^{-1}$, $ml \cdot kg\ (BW)^{-1} \cdot min^{-1}$, $ml \cdot kg\ (LBM)^{-1} \cdot min^{-1}$), leg extension power (W, $W \cdot kg\ (BW)^{-1}$, $W \cdot kg\ (LBM)^{-1}$). Stepwise multiple regression analysis was conducted using the explanatory variables to select the better explanatory variables. Subsequently, single as well as multiple linear regression analysis was performed to predict 2000 m rowing ergometer performance time. Ridge regression analysis was applied to the multiple regression analysis, and the correlation matrix was standardized again. The multiple correlation coefficients adjusted for the degrees of freedom were used to assess the proportion of each of the explanatory variables. The adjusted multiple correlation coefficients consider both the number of explanatory variables and the sample size, resulting in a shrinkage multiple correlation coefficient which is approximately corrected the upward bias of the correlation coefficients, thus providing a more accurate estimate of the goodness-of-fit of the each prediction models.

Standard error of estimate (SEM) for each model was calculated to assess the accuracy of prediction. Significance was set at $p \leqq 0.05$. All data were expressed as means±standard deviation (SD).

NII-Electronic Library Service

Japan Society of Exercise and Sports Physiology

Analyses of the data were performed using a STATISTICA statistical package.

Results

Correlation between 2000 m rowing ergometer performance time and physiological variables (Table 1).

Among anthropometric variables, LBM was most strongly correlated with 2000 m rowing ergometer performance time (Fig. 1a). BW and height were also strongly correlated with 2000 m rowing ergometer performance. Among VO_{2max} variables, absolute VO_{2max} expressed in $l \cdot min^{-1}$ was most strongly correlated with 2000 m rowing ergometer performance time (Fig. 1b). However, no correlation with 2000 m rowing performance time was observed in VO_{2max} expressed in $ml \cdot kg\ (BW)^{-1} \cdot min^{-1}$ or $ml \cdot kg\ (LBM)^{-1} \cdot min^{-1}$. Among leg extension power variables, absolute leg extension power (W) was most strongly, significantly correlated with 2000 m rowing ergometer performance time (Fig. 1c). However, no correlation with 2000 m rowing performance time was observed in leg extension power expressed in $W \cdot kg\ (BW)^{-1}$ or $W \cdot kg\ (LBM)^{-1}$.

The accuracy of prediction (Table 2).

Prediction of the 2000 m rowing ergometer performance time using "LBM (kg)" ($r^2 = 0.46$, SEM =

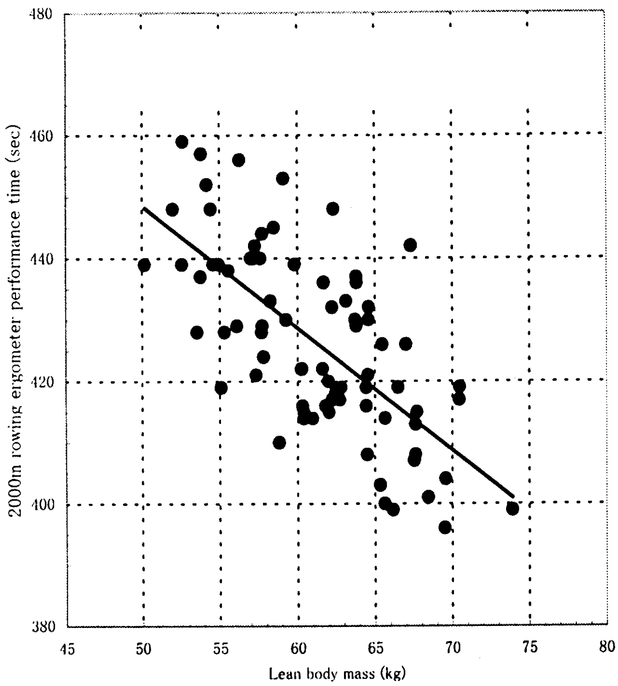

Fig. 1a The regression of 2000 m rowing ergometer performance time on LBM (kg) for 78 male rowers. Single linear regression model: 2000 m rowing performance ergometer time (sec) = 548 − 1.99 × LBM (kg), r = −0.68, p<0.001. Standard error of estimate = 11.0 sec.

