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Nonlinear and Non-Normal Regression Models in Physiological Research

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Abstract. Applications of nonlinear and non-normal regression models are in increasing order for appropriate interpretation of complex phenomenon of bio-medical sciences. This paper reviews critically some applications of these models in physiological research.

1. Introduction

Applications of regression models have become indispensable for better interpretation of biological phenomena related to different branches of biomedical sciences. With the increasing availability of electronic computers, it has been possible to utilize the advanced regression models in these sciences. Attempts have been made to establish the relationship between pulmonary ventilation and alveolar gas pressures using non-linear regression models[1]. The model was further generalized by Bliss and James[2]. Linear as well as nonlinear regression models also play a major role in the formulation of certain prediction formulae relevant to the field of physiology and physiological anthropometry. Bharadwaj et al[3], made use of stepwise linear regression analysis to develop suitable regression equations for estimating body density and lean body weight from body measurements at high altitude. Similar studies have been done on this aspect by Europeans and Americans [4,5,6,7&8] suggesting useful regression equations from which body density can be estimated at sea level. Direct estimation of leg muscle volume was an intricate procedure which was simplified[9] by suggesting a multiple linear regression equation to estimate leg muscle volume from X-ray radiographs and stature. The main object of the present paper is to review some applications of nonlinear and non-normal regression models in physiological research.

2. Nonlinear and Non-normal Regression Models

2.1 *Non-normal Distributions in Physiological Research*

Theory of statistical distribution plays an important role in the extrapolation of certain physiological responses and anthropometric measurements. Attempts have, therefore, been made to evaluate the distributions of maximal aerobic power, body temperature, initial sweat losses and of some anthropometric measurements etc. The distribution of maximal aerobic power has been studied by Verma et al[10] and reported its distribution to be lognormal in young healthy males having significant departure from symmetry with positive skewness and insignificant difference of kurtosis from normal distribution. These observations were in agreement with the results conjectured by Rao[11] regarding the distribution of biometric measurements. Winer et al[12] used extreme value distribution of type I for estimation of risks of heat stroke in human beings and the same distribution was used by Winer[13] for the estimation of parameter in singly censored samples. Later on Maritz and Munro[14] proposed a generalized extreme value distribution in estimating extreme percentiles of body temperature. These different forms of distribution were discussed depending on the severity of the heat stress imposed on the subject. The distribution of initial sweat losses was reported to be lognormal[15]. Similar attempts were made to exhibit the occurrence of lognormal distribution in applied biology by several workers[16,17,18,19,20,21]. The distributions of body height, weight and some other anthropometric measurements has been worked out by Camp[22] & Yuan[23]. They reported the existence of normal as well as lognormal distribution in some anthropometric measurements. The distributions of skinfold thicknesses have been reported to be skewed by Durnin and Womersley[24] and the exact form of the distributions of some skinfold thicknesses have been worked out by Verma et al[25]. They reported the lognormal distribution of three important skinfold thicknesses viz. subscapula, triceps and juxtanipple. Soong et al[26] derived the probability distribution of the functional residual capacity (FRC) and proposed the probability distributions for the lengths and diameters of airways and for the number and volume of alveoli based on morphometric data.

2.2 *Nonlinear Regression Models in Physiological Research*

Regression analysis is of fundamental importance in solving the problems arising in the field of physiology and physiological anthropometry. The applications of nonlinear regression models to predict some important physiological responses and some important variables related to physiological anthropometry is reviewed.

