Anthrop. Közl. *24;* 63–68. 1980.

ALLOMETRIC VERSUS MULTIVARIATE APPROACHES TO PROPORTIONALITY ASSESSMENT USING REFERENCE POPULATIONS

by D. T. DRINKWATER and M. A. VAN'T HOF

(Kinesiology Department, Simon Fraser University, Burnaby, B. C., Canada; Department of Statistical Consultation, University of Nijmegen, Nijmegen, The Netherlands)

Abstract. The assessment of proportionality may be done *directly* using an allometric approach where changes in body dimensions may be expressed as height to some power, or *less directly* using multivariate methods where, under most circumstances, body dimensions may be expressed as linear functions of height. The allometric approach of Ross and WILSON (1974) attempts to simplify proportionality assessment, however their assumption of geometrical similarity is not valid if one wishes to separate the normally expected proportionality changes which occur with increasing height from the effects of other influences. Using multivariate methods, control for these changes with height may be achieved by standardizing data to a real known reference rather than a hypothetical one. Furthermore, the multivariate approach allows for control of the confounding effects of other variables in addition to height. Thus the use of a multivariate approach and a real population reference may be preferable to the Ross–Wilson 'Phantom' stratagem for proportionality assessment.

Key words: allometry, multivariate analysis, proportionality.

Introduction

A frequent endeavour of human biologists is the comparison of the morphological characteristics of individuals or groups. Recently the assessment of height related proportionality characteristics of children and athletes has been of interest to investigators (EIBEN et al. 1976, EIBEN 1978, Ross et al. 1977, Ross et al. 1979). What is of concern is how such groups differ from one another and from a 'normal' population.

In 1974 Ross and WILSON proposed a method for the proportionality assessment of body dimensions. They used a hypothetical unisex reference or 'Phantom' as a universal standard, or 'normal' population, and presented a procedure for the transformation of morphological data to 'Phantom' standardized proportionality values. Their intent in standardizing all data geometrically adjusted to a height of 170.18 cm was to examine differences in proportionality as compared to an average male–female adult, and facilitate the comparison of proportionality among individuals or groups.

Provided one is interested *only* in describing and evaluating absolute proportionality for various groups, then the Ross–Wilson approach is a convenient means of doing this. If, however, one wishes to determine to what extent observed proportionality differences might be attributable to normally expected changes which occur with increasing height, then the Ross–Wilson geometric scaling approach is inappropriate.

Allometry and proportionality

If body dimensions increased geometrically with height then proportionality should remain constant with increasing height. But the proportionality value for any variable does not necessarily remain constant but rather may change with increasing height. This is illustrated in Fig. 1b for the data shown in Fig. 1a. This suggests that body dimensions do not increase geometrically with height.

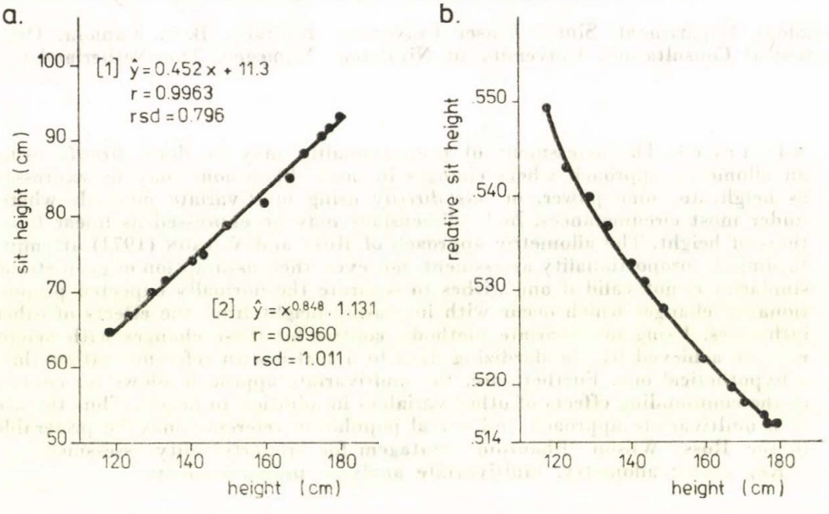

Fig. 1a: **Mean sit heights for boys 6—18 years from COGRO, Ross et al. 1979**
Fig. 1b: **Smoothed relative sit heights for boys 9—18 years calculated from est. sit heights using Eq. (1), Fig. 1a**

The rate of change of one variable with respect to another, or the dimensional relationship of any variable with another such as height, may be best expressed by the allometric equation as discussed by MARSHALL et al. (1979). Thus the rate of change of sit height with respect to height can be expressed as height to some power. If sit height were to increase geometrically relative to height such that the proportionality value remained constant, then the exponent should be 1. That the exponent is less than 1, specifically 0.848 as shown by Eq. (2), Figure 1a, indicates that the rate of increase in sit height is less than the rate of increase in height in this particular population.

