A PRELIMINARY STUDY OF THE ROBUSTNESS OF THREE DIFFERENT CONFIDENCE INTERVALS FOR CRONBACH'S ALPHA

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ABSTRACT

Three different methods of constructing confidence intervals for Cronbach's alpha instrument reliability measure are compared for their performance. Different conditions which both meet and violate the underlying assumption of normality of the instrument's item distributions are studied by means of a limited simulation study. The underlying information loss when converting from the assumed continuous to discrete Likert type scales is also investigated. A reason why the presumably inappropriate Fisher's *z* transform appears to perform best is discussed.

INTRODUCTION

If research in the behavioral or social sciences involves the use of some type of measurement instrument, then it is usually mandatory that some type of reliability measure for the instrument is reported. While a number of alternate measures of reliability exist, it is often the case that a reliability based on a single administration of an instrument is reported. The most commonly reported measure of this type is typically Cronbach's alpha (Cronbach, 1951). In a study of the frequency of use in a sample of 696 testing instruments, Cronbach's alpha was definitely used 66% of the time as the reliability measure and in tracing back ambiguous cases it was found likely this percentage increased to 75% of the cases as the reliability measure of choice (Hogan, Benjamin, & Brezinski, 2000). The primary shortcoming of alpha is the property that it will underestimate the true reliability if the condition of tau equivalence or better is not met. In this case alpha represents a lower bound on reliability (Zumbo, 1999), although in actual practice "such an estimate of reliability based on data from a single occasion will almost certainly overestimate reliability when interest is in generalizing over occasions" (Brennen, 2001, p.8). While Cronbach's alpha is usually reported as a simple descriptive measure, the actual purpose of most studies is in fact inferential in nature.

While a descriptive point estimate of reliability is useful, it contains no information about how closely it approximates a population value of a scales reliability coefficient. As with other parameter estimates, it is helpful to calculate confidence intervals (CIs) for point estimates of scale reliability. A large amount of work has been done on producing CIs for Cronbach's alpha (Bonett, 2002; Feldt, 1965; Feldt & Woodruff, et.al, 1987; Hakstian & Whalen, 1976; Iacobucci & Duhachek, 2003; Kistner & Muller, 2004; Koning & Franses, 2003; Van Zyl; Neudecker, & Nel, 2000; Zumbo, 1999). In addition, several recent Monte Carlo studies have been done to compare how these alternative methods would work when used with dichotomous and discrete rating scales. Kromrey & Romano et.al, (2008), compared the performance of eight different CI methods for alpha when based on strictly binary response measurements. Romano & Kromrey et.al, (20011), compared the performance of eight different CI methods for alpha when based on strictly discrete rating scale response measurements. The major results in both cases were that differences among the eight different CI methods for alpha were negligible in most cases. The one method that was most accurate overall was based on Fisher's *z* transformation.

The purpose of the current study is to use simulation to compare the performance of three methods of forming CIs for alpha. The first method studied is Feldt's (1965) classical method which is also used in the popular SPSS statistical package. The second method is based on the bias corrected and accelerated bootstrap (BCa) and was not included in the previously cited studies. The third method is based on Fisher's (1950) *z* transformation which proved to be most accurate in previous studies. Two basic continuous distributional forms are used for the underlying item distributions. The first is the normal distribution of item responses and is the assumed form for both the Feldt and Fisher *z* CI methods. The second is a skewed distribution and is based on the response form often observed in actual item distributions of administered instruments. In addition, the effects of information loss in converting the continuous distributional forms first to a seven point Likert type scale and then to a five point Likert scale on the alpha CIs are investigated.

COEFFICIENT ALPHA

Alpha may be conceptualized in several different ways. One appealing way is to view alpha as the average of all possible split-half correlations. A second way uses classical measurement theory as its basis. An observed score, X, can be thought of as being composed of a true score, T, plus an error term, E

$$X = T + E. \tag{1}$$

For a scale composed of a number of observed scores, the errors are assumed uncorrelated with the true scores and with each other. Reliability, alpha, is then defined as the ratio of the variance of the true scores, Vt, divided by the variance of the observed scores, Vo

$$\text{alpha} = Vt / Vo. \tag{2}$$

From this perspective, it can be seen that while reliability is often computed as a kind of correlation coefficient, it actually is conceptually a kind of R squared statistic. In fact, it is the R squared between the true score and the observed score. Cronbach's alpha can be computed in a way analogous to this classical definition of reliability by using analysis of variance (ANOVA). An example of how this calculation is made is given in Table 1.

