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BOOK REVIEW

A Primer of Multivariate Statistics (3rd ed.). Richard J. Harris. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2001, 632 pages, $60.00 (cloth).

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As pointed out in a recent review (Glaser, 1999), there are quite a few multivariate texts in the marketplace, each with their own emphasis, whether more laden toward the mathematics of multivariate statistics (e.g., Johnson & Wichern, 1999) or those with a decidedly nontechnical orientation (Grimm & Yarnold, 1995, 2000; Tacq, 1997). Coincidentally, the past couple of years have seen updated editions of such frequently used (at least in the social sciences) multivariate texts as Stevens (2002), Johnson and Wichern (1999), and Tabachhick and Fidell (2001). To add to this, Harris has a new edition, his first update since the 1985 second edition.

Chapter 1, titled "The Forest Before the Trees," provides an overview of the use of multivariate statistics and touches on some of the recent developments in analysis, including the ongoing (if somewhat waning) discussion of null hypothesis significance testing (NHST). An intriguing opening statement jumpstarts this chapter: "Statistics is a form of social control over the professional behavior of researchers" (p. 1). Thus, to some extent this text is not light on editorializing by the author. Some of the recent discussion on NHST, prompted in part by Cohen's (1994) article and then summarized in the edited text by Harlow, Mulaik, and Steiger (1997), is briefly summarized. Some recent developments in univariate statistics are reviewed, including power analysis, use of confidence intervals, and so forth. The descriptive and inferential roles that multivariate statistics plays is discussed with an extended section titled "A heuristic survey of statistical techniques." By heuristic, the author means that the formula is presented in a way that suggests the underlying meaning of the calculation. Many introductory texts refer to this as the *definitional* formula (e.g., Heiman, 1998) as opposed to the more calculation-friendly *computational* formula. Thus, a brief discussion, in a heuristic context, is provided for the various univariate statistics known to most researchers

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(e.g., *t* test, analysis of variance [ANOVA]) and then the various multivariate techniques covered in this text. Given the ubiquity of the use of linear combinations in multivariate statistics, this topic is given some attention in the context of contrast effects, profiling of scores, and averaging. As a note, just the introductory chapter is 57 pages in length, and given the text has eight chapters (not counting the "digression" chapters and appendixes), the instructor may see fit to segment some of the subsections.

"Multiple Regression: Predicting One Variable From Many" is the title for chapter 2. Harris starts off the chapter by delineating the terminology unique to regression as well as the primary reasons why one would be interested in conducting regression in the first place (given the researcher may already have access to *Y*). The constituent parts of a linear combination of predictors, and the regression equation, are reviewed in detail. Where Harris deviates from many multivariate texts is an elaboration on the effects of transformations on the linear equation. Throughout this book there are many elaborations and/or technical digressions; even though they may be of some interest for the seasoned researcher, this may not be the case for the graduate student taking their first multivariate course. Hence, instructors may find themselves emphasizing certain sections more than others. The next section covers "Choosing Weights," with a fairly drawn-out derivation in the narrative, including a reference to what Harris calls "digressions" appended at the end of the text; this digression covering finding *maxima* and *minima*. Thus, even though calculus is not a prerequisite for this text, many of the technical derivations will be more intelligible for the student educated in this domain. The application of matrix algebra to multiple regression is detailed, though it would be helpful for the reader to study the matrix algebra "digression" at the end of the text prior to digesting this section. The next section, titled "Relating the Sample Equation to the Population Equation," is fairly lengthy, but covers such integral areas as significance testing, cross-validation, sample size, confidence intervals, and so forth. However, even though Harris has updated some of the references in this text since his prior editions, many citations are 30 years or more older. Thus, with respect to sample size and regression, the reader would be well advised to consult a recent article by Maxwell (2000). There is also much discussion in this chapter, and specifically this section, about the use of *z* scores as the basis of prediction. Significance tests are then illustrated via MATLAB and SPSS, with specific attention paid to syntax development. The subsequent section reviews SPSS, SAS, and MATLAB and provides a litany of well-heeded warnings regarding the various "canned" programs. Properties of the covariance matrix are detailed, with an extended section regarding measuring the importance of the contribution of a single variable. ANOVA via regression analysis is the next subject matter, and is very much in the spirit of the general linear model (GLM) as elaborated by many researchers (e.g., Cohen, 1968; Keppel & Zedeck, 1989). The various coding structures that render an ANOVA-type analysis in a regression framework is briefly discussed; thus, the reader is encouraged to access a regression text, such as Cohen and Cohen (1968), for a more extensive profiling of coding options. The final section covers Path Analysis, with an extensive rendering of the decomposed equations. The analysis for this technique is demonstrated via regression analysis using SPSS; thus, those who prefer a structural equation modeling (SEM) approach to path analysis (via SEM software) will be advised to peruse the many introductory SEM texts.