Since the Ross—Wilson approach does recognize this dimensional aspect and provision is made in their z-value formula for the adjustment of the dimensional exponent to the appropriate population specific value, it is possible to correct for the confounding effect of height on proportionality in this manner. An extention of the 'Phantom' should, therefore, include the dimensional relationships of all variables with height as exist in a 'normal' population.

Referring to Table 1, if one uses the strictly geometrical relationship in the Ross—Wilson formula, significant differences in proportionality can be

shown to exist between the two groups. However, by using the appropriate dimensional exponent, thereby controlling for height related change, it can be shown that the proportionality differences dissappear. In other words, the observed differences are wholely attributable to 'normal' proportionality changes associated with increasing height and not to 'true' differences between the groups as a result of different treatments. Such partitioning out of the 'normal' proportionality changes would be particularly useful in assessing proportionality of various groups such as athletes for instance.

Table 1

Comparison of proportionality differences in sit height for boys using the 'Phantom' stratagem before and after using the appropriate dimensional exponent to control for height related proportionality changes. Data synthesized from COGRO, Ross et al. 1979.

$$z = \frac{1}{s} \cdot \left[v \cdot \left(\frac{170.18}{ht} \right)^d - P \right]$$

where $P = 70.98$, $s = 4.54$, d = dimensional exponent, v = variable of interest, ht = measured height

	where d = 1	where d = 0.848
group age 8 N = 22 ht = 129 cm sit height 70 (3) cm	z = 0.34 (.87)	z = −0.49 (.84)
group age 18 N = 21 ht = 179 cm sit height = 93 (3) cm	z = −0.52 (.63)	z = −0.37 (.63)
min t ($p \leq 0.05$), DF = 41 t = 2.02	t = 3.74 significant	t = −0.50 not significant

The use of peer reference groups and the 'Phantom' stratagem

In the absence of specific population information regarding the proportionality changes with height, one might make comparisons with an appropriately matched peer or 'norm' group. Such an approach was demonstrated by Ross et al. (1979) using an age matched peer group to assess proportionality in 11 years old female figure skaters. While the use of an age matched peer group whether there were proportionality differences between groups of a given age, a better assessment of the differences might have been made using a height matched as well as age matched peer group. But this example does illustrate an awareness that in growing children proportionality changes are age as well as height dependent.

Thus the Ross—Wilson 'Phantom' as a hypothetical and highly generalized description of average adult size can serve only as a useful reference for depicting a 'standardized' proportionality value — nothing more since the assumption of geometrical similarity is inappropriate for the control of height when one wishes to separate proportional differences observed as to expected height related changes and to the effects of other influences.

A multivariate approach and the use of real reference populations

An alternative approach for the evaluation of proportionality is to use multivariate techniques and look at the magnitudes of the variables of interest for each group after statistically controlling for height. Although one does not look at proportionality values directly using such techniques, one can infer whether one group is proportionally larger than the 'normal' population at a given height if the group value is greater than the estimated population value at that height. In this way one can compare groups controlling for the effect of height by determining how much each group differs from the population at their respective heights and hence from one another. Furthermore, whereas only the effect of height can be controlled in the Ross—Wilson approach by using the appropriate dimensional exponent for each variable, the multivariate approach allows for the control of other variables in addition to height. Thus, for example, one could look at the relative magnitude of arm girth in two groups of athletes after controlling for the effect of height and the size skinfold. Such partitioning out of the confounding effects of skinfold size could further aid in explaining differences between groups. The multivariate approach is our method of choice since many morphological relationships can be reasonably approximated over the range we are interested in by linear regressions such as shown in Eq. (1), Fig. 1a.

Because we are concerned principally with determining whether differences exist between our study groups and a 'normal' sex specific population we chose to standardize our data to a real rather than a hypothetical reference. Four our reference we require, ideally, a population with a large number of subjects (N greater than 1000) covering the height range in which we are interested and for which the variable we commonly use have been measured and the necessary statistics — means, standard deviations, and correlation matrix — have been reported. The large number of subjects ensures that the errors in the calculated coefficients, used in the regression equations developed via this multivariate approach to describe our 'normal' population, are negligibly small. The subsequent scores, standardized to our reference, that are derived by this approach, therefore, have negligible error associated with them.