Table 1: Two way ANOVA table, one observation per cell, for the last data set of a simulation run along with calculation of Cronbach's alpha.

Source	Sum of Squares	df	Mean Square	$F_{Persons}$
$SS_{Persons}$	484.0655	49	9.8789	10.2015
SS_{Items}	105.7522	7	15.1075	
SS_{Error}	332.1521	343	0.9684	
SS_{Total}	921.9698	399		

$$\text{Alpha} = (MSQ_{Persons} - MSQ_{Error}) / MSQ_{Persons}$$
$$= (9.8789 - .9684) / 9.8789$$
$$= 0.9020$$

For an interesting derivation of alpha, see Zumbo (1999). Alpha as an estimator of reliability requires several assumptions. First, the scale for which alpha is being used should be unidimensional, meaning it should measure only one thing. The error terms should all be uncorrelated with the true scores and with each other. The true scores for the items in the scale should all be equal, although this is not required of the error terms. This condition is called tau equivalence. For classical inferential purposes, such as forming CIs, the observed scores should be normally distributed. Violation of the first three assumptions usually leads to alpha underestimating the true reliability, although in some unusual circumstances, violating the assumption of uncorrelated errors can cause overestimation of reliability. Violation of the normality assumption can lead to CIs that have less than the specified confidence level.

ALPHA CONFIDENCE INTERVALS

Standard methods for developing CIs are quite simple and a review of such procedures is given by Steiger and Fouladi (1997). The first study of a sampling distribution for alpha which provided a method for producing CIs for alpha was given by Feldt (1965). This method can be considered the standard and is used in this paper because of its classical nature and its use in the standard SPSS statistical package. It is based on the interval inversion procedure and uses the F distribution as its basis. The sampling distribution was developed under the rather restrictive assumption of compound symmetry of the scale variance-covariance matrix. On the positive side this CI is very easy to compute and appears to have comparable performance to other Cis developed later (Romano & Kromrey et.al, 20011).

The second method that seemed worth looking at in a preliminary fashion is based on the use of bootstrapping CI for alpha. This approach had not been included in previous studies. The primary advantage of using nonparametric bootstrapping of CIs is that no knowledge of the underlying sampling distribution of a statistic is required to produce CIs for a given statistic such as alpha. Instead, a sampling distribution is formed by repeated random sampling with replacement from the given sample itself. For details of nonparametric bootstrapping theory and methodology see Efron and Tibshirani (1993). The type of bootstrap CI for alpha was based on the bias corrected and accelerated methodology. This form of CI is recommended for general use by Efron and Tibshirani (1993). In all cases, 5,000 bootstrap samples were generated for each simulation which is well beyond the minimal requirement for maintaining reasonable Monte Carlo sampling error. The primary possible advantage of a nonparametric bootstrapped CI for alpha is its potential robustness to violation of underlying assumptions of a parametric CI for alpha, provided it can be demonstrated to be reliable when the basic assumptions are approximately met.

The third method for forming CIs was by use of Fisher's (1950) *z* transformation, used to produce CIs for Pearson's product moment correlation coefficient. Arguably, Fisher's *z* transformation should not be appropriate for measures of internal consistency reliability like Cronbach's alpha, since conceptually alpha is an R squared statistic and not a simple product moment correlation. None the less, Fisher's z transformation produced the overall most accurate CIs for alpha in previous studies.

THE SIMULATION DATA AND PROCESS

For this simulation study, real data was used as the basis for deciding on the population parameters used to generate the simulated samples. The parameters, including the population alpha, used as a basis for the simulation population parameters are given in Table 2. The level of confidence used in constructing all CIs was the typically used 95% interval.

Table 2: The means and variance-covariance matrix used as the population data based on data from 206 subjects and 8 items using a 7 point likert scale.