Chapter 3 is titled "Hotelling's T^2: Tests on One or Two Mean Vectors." This chapter carries the reader through the rudiments of the single-sample *t* test up to its multivariate generalization. The multivariate counterpart (i.e., T^2) is illustrated via matrix algebra; thus, it will again behoove the reader to become acquainted with the discourse on matrix algebra appended at the end of the text. Significance testing (and the attendant problem of multiple comparisons) is reviewed. An extensive discussion follows in regard to the discriminant function and how it pertains to T^2. An example of linearly related outcome variables follows, though this is not the same as the multivariate analysis of variance (MANOVA) discussion to follow in the succeeding chapter. As is the case throughout the text, Harris thoroughly details the matrix algebra and attendant derivations for all his examples. The instructor should be forewarned that there are passages in this chapter that may prove arduous for the fledgling student. For example, in the context of linear dependence, Harris discusses how principal component analysis (PCA) may be used to examine linear dependencies, though the reader will not have yet been introduced to this subject matter. In the context of the two-sample design, T^2 is reviewed, with a detailed illustration of profile analysis and discriminant analysis following. Even though those analytical techniques may be deserving of chapters in and of themselves, they are all discussed in the context of T^2. Thus, given the lengthy chapters, the instructor will need to segment their assignments by topic within each chapter. The relation between T^2 and multiple regression is critical in further extending an understanding of the GLM to the student. The various assumptions associated with T^2 (e.g., equal covariance matrices, multivariate normality) are summarized, with the well-known caveats (e.g., sensitivity of Box's test to normality) expanded on. Repeated measures analysis is focused on next with an initial discussion concerning the various assumptions (e.g., compound symmetry). The repercussions of inflated Type I error due to multiple contrasts is reviewed, though the reader may want to consult the more recent literature, especially the body of work by Klockers and Hancock (1994, 1998, 2000) and Hancock and Klockers (1996). A detailed example of within-subjects analysis is provided, using data from a blood doping study.

Chapter 4 is titled "Multivariate Analysis of Variance: Differences Among Several Groups on Several Measures." The chapter starts off with a rudimentary overview of one-way ANOVA, then a focus on two post hoc procedures: Scheffé's contrast method and Bonferroni critical values. Harris recommends other texts (e.g., Kirk, 1995) as sources to examine other frequently used multiple comparison procedures such as Tukey's test or Dunnett's test. However, the latter are used enough in many researcher's arsenals that it would have been appropriate for Harris to at least provide a cursory summary of those techniques. Harris introduces one-way MANOVA via matrix algebra, with the objective being "a search for that linear combination of the variables that maximally discriminates among the *k* groups in the sense of producing the largest possible univariate *F* ratio" (p. 218). Much initial discussion focuses on Lagrangian multipliers, characteristic roots, characteristic vectors, and so forth, which again will require a certain level of sophistication by the reader/student. Where Harris deviates from other multivariate authors is his emphasis on using a table (located in Appendix A) of the greatest characteristic root (GCR) distribution for testing the null hypotheses. The table provides *p* values and critical values for the GCR, though a FORTRAN program is available from the author if values beyond what the table provides are needed. Extensive discussion follows about the use of contrast methods in the context of MANOVA, making a much-needed distinction between those contrasts that are a priori versus post hoc. Similar to the prior chapter, multiple profile analysis and multiple discriminant analysis are overviewed. Again, these topics could have served as separate chapters in their own right. The next section covers "Greatest Characteristic Roots Versus Multiple-Root Tests in MANOVA" in great detail, reviewing Wilks's Lambda, protected univariate tests, simultaneous test procedures, and finite intersection tests. This goes into much more detail than many multivariate texts, and may be of interest more to the advanced reader. In this section, and essentially throughout the text, Harris also provides some caveats about the canned (e.g., SPSS) solutions. Higher order ANOVA and MANOVA, with a brief description of interactions, is summarized; reference to the GCR appendix takes prominence when significance testing is outlined. Within-subject ANOVA versus MANOVA is the last topic under discussion prior to a demonstration of how to set up MANOVA via SAS and SPSS.

