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[1] Presently at the University of Strathclyde (Glasgow, Scotland), Great Britain.

ANNOTATED BIBLIOGRAPHY ON ROBUSTNESS STUDIES OF STATISTICAL PROCEDURES

Z. Govindarajulu and R. T. Leslie

SUMMARY

An annotated bibliography consisting of about 360 articles on robustness studies is prepared. Throughout the bibliography, a broad interpretation of robustness has been considered. In each annotation the authors have made every effort to summarize the entire article. However, we have not judged the relative merits of each article. Although we have taken care to include most of the articles on robustness, especially some unpublished technical reports, it is quite possible that some articles have inadvertently been omitted. This bibliography is by no means complete since quite a few papers belonging to the category of working papers and unpublished technical reports are not easily accessible. Each article has been classified under a broad classification scheme which distinguishes estimation from testing hypotheses, parametric from nonparametric, among various departures from postulated assumptions, and theory from Monte Carlo study.

INTRODUCTION

Robustness plays an important role in statistical inference and methodology. Broadly speaking, a statistical procedure is said to be robust if it is insensitive to slight departures from the postulated assumptions. These usually pertain to the parametric form of the underlying distribution and the independence of the random variables. However, as the sample size increases, owing to the operation of the central limit theorem, most of the statistical procedures become robust. For instance, the chi-square test arising either in goodness-of-fit or in contingency tables is robust as the total sample size increases. This is one of the oldest robust procedures, enunciated by Karl Pearson. Similarly the test procedures based on the arithmetic mean and "Student's" t become robust. In his thesis, Bryant (1960) has extensively studied the robustness properties of F, t, χ^2 and the correlation coefficient tests. However, Box and others have noted that the F-test is sensitive to kurtosis of the underlying distribution. While it can reasonably be inferred that large sample situations do not normally pose a problem regarding robustness, an interesting question one could ask is how large should the sample size be in order for the procedure to be "sufficiently" robust. There are no easy answers to this problem, the required sample size depending on the procedure itself. Hence, Monte Carlo studies are highly desirable to throw more light on this problem in certain areas.

Another form of robustness of a procedure is in terms of contamination. That is, a population whose exact distributional form is known may be "contaminated" with some other population. The question then arises as to when we can ignore the contamination, or attempt to devise a

procedure which is insensitive to small degrees of contamination. This problem has been extensively studied by Tukey and his colleagues, and they propose certain modified versions of the arithmetic mean and t.

The third phase of departure could be termed lack of randomness in the sample. However, it is hard to characterize the lack of randomness or the dependence of the observations in the sample. To the best of our knowledge, not much work has been done in this area. However, for Markovian dependence, Billingsley (1961) has established the asymptotic or large sample robustness of certain estimators and testing procedures. For small sample sizes, in order to conduct Monte Carlo studies, one should specify the types of dependence of interest. In this connection it is known that the product-moment correlation loses its significance as soon as the samples are from non-normal populations.

Another aspect of robustness is the effect on sampling distributions of estimators, due to departure from estimation procedures (like using ratio estimators instead of simple inflated estimators), or of post-stratification or other departures used to improve the efficiency of estimators. Thus there are many types of robustness. Of interest to us are robustness of estimation and testing procedures. Usually one is interested in robustness due to (i) departure from the postulated distribution, (ii) departure from the sampling method, especially from the assumption of independence of observations, and (iii) contamination with another population. The study of robustness could deal with other small samples (like Monte Carlo studies) or with large sample or asymptotic theory. Factors (i), (ii) and (iii) affecting the confidence coefficient or length of confidence interval in estimation problems and factors affecting the nominal level of significance and power of the test procedure would be of much interest.

Before one embarks on a research project in this area (for instance, Monte Carlo studies) one should know what has been done in this regard. As pointed out, there are fragmented Monte Carlo studies which have been conducted in the past and reports are scattered in the literature. Hence, there is a need for a systematic literature search in this area and a preparation of an annotated bibliography on robustness studies. Such a bibliography could be a time and dollar saving guide for a research worker, especially the one who wished to embark on a Monte Carlo study.

While we were preparing this bibliography two notable studies on robustness have come to our attention. The one by Hyrenius, Adolfson, et. al. (1964) is annotated although it is highly selective. The other by Fridshal and Posten (1966) is much broader, however it is not annotated. The latter work has been helpful to us especially in locating some of the early studies on robustness. Most of the leading journals in statistics including the *International Journal of Abstracts* have been searched for the period 1965-1969. We have searched all the articles and the papers listed at the back of each article in the work of Fridshal and Posten (1966). Professor Richard Savage's files on nonparametric statistical references together with his bibliography of nonparametric statistics have also been searched. Thus, the main sources of the literature searched are:

E. Earl Bryant:
Theoretical Sampling Distributions, Their Practical Limitations and Some Experimental Results. Master of Arts Thesis submitted to the American University, Washington, D.C. (1960).

Donald Fridshal and Harry O. Posten:
Bibliography on Statistical Robustness and Related Topics. Research Report No. 16, Department of Statistics, University of Connecticut, Storrs, (1966).

Lawrence Hatch and Harry O. Posten:
Robustness of the Student-Procedure: A Survey. Research Report No. 24, Department of Statistics, University of Connecticut, Storrs, Connecticut, (1966).

H. Hyrenius, and I. Adolfson, et. al.:
Selected Bibliography on Non-normality. Publication No. 12, Department of Statistics, University of Gothenburg, Sweden, (1964).

I. Richard Savage:
Bibliography of Nonparametric Statistics. Harvard University Press, Cambridge, Mass. (1962).

LIST OF PERIODICALS SEARCHED

The following journals were searched for the period 1965-1969 unless otherwise specified.

American Statistician

Annals of the Institute of Statistical Mathematics, Tokyo

Annals of Mathematical Statistics

Biometrics

Biometrika

Bulletin de l'Institute International de Statistique

Calcutta Statistical Association Bulletin

Econometrika

Human Biology

International Journal of Abstracts: Statistical Theory and Methods. (1959-1969)

Journal of the American Statistical Association.

Journal of the Royal Statistical Society, Series A.

Journal of the Royal Statistical Society, Series B.

SIAM Journal of Applied Mathematics

Mathematical Reviews (for abstracts only)

Sankhyā: Series A

Sankhyā: Series B

Technometrics

Theory of Probability and Its Applications

DESCRIPTION OF ENTRIES

Articles are, in general, listed with alphabetical order of the authors' names. Multiple-authored items are listed fully under the first named author only. The remaining authors are cross-referenced to the first author. The authors' names have been listed in the same way as they appear in the article. For each author, first the items of which he is the sole author are listed according to year, then follow the dual authored items of which he is the principal author which are given alphabetically by the second author and then by year. Multiple-authored items are listed after the contributions of the principal author involving single or dual authorship and they are ordered alphabetically by successive authors and then by year. The ordering by year, of course, is only applicable when the same set of authors have contributed several items. Cross-references are inserted accordingly. Certain abstracts are also annotated. All "classified" material is omitted from this bibliography. There are about 360 annotated items in this bibliography.

CLASSIFICATION OF REFERENCES

Every article has a classification which is in four parts. The first part classifies it into estimation (E) or hypothesis (H). The second part classifies it into parametric (P) or nonparametric (Np). The third part classifies it into (i) departure from postulated distribution (D), (ii) departure from the assumption of randomness (R), (iii) contamination or mixture with another population (C) or, (iv) other (O). The fourth part consists of classifying the article into (i) theory (Th) or (ii) Monte Carlo study (MC), or (iii) general (G) which includes expository articles and those that are heuristic. For example, if an article has the classification E-P-C-MC then it means that the article is concerned with parametric estimation when the population is contaminated with some other population and a Monte Carlo study has been carried out.

BIBLIOGRAPHY

ADICHIE, J. N. (1968a). Asymptotic efficiency of a class of nonparametric tests for regression parameters. *Annals of Mathematical Statistics,* 38, 884-893. **H-Np-D-Th**

The Pitman efficiency of the proposed tests relative to the classical F-test is proved to be the same as the efficiency of the corresponding rank score tests relative to the t-test in the two-sample problem.

ADICHIE, J. N. (1968b). Estimates of regression parameters based on rank tests. *Annals of Mathematical Statistics,* 38, 894-904. **E-Np-D-Th**

In a recent paper, Hodges and Lehmann proposed a general method of obtaining robust point estimates for the location parameter, from statistics used to test the hypothesis that this parameter has a specified value. In this paper this method is used to define point estimates $\hat{\alpha}$ and $\hat{\beta}$ of α and β, in terms of certain test statistics.

I. ADOLFSON, et. al. See: Hyrenius, H., and Adolfson, I., et. al. (1965). **E&H-P-D-MC&Th**

AFIFI, A. A. M., ELASHOFF, R. M., and LANGLEY, P. G. (1968). An investigation into the small sample properties of a two-sample test of Lehmann's. *Journal of the American Statistical Association,* 63, 345-352. **H-Np-C-Th**

The authors examine how well the asymptotic null distribution of a two-sample test due to Lehmann approximates the small sample distribution of the test, compare the validity of this Lehmann test with the validity of the two-sample t-test under the null hypothesis of equal means, and compare the power of this Lehmann test with the power of the t-test. The general conclusion is that experimenters will prefer to use the t-test when the underlying distribution is the scale contaminated compound normal distribution and the sample sizes are less than thirty.

AGGARWAL, P. O. and GUTTMAN, IRWIN (1959). Truncations and tests of hypothesis. *Annals of Mathematical Statistics,* 30, 230-238. **H-P-O-Th**

The authors consider the effects of symmetric truncation upon the size and power of the UMP test of the hypotheses $\mu = \mu o$ against $\mu > \mu o$ for nontruncated normal distribution with known σ^2. The writers in general conclude that symmetric truncation introduces serious losses in size rather than in power.

ANDERSEN, S. L. See: Box, G. E. P. and Andersen, S. L. (1955). **H-P-O-Th**

ARNOLD, H. J. (1964). Permutation support for multivariate techniques. *Biometrika,* 51, 65-70. **H-P-D-Th**

Behavior of a simple function of Hotelling's T^2 is examined when the underlying populations are bivariate normal, rectangular and double exponential. Only a mild disagreement is observed between theoretical significance levels assuming normality and the actual permutation significance levels. A method of adjusting the test criterion when one suspects that the data do not come from a normal population is discussed. It involves fitting the parameters of a standard β distribution by the first two permutation cumulants.

ARNOLD, HARVEY J. (1965). Small sample power of the one-sample Wilcoxin test for non-normal shift alternatives. *Annals of Mathematical Statistics,* 36, 1767-1778. **H-Np-D-Th**

The power of the one-sample Wilcoxon test is computed for the hypotheses that the medium is zero against various shift alternatives for samples drawn from several different non-normal distributions.

ATIQULLAH, M. (1962a). On the effect of non-normality on the estimation of components of variance. *Journal of the Royal Statistical Society,* Series B, 24, 140-147. **E-P-D-Th**

It is shown that for a wide variety of balanced situations, the interval estimation of the upper variance component is not affected by non-normality in the error component. A method is suggested for constructing a confidence interval for the ratio of variance components in a balanced model, without the assumption of normality.

ATIQULLAH, M. (1962b). The estimation of residual variance in quadratically balanced least-square problems and the robustness of the F-test. *Biometrika,* 49, 83-91. **H-P-D-Th**

The robustness of the F-test under conditions of non-normality is investigated for quadratically balanced designs. The effect of non-normality on the F-test is estimated in some cases of nonquadratically balanced designs.

ATIQULLAH, M. (1963). On the randomization distribution and power of the variance ratio test. *Journal of the Royal Statistical Society,* Series B, 25, 334-347. **H-P-D-Th**

A certain matrix representation is given for the usual sum of squares of treatments in some commonly used designs. This representation appreciably simplifies the calculation of randomization moments under null and non-null hypotheses. Fisher's z-transformation is applied to study the randomization distribution of the F-ratio. A comparison of the power curves under randomization and normal theory conditions is made.

ATIQULLAH, M. (1964a). The robustness of the covariance analysis of a one-way classification. *Biometrika,* 51, 365-372. **H-P-D-Th**

The effect of non-normality and the effect of treatment slope interaction in the analysis of covariance is studied. Unlike the analysis of variance F-test, covariance F-test is found to be appreciably affected by non-normality even in balanced classifications. The degree of sensibility is determined by the distribution of the concomittant variables. The interaction does not seem to have serious effect.

ATIQULLAH, M. (1964b). Robustness to non-normality of test for sensitivity in similar experiments. *Biometrics,* 20, 478-381. **H-P-D-Th**

The author studies the use of z-transformation while testing for the equality of variances in a random effects linear model without the assumption of normality. He concludes that the Schuman-Bradley test is fairly insensitive to moderate non-normality.

ADYANTHAYA, N. K. See: Pearson, E. S. and Adyanthaya, N. K. (1928). **H-P-D-Th**

ADYANTHAYA, N. K. See: Pearson, E. S. and Adyanthaya, N. K. (1929). **H-P-D-MC**

BALLAS, J. A. and WEBSTER, J. T. (1966). On dependent tests from a nonorthogonal design. *Journal of the American Statistical Association,* 61, 803-812. **H-P-R-Th**

This paper illustrates, through a special case, an effect of nonindependent numerators on F-tests in an analysis of variance. Symmetrical balanced incomplete block designs are considered with "blocks" a random effect and no interaction.

BAKER, FRANK B. See: Collier, Raymond O. and Baker, Frank B. (1963). **H-P-D-MC**

BAKER, FRANK B. See: Collier, Raymond O. and Baker, Frank B. (1966). **H-P-O-MC**

BAKER, F. B. and COLLIER, RAYMOND O. (1966). Some empirical results on variance ratios under permutations in the completely randomized design. *Journal of the American Statistical Association,* 61, 813-820. **H-P-O-MC**

Standard distribution theory for the variance ratio no longer holds if the basic data are permuted. In the present study, basic data sets possessing various combinations of skewness, kurtosis, and a number of observations were employed to study the effect of these factors on error probabilities. The empirical results indicate a good agreement with standard distribution theory over a reasonable range of skewness and kurtosis.

BAKER, FRANK B. and COLLIER, RAYMOND O. (1968). An empirical study into factors affecting the F-test under permutation for the randomized block design. *Journal of the American Statistical Association.* 63, 902-911. **H-P-D-MC**

Existing theoretical and empirical evidence indicates that, except for small samples, the null and non-null distributions of the variance ratios involved in the randomized block design, based upon normal theory agree reasonably well with those under permutation theory. The present paper investigated the combined effect of block-treatment interaction and block variance heterogeneity upon this agreement. Additionally, the combined effect of kurtosis and block-variance heterogeneity was studied. The results indicated that kurtosis of the basic data had negligible effect upon either the null or non-null distributions of the variance ratios involved.

BAKER, G. A. (1931). Random sampling from non-homogeneous populations. *Metron,* 7, 67-87. **E-P-C-Th**

Sampling distributions of mean, standard deviation, coefficient of variation, etc., are derived for cases when underlying distributions are essentially combinations of different distributions. Combinations of two normal, rectangular, type III populations are considered separately. Some empirical verification is attempted.

BAKER, G. A. (1931a). Distribution of the means of samples of n drawn from a population represented by a Gram-Charlier series. *Annals of Mathematical Statistics,* 1, 199-204. **E&H-P-D-Th**

It is the object of this paper to obtain exactly the distributions of the means of samples of n drawn from a population represented by a Gram-Charlier series.

BAKER, G. A. (1931b). The relation between the means and variances, mean-squared errors and variances in samples from combinations of normal populations. *Annals of Mathematical Statistics,* 2, 333-354. **E&H-P-C-MC**

The case of samples of two from combinations of normal populations is investigated. Also empirical sampling results for two special populations are presented.

BAKER, G. A. (1932). Distribution of the means divided by the standard deviations of samples from non-homogeneous populations. *Annals of Mathematical Statistics,* 3, 1-9. **E&H-P-C-Th**

This paper discusses the distribution of the means of samples of size two, measured from the mean of the population divided by the standard deviations of the samples for nonhomogeneous populations composed of two normal populations, and also presents experimental results for samples of size four.

BAKER, G. A. (1934). Transformation of non-normal frequency distributions into normal distributions. *Annals of Mathematical Statistics,* 5, 113-123. **E&H-P-D-Th**

Valuable approximations to the distributions of the statistics of the original non-normal populations are obtained using certain transformations.

BAKER, G. A. (1935). Note on the distributions of the standard deviations and second moments of samples from a Gram-Charlier population. *Annals of Mathematical Statistics,* 6, 127-130. **E&H-P-D-MC**

It is known that if the sampled population is normal there is a simple relation between the distribution of the standard deviations of samples of size n and the distribution of the second moments of the samples about the mean of the population. In case the sampled population can be represented by a Gram-Charlier series, there is no such relation. The author could not obtain a general law of distribution by obtaining the distribution of the standard deviations for samples of 2, 3, 4. . . .

BAKER, G. A. (1946). Distribution of the ratio of sample range to sample standard deviation for normal and combinations of normal distributions. *Annals of Mathematical Statistics,* 17, 366-369. **E-P-D-Th**

Distribution of the sample range in terms of sample standard deviation is empirically investigated for normal and bimodal parent distributions.

BANCROFT, T. A. See: Kale, B. K. and Bancroft, T. A. (1967). **E&H-P-D-Th**

BANERJEE, S. K. (1957). A theoretical lower bound to the probability of Student's ratio. *Sankhyā*, 18, 391-394. **H-Np-D-Th**

Theoretical lower bound as well as some numerical values are obtained for the probability of "Student's" t-statistic.

BARTLETT, M. S. (1935). Some aspects of the time-correlation problem in regard to tests of significance. *Journal of the Royal Statistical Society*, Series A, 98, 536-543. **H-P-R-Th**

In any statistical problem, it is always necessary to examine the validity of the specification on which a test of significance is based. The considerations provided by the author stress the frequent failure of the ordinary specification in the problem of correlating from series of economic and sociological character, and show therefore the especial need for caution in statistical references arising out of such problems.

BARTLETT, M. S. (1947). The use of transformations. *Biometrics*, 3, 39-52. **H-P-D-Th**

The author discusses the utility of the important transformations of the experimentally observed variable which has been used to make the underlying mathematical theory usefully applicable. Some of these are numerically illustrated.

BASU, A. P. (1964). Effect of truncation of a test for the scale parameter of the exponential distribution. *Annals of Mathematical Statistics*, 35, 209-213. **H-P-O-Th**

This paper investigates the effects on the operating characteristics of a test for the scale parameter of the exponential distribution on the assumption that the sample is from a "complete" exponential population when in reality it is known to have come from a truncated exponential population. The results derived are valid for samples of any size.

BATEN, W. D. (1934). The probability law for the sum of 'n' independent variables each subject to the law (1/2h) Sech (πx/2h). *Bulletin of the American Mathematical Society*, 40, 284-290. **E&H-P-D-Th**

The author computes the probability law for n finite as well as infinite by straight integration.

BELL, C. B. (1968). Randomized nonparametric tests for several hypotheses. *Technometrics*, 10, 420. **H-Np-D-Th**

Tests based on a randomized statistic corresponding to a maximal similar partition of the sample space are nonparametric and have good ARE (asymptotic relative efficiency) relative to several standard statistics.

BELL, C. B. and DOKSUM, K. A. (1966). "Optimal" one-sample distribution-free tests and their two-sample extensions. *Annals of Mathematical Statistics*, 37, 120-132. **H-Np-D-Th**

The object of this paper is the development of a theory of optimal one-sample goodness-of-fit tests (in the sense of being locally most powerful) and optimal two-sample randomized distribution-free statistics analogous to well-known results of Hoeffding, Terry, Lehmann, Chernoff and Savage, Capon, and others for two-sample nonrandomized rank statistics. Existence of locally most powerful tests for a class of alternatives consisting of "contaminated" Koopman-Pitman distributions is demonstrated.

Randomized versions of the two-sample most powerful and locally most powerful rank statistics are considered and shown to be asymptotically equivalent to the locally most powerful rank statistics.

BELL, C. B., MOSER, J. M., and THOMPSON, RORY (1966). Goodness criteria for two-sample distribution-free tests. *Annals of Mathematical Statistics*, 37, 133-142. **H-Np-D-MC**

Chapman's goodness criterion for comparing distribution-free tests, for finite sample sizes, over a large class of alternatives, is extended to the two-sample problem. Study is confined to rank tests which satisfy Scheffe's boundary condition and are strongly distribution-free. Some of the maximum powers of the Mann-Whitney-Wilcoxon, Fisher-Yates, van der Waerden, Doksum, Savage, Epstein-Rosenbaum and Cramer-von Mises statistics are tabulated.

BELZ, MAURICE H. and HOOKE, ROBERT (1954). Approximate distribution of the range in the neighborhood of low percentage points. *Journal of the American Statistical Association,* 49, 620-636. **E-Np-D-Th**

The authors carry out: (i) an investigation of the distribution of the range under the assumption of independence, and a comparison of the probability obtained from this distribution with that obtained from the exact distribution when the range is extreme, (ii) the development of a practical procedure for approximating the critical probabilities associated with the range based on the assumption that the order statistics in question are normally distributed.

BERK, ROBERT H. (1966). Limiting behavior of posterior distributions when the model is incorrect. *Annals of Mathematical Statistics,* 47, 51-58. **H-P-D-Th**

Under certain conditions it is shown that asymptotically, the posterior distribution for a parameter θ is confined to a set (called the asymptotic carrier) which may in general contain more than one point. An example shows that, in general, there need be no convergence (in any sense) of the posterior distribution over the asymptotic carrier. This is in contrast to the known asymptotic behavior when the model is correct.

BERRY, A. C. (1941). The accuracy of the Gauission approximation to the sum of independent random variates. *Transactions of the American Mathematical Society,* 49, 112-136. **E&H-Np-D-Th**

A refinement of the central limit theorem in case of finite third order absolute moments is proposed.

