DOCUMENT RESUME

ED 242 792 TM 840 214

AUTHOR Thompson, Bruce
TITLE Canonical Correlation Analysis: An Annotated Bibliography.
PUB DATE 26 Apr 84
NOTE 24p.; Paper presented at the Annual Meeting of the American Educational Research Association (68th, New Orleans, LA, April 23-27, 1984).
PUB TYPE Speeches/Conference Papers (150) -- Reference Materials - Bibliographies (131)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Annotated Bibliographies; *Correlation; Data Analysis; Factor Analysis; Matrices; *Multivariate Analysis; Sample Size

ABSTRACT

Several important issues related to canonical correlation have been recognized and resolved during the last several years. The purpose of this presentation is to offer an organized, comprehensive, and current annotated bibliography of the many recent developments and extensions of canonical methods. The bibliography does not emphasize references to highly mathematical treatments of conventional canonical methods, since many of these treatments have been widely available for years. The citations are organized in categories, as follows: Conceptual (Consumer) Explanations of Canonical; Literature Syntheses on Canonical; Basic Topics: Structure and Index Coefficients, Redundancy Coefficients and Analysis, Rotation of Canonical Matrices, and Cross-Validation and Invariance Procedures; and Special Topics: Variable Set Reduction, Sample Size Considerations, Part and Partial Methods, Canonical and Interbattery Factor Analysis, and Generalized Canonical Analysis. Each topic is briefly introduced in a short narrative prior to the presentation of the annotations associated with the various topics. (BW)

CANONICAL CORRELATION ANALYSIS:

AN ANNOTATED BIBLIOGRAPHY

Bruce Thompson

University of New Orleans 70148

Presented at the annual meeting of the American Educational Research Association (session #44.10), New Orleans, LA, April 26, 1984.

Some 15 years ago Cohen (1968) argued that regression models subsume analysis of variance techniques, and that several benefits can be realized by employing more general analytic methods. Since Cohen's article first appeared several authors have written textbooks that emphasize the use of regression models in analysis of variance designs (e.g., Edwards, 1979). Perhaps as a result, the method "has been extensively used" in recent research (Willson, 1982, p. 1).

However, several authors (Baggaley, 1981, p. 129; Fornell, 1978, p. 168) have pointed out that canonical correlation is an even more general analytic system and subsumes all parametric statistical procedures. Knapp (1978, p. 410) demonstrated this in detail and concluded that "virtually all of the commonly encountered parametric tests of significance can be treated as special cases of canonical correlation analysis, which is the general procedure for investigating the relationships between two sets of variables." So it is not too surprising that Krus, Reynolds, and Krus (1976, p. 725) argue that, "Dormant for nearly half a century, Hotelling's (1935, 1936) canonical variate analysis has come of age. The principal reason behind its resurrection was its computerization and inclusion in major statistical packages." Thus Wood and Erskine (1976) were able to devote a review entirely to applications of canonical methods.

Although at least one author (Levine, 1977) has asserted that "especially with respect to canonical correlation, there seem to be relatively few remaining puzzles to be solved," in fact several important puzzles regarding this most general analytic method have been both recognized and then resolved during the last several years. The purpose of this presentation is to offer an organized, comprehensive, and current annotated bibliography of the many recent developments and extensions of canonical methods. The bibliography does not emphasize references to highly mathematical treatments of <u>conventional</u> canonical methods, since many of these treatments have been widely available for years (e.g., Cooley & Lohnes, 1971, pp. 168-200; Marascuilo & Levin, 1983, pp. 177-215).

A unique feature of the present treatment involves the effort to identify "seminal works" regarding various aspects of canonical analysis. These generally are recent works that have made a major contribution to the understanding and development of canonical methods. If the reader were to consult only these works, notwithstanding the brief character of the perusal, a comprehensive understanding of canonical methods should be realized.

The seminal works are indicated by the use of asterisks in citations. The citations in the narrative and the accompanying annotations are organized in categories, as follows:

Basic Topics

Special Topics

Each topic is briefly introduced in a short narrative prior to the presentation of the annotations associated with the various topics.

A noteworthy indication of increased interest in canonical methods involves the recent publication of several articles which explain canonical methods in conceptual or essentially non-mathematical terms. It is particularly noteworthy that these pieces represent journals from such disparate disciplines--this pattern is a tribute to the potential power of canonical methods to address problems in various areas of behavioral or social science.

Baggaley, A.R. Multivariate analysis: an introduction for consumers of behavioral research. Evaluation Review, 1981, 5, 123-131.

Baggaley discusses parametric methods in general and non-mathematical terms. The author presents a figure to illustrate graphically the relationships among parametric techniques. Baggaley notes that "it is rather surprising" that canonical methods have not been used more often and cites some example applications of the techniques.

Balon, R.E., & Philport, J.C. Canonical correlation in mass communication research. Journal of Organizational Behavior, 1977, 21, 199-209.