Chapter 5 covers Canonical Correlation, and though some believe that this is one of the more general statistical models (e.g., Knapp, 1978), it still seems to be infrequently used, at least when scanning the empirical literature. Harris prefaces the chapter by drawing the comparison of canonical correlation and multiple regression, though he adds that "canonical correlation is a perfectly symmetric technique in which the distinction between the predictor set and the outcome set is not mirrored by any difference in statistical treatment of the two sets, and the distinction thus need not be made" (p. 268). The derivation via matrix algebra of canonical *r* is expanded on, again referencing the GCR. Examples of canonical analysis follow, using data collected for a drug use study. Harris then draws on the properties that canonical correlation shares with all of the other techniques (e.g., multiple regression MANOVA, etc.) discussed previously in the text. Various twists of canonical correlation are examined, including such rarely seen analyses as repeated-battery Canona (i.e., when a treatment or battery of tests is administered on two or more occasions). The next section covers rotation of canonical variates, with the reader advised to heed Harris's suggestion that if rotation is new to the audience, then they should review the section on rotation in the following chapter on PCA. Given that, it might have served this text better to have the chapter on PCA precede canonical correlation. Harris reviews the difficulty of interpreting variates, especially when one of the variables loads substantively on more than one variate. Methods by which to appreciably enhance interpretation (e.g., transformations) are discussed. Harris also emphasizes that "interpretation of canonical variates (rotated or not) should ... be based on the canonical variate coefficients and not on the loadings" (p. 290). However, there are some that believe that in canonical correlations (as well as discriminant analysis) a more comprehensive interpretation would entail examining both the structure coefficient matrices as well as the standardized coefficients (e.g., Thompson, 1998). After a brief review of redundancy analysis, Harris then brings up some of the deficiencies of canonical analysis (e.g., no unbiased estimate of the population value squared canonical correlation, test of the statistical significance of a given canonical variate coefficient, etc.). When providing software examples of canonical correlation, the reader should be advised that Harris runs canonical correlation via the MANOVA syntax on SPSS. However, the output is not particularly intuitive; thus, for some time now SPSS has had a canonical correlation macro that includes redundancy coefficients, and so forth, and segments the output by sets, thus, infinitely more user-friendly than the MANOVA syntax.

Chapter 6 is titled "Principal Components Analysis: Relations Within a Single Set of Variables." Harris commences this chapter with a definition of principal components and the terminology that is both unique and common to PCA and factor analysis (FA). Harris does make note that "many factor analysts consider PCA to be such a degenerate subcategory of FA that they take umbrage at the use of a common terminology" (p. 320). However, for the sake of clarity Harris does use notation that can be used for both PCA and FA. I have always found Tabachnick and Fidell's (2001) table of FA matrices to be most helpful for the student just getting their feet wet with this set of techniques. The scalar formula for PCA is then illustrated, with an attendant derivation of the characteristic vector and roots. Even though the trigonometric solution that follows may prove unwieldy for some students, there are some general geometric and trigonometric principles employed in factor analysis that add further clarity to the technique. What will be of some interest to the more seasoned modelers is the section on "Additional Unique Properties of PCs," in which Harris briefly discusses the equivalence of squared loadings and normalized variance, nature of uncorrelated principal components, and so forth. An extended discussion regarding factor/component interpretation follows, which at this juncture in the text is mostly presented algebraically. The various advantages and uses of principal components, such as computational convenience and the nature of orthogonal components, lead into a discussion of the "labeling problem." Harris argues that, instead of relying on the factor structure for the labeling of the components, "interpretations should be based on the factor-score coefficients" (p. 334). After a detailed discussion of methods by which to handle linear dependencies (i.e., as determinant approaches zero), examples and interpretation of PCA are provided. The next section on "Quantifying Goodness of Interpretation of Components" deviates (as the author admits) from other texts in that Harris recommends that a first step in interpreting the principal components is to "compute ... the normalized variance of that simplified PC ... and its correlations with the other simplified PCs" (p. 348). Thus, Harris follows with a justification for such an approach, given the "reduction in the risk of misleading your readers as to just how well your interpretations represent the PCs" (p. 351). Sections that follow include significance testing for PCs as well as the sampling properties of covariance and correlation-based PCs. An extended discussion and review of rotation follows, including the derivations of the rotated structures. An engaging discourse follows on "Objective Criteria for Rotation" and the often-mentioned subject/bane of factor indeterminacy. What will strike a chord with many readers, especially those savvy to testing alternative models in SEM, is the assertion that "factor structures having 'simple structure' are no more (nor less) valid than any of the other factor structures that are obtainable by rotation of our initial PCA" (p. 361). This is a key point that cannot be over-emphasized. Varimax and quartimax rotation are reviewed with examples following.