BHATTACHARJEE, G. P. (1965a). Distribution of range in non-normal samples. *Australian Journal of Statistics,* 7, 127-141. **E-P-D-Th**

The effect of non-normality on the distribution of range is investigated by deriving the probability integral and the first two moments of the range of a sample drawn from a population represented by the first four terms of an Edgeworth Series. The use of range in place of root mean-square deviation of a non-normal population is then examined by comparing the effects of non-normality on various statistical procedures based on the two estimates. The study shows that the range is more sensitive to non-normality than the root mean-square estimate.

BHATTACHARJEE, G. P. (1965b). Effect of non-normality on Stein's two-sample test. *Annals of Mathematical Statistics,* 36, 651-663. **E-P-D-Th**

The author derives the distribution of Stein's t for non-normal populations represented by the first four terms of an Edgeworth series. The power function of Stein's test and the confidence level of the fixed length confidence interval are also obtained. The study shows that Stein's t is less robust than "Student's" t.

BHATTACHARJEE, G. P. (1968). Non-normality and heterogeneity in two-sample t-test. *Annals of the Institute of Statistical Mathematics,* 20, 239-254. **H-P-D-Th**

In this paper, the effect of non-normality and variance-heterogeneity of the parent populations on the two-sample t-test for equality of means is investigated by deriving the distribution of the test criteria for parent populations represented by first four terms of Edgeworth series having unequal variances. The test is found to be very misleading under certain circumstances.

BHATTACHARJEE, G. P. and NAGENDRA, Y. (1964). Effect of non-normality on a sequential test for mean. *Biometrika,* 51, 281-287. **H-P-D-Th**

In this paper the operating characteristic and average sample number are derived for populations of Edgeworth type. Some tables are given. Moderate departure from normality does not affect the test.

BHATTACHARYYA, G. K. (1967). Asymptotic efficiency of multivariate normal score test. *Annals of Mathematical Statistics,* 38, 1753-1758. **H-Np-C-Th**

It is shown that (i) ARE relative to Hotelling's T^2 test is 1, (ii) ARE relative to Wilcoxon's test exceeds 1 irrespective of the direction when underlying distribution is nonsingular multivariate normal. Normal

scores test behaves very well when the parent distribution has marginal densities dropping down to zero discontinuously at either tail and also in gross error models when heavy tails are present in the contaminating distribution.

BHATTACHARYYA, G. K. (1968). Robust estimates of linear trend in multivariate time series. *Annals of the Institute of Statistical Mathematics,* 20, 299-310. **E-Np-D-Th**

Median and weighted median estimates are obtained for the linear trend parameters of univariate time series by applying the Hodges-Lehmann method to some well-known nonparametric tests for trend.

BHATTACHARYYA, G. K. and JOHNSON, RICHARD A. (1968). Approach to degeneracy and the efficiency of some multivariate tests. *Annals of Mathematical Statistics,* 39, 1654-1660. **H-P-D-Th**

Lower bound for the ARE of the multivariate normal scores test relative to Wilcoxon and Hotelling's tests is studied. It is arbitrarily close to zero for some direction.

BHUCHONGKUL, SUBHA (1965). On the estimation of contrasts in linear models. *Annals of Mathematical Statistics,* 36, 198-202. **E-Np-D-Th**

In linear models with several observations per cell, a class of estimates of all contrasts is defined in terms of rank test statistics such as the Wilcoxon or normal scores statistics, which extend the results of Hodges and Lehmann (1963) and Lehmann (1963). The asymptotic efficiency of these estimates relative to the standard square estimates, as the number of observations in each cell increases, is shown to be the same as the Pitman efficiency of the rank tests on which they are based to the corresponding t-tests.

BICKEL, PETER J. (1965a). On some asymptotically nonparametric competitors of Hotelling's T^2. *Annals of Mathematical Statistics,* 36, 160-173. **H-Np-D-Th**

This paper examines the properties of tests for shift similar to Hotelling's T^2, based on (i) asymptotically normal estimates, in particular, those of the type considered in Bickel (see *Annals of Mathematical Statistics,* 35, (1964) 1079-1090), and (ii) the originating univariate test statistics of the latter group.

BICKEL, PETER J. (1965b). On some robust estimates of location. *Annals of Mathematical Statistics,* 36, 847-858. **E-Np-C-Th**

A new method of Winsorizing and trimming of sample means is discussed. For symmetric and unimodal distributions minimum efficiency of the Winsorized mean with respect to mean is studied. Also the Winsorized mean is compared with Hodges-Lehmann and Huber estimates.

BILLINGSLEY, P. (1961). *Statistical Inferences for Markov Processes,* University of Chicago Press. **E&H-P-R-Th**

For Markovian dependence, the author has established asymptotic robustness of certain estimators and test procedures.

BIRCH, JOHN J. See: Leaverton, Paul and Birch, John J. (1969). **H-P-D-MC**

BIRNBAUM, ALLAN and LASKA, EUGENE (1967a). Efficiency robust two-sample rank tests. *Journal of the American Statistical Association,* 62, 1241-1251. **H-Np-D-Th**

A rank test is said to be efficiently robust when no other has a uniformly better local power performance (risk point) for a specified class of distribution function alternatives.

BIRNBAUM, ALLAN and LASKA, EUGENE (1967b). Optimal robustness: a general method, with applications to linear estimators of location. *Journal of the American Statistical Association,* 62, 1230-1240. **E-P-O-Th**

Certain general concepts of optimal robustness of estimators and tests are formulated and techniques are given for constructing estimators and tests with such properties. The method is applied to the problem of estimating the location parameter by a linear function of ordered observations.

BIRNBAUM, ALLAN and LASKA, EUGENE M. (1968). Optimally robust linear estimators of location. *Annals of Mathematical Statistics,* 38, 1932 (abstract 9). **E-P-D-Th**

A new approach developed by the two authors is applied to determine admissible and maximum-efficient linear unbiased estimators of location, and their efficiencies for various distributions.

BONEAU, C. A. (1960). The effects of violations of assumptions underlying the t-test. *Psychological Bulletin,* 57, 49-63. **H-P-D-Th**

Monte Carlo study of the robustness of t-test has been carried out. The author concludes that for large number of situations, the use of ordinary t-tests and their associate tables will result in probability statements which are accurate to a high degree even though the assumptions of homogeneity of variance and normality of the underlying distribution are untenable.

BOSE, P. K. and SEN, P. K. (1963). On sensitiveness of a Z-score to non-normality. *Bulletin of the Calcutta Statistical Association,* 12, 93-96. **H-P-D-Th**

For the non-normal frequency distribution of the score (say, for education or psychometric problems) the concept of equivalent scores has been found to be very useful, and this naturally obviates the limitation of the Z-score to the extent that the assumption of normality is not essential for the purpose.

In this paper, the authors provide discussion about the effect of departure from normality of the trait distribution on the Z-score, and study its sensitiveness to non-normality.

BOX, G. E. P. (1953). Non-normality and tests on variance. *Biometrika,* 40, 318-335. **H-P-D-Th**

The author investigates the effect of non-normality on Bartlett's test, M_1, for the quality of variances in k groups of observations from non-normal parent populations. For large samples from non-normal populations it is shown that the distribution of M_1 depends strongly on the value of kurtosis. In small samples experimental evidence points to the same conclusion. In fact M_1 is investigated as a test of normality. The author concludes that when little is known of the parent distribution, a test of the homogeneity of variance in an analysis of variance should not be used since the usual test on the homogeneity of means is very little affected by non-normality of the parent population.

BOX, G. E. P. (1955). Some theorems on quadratic forms applied in the study of analysis of variance problems. Effects of inequality of variance and of variance and of correlation between errors in the two-way classification. *Annals of Mathematical Statistics,* 26, 271. **H-P-D-MC**

Theorems already enunciated in a previous paper on quadratic forms [see *Annals of Mathematical Statistics,* 25, 290-302 (1954)]; are used to determine the effects of inequality of variance and first-order serial correlation of errors in the two-way classification on the analysis of variance. It is found that, when the appropriate null hypothesis is true, inequality of variance from column to column results in an increased chance of exceeding the significance point for the test on homogeneity of column means, and a decreased chance for the corresponding test on row means. For moderate differences in variance neither effect is large. First-order serial correlation within rows produces a large effect on the "between rows" comparisons, but little effect on the "between columns" comparisons.

BOX, G. E. P. (1964a). Some theorems on quadratic forms applied in the study of analysis of variance problems. Effect of inequality of variance in the one-way classification. *Annals of Mathematical Statistics,* 35, 290-302. **H-P-D-Th**

The author derives the exact distribution of a weighed sum of independent chi-squares with even degrees of freedom which is similar to the exact distribution of the ratio of independent sums of type. He tests numerically simple approximation to distributions. The results are used to determine the effect of variance-heterogeneity on the distribution of F in one-way classification. The largest deviations are found when the groups are unequal.

BOX, G. E. P. and ANDERSON, S. L. (1955). Permutation theory in the derivation of robust criteria and the study of departures from assumptions. *Journal of the Royal Statistical Society,* Series B, 17, 1-34. **H-P-O-Th**

Permutation theory is discussed and applied to the problem of comparing variances. It is shown how a more robust test based on Bartlett's criterion may be obtained. The paper is mainly expository.

BOX, G. E. P. and TIAO, G. C. (1962). A further look at robustness via Bayes's theorem. *Biometrika,* 9, 419-432. **H-P-D-Th**

Some statistical inference procedures are robust in that their distribution theory is valid even when the underlying assumptions are violated. However, in this situation the statistical procedures may not be the "appropriate" or optimum. Alternatively the extent of deviation from assumptions may be injected into a prior distribution. The paper discusses analysis of data using t-test and a prior distribution for β the measure of kurtosis. The method is claimed to have general application.

BOX, G. E. P. and TIAO, G. C. (1964a). A Bayesian approach to the importance of assumptions applied to the comparison of variances, *Biometrika,* 51, 153-167. **H-P-D-Th**

We have two distributions with different means and variances but common non-normality parameter β. Posterior distribution of variance ratio for given β with an associated measure of plausibility of this value of β, is studied when (i) means are known, (ii) means are unknown.

BOX, G. E. P. and TIAO, G. C. (1964b). A note on criterion robustness and inference robustness. *Biometrika,* 51, 169-173. **E&H-P-O-Th**

Most studies of robustness deal with the behavior of a certain criterion in inference when the underlying assumptions are not valid. The authors of this paper make a distinction between this "criterion robustness" and "inference robustness," a new concept introduced in the note. These criteria themselves change in non-normality parameter postulated by authors. This sensitivity measures the lack of "inference robustness." An illustration is also provided.

BOX, G. E. P. and TIAO, G. C. (1965). A change in level of non-stationary time series. *Biometrika,* 52, 181-192. **E-P-O-Th**

For an integrated moving average process, the authors consider the problem of making inferences about a possible shift in level of the series associated with the occurrence of an event at some particular time, using a finite number of equally spaced observations of the series before and after the event. The estimate of the shift is shown to be the difference of exponentially weighted averages of future and past (from the event). Problems of significance of the estimate, truncation of observations and ignorance of parameters defining the time series, are also discussed.

BOX, G. E. P. and TIAO, G. C. (1968). A Bayesian approach to some outlier problems. *Biometrika,* 55, 119-129. **E-P-C-Th**

The authors suppose that a "good" observation is normally distributed about its mean with fixed variance σ^2. A "bad" observation is normally distributed about the same mean but with a larger variance $k\sigma^2$. The probability of having some from the first model is $1-\alpha$ and from the second is α, which is small. The authors consider sensitivity of the results to changes in α and k.

BOX, G. E. P. and WATSON, G. S. (1961). *Robustness of Non-normality of Regression Tests.* University of Wisconsin, Technical Report No. 4 Contract NONR 1202 (17). NR 042-222. **H-P-D-Th**

The authors demonstrate the overriding influence which the numerical values of the regression variable have in deciding sensitivity to non-normality and to the essential nature of this dependency. They first obtained an approximation of the distribution of the regression F-statistics in the normal case. The authors illustrate these results using some examples of familiar special cases. Finally, they show that it is possible to choose the regression variables so that to the order of approximation we employ, non-normality in the y's is without effect on the distribution of the test statistic.

BRADLEY, J. V. (1959). *Compatability of Psychological Measurements with Parametric Assumptions.* Aerospace Medical Laboratories, WADC Technical Report 58-578 (I). **H-P-D-MC**

The work doesn't study robustness of a statistical technique but attempts to establish the extent of deviations from usual assumptions in psychological data derived from sound experiments. Typical measurements in this area, namely of time scores and errors, are studied. No attempt is made to justify mathematically the claim that drastic deviations are common. Approach is illustrative.

BRADLEY, J. V. (1962). *An Empirical Investigation of the Central Limit Theorem Applied to Time Scores.* Ph.D. Dissertation, Psychology Department, Purdue University. **E&H-P-D-MC**

Aim was to investigate (i) the rate at which the distribution of the sample mean approaches the normal distribution and (ii) the robustness of certain parametric tests with range 11 1/2 standard deviations was sampled. Ten thousand samples were drawn from it and standardized mean, t and χ^2 were computed. The first two compared well with the theoretical distributions under normality assumption. However computed χ^2 diverged from theoretical considerably, so also the F-ratios. The current generalizations about the speed of the central limit effect were found to be vastly overoptimistic.

BRADLEY, J. V. (1963). *A Sampling Study of the Central Limit Theorem and the Robustness of One-Sample Parametric Tests.* USAF Aerospace Med. Div., Report AMRL-TDR-63-29. **H-P-D-MC**

The body of this report is identical with that of the author's Ph.D. thesis, Psychology Department, Purdue University, 1962, except for additional graphs and tables.

BRADLEY, J. V. (1968). Consequences of violating parametric assumptions, facts, and fallacy. *Dissertation Abstracts,* 28, 4815-B. **H-P-D-MC**

Methods of investigating the effects of assumption-violation are examined. Particular attention is given to common belief of insensitivity of parametric tests to violation. Using a new method, the effect of non-normality upon power of the critical ratio test is investigated. Results show that under perfectly realistic conditions, the test can be rendered completely powerless by assumption-violation.

BRADLEY, RALPH ALLAN (1952a). The distribution of the t and F-statistics for a class of non-normal populations. *Virginia Journal of Science,* 3, 1-32. **H-P-D-Th**

The distribution of the one-sample "Student"-Fisher t for a general class of sampled universes is derived as a multiple quadrature. This is developed in powers of 1/t with methods for evaluating the coefficients. Examples are worked for universes obeying the Cauchy distribution and the "squareed hyperbolic secant" distribution. Similar developments in the case of the two-sample "Student"-Fisher t and the variance ratio F are outlined.

BRADLEY, RALPH ALLAN (1952b). Corrections for non-normality in the use of the two-sample t and F-tests at high significance levels. *Annals of Mathematical Statistics,* 23, 103-113. **H-P-D-Th**

The author outlines a geometrical method of derivation of the distribution of the two-sample "Student"-Fisher t test in samples from a general class of populations which gives the result in terms of quadratures which reduce to the usual result when the population is normal. To simplify the result an approximation is introduced which may be expected to be useful for high significance levels. This gives the final distribution of t in the form of the distribution for normal universes multiplied by a sum of two functions which serves as a correction factor for non-normality. A similar development is given for the distribution of the variance ratio F. A method for the approximate evaluation of the correction factors is developed.

BRADLEY, R. A. (1963). Some relationships among sensory difference tests. *Biometrics,* 19, 385-397. **H-Np-O-Th**

Power efficiencies of a group of tests (with special reference to triangle and duo trio tests) are obtained. Tables are also provided.

BRADLEY, R. A. See: Layman, J. C. and Bradley, R. A. (1955). **H-P-D-Th**

BROWN, BYRON W. (1958). Notes on the Spearman-Karber procedures in bioassay. *Annals of Mathematical Statistics,* 29, 617. **E-Np-D-Th**

The maximum bias of the Spearman-Karber estimator of the L.D. 50 over possible choices of dose levels is examined under various conditions on the distribution function, such as unimodality and symmetry. The maximum mean square error of the estimator is also examined. The results are compared with actual values for several distributions. The results are also used to make some comparisons of the Spearman-Karber estimator with some commonly used parametric methods of estimating the L.D. 50.

BRYANT, E. EARL (1960). See Addendum.

BURR, I. W. (1967). The effect of non-normality on constants for $\bar{x}$ and R charts. *Industrial Quality Control,* 23, 563-568. **E-P-D-Th**

It is shown that standard tables used are stable. Modified tables are given as guidelines when the population under study is markedly non-normal.

BURR, I. W. (1968). On a general system of distributions: III. The sample range. *Journal of the American Statistical Association,* 63, 636-643. **E-P-D-Th**

Distribution of range is studied for a general system of distributions. The standardized mean range and standardized standard deviation are both found to be stable for fixed n, for considerable degree of non-normality.

BURR, I. W. and CISLAK, PETER J. (1968). On a general system of distribution. I. Its crude-shape characteristics. II. The sample median. *Journal of the American Statistical Association,* 63, 627-635. **E-P-D-Th**

Density, bias, efficiency relative to sample mean and such other aspects of median are studied for a variety of distributions. Median appears to be more efficient than the mean at about the degree of non-normality of the exponential distribution.

BURR, I. W. See: Zimmer, W. J. and Burr, I. W. (1963). **H-P-D-Th**

CAMP, BURTON H. (1946). The effect on a distribution function of small changes in the population function. *Annals of Mathematical Statistics,* 17, 226-231. **E&H-Np-D-Th**

This paper presents three theorems and corollaries establishing for an arbitrary statistic, inequalities which serve to justify under very general conditions the customary uncritical acceptance of the notion that if the actual population function is not very different from one assumed in theory, then the true sampling distribution of the statistic will not differ greatly from that obtainable from the theory.

CARLSON, J. L. (1932). A study of the distribution of means estimated from small samples by the method of maximum likelihood for Pearson's type II curve. *Annals of Mathematical Statistics,* 3, 86-107. **E-P-D-Th**

The author investigates whether an optimum statistic approaches normality in small samples. Also, he studies the assumption that optimum statistics have minimum variance and always give better fits than do statistics calculated by the method of moments for small samples.

CHAMPERNOWNE, D. G. (1960). An experimental investigation of the robustness of certain procedures for estimating means and regression coefficients. *Journal of the Royal Statistical Society,* Series A, 123, 398-412. **E-P-D-MC**

This paper describes an investigation of the misleading conclusion which may result from the uncritical use of orthodox procedures of estimation for mean-values and regression coefficients when the underlying conditions are not satisfied. The paper is largely concerned with econometric inquiries but can be applied in other fields. Certain Monte Carlo studies pertaining to the robustness of t and regression coefficients are carried out.

CHAPMAN, R. A. (1938). Applicability of the F-test to a Poisson distribution. *Biometrics,* 30, 188-190. **H-P-D-Th**

Several investigators have studied the distribution of F obtained from non-normal populations. This paper presents a brief report on an extremely skewed distribution. The parent population sampled was a Poisson distribution with a mean equal to 1, $\beta_1 = 1.0401$, $\beta_2 = 4.1031$.

CHATTERJEE, SHOUTIR KISHORE (1966). A bivariate sign test for location. *Annals of Mathematical Statistics,* 37, 1771-1782. **H-Np-D-Th**

The author proposes a strictly distribution-free test which is unbiased and consistent. The ARE relative to Hotelling's test and Hodges' test are found to be satisfactory.

CHERIYAN, K. C. (1945). Distributions of certain frequency constants in samples from non-normal populations. *Sankhyā*, 7, 159-166. **E&H-P-D-MC**

Samples from χ^2 distributions were used to construct 3 bivariate populations. Two hundred samples of 5 were taken from each of these populations to test agreement of the distribution of r and z with normal theory. The first two moments and betas were computed for the means and variances of these 200 samples, the mean variance was smaller than expected in populations I and III but no test of significance was given. The agreement for means was, in general, good.

CHESIRE, L., OLDIS, E., and PEARSON, E. S. (1932). Further experiments on the sampling distribution of the correlation coefficient. *Journal of the American Statistical Association*, 27, 121-128. **E&H-P-D-Th**

Sampling distribution of r is obtained theoretically only when two normal variates are correlated. Some experimental investigations have been carried out which suggest that the distribution is not very sensitive to changes in population form.

CHU, J. T. (1956). Errors in normal approximations to the t, T and similar types of distributions. *Annals of Mathematical Statistics*, 27, 780-799. **E&H-P-D-Th**

Upper and lower bounds are obtained for the errors, using standard and new inequalities involving standard normal distribution. Approximations to the distributions of partial and multiple correlations are also considered. Some difficulty is encountered in working with chi-square distribution.

CHUNG, K. L. (1946). The approximate distribution of Student's statistic. *Annals of Mathematical Statistics*, 17, 447-465. **H-Np-D-Th**

The author derives the sampling distribution of the "Student's" t-statistic when the underlying distribution is not normal. It is shown that the distribution function of t can be expressed as the sum of, (i) standard normal distribution function, (ii) linear combination of certain derivatives of the normal density, and (iii) a remainder term which tends to zero as the sample size becomes larger.

CHURCH, A. E. R. (1925). On the moments of the distribution of squared standard deviations for samples of m drawn from an indefinitely large population. *Biometrika*, 17, 79-83. **E&H-P-D-Th**

"Student" has given the 3rd and 4th moments of the distribution of means and σ^2 of samples of n drawn from a normal population. This paper extends the method to obtain the 3rd and 4th moments for samples from any population.

CHURCH, A. E. R. (1926). On the means and squared standard deviations of small samples from any population. *Biometrika*, 18, 321-394. **E&H-P-D-Th**

An extensive study of the distributions of means θ and σ^2 of small samples from infinite and finite populations is made.