This work is notable for its use of Venn diagrams and other devices to discuss canonical methods in conceptual terms. The article is comprehensive in its coverage, and discusses in turn a variety of "issues" that should be considered in applying the technique. However, the work was accepted for publication in 1976 and consequently does not reflect some of the insights that have developed in the interim. The discussion of redundancy coefficients particularly suffers in this regard.

*Knapp, T.R. Canonical correlation analysis: a general parametric significance-testing system. Psychological Bulletin, 1978, 85, 410-416.

Although Knapp indicates that his article assumes familiarity with matrix algebra, most of the discussion can be conceptually digested even by readers who wish to skip some of the brief mathematical proofs which are offered. The author discusses various parametric methods (simple correlation, t-test, ANOVA, etc.) and shows that these methods are special cases of canonical analysis.

Kuylen, A.A.A., & Verhallen, T.M.M. The use of canonical analysis. Journal of Economic Psychology, 1981, 1, 217-237.

The presentation of canonical methods in this article is logically organized around topics and questions such as "1.1. What is canonical analysis?" and "1.4. When to use canonical analysis?". The article includes concrete heuristic examples of methods. For example, results from a canonical analysis are compared with results from a redundancy analysis.

McLaughlin, S.D., & Otto, L.B. Canonical corrlation analysis in family research. Journal of Marriage and the Family. 1981, 43, 7-16.

The authors include an appealing graphic illustration of the canonical model, as well as both "a contrived example" and actual research applications of the methods. The article's treatment of some issues associated with canonical significance testing is particularly noteworthy, although of a more technical nature.

Carlson, J.E. Use and interpretation of canonical analyses. Paper presented at the annual meeting of the American Educational Research Association, New York, 1982.

Carlson's discussion of canonical analyses is broadly representative of the literature. The treatment is somewhat mathematical but is complemented by an understandable presentation of associated logic. In general the references are current, except as regards rotation of canonical matrices. The paper is especially noteworthy for its discussion of canonical computer programs, although some available software is ignored (e.g., Thompson, 1982). The discussion of the use of the SPSS MANOVA routine to generate fairly complete canonical results (by declaring one set of variables to be the dependent variables and by declaring the other set of variables to be covariates) may be helpful to some researchers who have not explored this possibility. (Carlson's address: University of Ottawa; Ottawa, Canada K2L 1A1)

Darlington, R.B., Weinberg, S.L., & Walberg, H.J. Canonical variate analysis and related techniques. Review of Educational Research, 1973, 43, 433-454.

This article is somewhat unique in that the treatment emphasizes reflection on the logic of canonical methods with a view toward delineating the problems which might be most appropriate to investigate with canonical analysis. This feature of the work somewhat compensates for datedness. An example of datedness is the discussion of the importance of structure coefficients in interpreting canonical results. The authors are in agreement with an emerging consensus that these coefficients must be consulted to interpret canonical results. However, the authors' argument in favor of using structure coefficients is based on an assertion that these coefficients should be more stable than function coefficients. Most researchers argue a different but equally compelling logic. Furthermore, more recent empirical studies do not establish that structure coefficients have inherently less sampling error than other coefficients.

Thompson, B. Canonical analysis as the multivariate general linear model. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April. 1984.

This paper is comprehensive in its scope. For example, there are 103 references in the work and a computer program which computes several canonical variants is presented. One somewhat unique feature of the work involves the author's tendency to use quotations to convey a more direct sense of the literature on various topics. (Thompson's address: College of Education; University of New Orleans; New Orleans, LA 70148)

A structure coefficient is the product-moment correlation between a variable in a canonical set with the canonically-weighted aggregate of all the variables in the same set. An index coefficient is the product-moment correlation between a variable in a canonical set with the canonically-weighted aggregate of all the variables in the other variable set. More complete, conceptual, and concrete explanations of these coefficients are available elsewhere (Thompson, 1984, pp. 20-37). Thompson and Borrello (in press) provide a thorough discussion of the relationships between regression and canonical results and between the structure coefficients which both procedures yield.

It is particularly noteworthy that so many authors now agree that structure coefficients must be interpreted to understand canonical results. In a scholarly literature characterized by a staid and reserved tone, several authors have been emphatic and somewhat emotional in arguing this position (Kerlinger & Pedhazur, 1973, p. 344; Levine, 1977, p. 20; Meredith, 1964, p. 55). However, contemporary analytic practice does not yet sufficiently reflect the insights presented by these authors.

Meredith, W. Canonical correlations with fallible data. Psychometrika, 1964, 29, 55-65.

Meredith presents methods for correcting canonical results for the attenuation associated with measurement error. However, researchers may be inclined to collect new, more reliable data when measurement error is so severe as to warrant correction. Concern about measurement error is also somewhat less likely to be a concern if cross-validation or invariance techniques are applied to detect the serendipidous effects of error influences. Still, this work merits attention as the first piece to argue for greater attention to structure coefficients.

