Def Sci J, Vol 40, No. 3, July 1990, pp 293-298

Regression Models for Estimation of Maximal Aerobic Power in Man

S.S. Verma and J. Sen Gupta

Defence Institute of Physiology and Allied Sciences, Delhi Cantt–110 010

ABSTRACT

Regression models have been proposed by various workers for predicting physical work capacity of man. This paper reviews critically the applications of these models for indirect estimation of maximal aerobic power in man, which is the best single physiological index for the assessment of work performance capacity of man.

1. INTRODUCTION

Maximal aerobic power ($\dot{V}O_2$ max) of an individual is perhaps the single most valid physiological measure of the functional capacity of cardiorespiratory system to perform strenuous physical work. Direct estimation of $\dot{V}O_2$ max of an individual is time-consuming and needs well-equipped laboratory with trained staff. Moreover, the exertion required to attain $\dot{V}O_2$ max needs motivation and cooperation from the subject and may be hazardous to the health and well-being of older individuals. Considerable attempts have, therefore, been made for indirect estimation of VO_2 max from heart rate measured at submaximal work loads using simple linear regression models[1-6]. Respiratory exchange ratio was also used as concomitant variable by Issekutz *et al.*[7] for estimation of $\dot{V}O_2$ max. A simple multiple regression model was developed by Jessup *et al.*[8] for predicting $\dot{V}O_2$ max by using Åstrand-Ryhming test, 12 minutes run and some anthropometric measurements as concomitant variables. The main object of the present paper is to review critically the applications of these regression models for indirect estimation of $\dot{V}O_2$ max in men.

Received 29 July 1988, revised 3 October 1989.

2. REGRESSION MODELS

Regression models, both linear and non-linear, are of fundamental importance for solving practical problems related to different branches of physiology and other biomedical sciences.

2.1 Linear Regression Models

Åstrand and Ryhming[1] developed a simple linear regression model for estimation of VO_2 max from the heart rate (HR) measured at submaximal work loads. The method suggested by Maritz *et al.*[3] by extrapolation of the value of oxygen consumption for maximal value of HR using a simple regression model between oxygen consumption and HR relationship at submaximal exercises was of practical applicability. Similar models were also developed by other research workers[2,4-6,9,10].

Multiple linear regression models are more efficient and accurate than the simple linear regression models. In view of this, Mastropaolo[11] developed a multiple linear regression model for $\dot{V}O_2$ max using respiratory exchange ratio (*R*), work rate (*WR*), diastolic blood pressure (*BPd*), expired volume (*VE, BTPS*, l/min) and expired O_2 (FEO_2) as concomitant variables. This model was developed on the basis of data collected on 13 middle aged men with $\dot{V}O_2$ max ranging from 2.03 to 3.25 l/min (mean 2.62). The multiple correlation was 0.93 ($R^2 = 0.86$) and the standard error of the estimate was 0.172 l/min. Thus it was suggested that multiple linear regression model developed for middle aged men from FEO_2, *R*, *VE*. HR, *BPS*, *BPd* and *WR* may predict $\dot{V}O_2$ max significantly better than simple regression models using HR. Hermiston and Faulkner[12] have also pointed out that maximal oxygen uptake cannot be predicted with precision from the HR measured during submaximal work using simple linear regression model. They have used a stepwise multiple regression technique to develop suitable multiple linear regression models for the prediction of maximal oxygen uptake of physically active and physically inactive men. The data has been collected during a submaximal treadmill walk. The most accurate prediction for physically active men was obtained from a regression model which inculded the subject's age, fat-free weight, HR, fraction of carbondioxide in expired gas, and tidal volume at a submaximal work level, in addition to the rate of change of the respiratory exchange ratio. For the physically inactive men, the most accurate prediction model included age, fat-free weight, respiratory exchange ratio and tidal volume at a submaximal work level. The coefficient of correlation was 0.91 ($R^2 = 0.82$) between predicted maximal oxygen uptake measured on two different occasions and 0.90 ($R^2 = 0.81$) between observed and predicted maximal oxygen uptake. Jessup *et al.*[8] obtained multiple correlation of the order of 0.814 ($R^2 = 0.663$) by the method proposed by them (Table 1).