CHURCH, A. E. R. See: Holzinger, K. J. and Church, A. E. R. (1928). **E&H-P-D-MC**

CISLAK, PETER J. See: Burr, I. W. and Cislak, Peter J. (1968). **E-P-D-Th**

CLAY, P. P. F. See: Hopkins, J. W. and Clay, P. P. F. (1963). **H-P-D-MC**

COCHRAN, W. G. (1940). The analysis of variance when experimental errors follow the Poisson or binomial laws. *Annals of Mathematical Statistics*, 11, 335-347. **H-P-D-Th**

The author applies normal approximation transformations to variates in a Latin square arrangement assuming the variates to be distributed according to the Poisson and binomial law. Two numerical examples are included for illustrative purposes.

COCHRAN, W. G. (1947). Some consequences when the assumptions for the analysis of variance are not satisfied. *Biometrics,* 3, 22-38. **H-P-D-Th**

This is an expository survey paper dealing with robustness in analysis of variance.

COHEN, M. L. See: Gastwirth, J. L. and Cohen, M. L. (1968). **E-Np-C-MC**

COLLIER, RAYMOND and BAKER, FRANK B. (1963). The randomization distribution of F-ratios for the split-plot design—an empirical investigation. *Biometrika,* 50, 431-438. **H-P-D-MC**

Comparisons are made between observed and theoretical frequencies for F-ratios. Mostly the discrepancy found is insignificant, except for samples from the lognormal distribution. It is conjectured that the discrepancy is due largely to an excess of cases in the central portion of the distributions.

COLLIER, RAYMOND O. and BAKER, FRANK B. (1966). Some Monte Carlo results on the power of the F-test under permutation in the simple randomized block design. *Biometrika,* 53, 199-203. **H-P-O-MC**

The authors obtain the power of the usual F-test of null treatment-effects under permutation for two randomized block designs with one observation per cell. The results suggest that the power of the F-test under permutation compares favorably with its normal theory counterpart.

COLLIER, R. O. See: Baker, F. B. and Collier, R. O. (1966). **H-P-O-MC**

COLLIER, R. O. See: Baker, F. B. and Collier, R. O. (1968). **H-P-D-Th**

COOPER, P. W. (1964). Hyperplaces, Hyperspheres, and Hyperquadrics as Decision Boundaries. *Computer and Information Sciences,* 11-138. Edited by J. T. Tou and R. H. Wilcox, Spartan Books Inc., Washington, D.C. **H-P-D-Th**

Viewing pattern recognition as a problem in statistical classification, wherein an n-dimensional space is partitioned into category regions with decision boundaries, this paper focuses attention on certain tractable and general boundary forms. It turns the usual classification problem around and shows that these selected boundary forms are fully optimum for a wide range of probability distributions. Classes of distributions for which this is true are presented, techniques are given for determining the actual decision boundary for known samples and for efficiently reducing the dimensionality, and measures of merit are included.

CONEA, P. H. (1958). Statistical inference on the parameters of non-normal populations. *Trabajos de Estadistica,* 9, 117-140. **E-Np-D-Th**

Under quite general circumstances, averages of (random) groups of homogeneous observations will be more nearly normal than the observations themselves. This suggests variants of standard statistical techniques, especially those relating to population averages, when non-normality is feared: namely, replace a set of homogeneous observations by a smaller number of averages formed from (random) grouping followed by averaging and then proceed as if these averages were the observations. The present paper applies this idea to getting confidence intervals for the population mean, with both single sample and Stein two-sample designs.

CONNOR, W. S. See: Mazuy, Kay Knight, and Connor, W. S. (1965). **H-P-O-Th**

COX, D. R. (1954). The mean and coefficient of variation of range in small samples from non-normal populations. *Biometrika,* 41, 469-481. (correction 42, p. 277.) **E-P-R-Th**

By examining special populations, a table is obtained for predicting approximately the mean and coefficient of variation of the range of random samples of sizes up to 5, drawn from a population of specified kurtosis. Thus if kurtosis is shown, the author concludes that a rough correction for non-normality can be made in methods that use ranges of small samples, and that on the whole, these methods are less affected by non-normality than corresponding methods using variances of small samples.

COX, D. R. (1958). The interpretation of the effects of nonadditivity in the Latin Square. *Biometrika,* 45, 69-73. **H-P-O-G**

This paper discusses the practical interpretation of nonadditivity and a sense in which the Latin Square is always unbiased.

CRAGG, J. G. (1966). On the sensitivity of simultaneous-equations estimators to the stochastic assumptions of the models. *Journal of the American Statistical Association,* 61, 136-151. **E-P-O-MC**

This paper reports the results of several sampling experiments investigating the sensitivity of various simultaneous-equations estimators to errors in the exogenous variables, stochastic coefficients, heteroskedastic disturbances and autocorrelated disturbances.

CRAIG, A. T. (1932). The simultaneous distributions of mean and standard deviation in small samples. *Annals of Mathematical Statistics,* 2, 126-140. **E&H-P&Np-D-Th**

This paper determines the simultaneous frequency function of the arithmetic mean and standard deviation in samples of small numbers of items selected at random from a rather arbitrary universe.

CRAWFORD, CHARLES R. See: Jacques, John A., Mather, Frances J., and Crawford, Charles R. (1968). **E-P-O-MC**

CROW, EDWIN L. and SIDDIQUI, M. M. (1967). Robust estimation of location. *Journal of the American Statistical Association,* 62, 353-389. **E-Np-D-MC**

The problem is attacked by deriving estimators which are efficient over a class of two or more "pencils" of continuous symmetric unimodal distributions. The estimators considered are special symmetric linear combinations of order statistics. They are compared asymptotically with Hodges-Lehmann estimator. Efficiencies are also tabulated.

CURNOW, R. N. (1958). Consequences of errors of measurements for selection from certain non-normal distributions. *Bulletin of the Institute of International Statistics,* 37, 291-308. **E-P-D-Th**

Observed values of a certain characteristic of interest in problems like plant breeding are subject to errors of measurement. A new population is formed by selecting a predetermined fraction of the original population possessing highest observed values. The distribution of true values in the selected fraction is of interest. Usually the error of measurement and the value of the characteristic before selection are assumed to be normal. This paper gives methods to use when errors are normal but the values of the characteristic are from rectangular, gamma and chi-distributions.

DANIEL, C. and WILCOXON, F. (1965). Factorial 2^{p-q} plans robust against linear and quadratic trends. *Technometrics,* 8, 259-278. **H-P-O-Th**

Basic idea is that certain ordered contrasts are orthogonal to linear and quadratic trends, some are nearly orthogonal and some heavily correlated. Design problem handled here is choosing those ordered contrasts that permit efficient estimation of desired effects and interactions. Some plans and computational methods are given.

DANIELS, H. E. (1938). The effects of departures from ideal conditions other than non-normality on the t and z tests of significance. *Proceedings of the Cambridge Philosophical Society,* 34, 321-328. **H-P-R-Th**

It is shown that slight departures from assumptions of independence and equal weight of the sample observations introduce a bias into Fisher's z, but that the distributions of the variances "within and between groups," and of Fisher's z would appear to maintain their form to the first order, although the extent to which the approximations hold in practice has not been considered.

DANIELS, H. E. (1954). A distribution-free test for regression parameters. *Annals of Mathematical Statistics,* 25, 499-513. **H-Np-D-Th**

A geometric test-device is developed and its power compared with rough and rapid test by A. M. Mood [*Introduction to the Theory of Statistics,* McGraw-Hill, New York, (1950) 407]. No applied work is given to display situations where the gain in uniform power does in practice out-weigh the heavier computations.

DANNEMILLER, M. C. See: Zelen, M. and Dannemiller, M. C. (1960). **H-P-D-Th**

DANNEMILLER, M. C. See: Zelen, M. and Dannemiller, M. C. (1961). **H-P-D-Th**

DARROCH, J. G. See: Hutton, Lajon R. and Darroch, J. G. (1967). **H-P-D-Th**

DAS, N. G. and MITRA, S. K. (1964). Effect of non-normality on plans for sampling inspection by variables. *Sankhyā:* Series A. 26, 169-176. **H-P-D-Th**

Probabilities of rejection of lots of AQL quality and acceptance of lots of LTPD quality are obtained for some typical variables sampling plans, assuming a non-normal distribution of the type given by first few terms of Gram-Charlier series. Effect of asymmetry is found to be more serious than kurtosis.

DAVID, F. N. (1949a). Notes on the application of Fisher's k-statistics. *Biometrika,* 36, 383-393. **E&H-P-D-Th**

The author reviews the theory of cumulants as developed and extended by R. A. Fisher, J. Wishart and M. G. Kendall. The results are used in the investigation of the approximate distribution of the coefficient of variation under the assumption that the parent population from which the sample is drawn is a type A Gram-Charlier series of three terms. The first four central moments of the coefficient of variability are determined to the order of n^{-2} where n is the sample size.

DAVID, F. N. (1949b). The moments of the z and F distributions. *Biometrika,* 36, 394-403. **H-P-D-Th**

The author finds the mean and essentially the first four cumulants of z and F approximately, without the assumption of normality. The results are applied to investigate the effects of skewness on z if both π_1 and π_2 are assumed to be the same A Gram-Charlier series.

DAVID, F. N. (1959). The z-test and symmetrically distributed random variables. *Biometrika,* 46, 123-129. **H-P-R-Th**

For usual one-way classification in the analysis of variance, the author investigates the stability of the α-significance level when the underlying variables have a common symmetrical distribution. The method is an alternative to that of David and Johnson [*Annals of Mathematical Statistics,* 22, (1951) 382-392] and makes use of an expression in terms of cumulants, for Z=(1/2)log F, from which the effects of unequal group frequencies and non-normality can be studied.

DAVID, F. N. and JOHNSON, N. L. (1951a). The effects of non-normality on the power function of the F-test in the analysis of variance. *Biometrika,* 38, 43-57. **H-P-D-Th**

Given one-way classifications, the authors compute the moments of the statistic which is a linear combination of within sum of squares and between sum of squares in terms of given cumulants of distributions of Z_{tj}, all variables corresponding to identical values of t having the same cumulants. By fitting various frequency distributions to these moments, the approximate power of the F-test with respect to alternatives characterized by the given cumulants may be found.

DAVID, F. N. and JOHNSON, N. L. (1951b). A method of investigating the effect of non-normality and heterogeneity of variance on tests of the general linear hypothesis. *Annals of Mathematical Statistics,* 22, 382-392. **H-P-D-Th**

Under very general departures from the null hypothesis formulae for the first four cumulants of S minus CT are derived, where C is a non-negative parameter and S and T are numerator and denominator of the F-test of a general linear hypothesis. Interesting specializations of these formulas are given. Some evidence is adduced that the distribution of S minus CT is reasonably well approximated by type IV distribution; agreeing with it in the first four cumulants. This is of course tantamount to recommending a certain approximation for the distribution of S/T.

DAVID, F. N. and JOHNSON, N. L. (1951c). The sensitivity of analysis of variance tests with respect to random variation between groups. *Trabajos de Estadistica,* 2, 179-188. **H-P-D-Th**

Given a one-way classification with random effects model, the authors study the insensitivity of the F-test when some of the usual assumptions are not satisfied. Various cases are also considered.

DAVID, F. N. and JOHNSON, N. L. (1952). Extension of a method of investigating the properties of analysis of variance tests to the case of random and mixed models. *Annals of Mathematical Statistics,* 23, 594-601. **H-P-D-Th**

Results are given whereby the methods described in an earlier paper dealing with the parametric case, may be applied also to the case of random, or mixed random and parametric components (author's summary).

DAVID, H. A. (1954). The distribution of range in certain non-normal populations. *Biometrika,* 41, 463-468. **E&H-P-D-Th**

Some exact results regarding the expectation and probability integral of sample range in asymmetric populations are derived.

DAVID, H. A. and MISHRIKY, R. S. (1968). Order statistics for discrete populations and for grouped samples. *Journal of the American Statistical Association,* 63, 1390-1398. **E-Np-D-Th**

The effects are assessed of grouping on the distribution of order statistics and the convenience, under suitable conditions, of using order statistics for the estimation of parameters from grouped data with or without censoring are indicated.

DAY, N. E. (1969). Two-stage designs for clinical trials. *Biometrics,* 25, 111-118. **E-P-D-Th**

By the use of a gain function relevant to clinical trials, and perhaps other fields, various two-stage designs are constructed. The performances of these designs are compared especially with regard to errors in the specification of the gain function.

DE JONGE, H. (1960). The Influence of Non-normality on the Probability of a Type I Error of Student's Two-Sample Test. *Quantitative Method in Pharmacology,* Interscience Publishers, New York, 135-139. **H-P-D-Th**

This paper describes a small experiment on the robustness of the null hypothesis behavior of the two-sample t-test against non-normality and nonidentity of distribution. From each of four moderately non-normal populations 500 pairs of random samples of size 5 are drawn. The empirical distributions are compared with the t-distribution. Agreement seems to be reasonably good.

DEMING, L. S. See: Eisenhart, C., Deming, L. S., and Martin, C. S. (1948). **E&H-P-D-MC**

DEMING, L. S. See: Eisenhart, C., Deming, L. S. and Martin, C. S. (1948). **E&H-P-D-MC**

DIXON, W. J. and TUKEY, J. W. (1968). Approximate behaviour of the distribution of Winsorized t (trimming & Winsorization). *Technometrics,* 10, 83-98. **H-P-C-MC**

The authors have carried out a Monte Carlo study to substantiate their conjecture that the Winsorized t has an approximate t distribution with a certain number of degrees of freedom.

DOKSUM, K. (1965). Robust inference in some linear models with one observation per cell. *Annals of Mathematical Statistics,* 30, 733-734 (abstract). **H-Np-D-Th**

Substituting sample medians in place of sample means in classical analysis of variance, a robust procedure is obtained, after suitable modification. Its asymptotic relative efficiency is studied.

DOKSUM, KJELL (1966). Asymptotically minimax distribution-free procedures. *Annals of Mathematical Statistics,* 37, 619-628. **H-Np-D-Th**

Optimality properties for nonparametric classes of alternatives are treated. Tests that maximize the minimum power asymptotically over classes of nonparametric alternatives are considered. Finally, the results are used to obtain asymptotic efficiencies that are defined for nonparametric classes of alternatives.

DOKSUM, K. A. (1966). See: Bell, C. B. and Doksum, K. A. (1966). **H-Np-C-Th**

DOKSUM, K. A. See: Thompson, Rory, Govindarajulu, Z., and Doksum, K. A. (1967 & 1966). **H-Np-D-MC**

DONALDSON, THEODORE S. (1968). Robustness of the F-test to errors of both kinds and the correlation between the numerator and denominator of the F-ratio. *Journal of the American Statistical Association,* 63, 660-676. **H-P-D-MC**

In this study of robustness the insensitivity of the F-test between means to its underlying assumptions (normally distributed populations with equal variances) is investigated. Using two non-normal distributions (exponential and log-normal), it is found that the test is fairly insensitive for moderate and equal sample size ($n = 32$) when the variances are equal. Further, for small samples ($n < 32$), the test is conservative with respect to Type I error. It is also conservative with respect to Type II error for a large range of ϕ (noncentrality), depending on the size of the sample and α. When the within cell error variances are heterogeneous, the test continues to be conservative for the upper values of ϕ and slightly biased toward larger Type II errors for smaller values of ϕ depending on the size of α. Analysis of the correlation between the numerator and denominator of F under the null hypothesis indicates that the robustness feature is largely due to this correlation. Analytic proofs under the non-null hypothesis were not possible, but some empirical results are presented.

DORFF, M. and GURLAND, J. (1960). Small sample behavior of parameters in a linear functional relationship. *Annals of Mathematical Statistics,* 31, 233-234 (abstract). **E-P-D-MC**

It is shown that bias and mean square error of a certain simple estimator of slope are insensitive to widespread departure from assumptions that make it equivalent to least squares estimator.

DRASGOW, J. (1957). Nefzger, M. D. and Drasgow, J. **E&H-P-D-G**

DUDEWICZ, E. J. (1969). A non-parametric selection procedure's efficiency: largest location parameter case. *Annals of Mathematical Statistics,* 40, 1155-1157. **H-Np-D-Th**

Performance of a certain selection procedure under various parametric alternatives is studied. It turns out that the nonparametric procedure has low efficiency relative to specific parametric alternatives and will therefore be useful only when real doubt exists as to the form of the actual distribution.

DUNLAP, H. F. (1931). An empirical determination of the distribution of means, standard deviations and correlation coefficients drawn from rectangular populations. *Annals of Mathematical Statistics,* 2, 66-81. **E&H-P-D-MC**

This paper presents empirical evidence of the applicability of the formulae for a normal distribution where these formulae approximate means and standard deviations of samples of ten from a rectangular discontinuous population, and of correlation coefficients of samples of fifty-two from a rank distribution.

DUNN, OLIVE JEAN. See: Holloway, Lois Nelson, and Dunn, Olive Jean (1967). **H-P-D-MC**

EDEN, CONSTANCE VAN (1970). Efficiency-robust estimation. *Annals of Mathematical Statistics,* 41, 172-181. **E-Np-D-Th**

In two-sample situation estimates are proposed for the difference in location, which are asymptotically efficient, i.e., attain Cramér-Rao lower bound for variance uniformly for all F belonging to a large class. The estimates are based on Hajék's uniformly asymptotically efficient test for equality of the two distribution functions.

EDEN, T. and YATES F. (1933). On the validity of Fisher's z-test when applied to an actual example of non-normal data. *Journal of Agricultural Science,* 23, 6-17. **H-P-D-MC**

Previous work on the validity of t- and z-test on non-normal distributions is reviewed. An investigation is made on a skew distribution obtained from actual agricultural experiment. The distribution of the values of Fisher's z from a thousand random samples is obtained and found to agree satisfactorily with the theoretical distribution.

EDWARDS, D. S. and PARKIN, S. J. (1954). An empirical investigation of the problem of disproportionate frequencies in analysis of covariance as applied to a methods experiment. *Journal of Experimental Education,* 22, 257-264. **H-P-O-MC**

While experimenting in an English secondary school, the students who are always grouped according to ability necessarily afford only nonrandom samples. Also the number of experimental units in a block is not constant. The first difficulty was overcome by analysis of variance but the second was left uncorrected. The results indicated insensitivity of the statistical method to moderate deviations from assumption of proportionate frequency.

EISENHART, CHURCHILL (1947). The assumptions underlying the analysis of variance. *Biometrics,* 3, 1-21. **E&H-P-D-G**

This is the first of a set of three expository papers which critically discuss aspects of the analysis of variance for the benefit of those interested in the general applicability of this important statistical method. The present paper points out with clarity and emphasis the distinction between the two main types of applications: (i) the "detection and estimation of fixed relations among the means of subsets of the universe of objects concerned," (ii) the "detection and estimation of components of variations associated with composite population." The greater part of the paper is devoted to the statement and discussion of the meaning of the assumptions on which the mathematical theory leading to the significance tests is based.

EISENHART, C., DEMING, L. S., and MARTIN, C. S. (1948). The probability points of the distribution of the median in random samples from any continuous population. *Annals of Mathematical Statistics,* 19, 598-599 (abstract). **E&H-P-D-MC**

The aim is to give greater publicity for certain probability identities valid for F, z and β distributions. Some of the quantities involved are tabulated.

EISENHART, C., DEMING, L. S. and MARTIN, C. S. (1948). On the arithmetic mean and the median in small samples from the normal and certain non-normal populations. *Annals of Mathematical Statistics,* 19, 599-600. **E&H-P-D-MC**

Numerical evaluation of certain quantities is carried out for a number of distributions, in connection with an earlier paper by the authors titled "The probability points of the distributions of the median in random samples from any continuous population."

EISENSTAT, S. See: Leone, F. C., Jayachanchan, T. and Eisenstat, S. (1967). **E-P-C-MC**

EISENSTAT, STANLEY. See: Leone, Fred C., Nelson, Lloyd S., Johnson, Norman L. and Eisenstat, Stanley (1968). **E-P-D-MC&Th**

EKLUND, DARREL L. and WALLER, RAY A. (1970). The construction of a clustered population with intraclass correlation approximately specified. Contribution No. 134, Department of Statistics and Computer Science, Kansas Agricultural Experiment Station, Manhattan. **H-P-R-MC**

The authors propose a method for computer simulation of clustered populations, of any size, with intra-class correlation approximately specified. Simulated populations sampled by Monte Carlo methods enable one to study the sampling characteristics of various statistics, and to formulate the distribution theory of the same.

ELASHOFF, R. M. See: Afifi, A. A., Elashoff, R. M. and Langley, P. G. (1968). **H-Np-C-Th**

EPSTEIN, BENJAMIN (1955). Comparison of some non-parametric tests against normal alternatives with an application to life testing. *Journal of the American Statistical Association,* 50, 894-900. **H-Np-D-Th**

Four non-parametric tests are compared experimentally regarding their power in detecting differences in means of two normal populations with common variance. The results indicate, for two samples of ten, that various exceedance and truncated maximum deviation criteria are superior to the run test but inferior to the rank sum test. However, the first two methods may be applied in truncated samples and their possible usefulness in life-tests is stressed (from Math Reviews).

ESSEEN, C. G. (1945). Fourier analysis of distribution functions, a mathematical study of Laplace-Gaussian law. *Acta Mathematica Academiae Scientiarum Hungaricae,* 77, 1-25. **E&H-Np-D-Th**

This is an exhaustive study of the deviation of the distribution function of a sum of independent random variables from the normal distribution. Apart from new and often striking results a thorough review of the whole subject is also given.

EWENS, W. J. (1961). Departures from assumption in sequential analysis. *Biometrika,* 48, 206-211. **H-P-D-Th**

Two cases are distinguished, namely testing for the mean and testing for the variance. A single formula is derived from which complete sets of power and average sample number curves may be found. Special reference is made to normal distribution. It is noticed that the test for the mean is more robust than the test for the variance.

