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Hummel T J & Sligo J R. Empirical comparison of univariate and multivariate analysis of variance procedures. *Psychol. Bull.* 76:49-57, 1971.
[Student Personnel Office, University of Minnesota, Minneapolis, MN and Ohio University, Athens, OH]

The paper describes a Monte Carlo study in which univariate and multivariate analysis of variance procedures were used singly or in combination to form three approaches to the analysis of multivariate normal data. [The *SSCI*® indicates that this paper has been cited in over 190 publications.]

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I was introduced to multivariate analysis of variance (MANOVA) by Joseph Sligo, my coauthor, while taking statistics courses as part of the PhD program at Ohio University. It was a rather new topic in educational and psychological research, and, while pieces had been written on the subject, practice had not been greatly affected.

Researchers were sometimes admonished to use MANOVA lest the probability of a Type I error be unknown. I absorbed this advice thoroughly and was guilty in my student days of having what I later coined as the "p-variate knee-jerk response." It was based on a simple rule: use MANOVA if there is more than one dependent variable.

As I began to think more deeply about the topic, I realized that I did not know exactly *how* "the probability of a Type I error" would be affected. My first speculations were altogether wrong. I thought the p-values for the individual univariate tests must be affected, and, since there was concern, they must be inflated. Shortly thereafter, I found out about "family-wise error rate" and realized that, while the rates were well known for the limit conditions of complete independence or dependence of the criterion variables, no one had estimated family-wise rates for more realistic cases where some degree of correlation exists between p-variables distributed according to multivariate normal distribution with population covariances unknown. (This was the stimulus for the research.)

I studied the two-group p-variate case using Monte Carlo methods. The particular multivariate *t*-distribution involved when univariate *t*-tests are used on p different variables is exceedingly difficult to deal with. Complicating matters further was the need to know the joint distribution of the p univariate t statistics and the multivariate test criterion. To my knowledge, obtaining the required error rates using analytic methods has not been accomplished and might be considered an intractable problem. This made Monte Carlo methods a viable approach, for at least estimates could be obtained.

The only problem I had in designing and programming the computer (beyond the usual "bugs" that most programmers encounter) was in programming the multivariate data generator. This subroutine worked perfectly when the off-diagonal elements in the population covariance matrices were equal (the case I studied) but not when they were unequal (which I was not studying). I was hurrying to finish the research so I could be off to my new position at the University of Minnesota, so I asked my PhD committee if I needed to resolve the problem since it would not affect my results. All members, except Sligo (my mentor but not my adviser), said I need not bother. I found the error and to this day I thank him for his stance on the matter. I would always have worried that the error would be found, and, even though my results would not have changed, it would still have been an embarrassment.

At least one researcher has suggested that the use of equal off-diagonal elements, mentioned in the preceding paragraph, caused the data to be different from any that would be found in actual research.[1] I have never accepted this as a valid criticism. Covariance matrices with equal off-diagonal elements provide benchmarks for judging other matrices.

Publication of the manuscript was rather straightforward except for one hitch. The editor of the journal labeled a term I had used, "experiment-wise error rate," as a barbarous neologism. I had to respond with a lengthy letter containing a half dozen or so references showing that the term was well accepted in the statistical literature. Following publication of the article, I was gratified to receive hundreds of letters from both within and outside of the US.

I think the paper generated so much interest because it was the first time that any family-wise error rate estimates were available for the multivariate case I investigated. Furthermore, recommendations made in the paper were supported with evidence, and the risks associated with continuing current practice were identified clearly for the first time.

Recently, I finished a research project with Charles B. Johnston that revisits and greatly expands on my earlier work with Sligo, and it presents new recommendations for researchers using MANOVA.[2] A report of the work was made at the American Educational Research Association's 1986 convention (and is available through ERIC) and in Johnston's doctoral thesis, which was completed under my supervision at the University of Minnesota.[3] The work has been submitted for journal publication.

1. **Wilkinson L.** Response variable hypotheses in the multivariate analysis of variance. *Psychol. Bull.* 82:408-12, 1975.
2. **Hummel T J & Johnston C B.** An empirical comparison of size and power of seven methods for analyzing multivariate data in the two-sample case. (Abstract.) *Res. Educ.* 21:201, 1986. ERIC Document No. ED 269 480.
3. **Johnston C B.** *An empirical comparison of size and power of seven methods for analyzing multivariate data in the two-sample case.* PhD dissertation, University of Minnesota, 1986.