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Differentiations according to the sample size of different reliability coefficients are examined. It is concluded that the estimates obtained by Cronbach alpha and teta coefficients are not related with the sample size, even the estimates obtained from the small samples can represent the population parameter. However, the Omega coefficient requires large sample sizes.

Key words: Cronbach alpha, theta, omega, reliability, scale, sample size.

Introduction

A scale is needed to measure and that scale must be reliable and valid. The scale's reliability does not matter in the case of measuring the concrete characteristics. But, it is an important problem in the case of measuring the abstract characteristics. So, it is necessary to analyze the reliability of the scales using some statistical methods. In making a reliability analysis, the reliability coefficients that are suitable in obtaining the reliability of the scale and the structure of the empirical study must be examined. Sample size is also important to determine the reliability level of the scale. Thus, one of the dimensions that must be examined is the changes in Cronbach alpha, theta, and omega coefficients according to the sample size.

Reliability

The scale, used to get some information on a defined subject, must have some properties. Reliability, a property that a scale must have, is an indicator of consistency of measurement values obtained from the measurements repeated under the same circumstances (Gay, 1985; Carmines & Zeller, 1982; Arkin & Colton, 1970; O'Connor, 1993; Carey, 1988).

The reliability of the scale can be examined by different ways. The reliability of the scale can be examined by applying the scale once, applying the scale twice or applying the equivalent scales once. In case of applying the scale once, the reliability of internal consistency is examined. The reliability coefficient ranges between 0 and 1.

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Methods of Internal Consistency

If the reliability can be estimated by applying the scale once, the error in reliability estimation will be less than the other reliability estimation methods. In this kind of reliability estimation, wrong management, scoring, temporary changes in personal performance affect the internal consistency, the leading affect will be the content sampling (O'Connor, 1993).

Another method, split-half, denotes the homogeneity indices of the items in the scales. It pertains to the relationship level between the responses of the items and the total scale score (Oncu, 1994). An increase in homogeneity in the set of items increases this reliability estimate (O'Connor, 1993). The idea that the internal consistency methods depend upon is that every measurement tool is constructed to realize an objective and those have known equal weights (Karasar, 2000). The internal consistency methods are preferred because they are economical and easy to apply (Oncu, 1994).

Cronbach Alpha

The Alpha coefficient method (Cronbach, 1951), is a suitable method that can be used for likert scale items (e.g., 1-3, 1-4, 1-5). Thus, it is not limited to the true-false or correct-incorrect format (Oncu, 1994).

Cronbach alpha coefficient is weighted standard variations mean, obtained by dividing the total of the k items in the scale, to the general variance (Thorndike et al., 1991).

$$\alpha = \frac{n}{(n-1)}\left[1 - \frac{\sum_{i=1}^{n} \sigma_{Y_i}^2}{\sigma_x^2}\right]$$

n : Number of the items

σ_{Y_i} : ith item's standard deviation

σ_X : General standard deviation

(2.1)

If the items are standardized, coefficient is calculated by using the items' correlation mean or variance-covariances' mean (Carmines & Zeller, 1982; Ozdamar, 1999a; SPSS, 1991; SPSS, 1999).

Calculation of alpha coefficient due to the correlation mean,

$$\alpha = \frac{n\,\overline{\rho}}{1+(n-1)\overline{\rho}} \tag{2.2}$$

Calculation of alpha coefficient due to the variance-covariance mean,

$$\alpha = \frac{n\,\overline{\sigma_{XX}} / \overline{\sigma_X}}{1+(n-1)\overline{\sigma_{XX}} / \overline{\sigma_X}} \tag{2.3}$$

When the formula for calculating Cronbach alpha using the correlation means between items is examined, it can be seen that it is proportionally related with the number of the items and the mean of the correlation between items (Carmines & Zeller, 1982). If the correlation between the items is negative, alpha coefficient will also be negative. Because this situation will spoil the scale's additive property, it also causes a spoil in the reliability model and the scale is no more additive (Ozdamar, 1999a). The coefficient is equal to the mean of all probable coefficients using split-half method (Carmines & Zeller, 1982; Gursakal, 2001).