FELSENSTEIN, J. See: Lewontin, R. C. and Felsenstein, J. (1965). **H-P-O-MC**

FINCH, D. J. (1950). The effect of non-normality on the z-test when used to compare the variances in two populations. *Biometrika,* 37, 186-189. **H-P-D-Th**

Under the assumption that two populations have the functional form of a Gram-Charlier type A series (including the kurtosis term), the author investigates the effect of non-normality on the z-test for the comparison of two variances. A table showing the power function of the z-test is given for the sample size $n_1=25$, $n_2=61$, at the 5 percent level of significance for various values of the population variances, both for leptokurtic and platykurtic distributions.

FISHER, FRANKLIN M. (1966). The relative sensitivity to specification error of different k-class estimators. *Journal of the American Statistical Association,* 61, 345-356. **E-P-D-Th**

It is shown that there exists no case in which either of the two leading estimators is uniformly more robust than the other if the criterion is any positive semidefinite quadratic form in the inconsistencies.

FISHER, R. A. (1929). Statistics and biological research. *Nature,* 124, 266-267. **E&H-P-D-G**

In this letter to the editor the author declares that techniques described in *Statistical Methods for Research Workers* can not be used under general conditions. He assures the biologists, however, that in their work there is rarely any imperfect normality of the variation.

FRANCIS, V. J. (1946). On the distribution of the sum of n sample values drawn from a truncated normal population. *Supplement to the Journal of the Royal Statistical Society,* 8, 223-232. **E&H-P-D-MC**

Tables are computed of the cumulative distribution function of the sum of several independent observations from a normal distribution truncated at one end. An illustration of the industrial use of these tables is given.

FRASER, D. A. S. (1967). Data transformations and the linear model. *Annals of Mathematical Statistics,* 38, 1456-1465. **E&H-P-D-Th**

In this paper a comprehensive statistical model is proposed; it is a revision of the structural model proposed earlier by the author. It gives stronger inference statements in the contest for the linear model.

FRÉCHET, MAURICE (1940). Sur une limitation tres generale de la dispersion de la mediane. *Journal de la Societe Statistique de Paris,* 81, 67-78. **E-P-D-Th**

The author compares the sample mean with respect to certain properties principally for unimodal distributions with finite variance for large samples. The author concludes that the sample median should be more widely used except when the distribution is known to be such that the sample mean is better.

FRIDSHAL, DONALD and POSTEN, HARRY O. (1966) See Addendum.

FURFEY, P. H. (1958). Comment on "The needless assumption of normality in Pearson's r." *American Psychologist,* 13, 545-546. **E&H-P-D-G**

Any meaningful interpretation of r, the correlation coefficient of a bivariate distribution, demands a normal correlation surface. And even when the relationship between two variables departs considerably from linearity r can be treated as an underestimated index of the "closeness of relationship." The paper is expository.

GASTWIRTH, JOSEPH L. (1966). On robust procedures. *Journal of the American Statistical Association,* 61, 929-948. **E-Np-D-Th**

This paper discusses a procedure for finding robust estimators of the location parameter of symmetric unimodal distributions. The estimators are based on robust rank tests and the methods used are applicable to other one parameter problems.

GASTWIRTH, J. L. (1969). On asymptotically robust rank tests. *Annals of Mathematical Statistics,* 40, 1143 (abstract). **H-Np-D-Th**

This is an extension of the author's paper which appeared in *Journal of American Statistical Association,* 61 (1966), 929-948. A general setup is introduced involving a new definition of optimality, local and global. Some properties of tests optimal in this sense are studied.

GASTWIRTH, J. L. and COHEN, M. L. (1968). *The Small Sample Behavior of Some Robust Linear Estimators of Location.* Johns Hopkins University, Technical Report No. 91, Baltimore, Maryland. **E-Np-C-MC**

Behavior of trimmed mean and other estimators where observations are from contaminated normal distributions is empirically studied. Conclusions based on small sample situations confirm the indications given by asymptotic results.

GASTWIRTH, JOSEPH L. and RUBIN, HERMAN (1968). The behavior of some robust estimators on dependent data. *Annals of Mathematical Statistics,* 39, 1087 (abstract #8). **E-P-R-Th**

The authors study the effect of serial dependence in the data, on the efficiency of some robust estimators. If one has first order autoregress (i.e., normal data) the Hodges-Lehmann estimator is the most robust.

GASTWIRTH, JOSEPH L. and RUBIN, HERMAN (1969). On robust linear estimators. *The Annals of Mathematical Statistics,* 40, 24-39. **E-P-D-Th**

The problem of finding robust estimators for the location parameter of symmetric unimodal distribution has been the subject of much recent research. This paper is concerned with finding robust estimators which are linear functions of the ordered observations. The existence proofs given in this paper are mainly of theoretical interest.

GAYEN, A. K. (1949). The distribution of "Student's" t in random samples of any size drawn from non-normal universes. *Biometrika,* 36, 353-369. **H-P-D-Th**

Assuming that the parent population has density given by the first four terms of the Edgeworth series, the author derives an expansion for the distribution of the "Student's" t-statistic in terms of the population cumulants. The author indicates that the derived expression provides satisfactory estimates of the

probabilities for a fairly wide class of non-normal universes, especially when the sample size is not too small. The values of the cumulants of the population have been assumed to be known, and the question of their estimation has not been considered.

GAYEN, A. K. (1950a). The distribution of the variance-ratio in random samples of any size drawn from non-normal universes. *Biometrika,* 37, 236-255. **H-P-D-Th**

The paper investigates the distribution of the variance ratio used for testing (i) the homogeneity of means in one-way classifications and (ii) the compatibility of two variances in samples from populations, the distributions of which are given by the first four terms of the Edgeworth series. Formulas for the upper tail probabilities are given and corrective functions for determining these probabilities at the upper 5% normal-theory significance levels have been tabulated. The author indicates that the formulas are valid asymptotically for any form of universe and expresses the belief that for moderate sample sizes they have "quite an extended range of applicability."

GAYEN, A. K. (1950b). Significance of difference between the means of two non-normal samples. *Biometrika,* 37, 399-408. **H-P-D-Th**

The distribution of the ratio of the difference in the means to the estimate of the standard error of the difference based on the pooled sum of squares is studied for samples from two populations having the same variance when the populations are adequately represented by the first four terms of Edgeworth's series. One of the author's conclusions is that the formulas given will be widely applicable even though normal theory does not yield an accurate answer in certain cases.

GAYEN, A. K. (1951). The frequency distribution of the product moment correlation coefficient in random samples of any size drawn from non-normal universes. *Biometrika,* 38, 219-247. **E&H-P-D-Th**

The distribution of the product-moment correlation coefficient r drawn from a certain bivariate Edgeworth surface is derived. When ρ (the true correlation) is not zero, the distribution is sensitive to departures from normality. However, when $\rho=0$, the effect of non-normality on the distribution of r is not very serious. Same comment holds for the distribution of the transformed variable z.

GAYEN, A. K. (1952). The inverse hyperbolic sine transformation on Student's t for non-normal samples. *Sankhyā,* 12, 105-108. **H-P-D-Th**

Anscombe (see *Journal of the Royal Statistical Society,* Series A, 113 (1950), 228-229) has shown that an inverse hyperbolic sine transformation of "Student's" t-statistic accelerates its approach to normality, when the parent population is normal. From a study of the moment functions, the author finds the transformation not helpful for non-normal samples.

GEARY, R. C. (1936). The distribution of "Student's" ratio for non-normal samples. *Journal of the Royal Statistical Society,* Supplement, 3, 178-184. **H-P-D-Th**

Asymptotic formulas for moments of t for any universe are obtained. It is observed that "Student's" distribution is more accurate in its application to symmetric non-normal universes than to skew universes. Distribution of "Student's" ratio is obtained for samples of any size drawn from a slightly asymmetric universe.

GEARY, R. C. (1947). Testing for normality. *Biometrika,* 34, 209-242. **E&H-P-D-Th**

The author is concerned with the degree to which the results of classical theory are sensitive to departure from postulated normality, and finds it is considerable. He exhibits instances when relatively inconsiderable departure from normality causes the usual tests in the analysis of variance to be seriously vitiated. The efficiencies of several tests of skewness and kurtosis are compared.

GEARY, R. C. (1966). A note on residual heterovariance and estimation efficiency in regression. *American Statistician,* 20, No. 4, 30-34. **E-P-D-MC**

The author presents a table showing the effect of a particular kind of residual variance heterogeneity on the efficiency of estimation of coefficients in least squares regression.

GEBHARDT, FRIEDRICH (1966). On the effect of stragglers on the risk of some mean estimators in small samples. *Annals of Mathematical Statistics,* 37, 441-450. **E-P-C-Th**

In a previous paper, the risk of certain mean estimators which allow for observations with a different mean or larger observations with a different mean or larger variance have been numerically computed assuming knowledge of variances of stragglers and nonstragglers. This assumption is relaxed in the present paper. Applications are also given.

GEHAN, EDMUND A. and THOMAS, DONALD G. (1969). The performance of some two-sample tests in small samples with and without censoring. *Biometrika,* 56, 127-132. **H-P-D-MC**

The tests considered are: F ratio, a modified F ratio, and a generalized Wilcoxon test. Monte Carlo methods are used to obtain power curves for each test with sample sizes 20 and 50. The power is considered in small samples of the three two-sample tests of the null hypothesis that $F_1(t) = F_2(t)$ $(t \leqslant T)$ against the alternative that $F_1(t) < F_2(t)$ $(t \leqslant T)$ where the times to failure are from continuous cumulative distribution function F_1 and F_2 and the upper limit is fixed at T.

GERTSBACH, I. B. (1967). On an estimation of parameters of a distribution with an exponential factor. *Theory of Probability and Its Applications,* 12, 110-111. **E-Np-D-Th**

Let X be a positive random variable having distribution function G where $[1-G(x)] / [1-F(x)] = \exp\{-x/\theta\}$ where F is unknown. The author gives a method of estimating θ which does not require the exact knowledge of F(x).

GHURYE, S. G. (1949). On the use of Student's t-test in an asymmetrical population. *Biometrika,* 36, 426-430. **H-P-D-Th**

An approximate expression is found for the power of "Student's" t-test when used to test a one-sided hypothesis concerning the mean of a non-normal population where the critical region has been determined on the erroneous assumption of normality in the parent population. The non-normal population considered differs only from normality in having a nonzero third cumulant; in the derivation, the author assumes the standardized third cumulant is "sufficiently small." Subject to this restriction the change in the power of the test from the normal case is negligible.

GIBBON, JEAN D. (1964). Effect of non-normality on power function of sign test. *Journal of the American Statistical Association,* 59, 142-148. **H-Np-D-Th**

The power of one-sided sign test is studied when the population density function is the Edgeworth expansion through the terms of $O(N^{-1})$. Three sets of null hypotheses and alternatives are considered. With sample size 10 and $\alpha = .05$, numerical values of the power are evaluated. Graphical and tabular comparisons with power of t-test are given. On the basis of this empirical study, it is surmised that the performance of the sign test is reasonably good.

GIRI, N. (1965). On F-test in the intrablock analysis of a class of two associate PBIB designs. *Journal of the American Statistical Association,* 60, 258-293. **H-P-O-Th**

First two moments of the ratio (treatment sum of squares/treatment s.s. + error s.s.) over all possible random assignments of treatments to plots for certain PBIB designs are computed. They are compared with corresponding moments of a beta distribution. Approximating the randomization test by usual F-test is found to be reasonable subject to a slight modification in degree of freedom.

GODARD, R. H. and LINDQUIST, E. F. (1940). An empirical study of the effect of heterogeneous within-groups variance upon certain F-tests of significance in analysis of variance. *Psychometrika,* 5, 263-274. **H-P-D-MC**

It is shown that in educational experiments the assumption of homoscedasticity underlying the theory of analysis of variance is violated. Actual distribution of F values for a large number of experiments involving such a violation is compared with theoretical distribution based on the assumption of homoscedasticity. Findings are not conclusive but apparently indicate that the departure does not invalidate the use of usual F-tests.

GOODMAN, LEO A. and MADANSKY, ALBERT (1962). The parameter-free and non-parametric tolerance limits, the exponential case. *Technometrics,* 4, No. 1, 75-95. **E-P&Np-C-Th**

Exact parameter-free tolerance intervals based on the first r ordered observations from an exponential distribution are developed. Certain optimum properties of these intervals are demonstrated. Their asymptotic behavior is also studied. Comparison with nonparametric intervals is made. Effect of assuming an exponential distribution, when in fact the distribution is a mixture of two exponentials, is also discussed.

GOVINDARAJULU, ZAKKULA See: Hayman, George E. and Govindarajulu, Zakkula (1966). **H-Np-D-Th**

GOVINDARAJULU, Z. See: Thompson, Rory, Govindarajulu, Z. and Doksum, K. A. (1967) & (1966). **H-Np-D-MC**

GRANGER, W. J. See: Neave, H. R. and Granger, W. J. (1968). **H-Np-D-MC**

GREENBERG, V. L. (1964). *Robust Inference in Some Experimental Designs.* Ph.D. Dissertation, University of California at Berkeley. **H-P&Np-D-Th**

For incomplete block designs, tests and estimates of contrasts are proposed whose performance is more robust than that of the corresponding classical procedures. These methods extend those proposed by Lehmann for complete block designs. The asymptotic efficiency of these procedures relative to the classical methods is shown to be at least equal to the Pitman efficiency of the Wilcoxon test relative to t-test. In the last section some random effect models are considered. Tests with more robust power against gross errors than the standard tests are proposed; various assumptions about the factors in the model are considered.

GREENBERG, VIDA L. (1966). Robust estimation in incomplete blocks designs. *The Annals of Mathematical Statistics,* 37, 1331-1337. **E-Np-D-Th**

Robust estimates of contrasts in treatment effects for experiments with one observation per cell were proposed by Lehmann for complete (randomized) blocks designs. The model for the observations $X_{i\alpha}$ ($i = 1,...,c_i$ $\alpha = 1,...,n$) is in this case $X_{i\alpha} = V + \xi_i + \Sigma\mu\alpha + V_{i\alpha}$ ($\Sigma\xi_i = \Sigma\mu\alpha = 0$) where the ξ's are the treatment effects, the μ's are the block effects, and the V's are independent with a common continuous distribution. Here the author generalizes these estimates to experiments in which the block size is smaller than the number of treatments to be compared, and she obtains their asymptotic efficiencies relative to the classical estimates.

GRONOW, D. G. C. (1951). Test for the significance of the difference between means in two normal populations having unequal variances. *Biometrika,* 38, 252-256. **H-P-D-MC**

The author considers two ways of weighting the variance of the samples to obtain a variance for testing the significance of an observed difference in the means. For several sample sizes, significance levels and comparative population variances he computes the power of the tests and the bias of assuming distribution to be that of t.

GURLAND, J. See: Dorff, M. and Gurland, J. (1960). **E-P-D-MC**

GURLAND, JOHN See: Mehta, J. S. and Gurland, John (1969). **H-P-R-Th**

GUTTMAN, IRWIN (1959). Optimum tolerance regions and power when sampling from some non-normal universes. *Annals of Mathematical Statistics,* 30, 926-938. **E-Np-D-Th**

The paper is concerned with finding optimum β-expectation tolerance regions for the single and double exponential distribution.

GUTTMAN, I. (1959). Truncation and test of hypotheses, II. *Annals of Mathematical Statistics,* 30, 620 (abstract). **H-P-O-MC**

The distribution of the sum of squares of n truncated normal variables is derived for n–1(1)4. The difference in power and size of tests of hypotheses concerning the variance (mean known) is contrasted with usual procedure, i.e., assuming a random variable has a complete normal distribution.

GUTTMAN, IRWIN See: Aggerwal, O. P. and Guttman, Irwin (1959). **H-P-O-Th**

GUTTMAN, IRWIN See: Tiao, G. C. and Guttman, Irwin (1967). **E-P-D-Th**

HALDANE, J. B. S. (1949). A note on non-normal correlation. *Biometrika,* 36, 467-468. **E&H-P-D-Th**

The effect of non-normality on the precision of the product moment estimate of a correlation coefficient is investigated for a particular case. It appears that skewness is of little effect, but that with high correlations, changes in kurtosis may effect precision of the estimate considerably.

HALL, P. (1927). The distribution of means for samples of size N drawn from a population in which the variate takes values between 0 and 1, all such values being equally probable. *Biometrika,* 19, 240-245. **E&H-P-D-Th**

The author obtains equations for the frequency distribution of means in samples drawn from a rectangular distribution by representing the sample of N by a point $(X_1, X_2,...,X_N)$ in an N-dimensional density space.

HALPERIN, MAX (1951). Normal regression theory in the presence of intra-class correlation. *Annals of Mathematical Statistics,* 22, 573-580. **E&H-P-R-Th**

It is shown that certain estimators and tests of significance used in normal regression theory when observations are independent are equally valid in the presence of intraclass correlation. As an application it is shown that the usual test of treatment effects in the analysis of variance with two-way classification remains valid when the blocks are independent and treatments are uniformly correlated.

HALTON, J. H. (1965). On the relative merits of correlated and importance sampling from Monte Carlo integration. *Proceedings of the Cambridge Philosophical Society,* 61, 497-498. **E&H-P-O-MC**

"Correlated sampling" and "importance sampling" are defined. In one of the two particular situations described, correlated sampling is preferable to importance sampling; in the other, the opposite is true. Corrigenda for this paper was published in July 1965 issue of *Proceedings of the Cambridge Philosophical Society.*

HAN, CHIEN-PAI (1968). Testing the homogeneity of a set of correlated variances. *Biometrika,* 55, 317-326. **H-P-R-MC**

In this paper, the pairwise correlation coefficients, ρ_{ij}, are assumed to be all equal to a common but unknown value ρ.

HARK, H. R. B. (1958). An empirical investigation into the distribution of the F-ratio in samples from two non-normal populations. *Biometrika,* 45, 260-265. **H-P-D-MC**

A root excavation study was used to investigate the distribution of the F-ratio in samples from two non-normal populations.

HATCH, LAWRENCE O. and POSTEN, HARRY O. (1966). See Addendum.

HAYMAN, GEORGE E. and GOVINDARAJULU, ZAKKULA (1966). Exact power of Mann-Whitney test for exponential and rectangular alternatives. *Annals of Mathematical Statistics,* 37, 945-953. **H-Np-D-Th**

A closed form expression for the exact distribution of the Mann-Whitney U-statistic has been derived. Expressions for its exact power of exponential and rectangular alternatives have been derived and are

compared with those for Mood's median test. Also the asymptotic efficiency of the U-test relative to Mood's test for exponential and rectangular alternatives is studied.

HEATH, H. A. (1961). An empirical study of correlation involving a half normal distribution. *Psychological Reports,* 9, 85-86. **E&H-P-D-MC**

This paper investigates effect of a half-normal distribution on Pearson product-moment correlations, empirically. It is claimed that the data support the view that Pearson's r need not be limited to normally distributed data.

HEMELRIJK, J. (1961). Experimental comparison of Student's and Wilcoxon's sample tests. *Quantitative Methods in Pharmacology,* Interscience Publishers, New York, 118-134. **H-Np-D-MC**

In a sampling experiment using fifty samples of size 10 it is found that Wilcoxon test has approximately .9 of the power of the t-test in case of normal samples. In the case of exponential parent, results were inconclusive. Sometimes t-test proved better, sometimes Wilcoxon did.

HEY, B. B. (1938). A new method of experimental sampling illustrated on certain non-normal populations. *Biometrika,* 30, 68-80. **E&H-P-D-MC**

Four non-normal populations empirically studied and distributions of correlation coefficients, regression coefficients, etc. are derived. They reasonably agree with the theoretical distributions which are derived under the assumption of normality of the parent population.

HILL, BRUCE M. (1967). Correlated errors in the random model. *Journal of the American Statistical Association,* 62, 1387-1400. **H-P-R-Th**

The usual one-way random model for the analysis of variance is broadened to allow for negative correlation between true residuals in the same row or cluster. This gives rise to an essential unidentifiability of parameters.

HILL, I. D. (1954). The distribution of the regression coefficient in samples from non-normal universe. *Biometrika,* 41, 548-552. **H-P-D-Th**

The author considers two statistics that are based on the deviation of the sample regression coefficient from its true value. One of these is based on normal regression assumption and the other is based on bivariate normal surface assumption. The insensitivity of the first statistic in terms of the level of significance is studied through the insensitivity of the second statistic to departures from normality.

HJELM, H. F. See: Norris, R. C. and Hjelm, H. F. (1961). **E&H-P-D-MC**

HODGES, J. L., Jr. and LEHMANN, E. L. (1963). Estimates of location based on rank tests. *Annals of Mathematical Statistics,* 34, 598-619. **E-Np-D-Th**

A new approach to the problem of robust point estimation is explored. Estimates of location are defined in terms of rank statistics such as Wilcoxon; certain regularity and invariance properties of these are proved.

HOEFFDING, W. (1956). The role of assumptions in statistical decisions. *Proceedings of the Third Berkeley Symposium,* 1, 105-114. **H-Np-D-Th**

In a given decision theoretic setup, for choosing between two hypotheses H_1 and H_2 a subclass of optimal rules for H_1 can be chosen which come closest to optimality under H_2. Their performance is compared with rules optimal under H_2.

HOGG, R. V. (1967). Some observations on robust estimation. *Journal of the American Statistical Association,* 62, 1179-1186. **E-Np-D-Th**

Estimators reasonable for different distributions are combined using weights depending on sample values. Empirical evidence indicating satisfactoriness of the proposed estimator for small samples is given. Under certain conditions, unbiasedness of the estimator is established for all symmetric underlying distributions.