Thompson, B. The instructional strategy decisions of teachers. Education, 1980, 101, 150-157. (b)

Kuylen and Verhallen (1981, p. 229) argue that "cross-loadings [index coefficients] are more conservative, less inflated than within-set loadings [structure coefficients] and form a more solid base for interpretation." However, most published studies do not report these coefficients, perhaps because most but not all (Thompson & Frankiewicz, 1978) computer programs do not compute index coefficients. This work is noteworthy in that it reports index coefficients and offers a rather intriguing substantive interpretation (p. 156) of the calculated values.

In 1968 Stewart and Love proposed a new coefficient, the redendancy coefficient, which they suggested might be helpful as a "summary tool" or as an aid to interpretation. This work led to a protracted and heated exchange of views regarding the psychometric meaning and value of the coefficiert (Nicewander & Wood, 1974). From this heat eventually came light which led back to the conclusions initially postulated by Stewart and Love in their original work.

Stewart and Love noted that in a canonical analysis involving x predictor variables and y criterion variables, x separate multiple correlation coefficients (R) for the x variables each predicted with all the y variables in the other set could be computed. The average of these squared R's is the pooled redundancy coefficient for the predictor variable set. The pooled redundancy coefficient for the criterion variable set can be computed in the complementary fashion this time computing y R's.

Researchers became somewhat disenchanted with these coefficients as it was realized (1) that redundancy coefficients involve regression coefficients which do not simultaneously consider all variables and thus are not totally multivariate and (2) that these coefficients are not optimized by canonical analysis and so may not be of much interest in an analysis which optimizes other conditions. However, Wollenberg (1977) proposed methods that do optimize redundancy, and both Johansson (1981) and DeSarbo (1981) proposed extensions of Wollenberg's redundancy analysis. In short, redundancy analysis may be of considerably more interest than redundancy coefficients, when they are calculated in a canonical analysis.

Stewart, D.K., & Love, W.A. A general canonical correlation index. Psychological Bulletin, 1968, 70, 160-163.

As noted previously, the authors present several computational procedures for calculating canonical redundancy. A graphic illustration of the "non-symmetric" character of these coefficients is presented. The illustration is reasonably effective at communicating the counterintuitive "non-symmetric" features of the index.

Dawson-Saunders, B.K. Correcting for bias in the canonical redundancy statistic. Educational and Psychological Measurement, 1982, 42, 131-143.

Some authors have argued that redundancy coefficients are less biased than canonical correlation coefficients and have recommended that the statistical significance of redundancy coefficients might be tested in place of testing canonical correlation coefficients. This Monte Carlo study indicates that both coefficients are biased when sample size is small and also explores the impacts of various correction formulae.

*Cramer, E.M., & Nicewander, W.A. Some symmetric, invariant measures of multivariate association. Psychometrika, 1979, 44, 43-54.

The authors present seven measures of multivariate association which, unlike redundancy coefficients, are truly multivariate and which "(a) are functions of canonical correlations; (b) can be considered to be symmetric measures...; (c) are invariant under nonsingular linear transformations of either set of variables; (d) reduce to the squared multiple correlation if one set contains a singular variable; (e) can be statistically evaluated using standard significance tests; and (f) have the same numerical ordering for all sets of data" (p. 44).

*van den Wollenberg, A.L. Redundancy analysis: an alternative for canonical correlation analysis. Psychometrika, 1977, 42, 207-219.

The author notes that canonical correlation analysis does not optimize redundancy and suggests that, logically, if redundancy is of interest, then it ought to be the focus of the analytic technique. Wollenberg then proposes a method which does optimize redundancy rather than multivariate relationship. The article includes an example application with artificial data.

Warwick (1975, p. 518) notes that "there can be no assurance that CANCORR [the SPSS canonical routine] will find any comprehensive patterning to the data at all. Moreover, just as factor analysis will produce factors which the researcher may or may not be able to identify in substantive terms, so canonical correlation analysis can produce canonical variates, even clearly defined ones, that may not make any sense to the researcher." However, several researchers have noted the identities between principal components analysis and factor analysis (Bartlett, 1948; Burt, 1948). Since rotation has proven so helpful to the interpretation of factor analytic results, logic suggests that rotation may be equally helpful in the more general canonical case.

However, conventional factor analytic rotation seems to violate the fundamental logic of canonical analysis. Thorndike (1976a, p. 4) puts the matter quite clearly and convincingly: "The two sets of variables presumably have been kept separate for a reason. If an investigator is interested in the structure of the combined sets, then he probably should have performed a traditional factor analysis in the first place." But Bentler and Huba (1982) have presented an elegant rotation procedure that simplifies interpretation while also honoring membership in variable sets. Huba, Palisoc and Bentler (1982) discuss a computer program that implements this procedure. (Huba's address: Department of Psychology; UCLA; Los Angeles, CA 90024)

There is some disagreement regarding which canonical matrix to rotate--either the function coefficients or the structure coefficients can be rotated. Cliff and Krus (1976, p. 38) recommend rotation of the structure coefficients and then proceed to present a heuristic example in which function coefficients are rotated. Reynolds and Jackosfsky (1981, p. 667) make a convincing case in favor of rotating structure coefficients. They note that "special notice however, should be made of the weights exceeding one. It should again be pointed out that the canonical weights [function coefficients] are analagous to regression betas and, thus, are not constrained to be less than one. This fact, in combination with the varimax criterion, tends to result in extreme solutions. Thus, the standardized nature of the structure coefficients becomes even more appealing when rotation for the sake of interpretability is considered."