The following chapter, titled "Factor Analysis: The Search for Structure," continues the psychometric/multivariate orientation of the proceeding chapter. Where this technique deviates from the prior delineation of principal components is the incorporation of error variance; that is, "a separation of shared and unique variance" (p. 394). The FA model is reviewed as well as the notation (with Harris admitting that the notation used in the chapter may not necessarily overlap with other FA texts). The reader will note that in the prior chapter, oblique rotation of the components was discussed, whereas early on in this FA chapter the topic of interrelated factors is introduced. Harris emphasizes additional considerations that need to be covered in FA: (a) estimating communalities, (b) the primary objective of reproducing **R** (as opposed to the PC goal of maximizing variance), and (c) difficulties in describing nonorthogonal factors (p. 397). Various strategies are presented for estimating communalities (e.g., direct theoretical solution so as to achieve minimum possible rank, empirical approximations, etc.). There is an engaging section that follows about the prudence of using the squared multiple correlation as the true communality. This is not a nontrivial issue, as it also impacts SEM users who choose to fix the reliability of their manifest indicators. Moreover, as the section on "Factor Analysis Procedures Requiring Communality Estimates" makes clear, the main diagonal entries of **R** are indeed the communalities. Methods by which to estimate the number of factors are reviewed, with the minimum-residuals (minres), and what will be familiar to many SEM users, maximum likelihood, covered in brief detail. In this context, confirmatory factor analysis (CFA) is introduced. The disadvantages of those methods are discussed (e.g., prior commitment to number of factors, computational procedures that are of some complexity, etc.), of which many SEM users are well aware. However, and as Harris notes, some of the concerns (e.g., computational complexity) have been somewhat allayed with the advances in computerized technology. Harris again brings up his bias toward interpreting pattern coefficients, even though he acknowledges that other researchers have also emphasized other matrices for interpretation (e.g., structure coefficients). Other approaches, such as image or cluster analysis, are briefly mentioned. The following section, titled "Factor Loadings Versus Factor Scoring Coefficients," continues Harris's contention that interpretation of loadings "should be supplanted in most cases by examination instead of the linear equation that relates subjects' scores in that factor to their scores on the original variables" (p. 410). An extended discussion of factor score indeterminacy follows, although again, it will behoove the reader to peruse more recent discussions on this issue, such as the Special Commentary Section in *Multivariate Behavioral Research* (Vol. 31, No. 4, 1996). However, Harris emphasizes that one of the more crucial (though ignored) sources of indeterminacy is the "tradition of interpreting factors in terms of loadings, rather than in terms of factor score coefficients" (p. 412). Even though this practice may have been widespread at the time of Harris's observation, it seems that more researchers are savvy to the notion of examining pattern matrices, structure matrices, factor scores, and so forth, so as to gather a more comprehensive assessment of model fit. The chapter concludes with a computerized EFA and interpretation of the output as well as an example of CFA via SAS PROC CALIS.