Table 1 Anthropometric characteristics, maximal oxygen uptake, leg power and 2000 m rowing ergometer performance time for 78 male rowers, and correlatiens with 2000 m rowing ergometer performance time.

Variables (unit)	Means ± SD	Range	Correlation with 2000 m rowing ergometer performance time
Height			
(cm)	176.3 ± 4.7	168.1 − 188.9	−0.35*
Weight			
(kg)	69.3 ± 5.8	58.1 − 84.1	−0.66**
Body fat			
(%)	11.7 ± 3.6	5.4 − 25.3	0.05
Lean body mass (LBM)			
(kg)	61.2 ± 5.1	50.2 − 74.7	−0.68**
Maximal oxygen uptake (VO_{2max})			
($l \cdot min^{-1}$)	4.23 ± 0.34	3.34 − 5.00	−0.64**
($ml \cdot kg\ (BW) \cdot min^{-1}$)	61.1 ± 3.9	51.8 − 70.7	0.06
($ml \cdot kg\ (LBM) \cdot min^{-1}$)	69.3 ± 4.7	57.5 − 79.6	0.08
Leg extension power			
(W)	2300 ± 379	1517 − 3198	−0.52**
($W \cdot kg\ (BW)^{-1}$)	33.2 ± 4.8	23.5 − 46.5	−0.21
($W \cdot kg\ (LBM)^{-1}$)	37.6 ± 5.1	25.7 − 51.2	−0.21
The 2000 m rowing ergometer performance time			
(sec)	426.3 ± 14.9	396 − 459	

*P<0.01 **P<0.001

NII-Electronic Library Service

Japan Society of Exercise and Sports Physiology

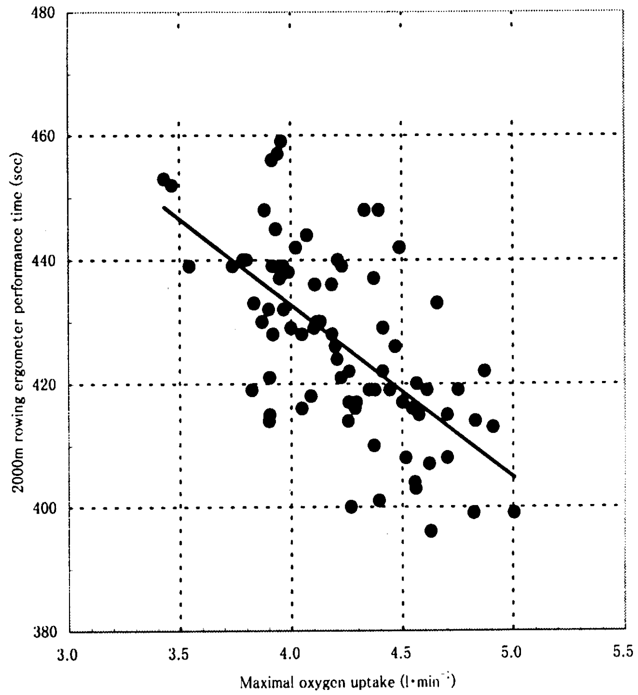

Fig. 1b The regression of 2000 m rowing ergometer performance time on VO_{2max} ($l \cdot min^{-1}$) for 78 male rowers. Single linear regression model: 2000 m rowing performance ergometer time (sec) $= 574 - 27.2 \times VO_{2max}$ ($l \cdot min^{-1}$), $r = -0.64$, $p < 0.001$. Standard error of estimate $= 11.6$ sec.