*Cliff, N., & Krus, D.J. Interpretation of canonical analysis: rotated vs. unrotated solutions. Psychometrika, 1976, 41, 35-42.

The authors recommend the use of varimax rotation to simplify canonical results. However, as noted previously, this procedure seems to violate the fundamental logic of canonical methods. This work is still seminal in that the authors demonstrate that rotation does not alter either canonical communality coefficients or the sum of all possible squared canonical correlation coefficients.

*Bentler, P.M., & Huba, G.J. Symmetric and asymmetric rotations in canonical correlation analysis: new methods with drug variable examples. In N. Hirschberg & L.G. Humphreys (Eds.), Multivariate applications in the social sciences. Hillsdale, NJ: Erlbaum, 1982.

Bentler and Huba present their canonical rotation strategies using a liberal application of graphic and intuitive explanations. The article includes example analyses for both "artificial" and real data.

Thompson, B. Rotation of results from canonical correlation analysis. Paper presented at the annual meeting of the Mid-South Educational Research Association, Nashville, November, 1983.

Thompson both discusses the logic of various rotation methods and presents example applications. Two aspects of the treatment are somewhat unique. The author discusses calculation of canonical correlation and function coefficients when structure coefficients are rotated. An example application of confirmatory rotation is also presented.

The tendency of correlation methods to capitalize on chance is widely recognized. As Nunnally (1967, p. 280) notes, "one tends to take advantage of chance in any situation where something is optimized from the data at hand." Thompson (1981b) labelled coefficients which estimate the sampling specificity of results "invariance coefficients." In the canonical case two methods for computing invariance coefficients have been identified.

Thorndike, R.M. Correlational procedures for research. New York: Gardner, 1978.

Thorndike discusses canonical correlation (pp. 175-202) and proposes the following method for computing canonical invariance coefficients: "The predictor and criterion standard [Z] scores of each individual in the cross-validation group are multiplied by the appropriate canonical weights for a pair of composites and summed to yield scores on the two composites. The product moment correlation between these composite scores is the cross-validation canonical correlation. Although this correlation may be tested for statistical significance by the procedures appropriate for bivariate correlations, its magnitude relative to the original canonical correlation is generally of more interest than the probability that it is zero in the population."

Thompson, B. Comparison of two methods for computing canonical invariance coefficients. Paper presented at the annual meeting of the Southwest Educational Research Association, Austin, 1982. [Order document #03991, National Auxillary Publication Service, P.O. Box 3513, Grand Central Station, New York, NY 10017] (b)

Thompson notes that "best fit" rotations of results across sample splits could be employed in canonical analysis, just as the methods are employed to compute the correlations among factors across samples. The procedure can be implemented with a computer program presented by Veldman (1967). The paper includes an actual application of both this procedure and Thorndike's.

Thorndike (1978, p. 188) has expressed the law of parsimony in the canonical context: "as the number of variables increases, the probable effect of these sources of [error] variation on the canonical correlations increases. Therefore, the fewer variables there are in a canonical analysis which yields a correlation of a given magnitude, the greater is the likelihood that that correlation is due to real, population-wide sources of covariation, rather than to sample-specific sources." Logically, canonical results should be more invariant if variables can be eliminated in an analog of stepwise, backward regression analysis. Several methods for such an analysis have been proposed, and Thompson (1982a) presents a computer program which automates one procedure.

*Rim, E. A stepwise canonical approach to the selection of "kernel" variables from two sets of variables (Doctoral dissertation, University of Illinois at Urbana-Champaign, 1972). Dissertation Abstracts International, 1973, 34, 623A. (University Microfilms No. 73-17,386)

Rim presents seven possible indices which might be used to guide variable elimination. The author then investigated the effects on shrinkage of eliminating variables based on consultation of either of two indices--function coefficients for the first canonical function only or the sum of the absolute products of significant squared canonical correlations and the function coefficients on these significant functions. The investigator conducted Monte Carlo studies and also applied the methods with actual data. The methods tended to yield results that brought about less shrinkage, as expected.

Thompson, B. Stepwise canonical correlation analysis. Paper presented at the annual meeting of the Southwest Educational Research Association, Austin, 1982. (e)

Thompson proposed an alternative procedure derived from a logic that acknowledges identities between canonical analysis and factor analysis. Canonical communality coefficients are consulted to determine which variables should be eliminated. The article presents an application of the method in an actual study.