HOLLANDER, MYLES (1967a). Asymptotic efficiency of two nonparametric competitors of Wilcoxon's two-sample test. *Journal of the American Statistical Association,* 62, 939-949. **H-Np-D&C-Th**

Wilcoxon's signed rank test and a test based on the uniform minimum variance unbiased estimator of $P(X_1 + X_2 < Y_1 + Y_2)$ are considered as competitors of the Mann-Whitney-Wilcoxon (V) test. The criteria used to compare the tests are Bahadar and Pitman Efficiency. For pure translation alternatives V is superior, but both tests compare favorably with respect to V for certain contamination alternatives.

HOLLANDER, MYLES (1967b). Rank tests for randomized blocks when the alternatives have a priori ordering. *Annals of Mathematical Statistics,* 38, 867-877. **H-Np-D-Th**

A test statistics based on a sum of Wilcoxon signed-rank statistics is introduced. An asymptotically distribution-free test procedure is proposed. Necessary and sufficient conditions for consistency of the test are given. Power comparison is made with Jonkjere's and Pages' tests.

HOLLOWAY, LOIS NELSON, and DUNN, OLIVE JEAN (1967). The robustness of Hotelling's T^2. *Journal of the American Statistical Association,* 62, 124-136. **H-P-D-MC**

Monte Carlo methods are used to study the effect of inequality of covariance matrices on the distribution of Hotelling's T^2 statistic.

HOLZINGER, K. J. and CHURCH, A. E. R. (1928). On the means of samples from a U-shaped population. *Biometrika,* 20-A, 361-388. **E&H-P-D-MC**

When distributions of means in samples of N are obtained by actual sampling from a U-shaped population their representation by a simple continuous curve seems to be quite unsatisfactory until N=50. When such a distribution of means begins to be representable by a Pearson curve, the goodness-of-fit appears to depend more on the way the actual distribution of discontinuous means is grouped into frequency groups than on the actual number of samples taken.

HOOKE, ROBERT See: Belz, Maurice H. and Hooke, Robert (1954). **E-Np-D-Th**

HOPKINS, J. W. and CLAY, P. P. F. (1963). Some empirical distributions of bivariate T^2 and homoscedasticity criterion M under unequal variance and leptokurtosis. *Journal of the American Statistical Association,* 58, 1048-1153. **H-P-D-MC**

Computer generated psuedo random numbers used to simulate drawing 1,000 pairs of samples from bivariate normal populations and from circular bivariate symmetrical leptokurtic populations with zero means, equal variances and $\beta_2 - 3 = 3.2$ or 6.2. Results suggest that the null distribution of T^2 for pairs of bivariate normal samples is rather robust against variance inequality but that this robustness does not extend to disparate sample sizes, and that upper tail frequencies of the distribution of bivariate T^2 for N_1, $N_2 \geq 10$ are not substantially affected by moderate degrees of symmetrical leptokurtosis.

HORSNELL, G. (1953). The effect of unequal group variances on the F-test for homogeneity of group means. *Biometrika,* 40, 128-136. **H-P-D-Th**

The author studies the effect of unequal group variances on the power of the F-test when used to investigate differences among a number of group means. He approximates the distribution of a certain linear combination of the usual between group and within group sum of squares and thereby approximates the power of the F-test when the number of groups is four.

HOTELLING, HAROLD (1947). Effects of non-normality at high significant levels. *Annals of Mathematical Statistics,* 18, 608-609. **H-P-D-Th**

Large samples tend to confirm the idea that non-normality makes little difference for a fixed range of values of the statistic while the sample size N increases. However the tail areas beyond a fixed deviation increase with N and behave quite differently than in sampling from a normal population. The author suggests that caution should be exercised in applying familiar tests with high significance levels. The problem here is concerned with large deviations.

HOTELLING, HAROLD (1961). The behavior of some standard statistical tests under non-standard conditions. *Proceedings of the 4th Berkeley Symposium of Mathematical Statistics and Probability,* 1, 319-359. **H-P-D-Th**

The distribution of the t-statistic which is used for testing deviations of means in samples from various non-normal populations, and in certain cases of observations of unequal variances and intercorrelations, is examined. Some new exact distributions of the t-statistic are obtained.

The marked effects of non-normality on the distributions of sample standard deviations and correlation coefficients are shown. The paper concludes with a discussion of the dilemmas with which statisticians are confronted by the anomalous behavior, in many instances, of standard statistical methods and of possible means of escape from such difficulties.

HØYLAND, ARNJOLT (1965). Robustness of the Hodges-Lehmann estimates for shifts. *Annals of Mathematical Statistics,* 36, 174-197. **E-Np-D-Th**

In the two-sample case where parent populations are assumed to be (i) symmetric, (ii) differing only in location, two estimates of the difference in locations are compared. Robustness of these estimates against deviations from the above assumptions is studied.

HØYLAND, ARNJOLT (1968). Robustness of the Wilcoxon estimates of location against a certain dependence. *Annals of Mathematical Statistics,* 39, 1196-1201. **E-Np-R-Th**

For a continuous distribution $F(v-\theta)$ symmetric about zero, two standard estimators of θ are compared when observations occur naturally grouped in n blocks, c observations per block with a (nuisance) random block effect, violating considerably the assumption of "independent and identically distributed" observations. An expression for relative asymptotic efficiency is obtained. Efficiencies are computed for normal and gross error models.

HSU, P. L. (1945). The approximate distribution of the mean and variance of a sample of independent variables. *Annals of Mathematical Statistics,* 16, 1-29. **E&H-Np-D-Th**

The author improves and generalizes certain well-known expansions of distribution functions, due to Cramér.

HUBER, P. J. (1964a). Robust estimation of a location parameter. *Annals of Mathematical Statistics,* 35, 77-101. **E-P-C-Th**

The problem is to estimate the location parameter when the prototype distribution function F is known only approximately. The class of estimators T is confined to maximum likelihood estimators. The paper is concluded by heuristic proposals concerning the estimation of location if the scale parameter, as well as the extent of contamination, is unknown, and by considering more general estimators based on minimizing the value of a U-statistic.

HUBER, P. J. (1964b). Robust methods. Presented at the Institute of Mathematical Statistics meeting in Berne. **E-Np-C-Th**

The author gives an illustrated exposition of the problem of robustness, distinguishing it from general problem of nonparametric methods. A brief review of results (given in detail in other papers by the author) is given.

HUBER, PETER J. (1965). A robust version of the probability ratio test. *The Annals of Mathematical Statistics,* 36, 1753-1758. **H-P-D-Th**

The problem of robustly testing a simple hypothesis P_0 against a simple alternative P_1 may be formalized by assuming that the true underlying distribution lies in some neighborhood of either of the idealized model distributions P_0 or P_1. The paper exhibits two different types of such neighborhoods for which a test called the censored probability ratio-test and defined by the author, is most robust in a well-defined minimax sense.

HUBER, P. J. (1967). *The Behavior of Maximum Likelihood Estimates Under Nonstandard Conditions.* Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability, 1, University of California Press at Berkeley and Los Angeles, 221,233. **E-P-O-Th**

The paper proves consistency and asymptotic normality of maximum likelihood estimators without assuming that the true distribution underlying the observations belong to the parametric family defining the M.L. estimator. The regularity conditions do not involve second and higher derivatives of the likelihood function.

HUNTSBERGER, D. V. See: Veale, James R. and Huntsberger, D. V. (1969). **E-P-C-Th**

HUTTON, LAJON R. and DARROCH, J. G. (1967). Examining some assumptions of the analysis of variance in experimental data. *Biometrics,* 23, 604 (abstract). **H-P-D-Th**

A number of sets of data from randomized block designs are examined with respect to properties of additivity, normality and constant variance, by an examination of orthonormal bases of the error space. Various tests of significance are applied as well as visual aids such as scatter diagrams. For sets of data which do not satisfy the assumptions, the appropriate transformations have been applied and the rectified data is examined in a similar fashion.

HYRENIUS, H. (1949). Sampling distributions from a compound normal parent population. *Skand. Aktuarietidskrift,* 32, 180-187. **H-P-C-Th**

Distributions of sample mean, average uncorrected sum of squares from compound normal distribution are derived. Joint distribution of means and variance, distribution of ratio of two-sample variances and "Studentized" statistic are derived.

HYRENIUS, HANNES (1950). Distribution of "Student"-Fisher's t in samples from compound normal functions. *Biometrika,* 37, 429-442. **H-P-O-MC&Th**

An important conclusion is that it is not sufficient to measure departure from normality of the underlying distribution by the first two β-coefficients or their equivalents. The structure of the underlying variation also has to be considered. The results of three sampling experiments are compared with the theoretical findings, showing on the whole good agreement.

HYRENIUS, H. Sampling from bivariate non-normal universes by means of compound normal distributions. *Biometrika,* 39, 238-246. **H-P-C-Th**

The author derives joint distribution of the sample means, variances and covariance, joint distribution of variances and covariance as well as individual distributions of these statistics for compound bivariate normal parent population. Some applications are also considered.

HYRENIUS, H. and I. ADOLFSON and et al. *Selected Bibliography on Non-normality.* Department of Statistics, University of Gothenburg, Sweden. **E&H-P-D-MC&Th**

The bibliography embraces studies of the effects of non-normality of normal-theory statistical methods. It does not include references to articles and books on distribution-free methods except when these also deal with the general problem of non-normality or with other ways of overcoming the difficulty. Short abstracts of almost all the references, are given. Articles dealing exclusively with problems of truncation have not been included.

ILLYASENKO, O. A. (1952). On the influence of grouping of empirical data on A. N. Kolmogorov's criteria of fit. *Dopovīdī Akademīī Nauk Ukraïns' koï RSR,* 3-6. **H-Np-O-Th**

The Kolmogorov's formula for the limiting distribution of the difference between sample and population function holds when the distribution function is continuous. An analogous formula is derived for a multinomial distribution.

IRWIN, J. O. (1927). On the frequency distributions of the mean of samples from a population having any law of frequency with finite moments, with special reference to Pearson's type II. *Biometrika,* 19, 225-239. **E&H-Np-O-Th**

The author uses a theorem of Euler to obtain the distributions of totals or means in samples from populations in which the variate has a continuous distribution.

ITO, KOICHI (1966). On heteroscedasticity in the linear normal regression model. *Research Papers in Statistics,* ed. F. N. David, John Wiley, and Sons, London, 147-155. **H-P-D-Th**

The paper investigates in a preliminary fashion the consequence to a test of linearity of regression, following from violation of the assumption of equality of residual covariance matrices in the multivariate regression model. It is numerically shown that in the case of k samples of equal size the test is not affected seriously by moderate inequality of covariance matrices as long as samples are very large. However, with unequal sample sizes quite large effects occur on the level of significance from even moderate variations of covariance matrices.

ITO, KOICHI and SCHULL, WILLIAM J. (1964). On the robustness of the T_0^2 test in multivariate analysis of variance when variance-covariance matrices are not equal. *Biometrika,* 51, 71-82. **H-P-D-Th**

It is shown that the test based on k(k>2) equal sample sizes is robust to variations in covariance matrices provided the equal sample size is very large.

JACQUEZ, JOHN A., MATHER, FRANCES J., and CRAWFORD, CHARLES R. (1968). Linear regression with non-constant, unknown error variances: Sampling experiments with least squares, weighted least squares and maximum likelihood estimators. *Biometrics,* 24, 607-626. **E-P-O-MC**

The theory of simple linear regression is extended to the case of nonuniform error variances for the situation in which replicates are available at each sample point in the domain of the independent variable.

JAYACHANCHAN, T. See: Leone, F. C., Jayachanchan, T., and Eisenstat, S. (1967). **E-P-C-MC**

JOHNSON, NORMAN L. See: Leone, Fred C., Nelson, Lloyd S., Johnson, Norman, and Eisenstat, Stanley (1968). **E-P-D-MC&Th**

JOHNSON, N. L. See: David, F. N. and Johnson, N. L. (1951a). **H-P-D-Th**

JOHNSON, N. L. See: David, F. N. and Johnson, N. L. (1951b). **H-P-D-Th**

JOHNSON, N. L. See: David, F. N. and Johnson, N. L. (1951c). **H-P-D-Th**

JOHNSON, N. L. See: David, F. N. and Johnson, N. L. (1952). **H-P-D-Th**

JOHNSON, RICHARD A. See: Bhattacharyya, G. K. and Johnson, Richard A. (1968a). **H-P-D-Th**

JOHNSON, RICHARD A. See: Bhattacharyya, G. K. and Johnson, Richard A. (1968b). **H-P-D-Th**

KALE, B. K. and BANCROFT, T. A. (1967). Inference from some incompletely specified models involving normal approximations to discrete data. *Biometrics,* 23, 335-348. **E&H-P-D-Th**

This paper considers the problem of pooling means of two independent random samples from discrete distributions (in particular, Poisson and binomial) which can be approximated by normal distributions after the appropriate transformations. The authors first develop the theory for two samples from $N(\mu_i, \sigma^2)$, $i = 1, 2$, σ^2 assumed known, and the parameter of interest being μ_1. Using a preliminary test of significance at level α to test $\mu_1 = \mu_2$, a new estimator $\bar{X}$ is proposed, both to estimate μ_1, and to test the hypothesis $\mu_1 = \mu_0$.

KAUFMAN, GORDON M. (1968). Optimal sample size in two-action problems when the sample observations are lognormal and the precision h is known. *Journal of the American Statistical Association,* 63, 653-659. **E-P-D-Th**

There is a brief synopsis of an empirical test of the robustness of a lognormal approximation to optimal sample size when sampling is in fact Bernoulli.

KEMP, KENNETH W. (1967). An example of errors incurred by erroneously assuming normality for CUSUM schemes. *Technometrics,* 9, 457-464. **E-P-D-Th**

The author discusses the errors which can occur when estimating the average sample run length of cumulative sum schemes when the distribution function of the cumulated parameter is incorrectly assumed to be normal.

KENDALL, M. G. and STUART, A. (1961). *The Advanced Theory of Statistics,* 2, Ch. 31, Hafner Publishing Company, New York. **E&H-P-D-G**

A general concept of robustness, its history, main contribution, etc. are discussed very briefly at an introductory level.

KIMBAL, A. W. See: Votow, D. F., Kimbal, A. W., and Rafferty, J. A. (1950). **H-P-R-Th**

KLOTZ, JEROME (1965). Alternative efficiencies for signed rank tests. *Annals of Mathematical Statistics,* 36, 1759-1766. **H-P-D-Th**

Asymptotic efficiency curves for the one-sample Wilcoxon and normal scores tests are obtained by comparing the exponential rate of convergence to zero of the type I error (α) while keeping the type II error (β) fixed ($0<\beta<1$). Comparisons yield small efficiency values for extreme alternatives.

KLOTZ, JEROME (1967). Asymptotic efficiency of the two-sample Kolmogorov-Smirnov test. *Journal of the American Statistical Association,* 62, 932-938. **H-Np-D-Th**

A simple derivation of asymptotic efficiency for the two-sample Kolmogorov-Smirnov statistic is given and evaluated for normal location and normal scale alternatives.

KONIJN, H. S. (1961). Non-parametric, robust and short-cut methods in regression and structural analysis. *Australian Journal of Statistics,* 3, 77-86. **E-P-D-G**

This paper is substantially a review of certain methods for estimating regression coefficients, which have been introduced to deal with the case where the regression variable is subject to errors of observation.

KRUSKAL, W. H. (1951). An approach to effects of non-normality in tests of significance. *Econometrika,* 19, 344-345 (abstract). **H-Np-D-G**

A summary of methods used so far, for attacking the problem, is given. A very general formulation of the problem in decision theoretic setup is proposed. No new solutions are reported.

KRUSKAL, W. H. (1954). The problem of non-normality and non-parametric tests. *Journal of the American Statistical Association,* 49, 329 (abstract). **H-Np-D-Th**

Arguments usually given in the defense of the common assumption of normality are stated and critically discussed. The advantages and disadvantages of the procedure of circumventing normality assumption (i.e., nonparametric methods) are discussed in general and some examples are given. The procedures of applied nonparametric analysis are classified and key references given.

LADERMAN, JACK (1939). The distribution of "Student's" ratio for samples of two items drawn from non-normal universes. *Annals of Mathematical Statistics,* 10, 376-379. **H-Np-D-Th**

A formal expression is derived for the distribution of the "Student" t-statistic for samples of two from any continuous universe.

LAFORGE, R. (1958). Comment of "The needless assumption of normality in Pearson's r." *American Psychologist,* 13, 546. **E&H-P-D-G**

Normality assumption is vital for interpretation of r in the context of psychology. Author suggests that such technical issues should not be discussed by psychologists, rather they should be left to the statisticians. The editor agrees.

LANCASTER, TONY (1968). Grouping estimators in heteroscedastic data. *Journal of the American Statistical Association,* 63, 182-191. **E-P-D-MC**

This paper gives numerical comparisons of the efficiency of Ordinary Least Squares (OLS) and Grouping Estimators in simple linear regression. It is shown that for some types of heteroscedasticity a Grouping Estimator can be more efficient than Ordinary Least Squares.

LANGLEY, P. G. See: Afifi, A. A., Elashoff, R. M. and Langley, P. G. (1968). **H-Np-C-Th**

LASKA, E. M. (1962). *A General Theory of Robustness.* Ph.D. dissertation, New York University. **E-P-D-Th**

Definitions of robustness are formulated in decision theoretic terms. Specific results include (i) the determination of a complete class of unbiased estimators under some minor restrictions, (ii) proof that the admissible class (over a family of linear unbiased estimators) may be determined by finding the best linear unbiased estimators for the totality of convex combinations of the distributions in the aforementioned family, (iii) demonstrations that the admissibly robust locally most powerful rank test is the totality of convex combinations of locally most powerful rank tests under some minor restrictions.

Examples for the case where the underlying distribution is normal or double exponential are presented.

LASKA, EUGENE See: Birnbaum, Allan and Laska, Eugene (1967a). **H-Np-D-Th**

LASKA, EUGENE See: Birnbaum, Allan, and Laska, Eugene (1967b). **E-P-O-Th**

LASKA, EUGENE M. See: Birnbaum, Allan and Laska, Eugene M. (1968). **E-P-D-Th**

LAYMAN, J. C. and BRADLEY, R. A. (1955). The effects of bimodality and of skewness in a population of the distribution of "t". *Journal of the American Statistical Association,* 50, 586 (abstract). **H-P-D-Th**

Effects of sampling from a compound normal distribution are partially studied. In a detailed study of a special case, robustness of t is observed.

LEAVERTON, PAUL and BIRCH, JOHN J. (1969). Small sample power curves for the two-sample location problem. *Technometrics,* 11, 299-307. **H-P-D-MC**

The two major assumptions required by the two-sample t-test to guarantee α are normality and a known ratio (usually 1) of variances in the two populations. Alternatives to this test are reviewed for situations where either or both of these assumptions are in doubt. Small sample power curves were derived for each test procedure by Monte Carlo sampling. The sampling was done under conditions most favorable to the t-test. The results showed that, for the cases studied, the power curves for two of the alternative tests compared very well with the t even for small samples.

LEHMANN, E. L. (1963). Robust estimation in analysis of variance. *Annals of Mathematical Statistics,* 34, 957-966. **E-Np-D-Th**

A linear model involving errors with common median is used. Certain least square estimators are studied.

LEHMANN, E. L. See: Hodges, J. L., Jr. and Lehmann, E. L. (1963). **E-Np-D-Th**

LEHMAN, F. (1967). General survey of Monte Carlo methods–(in German). *Blatt Deutsches Gesellschaft Versicherungs Mathematik,* 8, 431-456. **E&H-P-O-MC**

The author cites certain conditions under which one resorts to Monte Carlo method. He also provides methods of generating random numbers and of testing random number-generators, transformation of standard random numbers to obtain random numbers of specified distribution, and techniques for reduction of variance of statistical estimates obtained by Monte Carlo methods. The last section deals with application of Monte Carlo methods which are useful for evaluating multi-dimensional integrals and for simulating complex systems. The paper concludes with a list of 200 references, 44 of which are cited in the text.

LEONE, F. C., JAYACHANCHAN, T., and EISENSTAT, S. (1967). A study of robust estimates. *Technometrics,* 9, 652-660. **E-P-C-MC**

Results of an empirical study of the properties of two estimators (Hodges-Lehmann and Huber) of location and one of dispersion (Huber) for various distributions are presented.

LEONE, FRED C., NELSON, LLOYD S., JOHNSON, NORMAN L., and EISENSTAT, STANLEY. Sampling distributions of variance components II. Empirical studies of unbalanced nested designs. *Technometrics,* 10, 719-737. **E-P-D-MC&Th**

A development of the mathematical structure of nested designs is presented using, for a general case, a four-stage nested design. For the cases where the variables at each stage are normally distributed, analytical results can be obtained. This is done for the unbalanced "staggered" and "inverted" designs. Empirical estimates of variance for the non-normal case are obtained. These are compared with the analytical solutions.

Le ROUX, J. M. (1931). A study of the distribution of the variance in small samples. *Biometrika,* 13, 134-190. **E&H-P-D-Th**

The author traces out the manner in which the variance curves alter as the population and sample size alter, and shows how, if the moments of the sampled population are known, these distributions may be adequately represented by certain Pearson curves.

LEVINE, H. (1960). Robust tests for equality of variance. *Contributions to Probability and Statistics,* Stanford University Press, 278-292. **H-P-D-Th**

The paper discusses a new approach to the problem of modifying F-test and Bartlett's test with a view to attaining robustness. Sampling distribution of a statistic of the type $|X_{ij}-\mu_i|$ is worked out empirically. Efficiencies also are computed.

LEW, R. A. (1969). Robustness and sensitivity analysis. *Annals of Mathematical Statistics,* 40, 1145 (abstract). **H-P-D-Th**

Range of effectiveness of a statistical procedure over a certain family of distributions is defined for testing hypotheses, and is computed for some special procedures.

