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Authors
Nygren, Thomas E
Widaman, Keith F

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Using Nonorthogonal Analysis of Variance Designs in Psychological Research: Comment on Donahue and Costar

Thomas E. Nygren and Keith F. Widaman
Ohio State University

In an attempt to demonstrate bias in high school counselors' choices of careers for female students and to identify possible counselor characteristics associated with such bias, Donahue and Costar (1977) had high school counselors select an appropriate occupation for each of six case studies (three males and three females). Interpretation of the results of the study is complicated, however, in that the experimental design is not clearly reported in sufficient detail. It appears that the authors used additional demographic information about the respondents to generate a nonorthogonal between-subjects analysis of variance design with at least nine factors—sex, marital status, age, education, "professionalism" (an undefined variable or set of variables), mother's education level, father's education level, demographic location, and "idealism" (also undefined). On the basis of multivariate and separate univariate analyses, Donahue and Costar purported to show that the counselors tended to discriminate against females.

There are a number of potential problems with the methodology employed in the study. None of these issues are appropriately addressed in the study in order to provide the reader with a means of evaluating the correctness of the measurement instrument, the hypotheses being tested, and the data analysis procedures.

One serious problem has already been addressed by Smith (1979) in her examination of an aspect of the data not reported in the Donahue and Costar article. Smith found large differences in scores associated with the occupations chosen by the counselors for the case studies on the two different forms used. She has shown how the authors' failure to control for such an effect due to nonequivalent forms leads to an uncorrectable confounding in the design. This confounding seriously weakens the conclusions cited in the study.

Additional Methodological Problems

Dependent variables. Each of the 28 occupations used in the study were initially scored on 7-point scales of salary range, level of education required, and level of supervision. These three scales served as the bases for the dependent variables in the multivariate analysis of variance (MANOVA) procedure. It is not clear why the authors chose to destroy the interval continuum on the remuneration variable when the MANOVA procedure assumes such a scale of measurement. The education and supervision variables are also rated variables with at best only ordinal properties. This is particularly relevant, since the authors proceeded to obtain *difference* scores based on the difference between the sum of the scale values for the occupations chosen for the males and the sum for the females. This is meaningful only for interval-scaled data. In addition, since the latter two dependent variables are clearly rated variables, interrater reliabilities for each should have been obtained. There is, then, some question as to the meaningfulness of the dependent variables used in the MANOVA.

Analysis of variance. There is, however, a potentially more damaging problem with the actual data analyses that makes the results rather tenuous. Donahue and Costar (1977) used a multifactor experimental design for which, by the very nature of the

Requests for reprints should be sent to T. E. Nygren, Psychology Department, Ohio State University, 404C W. 17th Avenue, Columbus, Ohio 43210.

variables used, it was not possible to control cell frequencies. Respondents were placed at various levels of the nine variables on the basis of their answers to the personal data form. The number of degrees of freedom for testing main effects and interactions in such a design far exceeds the number of respondents (N = 228). This limitation in conjunction with the unequal cell frequencies makes it impossible to use a standard analysis of variance procedure. The only possible analysis that can be done is a least squares procedure for a nonorthogonal analysis of variance (Overall & Klett, 1972; Overall & Spiegel, 1969). It appears that this was done in the Donahue and Costar study with a restriction to main effects and two-way interactions. This information is not actually presented in their article.

Nonorthogonal analyses are not uncommon in psychological research, although their complexity requires a clear understanding of their potential applications. The complexity arises from the fact that there are three general least squares procedures for accomplishing the analysis—each leading to different hypotheses actually being tested as well as different numerical results (Overall & Klett, 1972; Overall, Spiegel, & Cohen, 1975). Hence, these different least squares methods may lead to tests of hypotheses (like those presented by Donahue and Costar in their Table 1; Donahue & Costar, p. 483) about main effects and interactions that may not be interpretable in the same way as for ordinary balanced designs. In fact, one of the least squares procedures, Overall and Spiegel's (1969) Method 3, is dependent upon an a priori ordering of the main effects and interactions. What this means, very simply, is this: (a) The results one obtains using this procedure are dependent on the ordering of the effects the researcher wishes to test. (b) The procedure "can never be expected to test the same hypotheses in a nonorthogonal design that can otherwise be tested in an orthogonal design involving the same factors" (Overall et al., 1975, p. 185). (*c*) One could use exactly the same data as Donahue and Costar and obtain different "significant" results.

There is, however, one least squares method that appears to be most suitable for this data—Method 1 as described by Overall et al. (1975). Although it would not be useful to detail the foundations of this procedure here, one crucial remark needs to be made. Without specifying the least squares procedure that they have used, Donahue and Costar (1977) have reduced their results to a set of numbers that have no justifiable implications.

Number of tests vs. Type I errors. Even if it could be assumed that the authors have used the appropriate least squares procedure, there is still a question of whether all of the obtained significant effects are really "significant." For nine independent variables there are 45 tests in each univariate analysis of variance (ANOVA). Of the total 135 tests (9 main effects and 36 two-way interactions for each dependent variable), an α level of .05, which appears to be the significance level used in this study, would suggest an expectation of about seven significant results by chance alone. Excluding the initial tests for all counselors, this is about what was actually reported in their Table 1. In fact, for this many tests, the probability of getting *at least* one Type I error when α = .05 is about .999! Hence, even if all other aspects of the study were valid, the "significant" results in Table 1 of the Donahue and Costar (1977) article should be accepted very cautiously.

Mean difference scores in Table 1. As a final comment on the results presented in their Table 1, it is worth looking at the mean difference scores and standard deviations for "all counselors" (first row) and for the two interactions (last two rows). It should be noted that these values are identical in each univariate ANOVA. This is because these numbers have nothing to do with the interactions. It does not make sense to use these mean difference scores to represent an interaction. The interactions are only understandable if presented graphically or if *all* cell means are shown. Finally, since all three dependent variables are described as important in the study, the authors should have presented the results of the multivariate tests.

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