Means

3.74272	3.75728	3.56311	4.39806	5.08738	4.21359	4.46117	4.13107

Variance-covariance Matrix

2.58226	1.98115	2.14558	1.32730	0.79820	1.28937	0.95337	0.87291
1.98115	2.71153	2.04954	1.24343	0.83595	1.09600	0.74175	0.91977
2.14558	2.04954	2.83258	1.44305	0.88714	1.33280	1.00246	1.03803
1.32730	1.24343	1.44305	1.92858	0.92115	1.29505	0.97651	1.05001
0.79820	0.83595	0.88714	0.92115	1.46550	0.92271	0.76439	0.81776
1.28937	1.09600	1.33280	1.29505	0.92271	2.10050	1.04736	1.06943
0.95337	0.74175	1.00246	0.97651	0.76439	1.04736	1.70336	1.01731
0.87291	0.91977	1.03803	1.05001	0.81776	1.06943	1.01731	1.97786

Alpha = 0.898678

The data in Table 2 converted to a correlation matrix and showing the two subscales of the factor structure are shown in Table 3. It should be noted that in this case Cronbach's alpha is given in standardized form and is slightly higher than in raw form. This is usually, but not always the case.

Table 3: The correlation matrix used as the population data based on data from 206 subjects and 8 items using a 7 point Likert scale showing the two subscales.

1.00000	0.74870	0.79333	0.59477	0.41032	0.55362	0.45458	0.38625
0.74870	1.00000	0.73953	0.54374	0.41935	0.45924	0.34514	0.39717
0.79333	0.73953	1.00000	0.61741	0.43542	0.54640	0.45638	0.43855
0.59477	0.54374	0.61741	1.00000	0.54792	0.64344	0.53877	0.53762
0.41032	0.41935	0.43542	0.54792	1.00000	0.52591	0.48380	0.48033
0.55362	0.45924	0.54640	0.64344	0.52591	1.00000	0.55371	0.52468
0.45458	0.34514	0.45638	0.53877	0.48380	0.55371	1.00000	0.55425
0.38625	0.39717	0.43855	0.53762	0.48033	0.52468	0.55425	1.00000

Alpha = 0 .898792

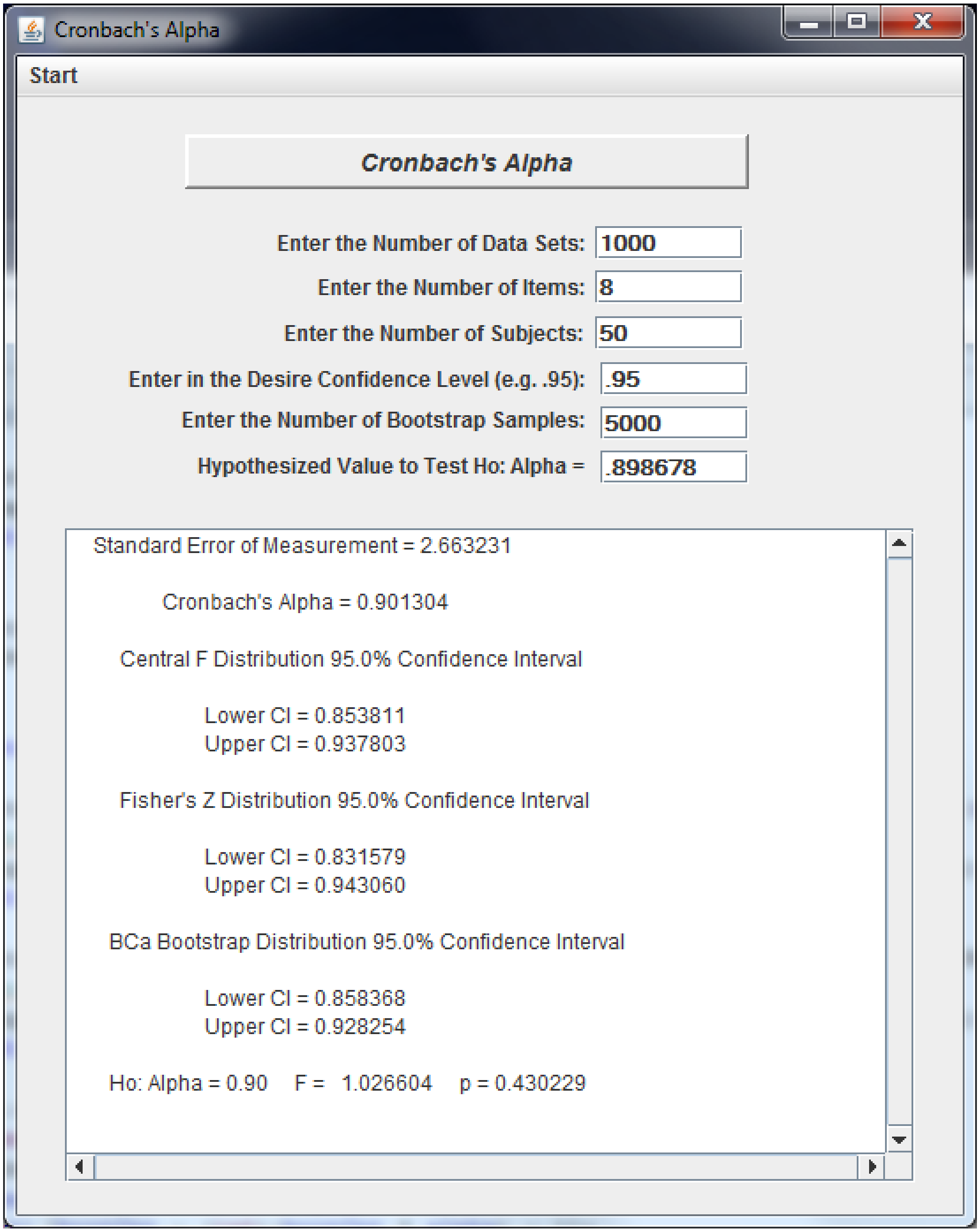
The data was based on an eight item instrument used to measure end-user computing satisfaction (Doll & Torkzadeh, 1988) designed by one of the authors. The basic assumptions of tau equivalence and normality of the item distributions was not strictly met as with most real data; however, the deviation from tau equivalence was not extreme while there was considerable deviation from normality.