The importance of large sample size when canonical correlation analysis is applied has been widely recognized. Thorndike (1978) explains that canonical analysis in particular provides numerous opportunities to capitalize on chance on recommends (p. 184) that the influence of sampling error might be minimized by requiring as a rule of thumb that there be roughly 10 persons per variable in any study. Thorndike also indicates that a more stringent rule involving squaring the number of variables should be considered. These rules become acutely critical if researchers neglect to perform invariance analyses.

Sweet, R.A. _Distribution of canonical correlations and Gaussian rank canonical correlations for small samples from various distributions with various correlation matrices_. Unpublished doctoral dissertation, University of California, Berkeley, 1973.

For the canonical case involving 10 variables (five in each set) Sweet investigated the positive bias of canonical correlation coefficients with $n = 25$ ($n/v = 2.5$). With the bivariate correlations in the populations in the Monte Carlo study all "set" to be zero, the median canonical correlation for the first canonical function extracted in 1000 samples was .66. The result dramatically underscores the importance of securing adequate samples in order to conduct canonical analyses.

Weinberg, S.L., & Darlington, R.B. Canonical analysis when number of variables is large relative to sample size. _Journal of Educational Statistics_, 1976, _1_, 313-332.

Weinberg and Darlington present an analog to canonical correlation analysis which they demonstrate is less likely to capitalize on sampling error. The procedure is rather cumbersome but the article is instructive relative to the considerations involving sample size.

Rao (1969) proposed canonical analogs of part and partial correlational procedures. Although these procedures and some of their extensions (Lee, 1978) are conceptually intriguing, "little is known about the characteristics of the estimates and dimensionality tests for partial canonical analysis" (Carlson, 1982, p. 11). More importantly, as Timm and Carlson (1976, p. 175) note, "the interpretation of partial, part, and bipartial canonical correlations are far from clear when variates are 'partialled out' of variates they do not directly influence."

Tucker (1958) proposed a factor analysis model that can be used to determine which factors are common to two domains of variables. The problem considered by the model is very similar to the problem addressed by canonical analysis. Thus the computer program presented by Huba, Palisoc and Bentler (1982) both performs rotations of canonical results and presents the corresponding interbattery factor analytic solution.

Huba, G.J., Newcomb, M.D., & Bentler, P.M. Comparison of canonical correlation and interbattery factor analysis on sensation seeking and drug use domains. Applied Psychological Measurement, 1981, 5, 291-306.

In understandable and concrete terms, the authors compare canonical and interbattery factor analytic results using an actual data set. They note that the interbattery solution involves only a variance adjustment of the canonical results. Since the adjustment involves a constant, the relative contributions of variables to solutions are not adjusted and so both techniques should lead to similar substantive interpretations.

The classical presentation of canonical analysis (Hotelling, 1935) is limited to investigating relationships involving two sets of variables. Horst (1961) presents a generalization of canonical methods to cases involving _m_ sets of variables. Jain (1972) has presented a computer program which implements the procedure. Tate (1982) provides an illustration in which the method is applied.

References

Allen, M.J., & Yen, W.M. Introduction to measurement theory. Monterey, CA: Brooks/Cole, 1979.

Baggaley, A.R. Multivariate analysis: an introduction for consumers of behavioral research. Evaluation Review, 1981, 5, 123-131.

Balon, R.E., & Philport, J.C. Canonical correlation in mass communication research. Journal of Organizational Behavior, 1977, 21, 199-209.

Barcikowski, R.S., & Stevens, J.P. A Monte Carlo study of the stability of canonical correlations, canonical weights and canonical variate-variable correlations. Multivariate Behavioral Research, 1975, 10, 353-364.

Bartlett, M.S. The statistical significance of canonical correlations. Biometrika, 1941, 32, 29-38.

Bartlett, M.S. Internal and external factor analysis. British Journal of Psychology: Statistical Section, 1948, 1, 73-81.

*Bentler, P.M., & Huba, G.J. Symmetric and asymmetric rotations in canonical correlation analysis: new methods with drug variable examples. In N. Hirschberg & L.G. Humphreys (Eds.), Multivariate applications in the social sciences. Hillsdale, NJ: Erlbaum, 1982.

Burt, C. Factor analysis and canonical correlation. British Journal of Psychology, 1948, 1, 96-106.

Campbell, D.T., & Erlbacher, A. How regression artifacts in quasi-experimental evaluations can mistakenly make compensatory education look harmful. In M. Guttentag & E.L. Struening (Eds.), Handbook of evaluation research (Vol. 1). Beverly Hills: Sage, 1975.

Carlson, J.E. Use and interpretation of canonical analyses. Paper presented at the annual meeting of the American Educational Research Association, New York, 1982.

Carver, R.P. The case against statistical significance testing. Harvard Educational Review, 1978, 48, 378-399.

Cohen, J. Multiple regression as a general data-analytic system. Psychological Bulletin, 1968, 70, 426-443.