The problem of nonlinear regression model has been dealt by Sen Gupta et al[27] to evolve a prediction formula for estimating human endurance time from cardiorespiratory strains imposed on the subject. Sen Gupta et al[28] evolved a nonlinear regression model for predicting human endurance time in terms of aerobic-anaerobic fractions of total oxygen utilization. A nonlinear regression model has also been evolved by Verma et al[29] to predict maximal aerobic power from cardiorespiratory strains, oxygen consumption during submaximal exercise and rest. The validity of this regression model was tested for the data consisting of 135 observations on 45 moderately active subjects who were asked to exercise on bicycle ergometer at three submaximal and one maximal work rate. It was conclusively established that combined index of cardiorespiratory strains will be a better predictor of aerobic stress than either respiratory or cardiac strain alone, as commonly employed by several workers. Similar models have been utilized by Verma et al[30] to explain the phenomena of thermoregulation efficiency of human beings under cold stress on seven environmental situations including altitude. Hey and Hey[1] proposed a procedure for estimation of parameter of nonlinear regression models and illustrated its use by an example of respiratory physiology to establish the relationship between pulmonary ventilation and alveolar gas pressures. This theory was generalised later on by Bliss and James[2] covering different aspects of estimating the parameters of nonlinear regression models. Recently Verma et al[31], used nonlinear regression models for establishing the relationship of heat output and initial index finger temperature with ambient temperature.

2.3 *Non-normal Regression Models in Physiological Research*

In recent years a variety of non-normal regression models have come into common use. Exponential regression models[32,33,34], poison regression models[35] and binary models[36,37] are, for example used in diverse area of study ranging across the biomedical, engineering and allied sciences. Recently Verma et al[38], proposed a non-normal model for the estimation of endurance time by assuming the distribution of endurance time to be exponential. The statistical analysis of data under these models is generally based on maximum likelihood estimation. For these models *ML* estimates need to be determined iteratively, and so computational effort is a factor in certain situations. Since large amounts of computation may be required to do this, stepwise procedures have often been used to find good fitting models, and to screen regressor variables for importance[39,40]. Lawless and Singhal[41] has pointed out that stepwise procedures have a number of undesirable features and in particular, produce only a fraction of the models which fit the data well. They suggested efficient computational algorithms for normal linear model illustrating their use with non-normal models. The use of the procedures is illustrated on exponential, poison and binary regression models.

3. Discussion and Conclusion

Regression models reviewed in this paper are of fundamental importance to solve practical problems arising in various branches of physiology. The comparisons of these models with other models of well established workers exhibit good agreements. For example, the distributions of skinfold thickness worked out by Verma et al[25] are in close agreement with observations reported by Durnin and Womersley[24]. The lognormal distribution of physical work capacity[10] is also having a great resemblance with the results conjectured by Rao[11] about biometric measurements. The nonlinear regression models for estimating aerobic power[29] yielded better predictability than the earlier models using either respiratory or cardiac strain alone as commonly employed. Similar comparison has been made by Sen Gupta et al[27] for the assessment of endurance time. These workers reported the better precision of their models and constructed nomograms for the practical use of their work without involving complicated mathematical computations. In some situations the nonlinear regression models are applied to a new field to describe the mechanism of human system and these models may be compared in future studies carried out in that direction. Thus the nonlinear and non-normal regression models described in this paper have wide applications in physiological research and may be applied to other fields for, (a) Prediction of endurance efforts of human beings under sustained maximal effort; (b) Statistical evaluation of the distribution of important physiological variables; (c) Aid in the construction of nomogram to simplify the statistical calculations; and (d) Aid in planning of physiological trials.