LEWONTIN, R. C. and FELSENSTEIN, J. (1965). The robustness of homogeneity tests on 2xn tables. *Biometrics,* 21, 19-33. **H-P-O-MC**

A Monte Carlo investigation of 2xn tables with fixed marginals, shows that the probability of type I error given by conventional x^2 test is in general conservative for 5 or more degrees of freedom even when expectations of successes are very small in each cell.

LINDLEY, D. V. (1961). The robustness of interval estimates. *Bulletin of the Institute for International Statistics,* 38, 209-220. **E-P-D-Th**

The main part of the paper concerns the effect of small departures from the class of hypotheses being considered in deriving Bayesian interval estimates. The calculations are applied to the effect of non-normality on the estimation of the mean and variance of a normal distribution, and the effect of autocorrelation on the estimation of a binomial parameter.

LINDQUIST, E. F. (1956). *Design and Analysis of Experiments in Psychology and Education.* Houghton & Mifflin Co., Boston, Mass. 78-86. **H-P-D-G**

These pages give a brief summary of the investigation on robustness of F-distribution reported in the Ph.D. dissertation by D. W. Norton. [See Norton, D. W.; for abstract of the thesis.]

LINDQUIST, E. F. See: Godard, R. H. and Lindquist, E. F. (1940). **H-P-D-MC**

MADANSKY, ALBERT See: Goodman, Leo A. and Madansky, Albert (1962). **E-P&Np-C-Th**

MANN, N. R. (1969). Cramér-Rao efficiencies of best linear invariant estimators of parameters of the extreme value distribution under type II censoring from above. *SIAM Journal of Applied Mathematics,* 17, 1150-1157. **E-P-O-Th**

The author considers the problem of estimating the location and scale parameters of the extreme-value distribution, with expected loss invariant under location and scale transformation (that is, the loss is squared error divided by the square of the scale parameter). She shows that the best linear invariant (BLI) estimators are functions of the minimum variance linear unbiased (MVLU) estimators and their covariance matrix. Further, the expected loss of any BLI estimator is uniformly less than that of the corresponding MVLU. Also the efficiencies of BLI relative to Cramér-Rao lower bound are studied.

MARDIA, K. V. (1966). A non-parametric test for the bivariate two-sample location problem, II: asymptotic power and efficiency relative to Hotelling's T^2. *Annals of Mathematical Statistics,* 37, 1975 (abstract). **H-Np-D-Th**

The author has developed an unconditional nonparametric test to test the equality of two-bivariate distributions. The test is invariant under linear transformations, and is asymptotically noncentral chi-square with two degrees of freedom. Its Pitman efficiency relative to Hotelling's T^2 is $\pi/4$ for normal alternatives. Its efficiency for Cramér-type of alternatives is also studied.

MARDIA, K. V. (1967). A non-parametric test for the bivariate two-sample location problem, IV: small sample power in the non-normal case and the effect of non-normality to T^2. *Annals of Mathematical Statistics,* 38, 643 (abstract 5). **H-Np-D-MC**

The U-square test proposed by the author is found to be better than Hotelling's T^2. This is an empirical study.

MARTIN, C. S. See: Eisenhart, C., Deming, L. S., and Martin, C. S. (1948). **E&H-P-D-MC**

MARTIN, C. S. See: Eisenhart, C., Deming, L. S., and Martin, C. S. (1948). **E&H-P-D-MC**

MATHER, FRANCES J. See: Jacquez, John A., Mather, Frances J., and Crawford, Charles R. (1968). **E-P-O-MC**

MAZUY, KEY KNIGHT, and CONNOR, W. S. (1965). Student's t in a two-way classification with unequal variances. *Annals of Mathematical Statistics,* 36, 1248-1255. **H-P-O-Th**

Scheffe's & Cochran's approaches are generalized to analyze fixed effects models (with or without interaction) using the t-statistic.

McHUGH, RICHARD B. and MIELKE, PAUL W. (1968). Negative variance estimates and statistical dependence in nested sampling. *Journal of the American Statistical Association,* 63, 1000-1003. **E-P-R-Th**

Negative components of variance estimates may arise when the usual specification of statistically independent random variables is false. A class of such situations is considered here, viz., those in which the assumption of sampling from infinite populations is incorrect.

McLAUGHLIN, D. H. and TUKEY, JOHN W. (1961). *The Variance of Mean of Symmetrically Trimmed Samples from Normal Populations and Its Estimation from Such Trimmed Samples (Trimming/Winsorization).* Department of Mathematics, Princeton University, Technical Report No. 42 Department of the Army Project-No. 5B 99-01-004. **E&H-P-C-Th**

The efficiency of the trimmed mean relative to the arithmetic mean is moderately, but probably not satisfactorily close to unity. Thus, they are led to an investigation of the equally many-times Winsorized sum of squares of deviations as a basis for a denominator for the trimmed mean.

McLAUGHLIN, D. H. See: Tukey, J. W. and McLaughlin, D. H. (1963). **E&H-P-C-Th**

McNEIL, D. R. (1967). Efficiency loss due to grouping in distribution-free tests. *Journal of the American Statistical Association,* 954-965. **H-Np-O-Th**

Wilcoxon's and Mood's tests for the two-sample problem, Mann's test for randomness and Pitman's test for independence are studied. It is assumed that ties within groups are broken randomly or replaced by average ranks. It is shown that loss of power which is generally small, depends on the width of grouping interval and also on the underlying distribution. Breaking ties by randomization is preferred.

MEHRA, K. L. (1968). Conditionally distribution-free tests for interactions. *Annals of Mathematical Statistics,* 39, 704 (abstract 8). **H-P-D-Th**

Conditional rank order tests for hypothesis of no interaction are given for a three-way layout.

MEHTA, J. S. and GURLAND, JOHN (1969). Testing equality of means in the presence of correlation. *Biometrika,* 56, 119-126. **H-P-R-Th**

The problem considered here is that of testing equality of means in the presence of correlation when a sample from a bivariate normal population is available. The procedure studied for this purpose involves a preliminary test of a hypothesis concerning the population correlation coefficient.

MIELKE, PAUL W. See: McHugh, Richard B. and Mielke, Paul W. (1968). **E-P-R-Th**

MIKE, VALERIE (1967). Contribution to robust estimation. *Annals of Mathematical Statistics,* 38, 1935 (abstract 19). **E-P-D-Th**

Birnbaum's method of "mixture models" is used to obtain generalized Pitman estimators. They are shown to be admissible and asymptotically efficient. Efficiency-robust linear unbiased estimators based on sample quantities are derived and optimal spacing of quantities is also discussed.

MILLER, RUPERT G. (1968). Jackknifing variances. *Annals of Mathematical Statistics,* 39, 567-582. **H-P-D-MC**

The author examines how Tukey's jackknife technique performs in testing hypothesis on variance. He finds it reasonably powerful and robust against uniform, double exponential, and sixth power distribution.

MISHRIKY, R. S. See: David, H. A. and Mishriky, R. S. (1968). **E-Np-D-Th**

MITRA, S. K. See: Das, N. G. and Mitra, S. K. (1964). **H-P-D-Th**

MONTZINGO, L. J. and SEVERO, N. C. (1961). The effect of convergence to normality on tests of hypotheses. *Annals of Mathematical Statistics,* 32, 920 (abstract). **E&H-P-D-Th**

Sufficient conditions are given for the power of the test based on asymptotically normally distributed statistic, to converge to the power of the test if the statistic were in fact normal.

MOORE, P. G. (1957). Normality in quality control charts. *Applied Statistics,* 6, 171-179. **H-P-D-Th**

Examples are given to show how certain departures from normality can affect the probabilities associated with control limits calculated by normal theory. It is demonstrated that estimation of standard

deviation by sample range is erroneous. The control charts using only upper or lower significance level instead of the two combined are shown to be more sensitive to non-normality.

MORRISON, D. F. (1962). On the distribution of squares and crossproducts of normal variates in the presence of intraclass correlation. *Annals of Mathematical Statistics,* 33, 1461-1463. **H-P-R-Th**

The sums of squares and cross products of groups or r random variables drawn from a multi-variate normal population whose covariance matrix has a certain pattern indicating intra-class correlations are shown to follow the Wishart distribution. It follows immediately from this result that the usual distributions of the single, partial and multiple correlation coefficients obtain, although with noncentrality parameters that reflect the effect of the intra-class correlations. (author's summary).

MOSER, J. M. See: Bell, C. B., Moser, J. M., and Thompson, Rory (1966). **H-Np-D-MC**

MOSES, L. E. (1956). Some theoretical aspects of the lot plot sampling inspection plan. *Journal of the American Statistical Association,* 51, 84-107. **H-Np-D-Th**

A lot-plot plan takes 50 observations and gives acceptance rules using sample histograms. It is shown that despite the use of a histogram no such plan can be distribution-free. The behavior of the plan is studied where the lot-distribution is t, symmetric β, χ^2 or mixed normal.

MOSTELLER, F. and WALLACE, D. L. (1962). Inference in an authorship problem: A comparative study of discrimination method applied to the authorship of "The Federalist Papers." A talk given at the IMS meeting, Minneapolis, Minnesota, September. *Inference and Disputed Authorship: The Federalist.* Addison Wesley Publishing Co., Reading, Mass. Chapter 6 (1964). **H-P-D-G**

The problem is to decide who wrote some of the papers called "Federalist," Madison or Hamilton. The distributions of use of typical words by the two authors are studied and disputed papers are examined in their light. Madison is the statistical choice.

Facility of use of prior distributions is stressed. Importance of Bayesian study of data distribution is brought out.

The study of distributions of often-used words is robust against the subject of discussion.

MURTHY, V. K. (1960). On the distribution of the sum of circular serial correlation coefficients and the effects of non-normality on its distribution. *Annals of Mathematical Statistics,* 31, 239-240 (abstract). **E-P-D-Th**

It is shown that the average of the circular serial correlation coefficients of all possible lags computed from a random sample of size (2m+1) drawn from the standard normal population, has a beta distribution. The effect of non-normality on the distribution of the same statistic is also studied.

NAGAO, HISAO See: Sugiura, Nariake and Nagao, Hisao (1969). **H-Np-D-Th**

NAGENDRA, Y. See: Bhattacharjee, G. P. and Nagendra, Y. (1964). **H-P-D-Th**

NAIR, A. N. KRISHNAN (1941). Distribution of Student's t and the correlation coefficient in samples from non-normal populations. *Sankhyā,* 383-400. **E&H-P-D-MC**

865 samples of size 6 from the negative exponential population (A) and 518 samples of size 5 from a certain gamma population (B) were drawn and "Student's" t was calculated in each case. Significant correlation was observed between mean and variance in samples. The regression of variance on mean was also calculated and it followed a second order parabola. The agreement between observed t-distribution and the corresponding normal-theory t-distribution is not very close. In using normal theory to test for significance, it is safe to use a higher level of significance than is usual with normal samples. It is also suggested that the error would be minimized by using different significance levels for positive and negative values of t.

NANDI, H. K. and SEN, P. K. (1963). On the properties of U-statistics when the observations are not independent II. Unbiased estimation of the parameters of a finite population. *Calcutta Statistical Association Bulletin,* 12, 124-148. **E&H-Np-D&R-Th**

Hoeffding's results on U-statistics (1948) are extended from the case of independent random variables, in Part I to that of m-dependent variables (See Sen, P. K. (1963). *Calcutta Statistical Association Bulletin,* 12, 69-92) and in Part II to the case that the variables are the values obtained when a sample is drawn (without replacement) from a finite population.

NATHAN, GAD (1970). *Approximate Tests of Independence in Contingency Tables from Complex Stratified Cluster Samples.* Unpublished Technical Report. Hebrew University and Central Bureau of Statistics, Jerusalem. **H-P-R-Th**

The author proposes a statistic which is a modification of the statistic proposed by Chapman (1966) and McCarthy (see *Revue of International Statistical Institute,* 37, (1969), 239-262) in order to test for independence in a contingency table obtained from a complex stratified cluster sample. The modified statistic has exactly zero expectation under the null hypothesis and its covariance can be evaluated approximately. Two test procedures based on large sample statistic and the other on Hotelling's T^2 are obtained on the basis of sample estimates of the covariance approximations. A numerical example illustrates that the effects of various assumptions and approximations made on the values of the statistics are very small.

NEAVE, H. R. and GRANGER, W. J. (1968). A Monte Carlo study comparing various two-sample tests for difference in means. *Technometrics,* 10, 509-522. **H-Np-D-MC**

A study was conducted on eight tests for differences in means under a variety of simulated experimental situations. Estimates were made of the power of the tests and measures of the extent to which they gave similar results. In particular the performance of a new quick test developed by Neave was studied and was found to be satisfactory: in fact it was by far the best of the quick tests considered. However, some of the classical and more general nonparametric tests, such as the runs and the Kolmogorov-Smirnov tests, were found to be less useful when testing for differences in means. Over the range of situations investigated, the Normal Scores test gave the most satisfactory results, followed closely by the Wilcoxon rank-sum test. Even when the populations were normally distributed, these tests were only slightly inferior to the t-test, and naturally were much superior in the cases of non-normal populations.

NEFZGER, M. D. and DRASGOW, J. (1957). The needless assumption of normality in Pearson's r. *American Psychologist,* 12, 623-625. **E&H-P-D-G**

The question is whether each of the correlated variables must be marginally normal. Standard statistical textbooks opine differently. Yule pointed out very early that the crucial assumption is that of a linear relation between two variables, given which, product-moment correlation coefficient can be meaningfully computed and interpreted. Also tests of significance of r *do not* in practice require normally distributed variates. This paper is an expository one. No theoretical justifications are offered for the opinions expressed.

NELSON, LLOYD S. (1968). See: Leone, Fred C., Nelson, Lloyd S., Johnson, Norman L., and Eisenstat, Stanley (1968). **E-P-D-MC&Th**

NEYMAN, J. and PEARSON, E. S. (1928). On the use and interpretation of certain test criteria for purposes of statistical inference, Part I. *Biometrika,* 20-A, 175-240. **H-P-D&R-Th**

The authors outline their plan for determining whether it is probable that a given sample, taken as a whole, has been drawn from a specified population. A discussion of faulty assumptions such as non-normality and nonrandomness is included.

NORRIS, R. C. and HJELM, H. F. (1961). Non-normality and moment correlation. *Journal of Experimental Education,* 29, 261-270. **E&H-P-D-MC**

Experimental and theoretical sampling distributions of r are compared. When population value of ρ is zero the non-normal populations gave only insignificant differences. However, when $\rho \neq 0$ the experimentally obtained sampling distribution of r for non-normal populations differed markedly from theoretical distribution under the assumption that parent populations are normal.

NORTON, D. W. (1952). *An Empirical Investigation of the Effects of Non-normality and Heterogeneity Upon the F-test of Analysis of Variance.* Ph.D. dissertation, Iowa State University. **H-P-D-MC**

Four investigations were undertaken in which populations (i) differed in form from normality and/or from each other, (ii) differed in variance from each other, (iii) and (iv) the two types of differences occurred together. Three thousand sets of samples were drawn. The results indicate that the F-test is robust over a wide variety of situations and never was it found absolutely unworkable.

OLDIS, E. See: Chesire, L., Oldis, E., and Pearson, E. S. (1932). **E&H-P-D-Th**

OLDS, E. G. (1954). On linear regression analysis when the dependent variable is rectangular. *Annals of Mathematical Statistics,* 25, 173 (abstract). **E-P-D-Th**

A method of obtaining a modified least squares' estimator which leads to admissible estimators is given.

OLDS, E. G. See: Severo, N. C. and Olds, E. G. (1956). **H-P-D-Th**

OWEN, D. B. See: Rao, J. N. K. and Owen, D. B. (1965). **E-P-D-Th**

PHAL, P. J. (1969). On testing for goodness-of-fit of the negative binomial distribution when expectations are small. *Biometrics,* 25, 143-151. **H-P-D-Th**

In the case of fitting the negative binomial distribution, it is shown, by means of an example, that a method of Nass provides a more suitable goodness-of-fit criterion than either Pearson's χ^2 statistic or the log likelihood ratio, and that the scope and power of all three criteria are considerably enhanced by relaxing the commonly used rule that all frequency classes should have an expectation greater than 5.

PARKIN, S. J. See: Edwards, D. S. and Parkin, S. J. (1954). **H-P-O-MC**

PEARSON, E. S. (1929). Some notes on sampling tests with two variables. *Biometrika,* 21, 337-360. **H-P-D-Th**

The author examines how far deviations from normality are likely to affect Fisher's goodness-of-fit of regression curves. The experimental results used to illustrate this point also help to throw some light on the distribution of the correlation coefficient in small samples from non-normal populations.

PEARSON, E. S. (1931). The analysis of variance in cases of non-normal variation. *Biometrika,* 23, 114-133. **H-P-D-MC**

The author considers the problem of testing for the significance of η^2. The results of this paper indicate that within the range of the experimental populations indicated in figure 1, η^2 is adequately represented for very many purposes by the normal law.

PEARSON, E. S. (1937). Some aspects of the problem of randomization. *Biometrika,* 29, 53-64. **E&H-P-O-Th**

The author discusses the problem of randomization and failure of assumptions to hold in cases of estimation and testing hypotheses.

PEARSON, E. S. (1950). Some notes on the use of range. *Biometrika,* 37, 88-92. **E-P-D-Th**

The author investigates the estimation of the standard deviation of a population by use of the range of a sample or the mean range of a sample of N items subdivided into m groups of n items each (i) when the population is not normal, or (ii) when the sample includes one or more outlying observations. He feels that the case for using range, with adjustment appropriate for a normal population, as an estimator of standard deviation is well supported.

PEARSON, E. S. (1958). Note on Mr. Srivastava's paper on the power function of Student's test. *Biometrika,* 45, 429-430. **H-P-D-MC**

Srivastava's theory (see *Biometrika,* 45 (1958), 421-430) on the robustness of the t-test is compared with a sampling experiment carried out by Pearson and Adyanthaya (1928).

PEARSON, E. S. (1961). *Some Systems of Frequency Curves.* Princeton University Technical Report No. 46, Statistical Techniques Research Group, Princeton. **E&H-P-D-G**

The report suggests the use of Pearsonian system of curves in representing sampling distributions of statistics for which only moments of cumulants are known, and as typical forms of non-normal parent distributions useful to explore robustness of standard tests.

PEARSON, E. S. (1962). *Frequency Surfaces.* Princeton University Technical Report No. 49, Statistical Techniques Research Group, Princeton. **E&H-P-D-G**

The report is mainly concerned with representation of a bivariate distribution by an approximating function using moments or other means, and such allied matters. Difficulty in knowing what amount of departure from bivariate normality affects derived sampling distributions is stressed. The fact that $\tanh^{-1}$ transformation makes the correlation coefficients (Spearman's rho, Kendall's tau and Fisher's r_F) approximately normal leads to a study of a class of bivariate distributions whose members are convertible to bivariate normal form by monotonic transformation applied to the marginals.

PEARSON, E. S. (1963). Some problems arising in approximating to probability distributions, using moments. *Biometrika,* 50, 95-112. **H-P-D-Th**

This paper (i) considers the proportionate contributions, arising from different parts of the parent frequency, to each of the first six moments of certain selected distributions, (ii) makes a comparison of the distribution functions of three leptokurtic distributions, when the first four moments have identical values, (iii) applies some of the conclusions drawn from the studies (i) and (ii) to the problem of determining significant points for the moment ratio statistics used in testing for departure from normality.

PEARSON, E. S. and ADYANTHAYA, N. K. (1928). The distribution of frequency constants in small samples from symmetrical populations. *Biometrika,* 20-A, 356-360. **H-P-D-Th**

The results given show the extent to which the tests developed for the case of samples from a normal population are valid and suggest modification of these tests when required.

PEARSON, E. S. and ADYANTHAYA, N. K. (1929). The distribution of frequency constants in small samples from non-normal symmetrical and skew populations. *Biometrika,* 21, 359-386. **H-P-D-MC**

The authors study the small sample distribution of "Student's" one and two-sample t-test statistics when the underlying populations are not normal.

PEARSON, E. S. See: Chesire, L., Oldis, E., and Pearson, E. S. (1932). **E&H-P-D-Th**

PEARSON, E. S. See: Neyman, J. and Pearson, E. S. (1928). **H-P-D&R-Th**

PERLO, V. (1932). On the distribution of "Student's" ratio for samples of three drawn from a rectangular distribution. *Biometrika,* 25, 203-204. **H-P-D-Th**

This paper presents the distribution of t for samples of size three drawn from a rectangular distribution, and some comparisons are made with "Student's" distribution.

PITMAN, E. J. G. (1937). Significance tests which may be applied to samples from any populations, III: the analysis of variance tests. *Biometrika,* 29, 322-335. **H-Np-D-Th**

Expressions for the first four moments of the statistic used in the analysis of variance test are obtained. From these the author concludes that when the number of individuals in each batch, and the number of batches are both not too small, the usual test may be safely applied. A method of testing the

validity of the approximation which this test employs is stated, and modifications of procedure, when necessary, are suggested.

POSTEN, H. O. (1963). Robustness of uniform Bayesian encoding. *Technometrics*, 5, 122-125. **E-P-D-Th**

This paper is concerned with the investigation of the effects of removing the assumption of uniform input, on the optimum assignment of the received messages to a specific set of transmitted messages. The results show that if the deviation from uniformity is not too extreme, the optimum assignment will be one of the possible optimum assignments under the uniform input assumption. A measure of deviation from uniformity and a criterion for extreme deviation is included in the paper.