Cooley, W.W., & Lohnes, P.R. Multivariate data analysis. New York: Wiley, 1971.

Cooley, W.W., & Lohnes, P.R. Evaluation research in education. New York: Irvington, 1976.

*Cliff, N., & Krus, D.J. Interpretation of canonical analysis: rotated vs. unrotated solutions. Psychometrika, 1976, 41, 35-42.

*Cramer, E.M., & Nicewander, W.A. Some symmetric, invariant measures of multivariate association. Psychometrika, 1979, 44, 43-54.

Cronbach, L.J. The two disciplines of scientific psychology. American Psychologist, 1957, 12, 671-684.

Cronbach, L.J. Validity. In R.L. Thorndike (Ed.), Educational Measurement. Washington: American Council on Education, 1971.

Darlington, R.B., Weinberg, S.L., & Walberg, H.J Canonical variate analysis and related techniques. Review of Educational Research, 1973, 43, 433-454.

Dawson-Saunders, B.K. Correcting for bias in the canonical redundancy statistic. Educational and Psychological Measurement, 1982, 42, 131-143.

Dawson-Saunders, B.K., & Doolen, D.R. An alternative method to predict performance: canonical redundancy analysis. Journal of Medical Education, 1981, 56, 295-300.

DeSarbo, W.S. Canonical/redundancy factoring analysis. Psychometrika, 1981, 46, 307-329.

Edwards, A.L. Multiple regression and the analysis of variance and covariance. San Francisco: Freeman, 1979.

Fornell, C. Three approaches to canonical analysis. Journal of the Market Research Society, 1978, 20, 166-181.

Fornell, C. (Ed.) A second generation of multivariate analysis (Vol. 2). New York: Praeger, 1982.

Glass, G.V, McGaw, B., & Smith, M.L. Meta-analysis in social research. Beverly Hills: Sage, 1981.

Gorsuch, R.L. Factor analysis. Philadelphia: Saunders, 1974.

Green, P.E. Mathematical tools for applied multivariate analysis. New York: Academic Press, 1978.

Guilford, J.P. Fundamental statistics in psychology and education (4th ed.). New York: McGraw-Hill, 1965.

Gulliksen, H. Methods for determining equivalence of measures. Psychological Bulletin, 1968, 70, 534-544.

Hays, W. Statistics. New York: Holt, Rinehart & Winston, 1963.

Hicks, C.R. Fundamental concepts in the design of experiments (2nd ed.). New York: Holt, Rinehart & Winston, 1973.

Homans, G.C. The nature of social science. New York: Harcourt, Brace & World, 1967.

Horst, P. Generalized canonical correlations and their applications to experimental data. Journal of Clinical Psychology, 1961, 26, 331-347.

Hotelling, H. The most predictable criterion. Journal of Experimental Psychology, 1935, 26, 139-142.

Huba, G.J., Newcomb, M.D., & Bentler, P.M. Comparison of canonical correlation and interbattery factor analysis on sensation seeking and drug use domains. Applied Psychological Measurement, 1981, 5, 291-306.

Huba, G.J., Palisoc, A.L., & Bentler, P.M. ORSIM2: a FORTRAN program for symmetric and asymmetric orthogonal rotation of canonical variates and interbattery factors. The American Statistician, 1982, 36, 62.

Huba, G.J., Wingard, J.A., & Bentler, P.M. Longitudinal analysis of the role of peer support, adult models, and peer subcultures in beginning adolescent substance use: an application of setwise canonical correlation methods. Multivariate Behavioral Research, 1980, 15, 259-280.

Huck, S.W., Cormier, W.H., & Bounds, W.G., Jr. Reading statistics in research. New York: Harper & Row, 1974.

Jain, A.K. CANCOR: Program for canonical correlation of three or more sets of variables. Journal of Marketing Research, 1972, 9, 69-70.

Johansson, J.K. An extension of Wollenberg's redundancy analysis. Psychometrika, 1981, 46, 93-103.

Kaiser, H.F. The varimax method of factor analysis. Unpublished doctoral dissertation, University of California at Berkeley, 1956.

Kaiser, H.F. A second generation little jiffy. Psychometrika, 1970, 35, 401-415.

Kaiser, H.F., Hunka, S., & Bianchini, J. Relating factors between studies based upon different individuals. In H.J. Eysenck & S.B.G. Eysenck (Eds.), Personality structure and measurement. San Diego: Knapp, 1969. Pp. 333-343.