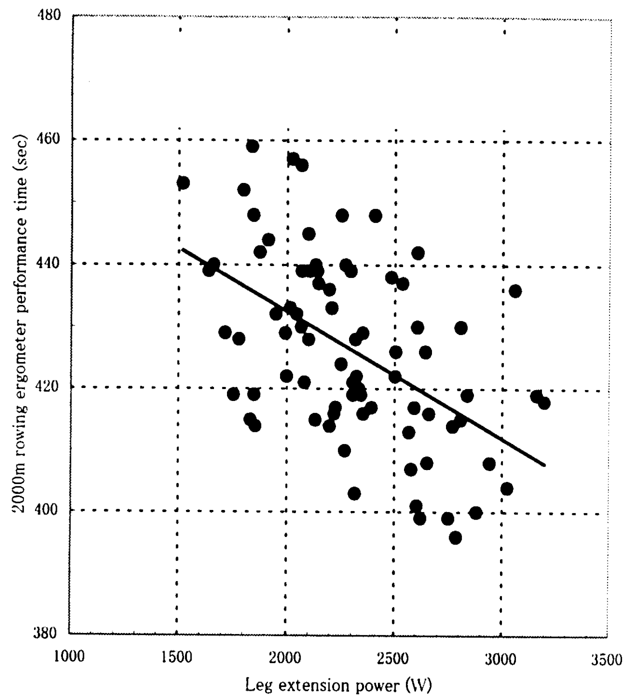

Fig. 1c The regression of 2000 m rowing ergometer performance time on leg extension power (W) for 78 male rowers. Single linear regression model: 2000 m rowing ergometer performance time (sec) $= 473 - 0.0205 \times$ leg extension power (W), $r = -0.52$, $p < 0.001$. Standard error of estimate $= 12.9$ sec.

Table 2 Criterion variable, regression coefficients, explanatory variables, constant terms, correlation coefficients, adjusted correlation coefficients, coefficient of determinations, adjusted coefficint of determinations, and standard error of estimations on single linear regression models and multiple linear regression model for 78 male rowers.

Criterion variable	Explanatory variable		Regression coefficient	Constant term (sec)	Correlation coefficient r	Adjusted correlation coefficient r	Coefficient of determination r^2	Adjusted coefficient of determination r^2	Standard error of estimate (sec)
⟨a single linear regresson model⟩									
2000 m rowing ergometer time (sec)	LBM	(kg)	− 1.99	548	-0.68^{**}		0.46		11.0
	VO_{2max}	($l \cdot min^{-1}$)	−27.2	574	-0.64^{**}		0.41		11.6
	Leg power	(W)	− 0.021	473	-0.52^{**}		0.27		12.8
⟨a multiple linear regression model⟩									
2000 m rowing ergometer time (sec)	LBM	(kg)	− 1.24						
	VO_{2max}	($l \cdot min^{-1}$)	−14.1	562		-0.69^{**}		0.48	10.8
	LBM	(kg)	− 1.50						
	Leg power	(W)	− 0.008	537		-0.67^{**}		0.44	11.2
	VO_{2max}	($l \cdot min^{-1}$)	−20.2						
	Leg power	(W)	− 0.11	537		-0.65^{**}		0.43	11.3
	LBM	(kg)	− 1.04						
	VO_{2max}	($l \cdot min^{-1}$)	−12.9						
	Leg power	(W)	− 0.007	559		-0.71^{**}		0.50	10.6

$^{**}P < 0.001$

NII-Electronic Library Service

Japan Society of Exercise and Sports Physiology

11.02 sec) was more accurate than that using "VO_{2max} ($l \cdot min^{-1}$)" ($r^2=0.41$, SEM = 11.59 sec) or "leg extension power (W)" ($r^2=0.27$, SEM = 12.87 sec).

Stepwise multiple regression analysis indicated that LBM (kg), VO_{2max} ($l \cdot min^{-1}$), and leg extension power (W) were selected as the explanatory variables in the order of strength of a standardized partial regression coefficient. The other variables were rejected at the criterion for significance 0.05.

