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Alternative Common Factor Models for Multivariate Biometric Analyses

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In prior research we have shown how linear structural equation models and computer programs (e.g., LISREL) may be simply and directly used to provide alternatives for the traditional biometric twin design. We use structural equations and path models to define biometric group differences, we write traditional common-factor models in the same way, and then we take a detailed look at some alternative multivariate and biometric models. We contrast the biometric-factors covariance structure approach used by Loehlin and Vandenberg (1968), Martin and Eaves (1977), and others with the psychometric-factors approach used by McArdle et al. (1980) and others. We use the multivariate primary mental abilities data on monozygotic (MZ) and dizygotic (DZ) twins from Loehlin and Vandenberg (1968) to detail fundamental differences in model specification and results. We extend both multivariate biometric approaches using exploratory and confirmatory multiple-factor models. These comparisons show that each alternative multivariate methodology has useful features for empirical applications.

KEY WORDS: twins; multivariate; factor analysis; structural equation models; LISREL; RAM; intelligence; primary mental abilities.

INTRODUCTION

One of the key insights of evolutionary genetics is that diversity plays an important role in the adaptation of species. This may be true of model building in behavioral genetics as well. For example, Martin and Eaves (1977) begin their

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treatment of multivariate biometric analysis by noting, "The techniques of factor analysis have been used extensively in the behavioral sciences to simplify the representation of relationships among multiple variables. Geneticists, rightly, are sceptical about the use of such methods in genetical research. . . ." This treatment introduced a confirmatory factor analysis with maximum-likelihood estimation for a multivariate form of the covariance among measures of various genetic and environmental factors. Technically, Martin and Eaves (1977) showed how the concepts of Jöreskog's (1970) ACOVS model could be extended to a multiple group case to estimate multivariate biometric models. This presentation formalized the earlier multivariate ideas of many others (e.g., Loehlin and Vandenberg, 1968) and partially allayed behavioral geneticists' skepticism about contemporary issues in factor analysis.

There have been numerous developments in structural equation modeling outside of behavioral genetics (e.g., Jöreskog and Sörbom, 1979; McDonald, 1985). In a 1980 conference paper, we showed how the widely available LISREL computer programs could be used to estimate multivariate biometric models (McArdle *et al.*, 1980). Our LISREL-based calculations directly followed Martin and Eaves (1977) ACOVS analyses but required less novel programming, and this proved to be practically useful. We extended this biometric methodology to other problems and issues in later conference papers and published reports (McArdle *et al.*, 1981; McArdle and Goldsmith, 1984; Goldsmith, 1983; McArdle, 1986; Horn, 1986).

Our work in this area has been recognized by several biometric researchers (e.g., Henderson, 1982; Boomsma and Gabrielli, 1985); independently developed and refined by several behavioral geneticists (e.g., Fulker *et al.*, 1983; Cantor *et al.*, 1983) and the LISREL programming techniques are now widely used (e.g., Martin *et al.*, 1984; Tambs *et al.*, 1984; Boomsma and Molenaar, 1986). In fact, this approach has become so popular that a whole issue of *Behavior Genetics* has been devoted to a conference on "Twin Methodology Using LISREL" (Martin *et al.*, 1989).

Our approach to these problems 10 years ago differed in at least two ways from these subsequent presentations. First, we employed a matrix specification that has little overt resemblence to standard LISREL notation. Our matrix notation is based on general path analysis graphics, and we have used it to demonstrate the convergence of available computer programs such as ACOVSM, COFAMM, LISREL, and COSAN (McArdle, 1980, 1986; McArdle and McDonald, 1984; McArdle and Horn, 1990). Second, and more relevant now, is the fact that we used structural modeling techniques to estimate some novel integrations of biometric and psychometric models. The factor loadings derived from the Martin and Eaves (1977) analyses yield genetic and environmental loadings on each of the observed measures. We termed this the *biometric-factors model* and we recognized it as the standard model in the field. As an alternative,