Defence Science Journal, Vol 43, No 3, July 1993, pp 281-284

REVIEW PAPER

Regression Models for Estimation of Human Endurance Time

S.S.Verma

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

ABSTRACT

The regression models proposed by different workers for predicting human endurance time have been reviewed critically in respect of their applications for indirect estimation of endurance time in man, which is considered as a direct measure of human endurance fitness in strenuous exercise.

1. INTRODUCTION

The endurance time of a subject may be defined as the maximum length of time taken for performing a fixed rate of work on a bicycle ergometer till exhaustion, which is taken as the moment when the subject fails to maintain the speed at the fixed value of 60 rpm[1,2]. Direct estimation of human endurance time is complicated and involves maximum exertion to the subject under investigation. Moreover, the exertion required to measure endurance time needs motivation and co-operation from the subject and may be hazardous to the health and well being of older individuals. It may be considered as a direct measure of human endurance fitness. Limited information is available on the reasonable maximal load for prolonged work. Lehman *et al*[3] assumed 2500 k cal to be available during a working day of 8 h or 5.2 k cal/min. These figures, however, do not take into account the large individual variations in physical work capacity. Müller[4], on the basis of his work pulse index (LPI), recommended an average work load of 20 per cent of maximum oxygen uptake capacity for an 8 h work schedule. Bink[5] and Bonjer[6,7] developed a regression model based on allowable energy expenditure and working time and suggested that about 33 per cent of maximal aerobic power can be sustained for 9 h. The corresponding figures for an 8 h work schedule, as obtained by Michael *et al*[8] and Åstrand[9] are 35 and 40 per cent repectively. A nonlinear regression model was developed by Sen Gupta *et al*[10] for estimation of human endurance time from exercise dyspnoeic index. In this paper, the application of these regression models for indirect estimation of endurance time in man is reviewed critically.

2. REGRESSION MODELS

Regression models, both linear and nonlinear, have played a major role in the solution of practical problems related to different branches of physiology and other biomedical sciences.

Bink[5] and Bonjer[6,7] proposed a nonlinear regression model for estimating endurance time from work load. This model reduces to a linear regression model bas on endurance time and work load after logarithmic transformation of both the variables. According to this model, the endurance time in any physical effort can be predicted for any individual from a knowledge of his aerobic capacity and the work load. Actual calculations using this model indicate that 36 per cent of the maximum aerobic capacity can be endured for an 8 h period, 50 per cent for 2 h 40 min and 100 per cent for 4.5 min. These workers also concluded that a heart rate of 140 beats/min could not be maintained for more than 4 h or a rate of 160 beats/min for more than 2 h without extreme fatigue. Glesser and Vogel[11] also derived a similar model on the basis of data obtained for eight subjects of an average fitness both before and after 4 weeks of physical training. Training has been shown to

Received 1 September 1992

affect the constants of the equation significantly, despite the fact that work load was expressed relative to the individual maximal aerobic power, which is by itself a measure of the degree of training.

Sen Gupta *et al*[1] derived a nonlinear regression model for estimation of endurance time from cardiorespiratory strains imposed on a subject during endurance effort. This model was based on the assumption that fractional increase in endurance time is proportional to the fractional decrease in cardiorespiratory strains imposed on the subject during endurance effort. The validity of the model was tested on the basis of experimental data for 13 subjects endurance time ranging from 6 to 31 min at different work rates. The multiple correlation between observed and estimated endurance time expressed in logarithm was 0.965 (R^2 = 0.93). There was a significant increase in multiple correlation over the product moment correlations of endurance time with respiratory and cardiac strains separately expressed in logarithm, indicating the superiority of the model based on the combination of cardiorespiratory strains for predicting endurance time.

Gross-Lordemann and Müller[12], on the other hand, suggested a general nonlinear regression model for estimating endurance time (T) from work load (W) which is equivalent to a linear regression model based on log (T) and log (W). Tornvall[13] also used a similar regression model from his studies on capacity for short and prolonged work. However, he related his results with the maximum work rate that could be sustained for 6 min instead of aerobic capacity. None of the above two types of models has been found to be valid over the range of endurance time (1-120 min).