Verma *et al.*[13] developed a multiple linear regression model for estimating $\dot{V}O_2$ max from anthropometric measurements. This model was evolved by examining the possible relationship of $\dot{V}O_2$ max with 27 anthropometric variables using stepwise linear regression analysis. Four variables namely, stature, body weight, elbow width and juxta nipple skinfold thickness were found to be significant predictors of $\dot{V}O_2$ max and accounted for 34.9 per cent of the variation in $\dot{V}O_2$ max with a multiple correlation accounted to 0.591 ($P < 0.001$). Verma *et al.*[14] have recently developed a multiple linear regression model from body weight and time for 3.2 km run. This model yielded the multiple correlation of 0.608 ($R^2 = 0.370$). Both the variables (body weight and time for 3.2 km run) were found to be significant predictors as tested by the analysis of variance technique. A second model was also established by including the exercise dyspnoeic index as a predictor variable. The multiple correlation for this model was 0.658 ($R^2 = 0.433$) indicating a significant improvement over the multiple correlation of 0.608 with two predictor variables (Table 1). The standard error of estimate of this model also decreased from 0.214 to 0.204 l/min.

2.2 Non-Linear Regression Models

The occurrence of non-linear regression models was realised due to the asymptotic nature of HR/VO_2 curve. Von Döbeln *et. al.*[15] worked out a non-linear regression model for estimating $\dot{V}O_2$ max using work load, HR and age of the subject as concomitant variables. The model gave standard error of 8.4 per cent. They validated the model on the basis of data collected on 84 male construction workers aged 30 to 70 yrs who were tested once at submaximal and maximal loads on a bicycle ergometer. Recently, Verma *et al.*[16] evolved a non-linear regression model based on the assumption that the fractional increase in aerobic stress due to work is proportional to the fractional increase in respiratory and cardiac strains respectively. The model has been validated on the experimental data of 45 subjects on three different submaximal work loads with a total of 135 observations. It has been observed that

Table 1. Regression models for estimation of maximal aerobic power

Regression model	Variables	R^2	References
Linear	Heart rate at submaximal exercise	0.58	Åstrand & Ryhming[1], Fox[2], Maritz *et al.*[3], Yuhasz[4], Margaria *et al.*[5], Wyndham[6], Asmussen & Molbeck[9], Åstrand[10]
	Respiratory quotient	0.22	Issekutz *et al.*[7]
Multiple linear	Åstrand-Ryhming test, 12 minutes run and some anthropometric measurements	0.66	Jessup *et al.*[8]
	Respiratory exchange ratio, work rate, diastolic blood pressure, expired volume, expired oxygen	0.86	Mastropaolo[11]
	Age, fat-free weight, HR, fraction of carbon-dioxide in expired gas, tidal volume at submaximal work level, rate of change of the respiratory exchange ratio	0.81	Hermiston & Faulkner[12]
	Body weight, elbow width, stature and juxtra nipple skinfold thickness	0.35	Verma *et al.*[13]
	Body weight, time for 3.2 km run	0.37	Verma *et al.*[14]
	Body weight, time for 3.2 km run and exercise dyspnoeic index	0.43	Verma *et al.*[14]
Non-linear	Cardiorespiratory strains	0.66	Verma *et al.*[16]

this model fits well with the experimental data on Indian males (Table 1). It has also been noticed that the absolute percentage variation and residual sum of squares were both lower in our model as compared to the other widely used methods.

3. DISCUSSION AND CONCLUSION

Regression models reviewed in this paper have played a significant role for indirect estimation of maximal aerobic power. The estimation of $\dot{V}O_2$ max based on the linear regression model between oxygen consumption and HR of submaximal work load was critically objected by several workers[17-19] after pointing out the serious limitations in the accuracy of prediction. The major drawback in the indirect estimation of $\dot{V}O_2$ max from HR and VO_2 data is due to the asymptotic nature of the HR/$\dot{V}O_2$ curve. The percentage error in the prediction values has been reported to be between 15 to 20 per cent and it is concluded that if an accuracy greater than $\pm$ 15 per cent is required, then $\dot{V}O_2$ max should be measured directly. In view of this limitation, Von Dobeln *et al.*[15] developed their model from work load, HR and age of the subject to improve the accuracy of prediction. Attempts had been made by Hermiston and Faulkner[12], and Mastropaolo[11] who have emphasized that the error in prediction of VO_2 max may be reduced significantly by relying on more than single cardiovascular or respiratory variables. The prediction efficiency was further improved by Verma *et al.*[16] by taking in to consideration the cardiorespiratory strains imposed on the subjects during maximal effort on bicycle ergometer.