Kerlinger, F.N. Foundations of behavioral research (2nd ed.). New York: Holt,

Rinehart & Winston, 1973.
Kerlinger, F.N., & Pedhazur, E.J. Multiple regression in behavioral resea.ch. New York: Holt, Rinehart and Winston, 1973.
Kim, J. Factor analysis. In N.H. Nie, C.H. Hull, J.G., Jenkins, K. Steinbrenner, & D.H. Bent (Eds.), Statistical package for the social sciences (2nd ed.). New York: McGraw-Hill, 1975.
*Knapp, T.R. Canonical correlation analysis: a general parametric significance-testing system. Psychclogical Bulletin, 1978, 85, 410-416.
Krus, D.J., Reynolds, T.J., & Krus, P.H. Rotation in canonical variate analysis. Educational and Psychological Measurement, 1976, 36, 725-730.
Kuylen, A.A.A., & Verhallen, T.M.M. The use of canonical analysis. Journal of Economic Psychology, 1981, 1, 217-237.
Lee, S. Generalizations of the partial, part and bipartial canonical correlation analysis. Psychometrika, 1978, 43, 427-431.
Levine, M.S. Canonical analysis and factor comparison. Beverly Hills: Sage, 1977.
Long, J.M. An extension of stepwise variable-reduction procedures for canonical analysis (Doctoral dissertation, University of Illinois at Urbana-Champaign, 1974). Dissertation Abstracts International, 1975, 35, 7128A. (University Microfilms No. 75-11,663)
McLaughlin, S.D., & Otto, L.B. Canonical corrlation analysis in family research. Journal of Marriage and the Family. 1981, 43, 7-16.
Marascuilo, L.A., & Levin, J.R. Multivariate statistics in the social sciences: a researcher's guide. Monterey, CA: Brooks/Cole, 1983.
Maxwell, A.E. Canonical variate analysis when the variables are dichotomous. Educational and Psychological Measurement, 1961, 21, 259-271.
Meredith, W. Canonical correlations with fallible data. Psychometrika, 1964, 29, 55-65.
Miller, J.K. The sampling distribution and a test for the significance of the bimultivariate redundancy statistic: a Monte Carlo study. Multivariate Behavioral Research, 1975, 10, 233-244.
Morrow, J.R., Jr., & Frankiewicz, R.G. Strategies for the analysis of repeated and multiple measures designs. Research Quarterly, 1979, 50, 297-304.
Muller, K.E. Relationships between redundancy analysis, canonical correlation, and multivariate regression. Psychometrika, 1981, 46, 139-142.
Nicewander, W.A., & Wood, D.A. Comments on "A general canonical correlation index." Psychological Bulletin, 1974, 81, 92-94.
Nunnally, J.C. Psychometric theory. New York: McGraw-Hill, 1967.
Ping, C., & Tucker, L.R. Transformation of both predictor and criterion variables to a simplified regression structure. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, 1976. (ERIC Document Reproduction Service No. ED 121 809)
Pitts, M.C., & Thompson, B. Cognitive styles as mediating variables in inferential comprehension. Reading Research Quarterly, in press.
Rader, B.T. The application of canonical correlation methodology with vocational education data. Journal of Industrial Teacher Education, 1975, 12, 51-61.
Rao, B.R. An asymptotic expansion of the distribution of Wilk's criterion. Bulletin of the International Statistics Institute, 1951, 33, 177-180.
l ao, R.B. Partial canonical correlations. Trabajso de estadistica y de investigacion operative, 1969, 20, 211-219.

Reynolds, T.J., & Jackosfsky, E.F. Interpreting canonical analysis: the use of orthogonal transformations. Educational and Psychological Measurement, 1981, 41, 661-671.

*Rim, E. A stepwise canonical approach to the selection of "kernel" variables from two sets of variables (Doctoral dissertation, University of Illinois at Urbana-Champaign, 1972). Dissertation Abstracts International, 1973, 34, 623A. (University Microfilms No. 73-17,386)

Stewart, D.K., & Love, W.A. A general canonical correlation index. Psychological Bulletin, 1968, 70, 160-163.

Stavig, G.R., & Acock, A.C. Applying the semistandardized regression coefficient to factor, canonical, and path analysis. Multivariate Behavioral Research, 1981, 16, 207-213.

Sweet, R.A. Distribution of canonical correlations and Gaussian rank canonical correlations for small samples from various distributions with various correlation matrices. Unpublished doctoral dissertation, University of California, Berkeley, 1973.

Tatsuoka, M.M. Validation studies: the use of multiple regression equations. Champaign, IL: Institute for Personality and Ability Testing, 1969.

Tatsuoka, M.M. Multivariate analysis: techniques for educational and psychological research. New York: John Wiley & Sons, 1971.

Tatsuoka, M.M. Multivariate analysis in educational research. In F.N. Kerlinger (Ed.), Review of research in education (1st ed.). Itasca, IL: Peacock, 1973.

Tate, R.L. Generalized canonical correlation analysis: an illustration. Paper presented at the annual meeting of the American Educational Research Association, New York, 1982.