The 2000 m rowing ergometer performance time predicted using two explanatory variables "LBM (kg)" and "VO_{2max} ($l \cdot min^{-1}$)" ($r^2=0.48$, SEM = 10.78 sec) was more accurate than those predicted using one explanatory variable (Fig. 2). However, the 2000 m rowing ergometer performance time predicted using "lean body mass (kg)" and "leg extension power (W)" ($r^2=0.44$, SEM = 11.15 sec) or that predicted using "VO_{2max} ($l \cdot min^{-1}$)" and "leg extension power (W)" ($r^2=0.47$, SEM = 11.00 sec) was less accurate than those predicted using only "LBM (kg)".

Finally, the highest linear adjusted coefficient of determination was obtained in multiple linear regression model using three explanatory variables "LBM (kg)", "VO_{2max} ($l \cdot min^{-1}$)" and "leg extension power (W)" ($r^2=0.49$, SEM = 10.60 sec). The prediction equation for 2000 m rowing ergometer performance time (sec) was $559.45-1.04 \times \text{LBM}$ (kg) $-12.85 \times VO_{2max}$ ($l \cdot min^{-1}$) $-0.0067 \times$ leg extension power (W) and the power of prediction is -0.71 ($p<0.001$).

Discussion

A major finding of the current study was four-fold. First, among anthropometric variables, LBM had the highest correlation ($r=-0.68$, $p<0.001$) and BW had the second highest correlation with 2000 m rowing performance time ($r=-0.66$, $p<0.001$). A previous study (21) had reported that BW correlated with 2000 m rowing ergometer performance time ($r=-0.41$, $p<0.05$, $n=19$). The results in the present study confirm that the heavier a rower is, the faster he can row a boat. Especially, the more LBM in a rower is associated with the greater performance in a rowing ergometer.

Second, VO_{2max} ($l \cdot min^{-1}$) had a strong and significant relation with 2000 m rowing ergometer per-