The actual program used to generate random samples from a population with a given mean vector, variance-covariance matrix, and a given distributional form was written in Java. One thousand simulated data sets were generated. The random number seed for generating the data sets and the bootstrap was fixed at 33,722. For each data set, a moderate but not unrealistic sample size of 50 responses to the eight item measuring instrument was generated based on the given population parameters and the assumption of normality. The same original 1000 data sets generated from a unit standard normal distribution and then converted to the desired population parameters by use of Cholesky factorization were used for all steps of the simulation study. This allows all results to be directly compared. The basic process used to generate the data follows:

1) Generate 1000 random data sets based on the standard unit normal distribution with each data set converted to desired population parameters using Cholesky factorization and analyze.
2) Convert original data sets to 7 point Likert scales and analyze.
3) Convert original data sets to 5 point Likert scales and analyze.
4) Convert original standard unit normal data sets to negatively skewed data sets using Tukey's G distribution with G set to -.6 and analyze after Cholesky factorization.
5) Convert original skewed data sets to 7 point Likert scales and analyze.
6) Convert original skewed data sets to 5 point Likert scales and analyze.

The number of BCa samples was set to 5000 in all cases. The interface of the Java program used for the analysis of the data is shown in Figure 1.

Figure 1: The Java program used to analyze the data.



While most researchers are well aware of the form of a normal distribution, they may well not be aware of the Tukey G distribution. The Tukey G distribution is used to convert a standard unit normal distribution to any desired degree of either positive or negative skewness. An example histogram of measurement item 5 in simulated data set 50 is given in Figure 2.

Figure 2: Example of a negatively skewed distribution from data set 50, item 5, with G set to -.6.