Thus, Sen Gupta *et al*[14] developed a nonlinear regression model for the estimation of endurance time from aerobic-anaerobic fractions of total oxygen utilization. The model was validated on the basis of experimental data for 13 subjects and on the data for single subject reported by Åstrand and Rodahl[15] respectively. It has been observed that the data for 13 subjects with endurance time ranging from 6 to 31 min reflects an insignificant contribution of aerobic fraction of total oxygen utilization and significant contribution of anaerobic fraction of total oxygen utilization for predicting endurance time. For a single subject with endurance time in the range of 1 — 120 min, both the aerobic and anaerobic fractions of total oxygen utilization were significant predictors of endurance time. This model is a general one, valid for a wide range of data, including both aerobic and anaerobic fractions of total oxygen utilization.

All the models described above have been developed for predicting endurance time during continuous work in a comfortable environment and may not be valid under heat and other environmental conditions. An attempt was, therefore, made by Dimri and Verma[16] to develop two multiple linear regression models for predicting endurance time during continuous work under heat environment from physiological and environmental variables. The first model was based on four predictor variables (sweat rate, work load, thermal stress expressed as oxford index (WD) and skin temperature) with a multiple correlation of 0.837 (R^2 = 0.70). The predictor variables selected in the second regression model were relative work load, sweat rate and thermal stress expressed as oxford index (WD) having multiple correlation of 0.876(R^2 = 0.78) between observed and estimated endurance times. These two regression models were based on limited data for 6 subjects and may require further validation on the basis of data for a larger number of subjects. The applicability of some regression models for the estimation of human endurance time is compared in Table 1.

Table 1. Regression models for estimation of human endurance time

Regression models	Predictor variables	R^2	Reference
Nonlinear	Cardiorespiratory strains	0.93	
	Exercise dyspnoeic index	0.69	10
	Aerobic-anaerobic fracations of total oxygen utilization	0.93	14
Multiple linear	Sweat rate, work load, thermal stress expressed as oxford index (WD) and skin temperature	0.70	
	Relative work load, sweat rate and thermal stress expressed as oxford index (WD)	0.78	

3. DISCUSSION AND CONCLUSION

Regression models reviewed in this paper have played a significant role in indirect estimation of human endurance time. The model developed by Sen Gupta *et al*[10] for estimation of endurance time from exercise dyspnoeic index was based on respiratory strain imposed on the subject during endurance effort. This model has a correlation of -0.831 (R^2 = 0.69) between endurance time and exercise dyspnoeic index. Later, it was thought that endurance time was a simultaneous function of respiratory and cardiac strains. Hence, a nonlinear regression model for estimating endurance time in terms of cardiorespiratory strains was developed by Sen Gupta, *et al*[1] by making use of multivariate regression analysis[17]. The multiple correlation for this model between observed and estimated endurance time expressed in logarithm was obtained as 0.965 (R^2 = 0.93). Thus, the model based on cardiorespiratory strains was superior to the one based on respiratory strain only.

Sen Gupta *et al*[14] developed a nonlinear regression model for estimating endurance time in terms of aerobic-anaerobic fractions of total oxygen utilization. It was observed that for a data on thirteen subjects having endurance time in the range from 6 - 31 min the aerobic fraction of total oxygen utilization was not a significant predictor, but the anaerobic fraction of total oxygen utilization was a significant predictor of endurance time, which may be due to the limited range of endurance time happening in the event of sprint running. During the validation of the same model on the basis of data for single subject having endurance time in the range 1-120 min it was observed that both aerobic and anaerobic fractions of total oxygen utilization were significant predictors of endurance time, which may be due to the wide range of endurance time.