Jessup *et al.*[8] made an attempt to predict VO_2 max from some physiological as well as anthropometric variables and obtained a multiple correlation of the order of 0.814 for their multiple regression model. Although some of the regression models based on physiological variables have achieved maximum precision, these may not be of practical utility in field situations for selecting personnel suitable for certain military services as well as sports. The multiple linear regression model suggested by Verma *et al*[13], has been considered as a simple approach in this direction because anthropometric measurements are easy to measure, non-invasive, quick and do not require the presence of a well-equipped laboratory and trained personnel in field situations. The prediction model[14] based on body weight and time for 3.2 km run is much simpler than the earlier models and may be considered more appropriate for preliminary screening of large number of personnel on the assumption of $\dot{V}O_2$ max as a measure of physical fitness. The second model[14] based on body weight, time for 3.2 km run and exercise dyspnoeic index as predictors has achieved better precision than the model based on two predictors. This requires some laboratory facility for estimating exercise dyspnoeic index. Thus various regression models described in this paper are of practical importance for preliminary screening of large number of personnel for recruitment in military services, mines, industrial work and sports, and the like.

REFERENCES

1. Åstrand, P.O. & Ryhming, I., *J. Appl. Physiol.*, **7** (1954), 218.
2. Fox, E.L., *J. Appl. Physiol.*, **35** (1973), 914.

3. Maritz, J.S., Morrison, J.P., Strydom, N.B. & Wyndham, C.H., *Ergonomics*, **4** (1961), 97.
4. Yuhasz, M.S., Doctoral dissertation, University of Illinois, Urbana, 1962.
5. Margaria, R., Aghemo, P. & Rovelli, E., *J. Appl. Physiol.*, **20** (1965), 1070.
6. Wyndham, C.H., *Canad. Med. Assoc. J.*, **96** (1967), 736.
7. Issekutz, B., Birkhead, N.C. & Rodahl, K., *J. Appl. Physiol.*, **17** (1962), 47.
8. Jessup, G.T., Tolston, H. & Terry, J.W., *Am. J. Phys. Med.*, **53** (1974), 200.
9. Asmussen, E. & Molbeck, S.V., Heller-up : Denmark, The Testing and Observation Institute of Danish National Association for Infantile Paralysis, Report 4, 1959.
10. Åstrand, P.O., *Physiol. Rev.*, **36** (1956), 307.
11. Mastropaolo, J.A., *Med. Sci. Sports*, **2** (1970), 124.
12. Hermiston, R.T. & Faulkner, J.A., *J. Appl. Physiol.*, **30** (1971), 833.
13. Verma, S.S., Bharadwaj, H. & Malhotra, M.S., *Z. Morphol. Anthropol.*, **71** (1980), 101.
14. Verma, S.S., Gupta, R.K. & Sen Gupta, J., *Eur. J. Appl. Physiol.*, **52** (1984), 336.
15. Von Döbeln, W., Åstrand, I. & Bergstrom, A., *J. Appl. Physiol.*, **22** (1967), 934.
16. Verma, S.S., Sen Gupta, J. & Malhotra, M.S., *Eur. J. Appl. Physiol.*, **36** (1977), 215.
17. Davies, C.T.M., *J. Appl. Physiol.*, **24** (1968), 700.
18. Glassford, R.G., Baycroft, G.H.Y., Sedwick, A.W. & Macnab, R.B.J., *J. Appl. Physiol.*, **29** (1965), 509.
19. Rowell, L.B., Taylor, H.L. & Wang, Y., *J. Appl. Physiol.*, **19** (1964), 919.