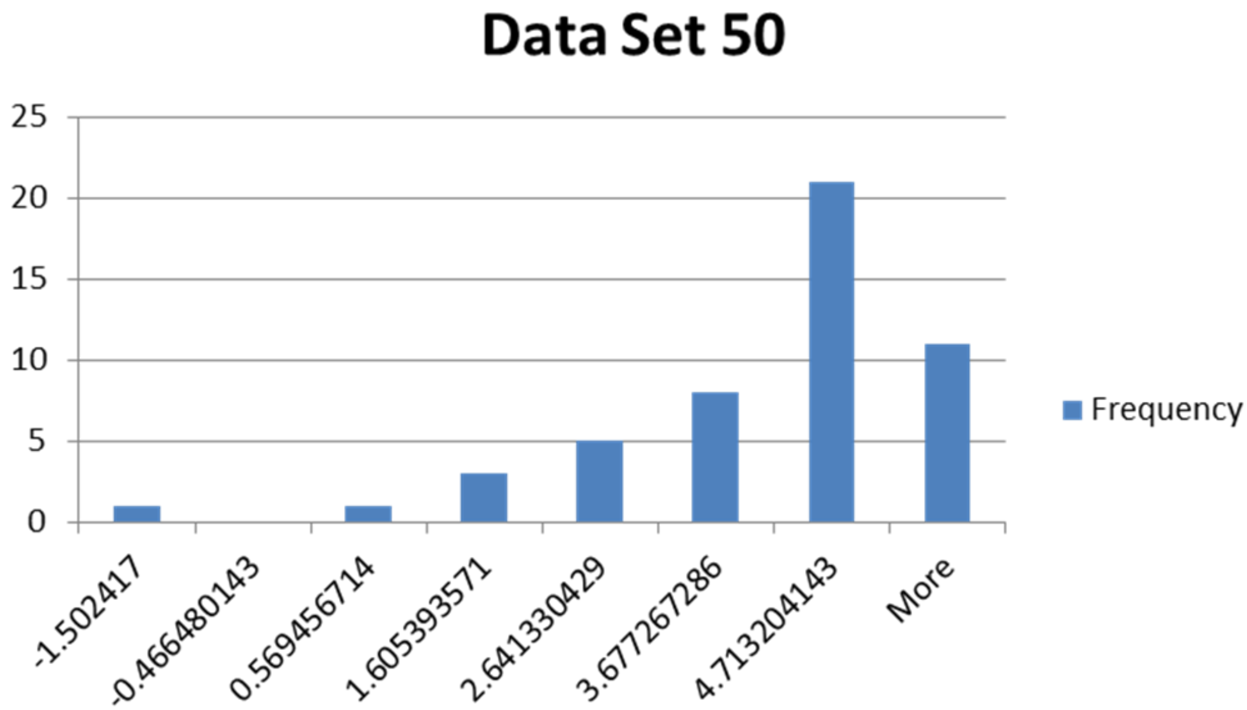


Figure 3 shows the histogram of same item after conversion to a 7 point Likert scale. The program used to perform the conversion from continuous to discrete 7 or 5 point Likert scales was also written in Java.

Figure 3: Data from Figure 2 converted to a 7 point Likert scale.