References

1. Hey, E. N., & Hey, M. H., *Biometrics*, **16** (1960), 505.
2. Bliss, C. I. & James, A. T., *Biometrics*, **22** (1966), 573.
3. Bharadwaj, H., Verma, S. S., Zachariah, T., Bhatia, M. R., Kishnani, S. & Malhotra, M. S., *Europ. J. Appl. Physiol.*, **36** (1977), 141.
4. Brozek, J. & Keys, A., *Brit. J. Nutr.*, **5** (1951), 194.
5. Durnin, J. V. G. A. & Rahaman, M. M., *Brit. J. Nutr.*, **21** (1967), 681.
6. Pascale, L. R., Morton, I. G., Sloan, H. S. & Frankel, T., *Hum. Biol.*, **28** (1956), 165.
7. Sloan, A. W., *J. Appl. Physiol.*, **23** (1967), 311.
8. Wilmore, J. H. & Behnke, A. R., *J. Appl. Physiol.*, **27** (1969). 25.
9. Bharadwaj, H., Jones, P. R. M., Verma, S. S. & Zachariah, T., *Z. Morph. Anthrop.*, **66** (1975), 202.
10. Verma, S. S.. Sen Gupta, J. & Malhotra, M. S., *Ind. J. Physiol. Pharmac.*, **23** (1979), 21.
11. Rao, C. R., 'Advanced Statistical Methods in Biometric Research', (John Wiley & Sons Inc., New York), 1952.
12. Winer, P., Maritz, J. S. & Wyndham, C. H., *Nature*, **193** (1962), 848.
13. Winer, P., *Biometrics*, **19** (1963), 460.
14. Maritz, J. S. & Munro, A. H., *Biometrics*, **23** (1967), 79.
15. Fox, R. H., Lofstedt, B. E., Woodward, P. M., Erikson, E. & Werkstrom, B., *J. Appl. Physiol.*, **26** (1969), 444.
16. Bartlett, M. S., *J. Roy. Statist. Soc. Suppl*, **4** (1937), 137.
17. Haldane, J. B. S. & Kermack, K. A., *Biometrika*, **37** (1950), 30.
18. Sinnott, E. W., *Proc. Nat. Acad. Sci. Washington*, **23** (1937), 224.
19. Williams, C. B., *Ann. Appl. Biol.*, **24** (1937), 404.
20. Williams, C. B., *Trans. Roy. Ent. Soc. London*, **90** (1940), 227.
21. Yates, F., *J. Amer. Statist. Assoc.*, **20** (1934), 51.
22. Camp, B. H., *Ann. Math. Statist.* **9** (1938), 221.
23. Yuan, P. T., *Ann. Math. Statist.*, **6** (1933), 30.

24. Durnin, J. V. G. A. & Womersley, J., *Brit. J. Nutr.*, **38** (1977), 271.
25. Verma S. S., Bharadwaj, H., Nandkishore, Ghadiok, A. K., Gupta, R. K. & Nayar, H. S., *Z Morph. Anthrop.* **72** (1981), 187.
26. Soong, T. T., Nicholaides, P., Yu, C. P. & Soong, S. C., *Respiration Physiology*, **37** (1979), 161.
27. Sen Gupta, J., Verma, S. S., Joseph, N. T. & Majumdar, N. C., *Europ. J. Appl. Physiol.*, **33** (1974), 83.
28. Sen Gupta, J., Verma, S. S., & Majumdar, N. C., *Ind. J. Physiol. Pharmac.*, **33** (1979), 169.
29. Verma S. S., Sen Gupta, J. & Malhotra M. S., *Europ. J. Appl. Physiol.* **36** (1977), 215.
30. Verma S. S., Gupta, R. K., Nayar, H. S. & Rai, R. M., *Ind. J. Physiol. Pharmac.*, **26** (1982), 47.
31. Verma, S. S., Gupta, R. K. & Rai, R. M., *Ind. J. Phpsiol. Pharmac.*, **27** (1983), 61.
32. Feigl, P. & Zelen, M., *Biometrics*, **21** (1965), 826.
33. Glasser, M., *J. Amer. Statist. Assoc.*, **62** (1967), 561.
34. Prentice, R. L., *Biometrika*, **60** (1973), 279.
35. Frome, E. L., Kutner, M. H. & Beauchamp, J. J., *J. Amer. Statist. Assoc.*, **68** (1973), 935.
36. Cox, D. R., 'The Analysis of Binary Data' (Methuen, London), 1970.
37. Truett, J., Cornfield, J. & Kannel, W. B., *J. Chron. Dis.*, **20** (1967), 511.
38. Verma, S. S., Sen Gupta, J. & Malhotra, M. S., *Math. Biosc.*, **48** (1980), 17.
39. Greenberg, R. A., Bayard, S. & Byar, D., *Biometrics*, **30** (1974), 601.
40. Krall, J. M., Uthoff, V. A. & Harley, J. B., *Biometrics*, **31** (1975), 49.
41. Lawless, J. F. & Singhal, K., *Biometrics*, **34** (1978), 318.