The regression models developed by Dimri and Verma[16] had multiple correlations of the order of 0.837 (R^2= 0.70) and 0.876 (R^2 = 0.78), indicating the superiority of relative work load over work load as a significant predictor of endurance time. This fact necessitates validation of the models on the basis of data for a large number of subjects. Assuming mechanical efficiency as found during submaximal cycling, a model in the form of differential equation has recently been developed by Ingen-Schenau *et al*[18] to predict realistic times at 100 , 200 and 400 m distances by solving the differential equation through simulation. This model seems to be quite complicated for use in practice by the biomedical scientists.

Obviously, the various regression models based on physiological variables are superior to the other models of endurance time (Table 1). Thus, the 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.

ACKNOWLEDGEMENTS

The author is grateful to Dr J Sen Gupta, Director, DIPAS, Delhi Cantt, for his keen interest in the study and for providing encouragement.

REFERENCES

1. Sen Gupta, J.; Verma, S.S.; Joseph, N.T. & Majumdar, N.C. A new approach for the assessment of endurance work. *Eur. J. Appl. Physiol.*, 1974, **33,** 83-94.
2. Verma, S.S.; Sen Gupta, J. & Malhotra, M.S. A statistical model for the estimation of endurance time. *Math. Biosci.*, 1980, **48,** 17-24.
3. Lehman, G.; Muller, E.A. & Spitzer, H. *Der kalorienbedarf beigewerblicher arbeit. Arbeitsphysiologie,* 1950, **14,** 166-235.
4. Muller, E.A. Occupational work capacity. *Ergonomics,* 1962, **5,** 445-52.
5. Bink, B. The physical working capacity in relation to working time and age. *Ergonomics,* 1962, **5,** 25-28.
6. Bonjer, F.H. Actual energy expenditure in relation to the physical working capacity. *Ergonomics,* 1962, **5,** 29-31.
7. Bonjer, F.H. Relationship between physical working capacity and allowable calorie expenditure. *In* International Colloquium on Muscular Exercise and Training, Darmstadt, 1968.
8. Michael, E.D.; Hutton, K.E. & Horvath, S.M. Cardiorespiratory responses during prolonged exercise. *J. Appl. Physiol.*, 1961, **16,** 997-1000.
9. Åstrand, I. Degree of strain during building work as related to individual aerobic capacity. *Ergonomics,* 1967, **10,** 293-303.
10. Sen Gupta, J.; Malhotra, M.S. & Ramaswamy, S.S. Exercise dyspnoea and work performance at sea level and at high altitude. *Indian J. Physiol. Pharmacol.*, 1972, **16,** 47-53.
11. Glesser, M.A. & Vogel, J.A. Endurance capacity for prolonged exercise on the bicycle ergometer. *J. Appl. Physiol.*, 1973, **34,** 438-42.

12. Grosse-Lordemann, H. & Muller, E.A. *Der einfluss der leistung under arbeitsgeschwindigkeit auf das arbeitsmaximum and den werkengsgrad beim radfahren. Arbeitsphysiologie,* 1937, **9**, 454-75.

13. Tornvall, G. Assessment of physical capacities. *Acta Physiol. Scand.*, 1963, **58**(Suppl.), 201.

14. Sen Gupta, J.; Verma, S.S. & Majumdar, N.C. Endurance capacity for continuous effort in terms of aerobic and anaerobic fraction of oxygen supply. *Indian. J. Physiol. Pharmacol.*, 1979, **23**(3), 169-78.

15. Åstrand, P.O. & Rodahl, K. Text book of work physiology. Mc Graw-Hill, New York, 1970. 303 p.

16. Dimri, G.P. & Verma, S.S. Prediction of endurance time during continuous work in heat. *In* Contributions to human biometeorology, progress in biometeorology, Vol. 4. The Hague, Netherlands, 1987. pp. 97-103.

17. Bliss, C.I. Statistics in biology, Vol. II. McGraw-Hill, New York, 1970. pp. 292.

18. van Ingen-Schenau, G.J.; Jacobs, R. & de Koning, J.J. Can cyclepower predict sprint running performance? *Eur. J. Appl. Physiol.*, 1991, **63**(3-4), 255-60.