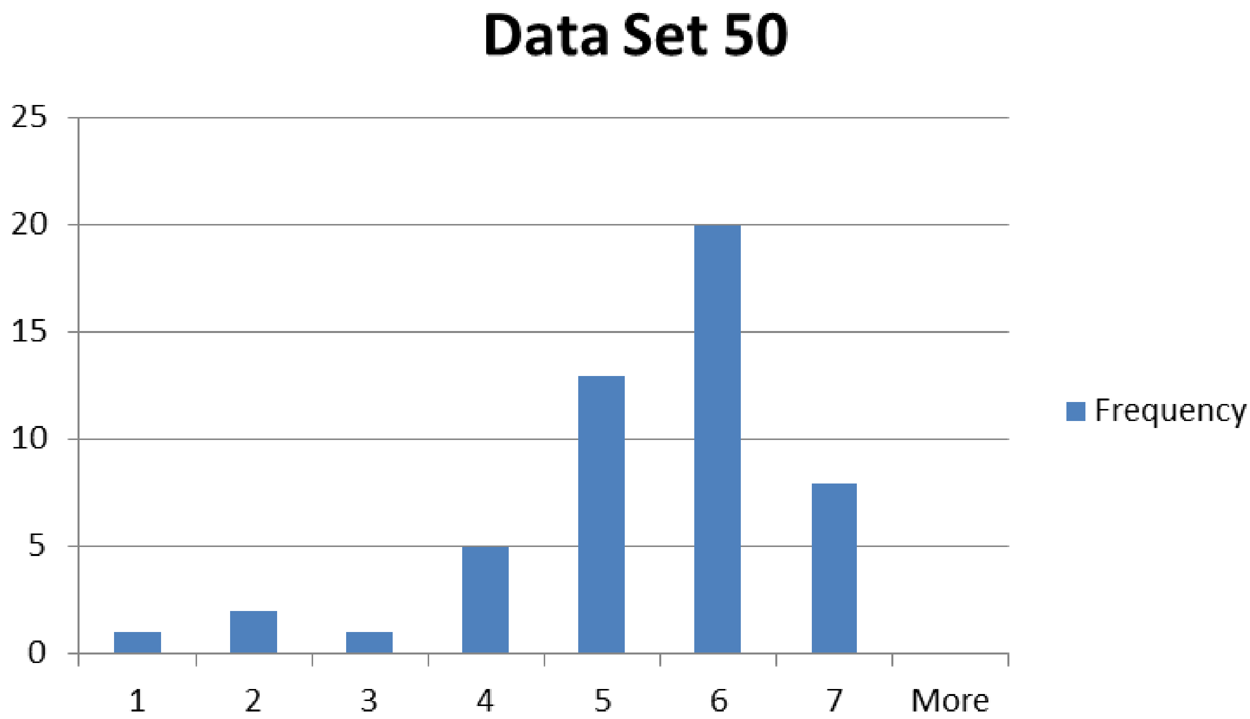
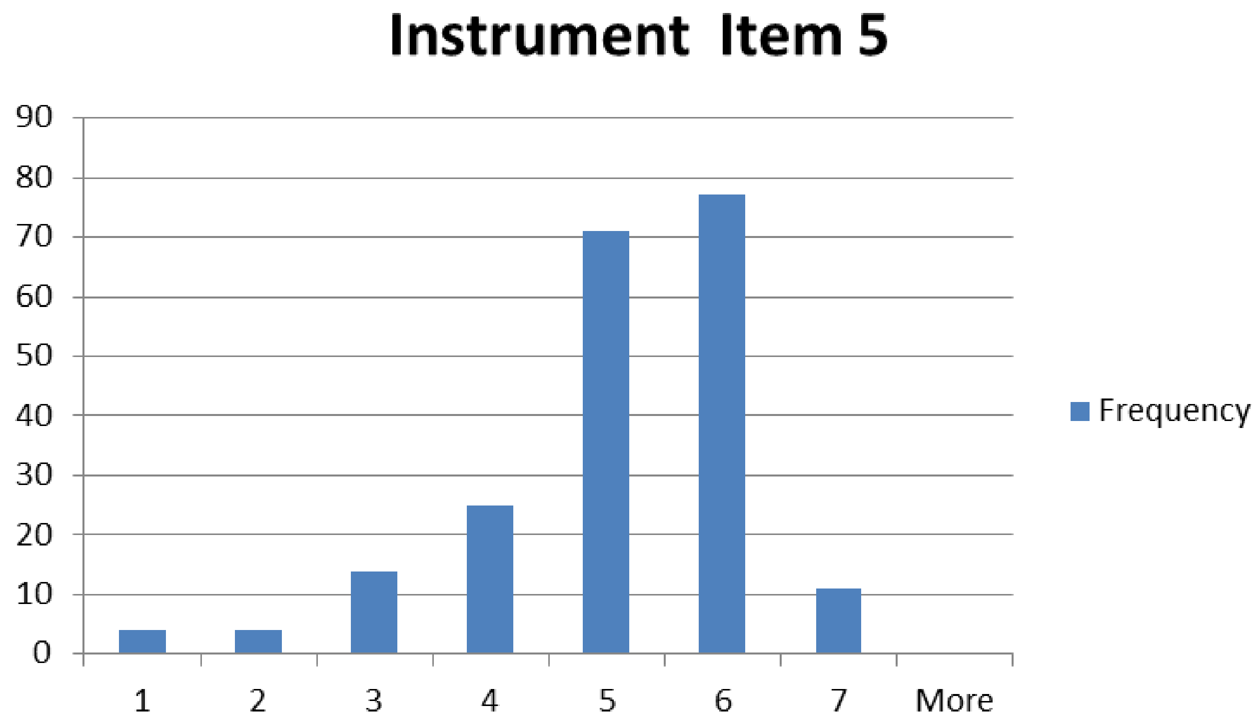


Figure 4 shows the histogram of the original 206 responses to item 5 taken from the actual data set used as the population parameters that form the basis of the simulated data sets.

Figure 4: Data from item 5 of the actual instrument which had 206 responses.



The similarity of the actual data distribution and the simulated distribution histograms should be apparent.

SIMULATION RESULTS

The simulation results of primary interest are given in Table 4 and Table 5. The number of times the 95% CIs included the population reliability coefficient when the data were generated starting from a continuous normal distribution are given in Table 4. For the continuous data, 95% CIs based on Fisher's *z* transformation are the most accurate at almost 99% containing the population alpha followed by Feldt's at approximately 96% and finally the BCa bases CIs at 94%. This same pattern of accuracy continues as the continuous data is converted to discrete data. In the case of the 7 point Likert scale the accuracy of CIs drops by approximately 1%. When the continuous data is converted to a five point Likert scale Fisher's *z* based CIs accuracy drops by about 4% and Feldt's and the BCa CIs accuracy drops by approximately 5%.