POSTEN, HARRY O. See: Fridshal, Donald and Posten, Harry O. (1966). **E&H-P-D&R-G**

POSTEN, HARRY O. See: Hatch, Lawrence O. and Posten, Harry O. (1966). **E&H-P-D&R-G**

PRATT, JOHN W. (1964). Robustness of some procedures for the two-sample location problem. *Journal of the American Statistical Association*, 59, 665-680. **H-Np-D-Th&MC**

The level of ordinary two-sample procedures is not preserved if the two populations differ in dispersion or shape. The effect of such differences, on the t, median, Mann-Whitney and normal scores procedures is investigated asymptotically and tables are given comparing the five procedures.

PRATT, JOHN W. (1965). Bayesian interpretation of standard statements (with discussion). *Journal of the Royal Statistical Society*, Series B, 27, No. 2, 169-203. **E&H-P-D-Th**

The author gives some ideas about the interpretation of standard influence statements from Bayesian point of view. First he considers the case of insufficient statistics, then provides discussion for estimation problems and those of the hypothesis-testing.

PURI, MADAN LAL and SEN, PRANAB KUMAR (1967). On some optimum nonparametric procedures in two-way layouts. *Journal of the American Statistical Association*, 62, 1214-1229. **E-Np-D-Th**

Properties of the proposed point estimators of contrasts such as symmetry, invariance and asymptotic relative efficiencies with respect to the corresponding least-square estimators are obtained. In particular, it is shown that the normal score procedures are asymptotically as efficient as the procedures based on the method of least squares, whatever be parent cumulative distribution functions.

QUADE, DANA (1967). Rank analysis of covariance. *Journal of the American Statistical Association*, 62, 1187-1200. **H-Np-D-Th**

Various methods are discussed for the problem of comparing two or more populations with respect to a response variable Y in the presence of a (possible multivariate) concomitant variable X– a situation in which the usual method is the standard one-way analysis of covariance. A method based on ranks is developed.

QUENSEL, C. E. (1938). The distribution of the second moment and of the correlation coefficient in samples from populations of type A. Lund Universities. *Arsskrift.* N.F. Avd. 2 BD. 34 NR4, 5-111. **E&H-P-D-Th**

Using characteristic functions the author derives approximations to the sampling distributions of certain statistics. The first terms in these approximations coincide with earlier results by "Student" and Fisher.

QUENSEL, C. E. (1943). An extension of the validity of "Student"-Fisher's law of distribution. *Skandinavisk Aktuarietidskrift*, 26, 210-219. **H-P-D-Th**

Samples $(x_1 \ldots x_n)$ are considered in which the x_i are independently normally distributed, each with mean zero but with variances not assumed equal. With the aid of moment generating functions, approximations are obtained for the joint and marginal distribution of the first and second sample moments

and for the distribution of the "Student"-ratio formed for the sample. The relation of the last approximation to the customary t-distribution is discussed.

QUENSEL, C. E. (1947). The validity of the z-criterion when the variates are taken from different normal populations. *Skandinavisk Aktuarietidskrift*, 30, 44-55. **H-P-D-Th**

Characteristic function of the joint distribution of the three sums of squares into which the sum of squares of the recorded values is divided is studied. An approximation to the variance ratios is obtained. Effects on observed variances, of the difference in population variances, are pointed out.

QUENSEL, C. E. (1952). The distribution of second order moments in random samples from non-normal multivariate universes. Lund Universities. *Arsskrift.* N.F. Avd. 2 BD. 48, NR4, 3-11. **E&H-P-D-Th**

The author is interested in procedures and general techniques for obtaining the distributions of all the second order moments from a multivariate Gram-Charlier type A series. He determines the characteristic function of the second order central moments and indicates in some special cases the results for the distribution functions themselves.

QUENSEL, C. E. (1953). The distribution of the partial correlation coefficient in samples from multivariate universes in a special case of non-normally distributed random variables. *Skandinavisk Aktuarietidskrift*, 36, 16-23. **E&H-P-D-Th**

Distribution of the partial correlation coefficient is derived assuming that the variables are linearly related and residuals are independent and normally distributed and alternatively, when the variables are linear combinations of random variables distributed in a Gram-Charlier type A series.

RAFFERTY, J. A. See: Votow, D. F., Kimbal, A. W., and Rafferty, J. A. (1950). **H-P-R-Th**

RAGHAVACHARI, M. (1965). The two-sample scale problem when locations are unknown. *Annals of Mathematical Statistics*, 36, 1236-1242. **H-Np-D-Th**

The author shows that a test of Klotz (see *Annals of Mathematical Statistics*, 33 (1962), 498-572), modified to the present problem, is asymptotically distribution-free, and discusses its asymptotic relative efficiency.

RAGHUNANDANAN, K. See: Siddiqui, M. M. and Raghunandanan, K. (1967). **E-Np-D-Th**

RAMACHANDRAMURTY, P. V. (1966a). On some nonparametric estimates for shift in the Behren-Fisher situation. *Annals of Mathematical Statistics*, 37, 593-610. **E-Np-D-Th**

The author considers two questions relative to estimation when scale parameters in populations are possibly different: (i) how do the members of the family of nonparametric estimators suggested by Hodges and Lehmann compare among themselves and (ii) how do these estimators compare with the classical estimators?

RAMACHANDRAMURTY, P. V. (1966b). On the Pitman efficiency of onesided Kolmogorov and Smirnov tests for normal alternatives. *Annals of Mathematical Statistics*, 37, 940-944. **E-Np-D-Th**

Lower bound for the Pitman efficiency of the one-sided Kolmogorov test for all normal alternatives and for the Smirnov test for normal shift alternatives are obtained.

RAO, J. N. K. and OWEN, D. B. (1965). Effect of non-normality on two-sided variables sampling plans and two-sided tolerance limits which control percentages in both tails of the normal distribution. *Annals of Mathematical Statistics*, 36, 1078 (abstract 28). **E-P-D-Th**

A mathematical investigation is made to examine in what way OC curves of Owen's variables plans, and tolerance limits are affected when distribution of the characteristic can be represented by the first three terms of an Edgeworth series.

RAO, M. M. (1960). Some results on transformations in the analysis of variance. *Annals of Mathematical Statistics,* 31, 819-820 (abstract). **H-P-D-Th**

It is shown that the usual normal theory is applicable to test the hypotheses on means of the untransformed variables. Sufficient conditions for the applicability of the normal theory are presented for a certain family of distributions.

REITSMA, A. (1963). On approximations to sampling distributions of the mean for samples from non-normal populations. *Annals of Mathematical Statistics,* 34, 1308-1314. **E&H-P-D-Th**

The paper presents a new approach for finding approximations which would fill the gap between the exact sampling distribution and its ultimate normal approximation for the mean of a random sample from a non-normal parent population. For certain skew parent distributions, sampling distribution of the mean tends to Pearson type-III distribution before approaching normality.

REITZ, H. C. (1939). On the distribution of the "Student" ratio for small samples from certain non-normal populations. *Annals of Mathematical Statistics,* 10, 265-274. **H-P-D-Th**

A description of interesting sampling experiments showing that the familiar ratio $\overline{X}/s$ follows pretty closely the "Student's" distribution even in cases where the sampled population is distinctly non-normal, causing a significant regression of s on $\overline{X}$, is given.

RICE, JOHN R. and WHITE, JOHN S. (1964). Norms for smoothing and estimation. *SIAM Review,* 6, 243-256. **E-P-D-MC**

The authors compare the variances of the median, mean and midrange in samples from various distributions by actual sampling. They draw the well-known conclusion that, depending on parent distribution, one or another statistic is more efficient.

RIDER, P. R. (1929). On the distribution of the ratio of mean to standard deviation in small samples from non-normal universes. *Biometrika,* 21, 124-143. **E&H-P-D-Th**

A number of statistics in samples from a rectangular universe are found to be distributed in polynomials, which are apparently, except in the case of greatest variate and least variate, of degree one less than the number in the sample. The author concludes that there appears to be little difference in the distributions of these variates when the universe is continuous and when it is discrete.

RIDER, P. R. (1931). On small samples from certain non-normal universes. *Annals of Mathematical Statistics,* 2, 48-65. **H-P-D-Th**

A triangular population and a U-shaped universe are studied using samples of four. The distribution of the ratio z, (mean of sample-mean of universe) ÷ standard deviation of sample, and the distribution of means is given. Also discussed is the probability corresponding to an interval of three sample standard deviations on each side of the sample mean.

RIDER, P. R. (1932). On the distribution of the correlation coefficient in small samples. *Biometrika,* 24, 382-403. **E&H-P-D-Th**

The paper attempts to discover the effect upon the distribution on random samples of the product-moment coefficient of correlation, r, when the samples are drawn from non-normal instead of a normal population. In Part I the results of sampling from certain populations which differ greatly from the normal are given. Also, the results of sampling from a normal population having a high degree of correlation are given. As the sampling was done experimentally, discrete populations were used. In Part II the effect of grouping upon the distribution of r is investigated.

ROACH, S. A. (1963). The frequency distribution of the sample mean where each member of the sample is drawn from a different rectangular distribution. *Biometrika,* 50, 508-513. **E&H-P-D-Th**

It is the purpose of this paper to show that the distribution of the sample mean where each member is drawn from a different rectangular distribution can be deduced by using n-dimensional geometry similar to the method Hall employed for the special case where the whole sample is drawn from one rectangular distribution.

RUBIN, HERMAN See: Gastwirth, Joseph L. and Rubin, Herman (1968a). **E-P-R-Th**

RUBIN, HERMAN See: Gastwirth, Joseph L. and Rubin, Herman (1968b). **E-P-R-Th**

RUBIN, HERMAN See: Gastwirth, Joseph L. and Rubin, Herman (1969). **E-P-D-Th**

SATTERTHWAITE, F. E. (1964). The mean of the tail of a distribution. *Technometrics,* 6, 331. **E-Np-D-G**

In response to a query, the author gives the following simple rule for approximating the mean of the tail of a distribution: use that value beyond which 40% of the area of the tail lies.

SAVAGE, RICHARD I. (1962). *Bibliography of Nonparametric Statistics.* Cambridge: Harvard University Press, Massachusetts. **E&H-Np-D-G**

The author provides a list of articles pertaining to nonparametric statistics, through April 1961. He uses a citation scheme which gives a list of all entries that cite a particular item. A classification scheme is also followed. At the end he also provides an index for cross references for multiple-authored entries.

SCHATZOFF, MARTIN (1966). Sensitivity comparisons among tests of the general linear hypothesis. *Journal of the American Statistical Association,* 61, 415-435. **H-P-D-MC**

Using the concept of expected significance level of a test the sensitivities of several proposed tests of the general linear hypothesis are compared by simulation under a wide variety of parameterizations.

SCHEFFÉ, HENRY (1956). Alternative model for the analysis of variance. *Annals of Mathematical Statistics,* 27, 251-271. **E&H-P-D-Th**

A historical background not very familiar to statisticians is sketched. Some difficulties in formulating the random interactions are discussed. Models reflecting a randomization in the experiment to assign the treatment contributions to finite populations of experimental units are also dealt with.

SCHULL, WILLIAM J. See: Ito, Koichi and Schull, William J. (1964). **H-P-D-Th**

SCHWARTZ, D. and LELLOUCH, J. Les Manquants Dane L'Essai Therapeutique (Withdrawals in therapeutic trials). *Biometrics,* 23, 145-152. **E-P-O-Th**

The authors show how withdrawals can be classified into various categories according to the reason of loss: subjects in certain categories can be included in the analysis without the introduction of bias or the invalidation of significance test. The inclusion of subjects in other categories cannot be justified, and hypothesis about the extremes of such missing values must be used to assess limits of possible error.

SEALE, L. M. (1955). *The Effects of Unequal Small Sized Samples on Statistical Tests of Significance.* Ph.D. dissertation, Psychology Department, Ohio State University. **H-P-D-Th**

This is an empirical study of robustness of t and v statistics. It indicates that distribution of v statistic will tend to systematically over-estimate significance with unequalness in sample sizes, when v-statistic is referred to the t-distribution with $N_X + N_Y - 2$ degrees of freedom. Instead when m is corrected for degrees of freedom by Welch's procedure, the bias in regard to significance statements vanishes.

SEN, PRANAB KUMAR (1968a). Asymptotic normality of sample quantiles for m-dependent processes. *Annals of Mathematical Statistics,* 39, 1724-1730. **E&H-Np-D-Th**

Robust-efficiency of the sample median is considered.

SEN, PRANAB KUMAR (1968b). Estimates of the regression coefficient based on Kendall's Tau. *Journal of the American Statistical Association,* 63, 1379-1389. **E-Np-C-Th**

The confidence interval of a regression coefficient β is sensitive to non-normality of the parent distribution. In this paper, a simple and robust (point as well as interval) estimator of β based on Kendall's rank correlation tau is studied.

SEN, PRANAB KUMAR (1968c). On a further robustness property of the test and estimator based on Wilcoxon's signed rank statistic. *Annals of Mathematical Statistics,* 39, 282-285. **E&H-Np-D-Th**

The robust-efficiency of the test and estimator based on Wilcoxon's signed rank statistic when the sample observations are drawn from different populations is studied here.

SEN, PRANAB KUMAR (1968d). Robustness of some nonparametric procedures in linear models. *Annals of Mathematical Statistics,* 39, 1913-1922. **E&H-Np-R-Th**

Nonparametric procedures for estimating and testing treatment contrasts, based on the Wilcoxon signed rank statistics, are due to Lehmann, Hollander, and Doksum among others. It is shown that the procedures mentioned above are robust against possible heterogeneity of the distributions of the error vectors $Y_i = (Y_{i1} ..., Y_{ir})$. i = 1,..., N. This situation may arise when the block effects are not additive or the errors are heteroscedastic. Thus, in this paper the independence of the errors is replaced by within block symmetric dependence, while the additivity of the block effects and homoscedasticity of the errors are relaxed.

SEN, P. K. (1969). On a robustness property of a class of nonparametric test based on U-statistics. *Calcutta Statistical Association Bulletin,* 18, 51-60. **H-Np-D-Th**

Robustness for heterogeneity of the distributions of the sample observations is established. The theory is illustrated by means of some known tests. For example, in hypothesis of independence in bivariate situation all well-known tests are valid even when marginal distributions are not the same for different observations.

SEN, P. K. See: Bose, P. K. and Sen, P. K. (1963). **H-P-D-Th**

SEN, P. K. See: Nandi, H. K. and Sen, P. K. (1963). **E&H-Np-D&R-Th**

SEN, PRANAB KUMAR See: Puri, Madan Lal and Sen, Pranab Kumar (1967). **E-Np-D-Th**

SEVERO, N. C. (1957). Asymptotic behavior of tests on the mean of a logarithmic-normal distribution with known variance. *Annals of Mathematical Statistics,* 28, 1044-1046. **H-P-D-Th**

Three tests were considered by Severo and Olds for testing an hypothesis on the mean of a logarithmic-normal distribution with known variance. The purpose of this note is to discuss the asymptotic behavior of these tests for large sample size.

SEVERO, N. C. and OLDS, E. G. (1956). A comparison of tests on the mean of a logarithmic-normal distribution with known variance. *Annals of Mathematical Statistics,* 27, 670-686. **H-P-D-Th**

Three tests are considered. The first one is based on a sample from log-normal distribution, the second one is based on the corresponding sample from normal universe, the third one uses Neyman-Pearson lemma. OC functions are shown to be convergent to normal distribution.

SEVERO, N. C. See: Montaingo, L. J. and Severo, N. C. (1961). **E&H-P-D-Th**

SHEWHART, W. A. and WINTERS, F. W. (1928). Small samples-new experimental results. *Journal of the American Statistical Association,* 23, 144-153. **H-P-D-Th&MC**

The problem is to estimate the error of the average obtained from a small sample. For sampling from a normal universe the empirical results here show that "Student's" theory applies even though the usual assumptions (e.g., X and s are not correlated) are not met. While in case of sampling from non-normal universe, theoretical reasons are provided for the failure of "Student's" theory. It is shown that discrepancy is of sufficient magnitude to warrant further extension of the theory before applying it.

SIDDIQUI, M. M. (1958). Covariance of least-square estimates when residuals are correlated. *Annals of Mathematical Statistics,* 29, 1251-1256. **E-P-R-Th**

Expressions are obtained for the covariance of the least squares estimates of regression coefficients when the regression is either linear or trigonometric. Asymptotic expressions are obtained for the covariances when the residuals are serially correlated.

SIDDIQUI, M. M. (1960). Tests for regression coefficients when errors are correlated. *Annals of Mathematical Statistics,* 31, 929-938. **H-P-R-Th**

The covariance matrix of errors is assumed to be of a certain form and the reasonableness of the assumption is supported. Application of the theory is made to testing for (i) the sample mean, (ii) the difference between the means of two samples, (iii) the coefficients in a linear trend, and (iv) the coefficients in regression with trigonometric functions.

SIDDIQUI, M. M. (1965). Approximations to the distribution of quadratic forms. *Annals of Mathematical Statistics,* 36, 677-682. **E&H-P-D-Th**

The present paper deals with approximations to the distribution of quadratic forms of normal (correlated) variables which does not necessarily reduce to a multiple of a chi-square variable.

SIDDIQUI, M. M. See: Crow, Edwin L. and Siddiqui, M. M. (1967). **E-Np-D-MC**

SIDDIQUI, M. M. and RAGHUNANDANAN, K. (1967). Asymptotically robust estimators of location. *Journal of the American Statistical Association,* 62, 950-953. **E-Np-D-Th**

The robustness properties of four estimators of location are studied with respect to eight distribution types. For each type, the probability density function is symmetric about the median and the range of variation is infinite. For the entire class of distributions, the estimator with the highest guaranteed efficiency is the mean of the middle fifty percent of the sample.

SOPHISTER (1928). Discussion of small samples drawn from an infinite skew population. *Biometrika,* 20-A, 389-423. **E&H-P-D-Th**

The purposes of this paper are to determine (i) how far considerable skewness in the population sampled influences the distribution of the constants of small samples; (ii) as far as possible derive equations describing the distribution of variance, standard deviation and "Student's" t in the case of such small samples, (iii) how far skewness may be a source of error when inferences are drawn on the hypothesis that the sampled population follows a normal curve of frequency.

SPECKMAN, JANACE A. (1964). Determinations based on duplication of readings. *Journal of Research of the National Bureau of Standards,* Section B, 68, 49-63. **E-Np-O-Th**

This paper is concerned with a statistical estimation procedure in which measurements of a quantity are taken until two identical readings are obtained. This duplicated value is then taken as the estimate of the magnitude of the quantity. The properties of this procedure of estimation are investigated numerically. It is shown that arithmetic mean of two rounded observations is almost always superior to the above estimate.

SPJØTVOLL, EMIL (1964). A note on robust estimation in analysis of variance. *Annals of Mathematical Statistics,* 39, 1386-1492. **E-Np-C-Th**

The author considers the Hodges-Lehmann estimators for the location parameters in the c-sample problem. He shows how these estimators may be modified to produce consistent estimators when some of the sample sizes n_i approach infinity at a faster rate than each of the remaining sample sizes.

SRIVASTAVA, A. B. L. (1958). Effect of non-normality on the power function of t-test. *Biometrika,* 45, 421-430. **H-P-D-Th**

The power of the one-sided t-test is examined for near normal populations described by the first four terms of an Edgeworth series, by a technique that follows from the work of Gayen. The computed power functions (for a test using the tabular significance level and a sample of 10) show that, for $|\lambda_4| < 2$, $|\lambda_3| \leq .6$, λ_4 has no effect and that the influence of λ_3 is small except in the region of the null hypothesis.

SRIVASTAVA, A. B. L. (1959). Effect of non-normality on the power of the analysis of variance test. *Biometrika,* 46, 114-122. **H-P-C-Th**

It is assumed that error terms divided by their variance have a certain contaminated normal distribution. The non-normal distribution of the F-ratio is derived. It is found that small deviation from normality has no great influence on the power. Several tables are included.

SRIVASTAVA, A. B. L. (1960). The distribution of regression coefficients in samples from bivariate non-normal populations "1. Theoretical investigation". *Biometrika,* 47, 61-68. **E&H-P-D-Th**

The distribution of the regression coefficient is derived when the parent population is specified by the Edgeworth surface. The distribution of the t-statistic used for testing the significance of the regression coefficient has also been derived for the cases of known and unknown marginal variances.

SRIVASTAVA, A. B. L. (1961). Variables sampling inspection for non-normal samples. *Journal of Science and Engineering Research,* 5, 145-152. **H-P-D-Th**

The author obtains approximations to the operating characteristics of the sampling plans based on the sample mean when the population variance is known and unknown, assuming that the density function of the standardized measurement has an Edgeworth series expansion up to terms of order 1/n.

STONE, K. J. (1949). Relations between the standard deviation and the distribution of range in non-normal populations. *Journal of the Royal Statistical Society,* Series B, 11, 85-88. **E&H-P-D-MC**

For sample sizes 1 to 5, the author obtains a relation of the standard deviation in terms of the mid-range and its standard deviation which holds for a variety of unimodal distributions.

STONE, M. (1963). Robustness of non-ideal decision procedures. *Journal of the American Statistical Association,* 58, 480-486. **H-P-D-Th**

A general discussion of robustness of decision procedures with respect to use of wrong prior distribution is given. The author emphasizes possible usefulness of nonideal procedures which impose restrictions on the class of decision procedures and which do not require full specification of the prior probability distribution. Applications are made to minimum mean-square estimation of a general mean, etc.

STUART, A. See: Kendall, M. G. and Stuart, A. (1960). **E&H-P-D-G**

"STUDENT" (1909a). The distribution of the means of samples which are not drawn at random. *Biometrika,* 7, 210-214. **E&H-P-R-Th**

The conclusions of the author are: (i) that the approach to normality of the distribution of means of samples drawn from a non-Gaussian population is delayed by the existence of correlation between the individuals composing the samples, (ii) that on certain arbitrary assumptions the constants of the new distribution can be found, given the constants of the old one.