That this approach can yield the same information as the modified Ross—Wilson method (Table 1) is shown in Table 2. Using synthesized values for a reference population of boys and disregarding age related changes, the data are transformed to scores standardized to this reference before and after statistically controlling for height.

Since it can be demonstrated that given a fairly high relationship between height and any variable, that the quotient or proportionality value calculated from the estimated value of a variable at a given height divided by that height is a good approximation of the mean the proportionality value for that height, should we wish to look at proportionality characteristics as such, it is possible to convert the transformed data obtained via our multivariate approach to Ross—Wilson z-values. While this is a somewhat indirect way of

Table 2

Comparison of sit height of boys using multivariate techniques and a reference population to control for height related changes. Data synthesized from COGRO, Ross et al. 1979.

regression of sit height(y) on height(x) — $\hat{y} = 0.452 \cdot x + 11.3$, $r = 0.996$, rsd $= 0.796$

	direct comparison	multivariate comparison
group age 8 N = 22 ht = 129 cm sit height = 70 (3) cm		z = 0.50 (3.77)
group age 18 N = 21 ht = 179 cm sit height = 93 (3) cm		z = 1.00 (3.77)
min t ($p \leq 0.05$), DF = 41 t = 2.02	t = −21.74 significant	*t = −0.43 not significant

* Note — By inference, proportional sit height of the 8 year-old boys is *not* significantly smaller than the 18 year-old boys after controlling for height.

assessing proportionality differences in the absence of the dimensional relationships being given for the reference population, it is doubtful that any more information would be gained from doing this.

What our approach allows, then, like the Ross—Wilson approach is the convenience of standardization of data to a common reference such that differences between groups becomes readily apparent. But unlike the Ross—Wilson method, our real population reference contains the information necessary to allow us to partition out height related changes in any variable and the effects of any other confounding variable to look at the 'true' differences between groups if we wish so. Since we are not looking directly at proportionality relationships in the manner of Ross and Wilson, it is not necessary to know the dimensional relationships with height for all variables in our population.

Conclusion

Like Ross and Wilson, we do propose that the use of standard population references could indeed be rewarding in the evaluation of morphological data. What is needed are adequate male and female reference groups, and perhaps even a unisex reference. Much would depend on the questions being asked. But for the assessment of proportionality, we suggest that a multivariate approach using a peer group of some sort might be more expedient than applying the Ross—Wilson approach in the absence of dimensional information for the 'Phantom', or the use of a series of height matched groups processed via the 'Phantom' stratagem.

REFERENCES

EIBEN, O. G. (1978): Changes in body measurements and proportion of children, based on Körmend Growth Study. — *In:* GEDDA, L.—PARISI, P. (Eds): *Auxology: Human Growth in Health and Disorder*, pp. 187—198. — Academic Press, London, New York, San Francisco.

EIBEN, O. G.—ROSS W. D.—CHRISTENSEN, W.—FAULKNER, R. A. (1976): Proportionality characteristics of female atheletes. — Anthrop. Közl. *20;* 55—67.

MARSHALL, G. R.—BAILEY, D. A.—LEAHY, R. M.—ROSS, W. D.—VAJDA, A. S. (1979): Allometric growth in boys studied longitudinally age seven to sexteen years. — *In:* NELSON, R. C.—MOREHOUSE, C. A. (Eds): *Kinanthropometry* I., — University Park Press, Baltimore, Md.

ROSS, W. D.—BROWN, S. R.—FAULKNER, R. A.—VAJDA, A. S.—SAVAGE, M. V. (1977): Monitoring growth in young skaters. — Can. J. Appl. Sport Sciences, *1;* 163—167.

ROSS, W. D.—DRINKWATER, D. T.—WHITTINGHAM, N.—FAULKNER, R. A. (1979): Anthropometric prototypes age six to eighteen years. — *In:* BERG, K.—ERIKSSON, B. O. (Eds): *Children and Exercise IX.* Pediatric Work Physiology IX, Marstrand, Sweden, — University Park Press, Baltimore, Md.

ROSS, W. D.—WILSON, N. C. (1974): A stratagem for proportional growth assessment. — *In:* BORMS, J.—HEBBELINCK, M. (Eds): *Children and Exercise.* VIth Internat. Symposium on Pediatric Work Physiology, den Haag, 1973. — Acta Pediatrica Belgica, Suppl. 169—182.

Authors' addresses: Dr. DONALD T. DRINKWATER
Dept. Kinesiology, Simon Fraser University
Burnaby 2. B. C. V5 A 1S6
Canada

Prof. MARTIN A. VAN'T HOF
Dept. Statistical Consultation, University of Nijmegen
Nijmegen
The Netherlands