Table 4: The number of times the confidence intervals included the population Cronbach's alpha for data derived from a normal distribution.

CI Type	In Interval	Outside Interval	Total
Continuous Central F	956	44	1000
Continuous Bootstrap BCa	940	60	1000
Fisher's Z	987	13	1000
Likert 7 Point Central F	944	56	1000
Likert 7 Point Bootstrap BCa	930	70	1000
Likert 7 Point Fisher's Z	980	20	1000
Likert 5 Point Central F	903	97	1000
Likert 5 Point Bootstrap BCa	878	122	1000
Likert 5 Point Fisher's Z	947	53	1000

Table 5 shows the accuracy of the 95% CIs when the data were generated starting with continuous skewed left distributions. The relative ranking of the accuracy of the three CI methods remains the same but there is a significant drop in absolute accuracy. Fisher's *z* based CIs were 94% accurate followed by the BCa method with 90% accuracy and Feldt's method with 86% accuracy. It is notable that no method met the required 95% accuracy CI criterion. When converting the continuous data to a 7 point Likert scale, Fisher's and the BCa based methods showed little change dropping only 0.5% while Feldt's method showed a tiny 0.6% increase (probably due to the loss of the effects of a few extreme data points). Converting the continuous data to a 5 point Likert scale again had the most significant effect on accuracy. Both the Fisher and the BCa methods dropped about 3% to 91% and 86% accuracy respectively.

Table 5: The number of times the confidence intervals included the population Cronbach's alpha for data derived from a negatively skewed distribution.

CI Type	In Interval	Outside Interval	Total
Continuous Central F	857	143	1000
Continuous Bootstrap BCa	903	97	1000
Fisher's Z	944	56	1000
Likert 7 Point Central F	863	137	1000
Likert 7 Point Bootstrap BCa	898	102	1000
Likert 7 Point Fisher's Z	939	61	1000
Likert 5 Point Central F	863	137	1000
Likert 5 Point Bootstrap BCa	864	136	1000
Likert 5 Point Fisher's Z	914	86	1000

The difference between the ideal population alpha reliability and the average or bias from the 1000 simulation runs is shown in Table 6. The degree of bias is slightly greater for the skewed distributions than for the normal distributions. Both show a very slight downward bias for the continuous distributions and an increasing bias as the conversion is made from the 7 point Likert scale to the 5 point Likert scale indicating the effects of information loss as conversion is made to cruder discrete scales.

Table 6: Mean and bias in alpha over the 1000 samples given the population alpha is .898678.

CI Type	Mean α	Bias
Continuous Normal	.89498	.0037
Likert 7 Point Normal	.885069	.013611
Likert 5 Point Normal	.874589	.024091
Continuous Skewed	.891992	.006688
Likert 7 Point Skewed	.88449	.01419
Likert 5 Point Skewed	.87431	.02437

Table 7 and Table 8 contain detailed summary statistics for the CIs. Although all of the statistics have some value, the statistics of primary interest are the average of the CI widths. For the normal distribution based three CI methods shown in Table 7, the mean CI width increases as the continuous data is converted to a 7 point and then to a 5 point Likert scale. While there is negligible difference in the average width of Feldt's and the BCa CIs, the average width of Fisher's z based CIs is noticeably wider. The standard deviation of the CI widths shows negligible increase as the continuous data is converted to courser discrete data.

Table 7: The summary statistics for the 1000 simulation runs using the normal distribution.

		Central F			Bootstrap BCa			Fisher's Z		
		LCL	UCL	Width	LCL	UCL	Width	LCL	UCL	Width
Continuous Normal	Mean	0.844	0.934	0.089	0.844	0.931	0.087	0.822	0.939	0.118
	Stdv	0.034	0.015	0.020	0.035	0.016	0.023	0.037	0.014	0.024
Likert 7 Point Normal	Mean	0.830	0.928	0.098	0.828	0.926	0.098	0.805	0.933	0.128
	Stdv	0.037	0.016	0.021	0.039	0.017	0.026	0.040	0.015	0.025
Likert 5 Point Normal	Mean	0.814	0.921	0.107	0.812	0.919	0.107	0.789	0.927	0.139
	Stdv	0.039	0.017	0.022	0.041	0.018	0.027	0.042	0.016	0.026

Note: The lower confidence limit is LCL, the upper confidence limit is UCL, the standard deviation based on N is Stdv.