Thompson, B. Canonical correlation: recent extensions for modelling educational processes. Paper presented at the annual meeting of the American Educational Research Association, Boston, 1980. (ERIC Document Reproduction Service No. ED 199 269) (a)

Thompson, B. The instructional strategy decisions of teachers. Education, 1980, 101, 150-157. (b)

Thompson, B. The problem of OVAism. Paper presented at the annual meeting of the Mid-South Educational Research Association, Lexington, 1981. [Order document #03980, National Auxillary Publication Service, P.O. Box 3513, Grand Central Station, New York, NY 10017] (a)

Thompson, B. Utility of invariance coefficients. Perceptual and Motor Skills, 1981, 52, 708-710. (b)

Thompson, B. CANBAK: a computer program which performs stepwise canonical correlation analysis. Educational and Psychological Measurement, 1982, 42, 849-851. (a)

Thompson, B. Comparison of two methods for computing canonical invariance coefficients. Paper presented at the annual meeting of the Southwest Educational Research Association, Austin, 1982. [Order document #03991, National Auxillary Publication Service, P.O. Box 3513, Grand Central Station, New York, NY 10017] (b)

Thompson, B. Factor analysis based on "doubly-centered" raw data matrices. Paper presented at the annual meeting the Southwest Educational Research Association, Austin, 1982. (ERIC Document Reproduction Service No. ED 219 404) (c)

Thompson, B. A logic for stepwise canonical correlation analysis. Perceptual and Motor Skills, 1982, 54, 879-882. (d)

Thompson, B. Stepwise canonical correlation analysis. Paper presented at the annual meeting of the Southwest Educational Research Association, Austin, 1982. (e)

Thompson, B. Rotation of results from canonical correlation analysis. Paper presented at the annual meeting of the Mid-South Educational Research Association, Nashville, November, 1983.

Thompson, B. Canonical analysis as the multivariate general linear model. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April, 1984.

Thompson, B., & Borrello, G.M. The importance of structure coefficients in regression research. Educational and Psychological Measurement, in press.

Thompson, B., & Frankiewicz, R.G. CANON: a computer program which produces canonical structure and index coefficients. Educational and Psychological Measurement, 1979, 39, 219-222.

Thompson, B., & Miller, A.H. Dissonance theory and education students' attitudes toward teachers. Journal of Experimental Education, 1978, 47, 55-59.

Thompson, B., & Rucker, R. Two-year college students' goals and program preferences. Journal of College Student Personnel, 1980, 21, 393-398.

Thorndike, R.M. Strategies for rotating canonical components. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, 1976. (ERIC Document Reproduction Service No. ED 123 259) (a)

Thorndike, R.M. Studying canonical analysis: comments on Barcikowski and Stevens. Multivariate Behavioral Research, 1976, 11, 249-253. (b)

Thorndike, R.M. Canonical analysis and predictor selection. The Journal of Multivariate Behavioral Research, 1977, 12, 75-87.

Thorndike, R.M. Correlational procedures for research. New York: Gardner, 1978.

Thorndike, R.M., & Weiss, D.J. A study of the stability of canonical correlations and canonical components. Educational and Psychological Measurement, 1973, 33, 123-184.

Thurstone, L.L. The vectors of the mind. Chicago: University of Chicago Press, 1935.

Thurstone, L.L. Multiple factor analysis. Chicago: University of Chicago Press, 1947.

Timm, N.H. Multivariate analysis with applications in education and psychology. Monterey, CA: Brooks/Cole, 1975.

Timm, N.H., & Carlson, J.E. Part and bipartial canonical correlation analysis. Psychometrika, 1976, 41, 159-176.

Tucker, L.R. An inter-battery method of factor analysis. Psychometrika, 1958, 23, 111-136.

Veldman, D.J. FORTRAN programming for the behavioral sciences. New York: Holt, Rinehart & Winston, 1967.

Warwick, P.V. Canonical correlation analysis: Subprogram CANCORR. In N.H. Nie, C.H. Hull, J.G. Jenkins, K. Steinbrenner, & D.H. Bent (Eds.), SPSS: Statistical package for the social sciences (2nd ed.). New York: McGraw-Hill, 1975.

Weinberg, S.L., & Darlington, R.B. Canonical analysis when number of variables is large relative to sample size. Journal of Educational Statistics, 1976, 1, 313-332.

Willson, V.L. Research techniques in AERJ articles: 1969 to 1975. Educational Researcher, 1980, 9, 5-10.

Willson, V.L. Misuses of regression approaches to ANOVA and ANCOVA. Paper presented at the annual meeting of the Southwest Educational Research Association, Austin, 1982.

Wilkinson, L. Confirmatory rotation of MANOVA canonical variates. Multivariate Behavioral Research, 1977, 12, 487-494.

Wimmer, R. Canonical correlation/factor analysis: similarities and differences. Journal of Organizational Behavior, 1977, 21, 211-213.

*van den Wollenberg, A.L. Redundancy analysis: an alternative for canonical correlation analysis. Psychometrika, 1977, 42, 207-219.

Wood, D.A., & Erskine, J.A. Strategies in canonical correlation with application to behavioral data. Educational and Psychological Measurement, 1976, 36, 861-878.

Zinkgraf, S.A. Performing factorial multivariate analysis of variance using canonical correlation analysis. Educational and Psychological Measurement, 1983, 43, 63-68.