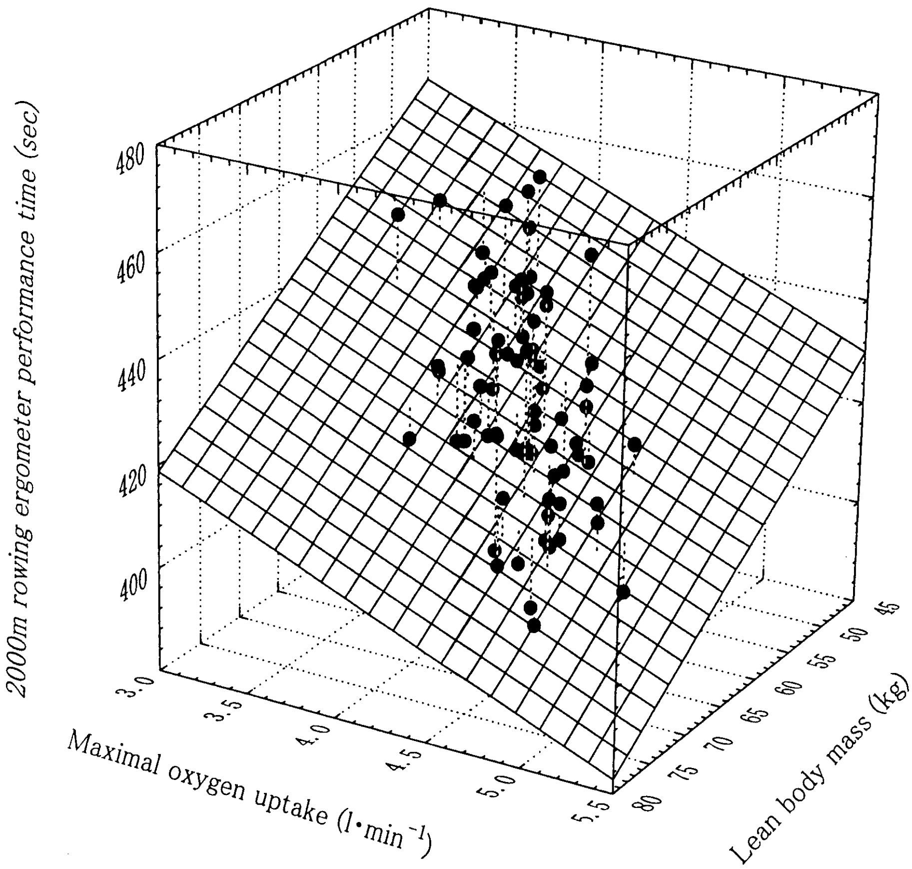

Fig. 2 The multiple regression of 2000 m rowing ergometer performance time on LBM (kg) and VO_{2max} ($l \cdot min^{-1}$) for 78 male rowers. Multiple linear regression model: 2000 m rowing ergometer performance time (sec) $=559-1.24 \times \text{LBM}$ (kg) $-14.1 \times VO_{2max}$ ($l \cdot min^{-1}$), $r=-0.69$, $p<0.001$. Standard error of estimate = 10.8 sec.

NII-Electronic Library Service

Japan Society of Exercise and Sports Physiology

formance time ($r = -0.64$, $p<0.001$). The mean of VO_{2max} (ml·kg (BW)$^{-1}$·min^{-1}) in this study is similar to that reported in previous studies (11, 12, 17). The VO_{2max} of rowers was mainly due to their large body dimension (24). When the VO_{2max} was expressed per BW or related to BW to the power 2/3, the smaller and less successful rowers showed similar or slightly larger values (26). Also, we could not find any significant relation between VO_{2max} (ml·kg (BW)$^{-1}$·min^{-1}) and 2000 m performance time ($r=0.06$).

The first and second findings suggest that what rowing performance demands to all rowers to be a successful rower is not relative VO_{2max} (ml·kg (BW)$^{-1}$·min^{-1}) but absolute VO_{2max} (l·min^{-1}) and LBM. We can suggest that it is not good to devote training time to elevating only VO_{2max} (ml·kg (BW)$^{-1}$·min^{-1}) without resistance training to raise LBM.

Third, leg extension power (W) was found to have significant correlation with 2000 m rowing ergometer performance time ($r = -0.52$, $p<0.001$). Although peak force during competitive rowing are not very high when compared to those in other sports such as explosive sports or sprint sports, the force must be maintained at a high level for about 200 strokes to compete successfully over 2000 m (10). At racing speed, the force applied to the oar was measured and the best oarsman developed the peak force varied between 700 N (71.43 kg) and 900 N (91.84 kg) (15). Our present findings are consistent with some previous studies that suggested that isokinetic knee extensor strength have significant correlation with rowing ergometer performance (20, 21). And isometric knee extension strength also correlated with rowing ergometer performance (28). Taken together these previous results and its present data suggested that muscular power in the leg is an important factor for the success in rowing.

Finally, we developed the prediction model of maximal physiological variables and variables so as to allow rowers and coaches to predict 2000 m rowing ergometer performance time and to identify potentially talent rowers and to develop and assess the training programs. In previous study (26), a direct relationship between placing in an international championship regatta and the average VO_{2max} (l·min^{-1}) of a crew has been established and it was reported that the average VO_{2max} (l·min^{-1}) for the first place was 6.11 (l·min^{-1}) and that for the 13th place was 5.10 (l·min^{-1}). Although the power of prediction model using a explanatory variable "VO_{2max} (l·min^{-1})" in the present study was lower than that in the previous study (26), our results have supported the previous result. Although the subjects in this study were lighter and had lower performance than those of the previous study (26), we can clarify the anthropometric, physiological variables of Japanese male collegiate rowers. This study is the first study that measured anthropometric and physiological variables on such a large number of Japanese male rowers. Thus, we believe that our study would give necessary information for coaches and rowers to consider which direction they should select so as to attain to their each goal.