For the negatively skewed distributions shown in Table 8, the average CI width increases as the data is converted from a continuous scale to a 7 point and then to a 5 point Likert scale. The mean width of the BCa CIs is larger than the mean width of Feldt's CIs and the mean width of Fisher's CIs is larger than the mean width of the BCa CIs. The standard deviations of the CIs show little change as the continuous data is converted to discrete data.

Table 8: The summary statistics for the 1000 simulation runs using the skewed distribution.

		Central F			Bootstrap BCa			Fisher's Z		
		LCL	UCL	Width	LCL	UCL	Width	LCL	UCL	Width
Continuous Normal	Mean	0.840	0.932	0.092	0.825	0.934	0.109	0.817	0.937	0.121
	Stdv	0.047	0.020	0.027	0.051	0.022	0.037	0.051	0.019	0.032
Likert 7 Point Normal	Mean	0.829	0.927	0.098	0.813	0.933	0.120	0.805	0.933	0.128
	Stdv	0.048	0.020	0.027	0.047	0.025	0.035	0.052	0.019	0.033
Likert 5 Point Normal	Mean	0.814	0.921	0.107	0.800	0.927	0.129	0.788	0.927	0.139
	Stdv	0.048	0.020	0.028	0.049	0.026	0.037	0.052	0.019	0.032

Note: The lower confidence limit is LCL, the upper confidence limit is UCL, the standard deviation based on N is Stdv.

DISCUSSION

Providing a confidence interval for a measure of scale reliability such as Cronbach's alpha gives important information about the precision with which such a point estimate is made. Because alpha is one of the most often employed measures of scale reliability, a number of methods have been developed for producing CIs for alpha. In this paper, three methods of producing CIs for alpha were compared for accuracy when the underlying distributions of the item responses were the ideal normal distribution and the more realistic skewed distribution. In addition, the effect of information loss on CI accuracy was investigated as the continuous distributions were converted first to 7 point and then to 5 point Likert scales. Most notable was the performance of Fisher's *z* based CIs which remained the most accurate under all conditions. For the continuous normal distribution, the accuracy Fisher's CIs exceeded the specified 95% confidence, acting more like a 99% confidence interval. Feldt's and the BCa CIs both had performance that was close to the specified 95% confidence accuracy. The effect of information loss when converting from a continuous normal to a 7 point Likert scale caused a slight decrease in accuracy while moving to a 5 point Likert scale gave a noticeable decrease in accuracy for all three of the CI methods.

When the more realistic negatively skewed distribution was used as the basis for the CIs, all three CI methods showed a marked decline in accuracy, with none actually meeting the specified 95% confidence level of accuracy. Feldt's based CIs showed the most drastic drop in accuracy, dropping almost 10% when moving from the continuous normal to the negatively skewed item response distributions. These results would indicate that in actual application with real data, the specified accuracy of alpha confidence intervals should be viewed as somewhat suspect and overly optimistic.

Finally, a comparison of the average width of the confidence intervals along with the accuracy statistics gives some indication of why Fisher's *z* based CIs appeared to be most accurate in all conditions studied. In all cases, Fishers *z* based CIs had the noticeably widest confidence intervals. In addition, the initial result indicates that the accuracy of the supposed 95% CI was approximately 99% under the continuous normal distribution which is actually the underlying assumption of Fisher's *z*. These simulation results lead to the conclusion that for coefficient alpha, which is not a Pearson product moment correlation as Fisher's *z* assumes, a presumed 95% CI is actually closer to a 99% confidence interval. These observations provide a plausible reason for the greater average width of the Fisher CIs compared to the others and would also provide a possible explanation for the superior performance of the supposed 95% Fisher *z* CIs.

Based on the simulation results, a Fisher's *z* based CI for alpha reliability would be a researcher's best choice. In addition to its being most accurate in the simulation results, it is very easy to compute. However, it should be kept in mind that if the specified confidence level is 95%, the actual CI produced may be somewhat more liberal than actually specified.

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