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of measurement uses, and consequently it should be viewed within a much larger system of reliability analysis, generalizability theory. Moreover, alpha focused attention on reliability coefficients when that attention should instead be cast on measurement error and the standard error of measurement.

For Cronbach, the extension of alpha (and classical test theory) came when Fisherian notions of experimental design and analysis of variance were put together with the idea that some "treatment" conditions could be considered random samples from a large universe, as alpha assumes about item sampling. Measurement data, then, could be collected in complex designs with multiple variables (e.g., items, occasions, and rater effects) and analyzed with random-effects analysis of variance models. The goal was not so much to estimate a reliability coefficient as to estimate the components of variance that arose from multiple variables and their interactions in order to account for observed score variance. This approach of partitioning effects into their variance components provides information as to the magnitude of each of the multiple sources of error and a standard error of measurement, as well as an "alpha-like" reliability coefficient for complex measurement designs. Moreover, the variance-component approach can provide the value of "alpha" expected by increasing or decreasing the number of items (or raters or occasions) like those in the test. In addition, the proportion of observed score variance attributable to variance in item difficulty (or, for example, rater stringency) may also be computed, which is especially important to contemporary testing programs that seek to determine whether examinees have achieved an absolute, rather than relative, level of proficiency. Once these possibilities were envisioned, coefficient alpha morphed into generalizability theory, with sophisticated analyses involving crossed and nested designs with random and fixed variables (*facets*) producing variance components for multiple measurement facets such as raters and testing occasions so as to provide a complex standard error of measurement.

By all accounts, coefficient alpha—Cronbach's alpha—has been and will continue to be the most popular method for estimating behavioral measurement reliability. As of 2004, the 1951 coefficient alpha article had been cited in more than 5,000 publications.

Jeffrey T. Steedle and Richard J. Shavelson

See also Classical Test Theory; Generalizability Theory; Internal Consistency Reliability; KR-20; Reliability; Split-Half Reliability

Further Readings

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COEFFICIENT OF CONCORDANCE

Proposed by Maurice G. Kendall and Bernard Babington Smith, Kendall's coefficient of concordance (W) is a measure of the agreement among several (m) quantitative or semiquantitative variables that are assessing a set of n objects of interest. In the social sciences, the variables are often people, called *judges,* assessing different subjects or situations. In community ecology, they may be species whose abundances are used to assess habitat quality at study sites. In taxonomy, they may be characteristics measured over different species, biological populations, or individuals.

There is a close relationship between Milton Friedman's two-way analysis of variance without replication by ranks and Kendall's coefficient of concordance. They address hypotheses concerning the same data table, and they use the same χ^2 statistic for testing. They differ only in the formulation of their respective null hypothesis. Consider Table 1, which contains illustrative data. In Friedman's test, the null hypothesis is that there is no

Table 1 Illustrative Example: Ranked Relative Abundances of Four Soil Mite Species (Variables) at 10 Sites (Objects)

	Ranks (column-wise)				*Sum of Ranks*
	Species 13	*Species 14*	*Species 15*	*Species 23*	R_i
Site 4	5	6	3	5	19.0
Site 9	10	4	8	2	24.0
Site 14	7	8	5	4	24.0
Site 22	8	10	9	2	29.0
Site 31	6	5	7	6	24.0
Site 34	9	7	10	7	33.0
Site 45	3	3	2	8	16.0
Site 53	1.5	2	4	9	16.5
Site 61	1.5	1	1	2	5.5
Site 69	4	9	6	10	29.0

Source: Legendre, P. (2005) Species associations: The Kendall coefficient of concordance revisited. *Journal of Agricultural, Biological, & Environmental Statistics, 10,* 230. Reprinted with permission from the *Journal of Agricultural, Biological, & Environmental Statistics*. Copyright 2005 by the American Statistical Association. All rights reserved.

Notes: The ranks are computed columnwise with ties. Right-hand column: sum of the ranks for each site.

real difference among the n objects (sites, rows of Table 1) because they pertain to the same statistical population. Under the null hypothesis, they should have received random ranks along the various variables, so that their sums of ranks should be approximately equal. Kendall's test focuses on the m variables. If the null hypothesis of Friedman's test is true, this means that the variables have produced rankings of the objects that are independent of one another. This is the null hypothesis of Kendall's test.

Computing Kendall's W

There are two ways of computing Kendall's W statistic (first and second forms of Equations 1 and 2); they lead to the same result. S or S' is computed first from the row-marginal sums of ranks R_i received by the objects:

$$S = \sum_{i=1}^{n} (R_i - \overline{R})^2 \text{ or } S' = \sum_{i=1}^{n} R_i^2 = SSR, \quad (1)$$

where S is a sum-of-squares statistic over the row sums of ranks R_i, and $\overline{R}$ is the mean of the R_i values. Following that, Kendall's W statistic can be obtained from either of the following formulas:

$$W = \frac{12S}{m^2(n^3 - n) - mT}$$

or

$$W = \frac{12S' - 3m^2n(n+1)^2}{m^2(n^3 - n) - mT}, \quad (2)$$

where n is the number of objects and m is the number of variables. T is a correction factor for tied ranks:

$$T = \sum_{k=1}^{g} (t_k^3 - t_k), \quad (3)$$

in which t_k is the number of tied ranks in each (k) of g groups of ties. The sum is computed over all groups of ties found in all m variables of the data table. $T = 0$ when there are no tied values.

Kendall's W is an estimate of the variance of the row sums of ranks R_i divided by the maximum possible value the variance can take; this occurs when all variables are in total agreement. Hence $0 \leq W \leq 1$, 1 representing perfect concordance. To derive the formulas for W (Equation 2), one has to know that when all variables are in perfect agreement, the sum of all sums of ranks in the data table (right-hand column of Table 1) is $mn(n+1)/2$ and that the sum of squares of the sums of all ranks is $m^2n(n+1)(2n+1)/6$ (without ties).

There is a close relationship between Charles Spearman's correlation coefficient r_S and Kendall's W statistic: W can be directly calculated from the

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