Russell et al. (21) measured anthropometric, metabolic, and strength and reported that the model using only anthropometric variables; sum of skinfolds, height, and BW predict better than the multiple model. In this study, we developed two multiple models using two variables from different categories, that is, from anthropometric category and physiological category, that could more accurately predict 2000 m rowing ergometer performance time than the multiple model using two variables from one category. The discrepancy between the present study and Russel et al may be that we measured body fat (%) and LBM (kg) using the BOD POD while Russel et al. (21) measured a skinfolds but did not report body fat (%) or LBM (kg).

Furthermore, we developed one multiple linear regression model using three explanatory variables after we selected the explanatory variables using stepwise regression analysis. The findings of the present study suggest that rowing exercise requires both anthropometric and physiological variables, especially LBM (kg), VO_{2max} (l·min^{-1}), and leg extension power (W).

Physiologically, the present finding of the association between the higher VO_{2max} (l·min^{-1}) and the better performance confirm the findings of previous results (27). The relative energy contribution from aerobic metabolism is 70–80 % during rowing 2000 m and the remaining energy is supplied by anaerobic metabolism (27). And the existence of correlation between LBM (kg) and 2000 m rowing ergometer performance time is reasonable considering that the VO_{2max} (l·min^{-1}) of rowers was mainly due to their large body dimension (24). The finding of the relation between the stronger leg extension and rowing performance is expected because high levels of leg strength are necessary to overcome water resistance or resistance of rowing ergometer during the drive phase of the stroke. Because leg drive is an initiator of each stroke, leg strength is required to maintain power through the duration of the exercise bout.

In conclusion, we determined the effects of

NII-Electronic Library Service

Japan Society of Exercise and Sports Physiology

anthropometric and physiological limiting factors that predict 2000 m rowing ergometer performance time and attempted to develop prediction models that coaches and rowers can apply for the assessment of their potential talent and for constructing successful training programs. The results of this study suggested that LBM (kg), VO_{2max} ($l \cdot min^{-1}$), and leg extension power (W) significantly and inversely correlated with 2000 m rowing ergometer performance time. Thus, the findings of the current study suggest that it is necessary for rowers who want to become successful rowers to emphasize their training program that increases LBM, VO_{2max}, and leg extension power.

Acknowledgement

This work was supported partly by the Research Grant of Human Science Foundation, No.21121 (PI: M. Higuchi) and a grant from the Japan Olympic Committee (PI: T. Fukunaga).

The authors thank Dr. Hirofumi Tanaka (University of Colorado, Boulder, Colorado, USA) for the generous suggestions and help in editing the English of the manuscript.