The final chapter, titled "The Forest Revisited," brings together four somewhat disparate topics: scales of measurement, violations of assumptions, nonlinear relations, and the utility of the multivariate general linear (MGL) hypothesis. The discussion on scales of measurement revolves around the much-debated issue of permissible statistics given the level of measurement. Harris makes clear that if we rigidly adhered to Stevens's typology, that being the requirement for interval scaled properties of our measures, many of our multivariate techniques would be deemed inappropriate. However, given that the distributions of the measures takes precedence over the scaling attributes, as well as the "robustness of statistical procedures under violation of normality or homogeneity of variance assumptions" (p. 445), it is argued by Harris, and has been by many (see, e.g., Velleman & Wilkinson, 1993), that the scaling attributes should not dictate the choice of statistical technique. Harris provides some evidence of the "low returns obtained by fretting over whether data have 'truly' interval scale properties" (p. 445) by way of measurers of association. For many readers, the stance on permissible arithmetic operations and transformations given the scale of measurement may seem to be much ado about nothing, especially given the longevity of this debate (see Gaito, 1980; Michell, 1986; Townsend & Ashby, 1984, for a spirited exchange). However, Harris continues this discussion with further provocative insights, especially as it pertains to transformations. The following section on assumptions sheds further light on robustness to violations in the univariate context, which seems to be fairly well understood by now. However, the same level of understanding is not as translucent for multivariate assumptions. Many multivariate texts urge the reader to be cautious of Box's *M* test of homogenous variance/covariance matrices, given its sensitivity to violations of multivariate normality. Hence, and as Harris points out, "large strides are still to be expected" (p. 452) in examining the robustness of multivariate violations. Nonlinear relations in multivariate statistics is the next subject briefly under examination, followed by a section titled "The Multivariate General Linear Hypothesis." In this section Harris asserts that all of the significance tests discussed in prior chapters "can be represented as tests of a single, very general hypothesis: the multivariate general linear hypothesis (MGL hypothesis)" (p. 456). Harris details the matrix algebra that forms the MGL model, with the computation of the GCR again serving as the test statistic. As Harris notes, given the all-encompassing nature of the MGL hypothesis, "one approach to teaching multivariate statistics would be to begin with the MGL hypothesis and present all other significance tests as special cases thereof," although he admits that the MGL hypothesis "is simply too abstract to be readily digestible until the user has built up a backlog of more specified procedures" (p. 459). I do concur with that statement, as the emphasis on testing the GCR throughout the text may indeed prove befuddling for many students who are just being introduced to multivariate statistics. The next section broadly covers SEM using CALIS LinEqs as the software of choice. The coverage of SEM is cursory at best and will not serve as a sufficient springboard for those desiring a more comprehensive introduction to SEM (e.g., as opposed to the SEM chapter by Ullman in Tabachnick and Fidell, 2001). Curiously, Harris states that SEM is not a general model for multivariate statistics, which would run counter to the opinions of others (e.g., Dawson, 1998) who have provided some preliminary evidence that SEM indeed may be the most GLM.

In summary, Harris's newest edition will be of interest to those who are interested in a slightly different angle to approaching multivariate statistics. Most salient is the emphasis on significance testing via the GCR. However, I'm not sure to which extent students just being introduced to multivariate statistics will find this leaning to be wholly intelligible, at least on initial perusal. This text is sufficiently mathematical for those who desire a text that is more technical than the user-friendliness of Stevens (2002) but not of the density of Johnson and Wichern (1999). Moreover, even though we must applaud Harris for the commendable act of "arrangement" for final camera copy as "prepared by the author" (p. iv), hence assumedly expediting the release of the publication, there are multiple formatting errors, typesetting, and so forth, that although trivial when compared to the substantive content, still may prove to be distracting to the reader of this text. I recently received an errata sheet, and there are probably close to 80 errors. Thus, I would be hard-pressed to recommend a text of this magnitude to a student until all the errors are rectified. Moreover, much research has been conducted in multivariate statistics since Harris's prior edition, and although he injects a few recent cites, for the most part the citations are relatively dated. Thus, the next edition (or printing) should update the reference list.

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