"STUDENT" (1909b). Statistics, in biological research. *Nature,* 124, 93. **H-P-D-Th**

In this letter to the editor the author warns against the erroneous impression many seem to have taken from Fisher's *Statistical Methods for Research Workers* that the procedures outlined therein can be used for any sample size and any parent universe. The author conjectures that his t-test is little affected by small departures from normality. He implores Dr. Fisher to show theoretically how the tables given would have to be modified when the underlying assumptions about the parent populations are not valid.

SUGIURA, NARIAKE and NAGAO, HISAO (1969). On Bartlett's test and Lehmann's test for homogeneity of variances. *Annals of Mathematical Statistics,* 40 (abstract 13). **H-Np-D-Th**

The authors have investigated the limiting distributions of Bartlett's and Lehmann's tests under the sequence of alternatives with arbitrary rate of convergence to the null hypothesis, as sample sizes tend to infinity. Depending on the rate of convergence, they are given by χ^2, noncentral χ^2, and normal distributions.

SWINDEL, BENNE F. (1968). On the bias of some least-square estimators of variance in a general linear model. *Biometrika,* 55, 313-316. **E-P-D-Th**

In the present paper, results previously attained by Watson regarding the effects of incorrect assumptions about the covariance matrix are generalized.

TAGO, Y. (1964). A note on the degree of normal approximation to the distribution functions of the mean of samples from finite populations. *Annals of the Institute of Statistical Mathematics,* (Tokyo) 16, 427-430. **E&H-Np-D-Th**

A bound on the error of the normal approximation to the standardized sum of observations drawn from a finite population is given in terms of the third absolute moment of the population.

TAKEUCHI, KEI (1967). *Robust Estimation and Robust Parameter.* Technical Report, Courant Institute of Mathematical Sciences, New York University, unpublished. **E-Np-D-Th**

The paper attempts a systematic approach to robust estimation problems. Some theoretical aspects of robust estimation are also pointed out.

TAMURA, RYJOI (1966). Multivariate nonparametric several-sample tests. *Annals of Mathematical Statistics,* 37, 611-618. **H-Np-D-Th**

A general class of tests is developed of which tests due to Puri, Kruskal and Wallis are particular cases. Asymptotic distribution of the test criterion is derived under Pitman alternatives.

TIAO, G. C. See: Box, G. E. P. and Tiao, G. C. (1962). **H-P-D-Th**

TIAO, G. C. See: Box, G. E. P. and Tiao, G. C. (1964a). **H-P-D-Th**

TIAO, G. C. See: Box, G. E. P. and Tiao, G. C. (1964b). **E&H-P-O-Th**

TIAO, G. C. See: Box, G. E. P. and Tiao, G. C. (1965). **E-P-O-Th**

TIAO, G. C. See: Box, G. E. P. and Tiao, G. C. (1968). **E-P-C-Th**

TIAO, G. C. and GUTTMAN, IRWIN (1967). Analysis of outliers with adjusted residuals. *Technometrics,* 9, 541-559. **E-P-D-Th**

The authors avoid the difficulty of correlated residuals by using information from an auxiliary experiment and give a set of rules for rejection of outliers. Then they investigate the effect of such rules on the sampling properties of the suggested estimators for μ, where observations are drawn from a normal population $N(\mu, \sigma^2)$, σ^2 known.

Generalization to the case of unknown variance and to the general linear model is also given.

TIKU, M. L. (1963). A Laguerre product series approximation to one-way classification variance-ratio distribution. *Journal of the Indian Society of Agricultural Statistics,* 15, 223-231. **H-P-D-Th**

The first few terms of the Laguerre product expansion of the distribution of variance components are obtained in terms of population cumulants, up to the eighth order. An explicit expression for the distribution of variance-ratio is also given.

TIKU, M. L. (1964a). Approximating the general non-normal variance-ratio sampling distributions. *Biometrika,* 51, 83-95. **H-P-D-Th**

Laguerre series expansions are developed of the frequency distribution of the non-normal variance-ratios used for testing (i) the homogeneity of a set of means in case of one-way classification for analysis of variance with different group to group error distributions; and (ii) the compatibility of two population variances. The effect of non-normality on the distributions is illustrated numerically.

TIKU, M. L. (1964b). A Laguerre product series expansion of the distribution of the variance-ratios in two-way classification. *Journal of the Indian Society of Agricultural Statistics,* 16, 304-316. **H-P-D-Th&MC**

A Laguerre product series expansion of the distribution of variance components of two-way classification for analysis of variance is developed. Approximations to the distributions of the variance-ratios are obtained. The effect of parental "excess in skewness" on the distributions of variance-ratios associated with "rows" and "interactions" is studied numerically. (author's summary).

THOMPSON, DONALD G. See: Gehan, Edmund A. and Thompson, Donald G. (1969). **H-P-D-MC**

THOMPSON, RORY See: Bell, C. B., Moser, J. M., and Thompson, Rory (1966). **H-Np-D-MC**

THOMPSON, RORY, GOVINDARAJULU, Z., and DOKSUM, K. A. (1967). Distribution and power of the absolute normal scores test. *Journal of the American Statistical Association,* 62, 966-975. See also: *Annals of Mathematical Statistics,* 37, 314 (1966) (abstract). **H-Np-D-MC**

The power of the absolute normal scores (k), Wilcoxon (W), binary (B), sign (S) and t (T) tests are estimated from Monte Carlo trials for shifts of symmetrical hypothesized populations which are normal, logistic, double exponential, and rectangular. The tests are ordered in terms of decreasing power with a comma marking an apparent substantial difference: for normal shift TKW, B, S: for logistic shift KTW, S, B: for small double exponential shift and large test size SWKT, B: as the shift increases and test size decreases W, SKT, B and WKST, B and for rectangular shift B, KT, W, S, and B, TK, W, S.

TRELOAR, A. E. and WILDER, MARION A. (1934). The adequacy of Student's criterion of deviations in small samples. *Annals of Mathematical Statistics,* 5, 324-341. **H-P-D-Th**

The rationality of segregation according to any given "level of significance" using "Student's" distribution is analyzed by considering the joint distributions due to errors of sampling in the means, standard deviations, and the ratio of these two for samples of any given size N. The percentage of irrationally segregated samples falls in the curvilinear manner as N increases. The so-called "large" samples, then are open to a considerable error of the kind.

TUKEY, J. W. (1948). Some elementary problems of importance to small sample practice. *Human Biology,* 20, 205-214. **H-P-D-Th**

The note poses the following problems for research workers in the field: (i) to develop a modified version of the t-test with greater resistance to skewness when used as a one-sided test, (ii) to develop an analogue to t for variance (a statistic is proposed for investigation), and (iii) to study the behavior of t for finite populations.

TUKEY, JOHN W. (1956). Variances of variance components. I Balanced designs. *Annals of Mathematical Statistics,* 27, 722-736. **E-P-D-Th**

Variances of variance components for random samples from finite populations are presented. The cases considered include balanced single and double classifications, Latin squares, and balanced incomplete blocks.

TUKEY, JOHN W. (1960). A survey of sampling from contaminated distributions. *Contributions to Probability and Statistics,* Stanford University Press, California, 448-485. **E&H-P-C-G**

This is a study centering around the question of relative asymptotic efficiency of the sample standard deviation and mean deviation for estimating the population standard deviation of a mixture of two normal distributions with equal means.

TUKEY, J. W. (1964). A citation index for statistics and probability. *Bulletin of the International Statistical Institute,* 40, II 747-755. **E&H-P&Np-O-G**

A citation index in a list of those papers which have referred to any chosen paper and thus it allows us to pass from a paper to its "children." This, combined with the list of references, gives us all "recognized

relatives" of the paper. This article points out the vastness of the growth of literature in any field and the difficulty in keeping track of them. This article gives four essential steps in the effective use of a citation index.

TUKEY, J. W. See: Dixon, W. J. and Tukey, J. W. (1968). **H-P-C-MC**

TUKEY, JOHN W. See: McLaughlin, D. H. and Tukey, John W. (1961). **E&H-P-C-Th**

TUKEY, J. W. and McLAUGHLIN, D. H. (1963). Less vulnerable confidence and significance procedures for locations based on a single sample: trimming/Winsorization 1. *Sankhyā:* Series A, 25, 331-352. **E&H-P-C-Th**

Amongst the most promising of the substitutes for t are ratios of trimmed means to square roots of suitable quadratic forms involving the same order statistics. Matching, across underlying distributions of ratios of average of denominator to variance of numerator, leads to selection of Winsorized sum of squared deviations as the basis for a denominator. Exact critical values of the trimmed t require Monte Carlo computation but use of a simple modified denominator allows use of conventional t tables as a reasonable approximation.

URY, HANS K. (1965). Asymptotic efficiency of some nonparametric tests of dispersion. *Annals of Mathematical Statistics,* 36, 1329. **H-Np-D-Th**

Asymptotic relative efficiencies of some rank tests applied to some index of dispersion computed within small subgroups (following the technique due to Moses) are studied. The question of decreasing efficiency because of an insufficient number of subgroups is considered in a numerical example.

VAN der VAART, H. R. (1961). On the robustness of Wilcoxon's two-sample test. *Quantitative Methods in Pharmacology,* North Holland Amsterdam. Interscience, New York, 140-158. **H-Np-D-Th**

This paper investigates the probability of type I error of Wilcoxon's two-sample tests when parent populations are normal with unequal variances, in the asymptotic case. The test fails to be uniformly more robust than t. In fact in certain situations it is less robust.

VEALE, JAMES R. and HUNTSBERGER, D. V. (1969). Estimation of a mean when one observation may be spurious. *Techniques,* 11, 331-339. **E-P-C-Th**

Given a sample of size n assumed to have been obtained from a normal population with mean μ and known variance α^2 it is possible that one of the observed values is distributed as $N(\mu + 6\alpha, \alpha^2)$. A weighted estimator for μ is proposed, and a weighing function based on the largest absolute deviation from the sample mean is obtained.

VOTOW, D. F., KIMBAL, A. W. and RAFFERTY, J. A. (1950). Compound symmetry tests in the multi-variate analysis of medical experiments. *Biometrics,* 6, 259-381. **H-P-R-Th**

This paper presents tests of several statistical hypotheses which assert that the observations are "stable" and satisfy certain "symmetry" conditions. Two of the statistical tests can be used to test hypotheses about "row effects" in analysis of variance. However, these hypotheses—unlike the conventional analysis of variance hypotheses—do not require the observations to be uncorrelated nor that there be homogeneity of variances. An illustrative example is provided. In the appendix, the hypotheses are stated in full generality and expressions for the corresponding sample criteria are given. For various special cases, the means, variances and exact cumulative distributions of the criteria are given together with χ^2 distributions that approximate the exact distributions.

WALKER, A. M. (1960). Some consequences of superimposed error in time series analysis. *Biometrika,* 47, 33-43. **E-P-D-Th**

The estimation equations are usually quite cumbersome and the author discusses alternative methods of estimation. These methods are compared in terms of asymptotic efficiency. The effect of non-normality of the observations is discussed.

WALLACE, D. L. (1959). Asymptotic approximations to distributions. *Annals of Mathematical Statistics,* 29, 635-654. **E&H-P-D-Th**

The author used the approach of finding asymptotic expansions in which the errors of approximation approach zero as some parameter, typically a sample size, approaches infinity. The approximations discussed are those based on the central limit theorem and those which use only the moments of the distribution to be approximated; and approximations using detailed information about the distribution.

WALLACE, D. L. See: Mosteller, F. and Wallace, D. L. (1962). **H-P-D-G**

WALSH, J. E. (1947). Concerning the effect of intraclass correlation on certain significant tests. *Annals of Mathematical Statistics,* 18, 88-96. **E&H-P-R-Th**

The author studies the effect of intraclass correlation (the constant correlation between any two observations in the sample) on the confidence coefficients and significance levels of several well known statistics. He shows that the "Student's" t, chi-square and F statistics based on the intraclass correlated normal samples, still have these same distributions, provided the statistics are multiplied by suitable constant factors. The effect of correlation on chi-square and F tests is not as great as for "Student's" t-test. These considerations are extended to two sample situations.

WALSH, J. E. (1949). On the midrange test and some tests with bounded significance levels. *Annals of Mathematical Statistics,* 20, 257-267. **H-Np-D-Th**

A robust test for means using range is proposed and compared with t-test. Some tests are given with bounded significance levels when the parent population is symmetric.

WALSH, J. E. (1951). A large sample t-statistic which is insensitive to randomness. *Journal of the American Statistical Association,* 46, 79-88. **H-P-R-Th**

It is shown that even a slight deviation from randomness can result in a substantial change in significance levels and confidence coefficients of the commonly used class of tests and intervals based on "Student's" t. A special type of t-statistic is developed to overcome the difficulty. Its tests are shown to be asymptotically as efficient as those based on the standard t-statistic.

WALSH, JOHN E. (1956). Validity of approximate normality values for $\mu \pm k\sigma$ areas of practical type continuous populations. *Annals of the Institute of Statistical Mathematics,* (Tokyo) 8, 79-86. **E-Np-D-Th**

The author makes the empirical observation that the fraction of a continuous distribution contained in $(\mu-k\sigma, \mu+k\sigma)$ often appears to be nearly equal to the value obtained under the assumption of normality. He investigates this remark for the class of distributions with frequency functions which can be "adequately" represented by the first seven terms of their Edgeworth series expansions.

WATSON, G. S. See: Box, G. E. P. and Watson, G. S. (1961). **H-P-D-Th**

WAUD, ROGER N. (1966). Small sample bias due to misspecification in the "partial adjustment" and "adaptive expectation" models. *Journal of American Statistical Association,* 61, 1130-1152. **E-P-D-MC**

The results of small sample experiments indicate that the bias in the estimated regression coefficients and the estimated mean lag which occurs when either one of the models is fitted by least squares to data generated by the more general model is quite serious. Also, it is found that the spread of the distribution of these estimates is very sensitive to this misspecification. The departure from normality of these distributions is notable for the smallest sample sizes examined, but less significant in view of the severity of the other problems noted.

WEBSTER, J. T. See: Ballas, J. A. and Webster, J. T. (1966). **H-P-R-Th**

WEIBULL, M. (1950). The distribution of the t and z variables in the case of stratified sample with individuals taken from normal parent populations with varying means. *Skandinavisk Akturietidskrift,* 33, 137-167. **H-P-D-Th**

Suppose you draw a single observation from each of N normal populations having unequal means but a common variance. The author derives the joint distribution of the sample mean and sample variance, that of the "Student's" t, and that of the variance ratio, z. The moment characteristics through order four suggest that this generalized z-distribution is less anormal than in the usual case of equal population means. Finally, if the population means are themselves a sample from a normal population, the resulting t and z distributions have the same form as if the sample arose out of a single normal population.

WEIBULL, MARTIN (1951). The regression problem involving non-random variates in the case of stratified sample from normal parent populations with varying regression coefficients. *Skandinavisk Akturietidskrift,* 34, 53-71. **E&H-P-D-Th**

The author's previous results [*Skandinavisk Akturietidskrift,* 32 (1950), 137-167] are extended to the regression problem. The usual statistics of the analysis of covariance having chi-square, t or F distributions if certain linear relations hold, are shown to have noncentral versions of these distributions otherwise, with the usual independence properties still valid.

WEIBULL, M. (1953). The distribution of t and F statistics and of correlation and regression coefficients in stratified samples from normal populations with different means. *Skandinavisk Akturietidskrift,* 36, 1-106. **H-P-D-Th**

It is shown that properties of independence, limiting properties as degrees of freedom increase, etc, of the central statistics are carried over to double noncentral t and F distributions. Noncentral Wishart distribution for two-dimensional population, and noncentral distribution of correlation coefficient are derived.

WEILER, H. (1958). Mean charts of constant false alarm risks for non-normal distributions. *Australian Journal of Applied Science,* 9, 326-331. **H-P-D-Th**

Since skewness of distributions encountered in industry is usually unknown, the control limits of quality control charts have to be taken very wide, say ±3 standard deviations, so that adequate protection against excessive false alarm rates can be assured. In this paper this risk is assessed and it is shown by how much the width of the control limits can be reduced using larger samples than the customary size of four or five.

WELCH, B. L. (1937a). On the z-test in randomized blocks and latin squares. *Biometrika,* 29, 21-52. **H-P-D-Th**

The author considers instead of z, a monotonically increasing function u of z, which is equal to treatment sum of squares divided by sum of treatment and residual sums of squares. Under null hypothesis of equality of treatments, the mean of u is the same with or without the usual normality assumption. However, disagreement occurs between two variances. Some empirical results are given.

WELCH, B. L. (1937b). The significance of the difference between two means when the population variances are unequal. *Biometrika,* 29, 350-362. **H-P-D-Th**

A large sample solution is proposed to the problem of testing for the equality of means of two normal populations when the population variances are unknown and unequal.

WELKER, E. L. (1947). The distribution of the mean. *Annals of Mathematical Statistics,* 18, 111-117. **E&H-P-D-Th**

The sampling distributions of the mean as approximated by the Pearson system are given. A new chart transforming the constants in the chart of Craig is given. The properties of this one-to-one transformation are used to discuss the approach to normality of the distribution of the mean.

WETHERILL, G. B. (1960). The Wilcoxon test and non-null hypotheses. *Journal of the Royal Statistical Society,* (B), 22, 402-418. **H-Np-D-Th**

The main results may be summarized as follows. The Wilcoxon test is somewhat more robust than the t-test to differences in variance, but it is much more sensitive to skewness and kurtosis than the t-test. Differences of skewness can obscure differences of means or medians which it is desired to test.

WHITE, JOHN S. See: Rice, John R. and White, John S. (1964). E-P-D-Th

WILCOXON, F. See: Daniel, C. and Wilcoxon, F. (1965). H-P-O-Th

WILDER, MARION A. See: Treloar, A. E. and Wilder, Marion A. (1934). H-P-D-Th

WILLIAMS, R. J. (1965). The effect of truncation on tests of hypothesis for normal populations. *Annals of Mathematical Statistics,* 36, 1509-1510. H-P-O-Th

This paper extends an earlier work by Aggarwal and Guttman (see *Annals of Mathematical Statistics,* 30 (1959), 230-238 and 31, 1213) to nonsymmetric truncation and arbitrary sample size. An asymptotic series for the distribution of sums of samples of size n from a truncated normal population is presented.

WINTERS, F. W. See: Shewhart, W. A. and Winters, F. W. (1928). H-P-D-Th&MC

YATES, F. See: Eden, T. and Yates, F. (1933). H-P-D-MC

YHAP, E. F. (1966). Asymptotically admissible linear unbiased estimators (value) for robust estimation of location and scale parameters. *Annals of Mathematical Statistics,* 37, 1071 (abstract 9). E-P-D-Th

Estimators are developed using some generalizations of methods of Jung and Birnbaum. They are compared with other efficiency-robust estimators.

ZASLAVSKII, A. E. (1967). On statistical tests for a simple hypothesis involving a multidimensional normal distribution. *Theory of Probability and Its Applications,* 12, 514-519. H-P-D-Th

The optimal test for equality of two multivariate normal distributions with a common covariance matrix, is simplified by replacing the diagonal terms of the covariance matrix by zeros. The effect of this on the behavior of the test is studied.

ZELEN, M. and DANNEMILLER, M. C. (1960). Are life testing procedures robust? *Proceedings of the Sixth National Symposium of Reliability and Electronics,* 185. H-P-D-Th

The common assumption, in life testing, of an underlying exponential distribution is rarely verified. The paper studies behavior of some statistical procedures, when true distribution of failures is Weibull. Results indicate frequent lack of robustness.

ZELEN, M. and DANNEMILLER, M. C. (1961). The robustness of life-testing procedures derived from the exponential distribution. *Technometrics,* 2, 29-49. H-P-D-Th

This is a follow-up work of an earlier paper on the same topic. In addition it develops techniques for approximating (i) the distribution of sums of independent random variables and (ii) the characteristics of sequential procedures, for non-negative random variables. They are applied to the Weibull distribution.

ZIMMER, W. J. and BURR, I. W. (1963). Variables sampling plans based on non-normal populations. *Industrial Quality Control,* 20, 18-26. H-P-D-Th

Tables are given for modified acceptance sampling plans for non-normal populations, the sample measures of skewness and kurtosis being used to "correct" the values. The theory is briefly elucidated and numerical examples as well as practical applications are discussed.

ADDENDUM

BRYANT, E. Earl (1960). *Theoretical Sampling Distributions, Their Practical Limitations and Some Experimental Results.* Dissertation for Master of Arts degree submitted to the American University, Washington, D.C. **E&H-P-D&R-MC**

Most of the theoretical sampling distributions are based upon the assumption of normality of the parent population and the mutual independence of the observations. In practice these requirements are never entirely realized. The validity of the theory in practical problems where these basic assumptions are not met is investigated in this thesis. Further, some other questions concerning problems arising in practice which may affect the applicability of the theory are discussed. The thesis, perhaps, is guided to the study of five sampling distributions, namely, the normal, chi-square, F, and t, and r distributions.

FRIDSHAL, DONALD, and POSTEN, HARRY O. (1966). *Bibliography on Statistical Robustness and Related Topics.* Research Report No. 16, Department of Statistics, the University of Connecticut, Storrs, Connecticut. **E&H-P-D&R-G**

The bibliography consists of 252 references in the area of statistical robustness. The authors attempt to provide an up-to-date comprehensive collection of references in this general area of statistics.

HATCH, LAWRENCE O. and POSTEN, HARRY O. (1966). *Robustness of the Student-Procedure: A Survey.* Research Report No. 24, Department of Statistics, the University of Connecticut, Storrs, Connecticut. **E&H-P-D&R-G**

The authors survey the robustness aspects of the one- and two-sample t-test procedures. They list 58 articles which constitute studies of the robustness of the t-"Student"-Procedure for departures from (i) normal distributions, (ii) independence of the observations.

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