References

1) Bouckaert J, Pannier J L, and Vrijens J (1983) Cardiorespiratory response to bicycle and rowing ergometer exercise in oarsmen. Eur. J. Appl. Phyisol. 51: 51-59.
2) Brozek J, Grand J, Anderson J T, and Keys A (1963) Densitometric analysis of body composition: revision of some quantitative assumptions. Ann NY Acad Sci 110: 113-140.
3) Caley P, Stensland M, and Hartley L H (1974) Comparison of oxygen uptake during maximal work on the treadmill and the rowing ergometer. Med. Sci. Sports 6: 101-103.
4) Clark J M, Hagerman F C, and Gelfand R (1983) Breathing patterns during submaximal and maximal exercise in elite oarsmen. J. Appl. Physiol. 55: 440-446.
5) Coyle E E, Coggan A R, Hooper M K, and Walters T J (1988) Determinations of endurance in well-trained cyclists. J. Appl. Physiol. 64: 2622-2630.
6) Crang N P, Norton K I, Bourdon P C, Woolford, S M, Stanef T, Squires B, Olds T S, Conyers R A, and Walsh C B V (1993) Aerobic and anaerobic indices contributing to track endurance cycling performance. Eur. J. Appl. Physiol. 67: 150-158.
7) Cunningham D A, Goode P B, Critz J B (1975) Cardiorespiratory response to exercise on a rowing and bicycle ergometer. Med. Sci. Sports Exerc. 7: 37-43.
8) Dempster P and Aitkens S (1995) A new displacement method for the determination of human body composition. Med. Sci. Sports Exerc. 27: 1692-1697.
9) di Prampero P E, Cortili G, Celentano F, and Cerretelli P (1971) Physiological aspects of rowing. J. Appl. Physiol. 31: 853-857.
10) Hagerman F C (1994) Physiology and Nutrition for Rowing. In: Physiology and Nutrition for Competitive Sport: Perspectives in Exercise Science and Sports Medicine. Lamb D R, Knuttgen H G, and Muray R (Eds.). Vol.7: 221-302.
11) Hagerman F C, McKirnan M D (1975) Maximal oxygen consumption of conditioned and unconditioned oarsmen. J. Sports Med. 15: 43-48.
12) Hagerman F C and Staron R S (1983) Seasonal variations among physiological variables in elite oarsmen. Can. J. Appl. Sport. Sci. 8: 143-148.
13) Harmansen L and Saltin B (1969) Oxygen uptake during maximal treadmill and bicycle exercise. J. Appl. Physiol. 26: 31-37.
14) Hirano Y, Noguchi K and Miyashita M (1994) The explosive leg extensor power output and its evaluation with function of sex and age. (Abstract in English) Jpn. J. Phys. Fitness Sports Med. 43: 113-120.
15) Ishiko T (1968) Application for telemetry to sports activities. In Biomechanics I. 138-146.
16) Kerbs P S, Zinkgraf S, and Virgilio S J (1986) Predicting competitive bicycling performance with training and physiological variables. J. Sports Med. 26: 323-330.
17) Mahler D A, Andrea B E, and Ward J L (1987) Comparison of exercise performance on rowing and cycle ergometer. Res. Q. Exerc. Sports 58: 41-46.
18) McCrory M A, Gomez T D, Bernauer E M, and Mole P A (1995) Evaluation of a new air displacement plethysmograph for measuring human body composition. Med. Sci. Sports Exerc. 27: 1686-1691.
19) Morgan D W, Baldini F D, Martin P E, and Kohrt W M (1989) Ten kilometer performance and predicted velocity at VO_{2max} among well-trained male runners. Med. Sci. Sports Exerc. 14: 440-444.
20) Pyke F S, Minikin B R, Woodman L R, Roberts A D, and Wright T G (1979) Isokinetic strength and maximal oxygen uptake. Can. J. Appl. Sports Sci. 4: 277-279.
21) Russell A P, Le Rossingnol P F, and Sparrow W A (1998) Prediction of elite schoolboy 2000 m- rowing ergometer performance from metabolic, anthropometric and strength variables. J. Sports Sci. 16: 749-754.
22) Saltin B and Åstrand P-O (1967) Oxygen uptake in athletes. J Appl Physiol 23: 353-358.
23) Secher N H (1975) Isometric rowing strength of experienced oarsmen. Med. Sci. in Sports. 7: 280-283.
24) Secher N H (1983) The physiology of rowing. J. Sports Sci. 1: 23-53.
25) Secher N H, Rube N, and Elers J (1988) Strength of two legs and one leg extension in man. Acta. Physiol. Scand. 134: 333-339.
26) Secher N H, Vaage O, and Jackson R C (1982) Rowing performance and maximal aerobic power in oarsman. Scand. J. Sports Sci. 4: 9-11.
27) Steinacker J M (1993) Physiological aspect of rowing training. Int. J. Sports Med. 14: S3-S10.
28) Yamakawa J and Ishiko T (1966) Standardization of physical fitness test for oarsmen. In *Proceeding of the International Congress on Sports Sciences* (Edited by Kato K). Tokyo: Japanese Union of Sports Science. 435-436.

(Received 14 February 2000, and in revised from 10 May 2000, accepted 1 June 2000)

NII-Electronic Library Service