Theta Coefficient

The Theta coefficient depends on the principal components analysis. In principal components analysis, the components are in descending order due to the variances of each of the constructions (Carmines & Zeller, 1982). The first component is the linear component with the maximum variance. The second component is the linear component with the second maximum variance. Components can be explained by the component variances defined by the percentage values to explain the variance of the original data set in order (Ozdamar, 1999b). Theta coefficient depends on that property. The Theta coefficient, takes into account the eigenvalue that maximum explains the event, is calculated as follows:

$$\theta = (N / N - 1)(1 - 1 / \lambda_i)$$

N : Number of items
λ_i : The largest eigenvalue (the first eigenvalue)

(2.4)

Omega Coefficient

Another coefficient for linear dependencies is the Omega coefficient proposed by Heise and Bohrnstedt (1970). It depends on the factor analysis model. Omega coefficient is modeled on factor analysis. In this type of modeling, in calculating the coefficient, before factoring "1" values on diagonal in the correlation matrix are replaced with the communality values. The Omega coefficient can be calculated with two ways, using variance-covariance matrix and correlation matrix (Carmines & Zeller, 1982).

When studied with variance-covariance matrix,

$$\Omega = 1 - \left(\sum \sigma_i^2 - \sum \sigma_i^2 h_i^2 \right) \Big/ \left(\sum \sum \sigma_{X_i X_j} \right)$$

h_i^2 : Communality of the i[th] item

(2.5)

When studied with correlation matrix,

$$\Omega = 1 - \left(a - \sum h_i^2 \right) \Big/ (a + 2b)$$

a: Number of items
b: Sum of the correlations among items

(2.6)

There are some differences between the Theta and Omega coefficients. They depend on different factor-analytic models. The Theta coefficient depends on principal components model, whereas the Omega coefficient depends on factor analysis model. Therefore, in calculating the eigenvalues for Theta coefficients, the diagonal 1.0 values are used, but in calculating the Omega coefficients, communality values that are not related with 1.0 values are used (Carmines & Zeller, 1982).

There is a relationship between Alpha, Theta, and Omega coefficients. If the items take parallel values, three coefficients are equal each other and will be 1.0. Otherwise, the relationship of magnitude for the coefficients will be $\alpha < \theta < \Omega$. Among these internal consistency coefficients, α gives the lower bound of the reliability coefficient and Ω gives the upper bound of the reliability coefficient (Carmines & Zeller, 1982).

Methodology

To compare the Alpha, Theta and Omega coefficients, a data set has been used from an instrument developed by Ercan et al. (2004) to measure patient satisfaction in the secondary health-care units. To obtain the effects of different number of items and different sample sizes, 3 different scales are constructed with 39, 34, and 30 items by subtracting some items from the scale with 43 items. Because all the subjects did not answer all the items, the subject numbers in the scales are also different. There are 170 subjects answered all of the 43 items, 240 subjects answered all of the 39 items, 230 subjects answered all of the 34 items, and 320 subjects answered all of the 30 items.

After giving a number to each of the subjects, samples are constructed by producing random numbers using MINITAB 13.2 beginning from 10 and increasing 10 units each of those random numbers. The same procedure was repeated 10 times and for each of the samples Cronbach alpha, Theta and Omega reliability coefficients are calculated.

SPSS 13.0 was used for these analyses. Statistical comparisons are performed in order to determine if alpha, theta and omega coefficients change or not according to the sample size and in order to determine the sample size that the reliability coefficients begin to get stable. Before the between group comparisons, the homogeneity of variances is tested using the Levene statistic. If the variances are found to be homogeneous, then analysis of variance

Table-4.1: The homogeneity test results for the scale with 30 items

	Levene Statistic	Degree of Freedom 1	Degree of Freedom 2	Significance level (p)
α	5.631	31	288	<0.001
θ	5.578	31	288	<0.001
Ω	1.531	31	288	0.040

Table-4.2: Significance level in comparison of α, θ and Ω reliability coefficients according to different sample sizes using Kruskal-Wallis test for the scale with 30 items

	α	θ	Ω
χ^2	23.706	46.720	259.636
Degree of freedom	31	31	31
Significance level (p)	0.822	0.035	<0.001

Bonferroni correction: $\alpha^* = 1-(1-\alpha)^{1/k}$

$$\alpha^* = 1-(1-0.05)^{1/32} = 0.0016$$

and Tukey HSD post-hoc comparison test are applied. If the variances are heterogeneous, Kruskal-Wallis and Mann-Withney U tests are applied to make reliability comparisons according to sample size. The level of significance in multiple comparisons is determined after Bonferrroni correction ($\alpha^* = 1-(1-\alpha)^{1/k}$ k: number of groups).

Results

The results of comparisons α, θ and Ω coefficients according to different sample sizes are given in Table 4.1, 4.2, 4.3, 4.4 for the scale with 30 items.

Table-4.3: Significance level (p values × 10^{-3}) in comparison of θ reliability coefficients according to different sample sizes using Mann-Whitney U test for the scale with 30 items ($\alpha^*=0.0016$).

n	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320
10		631	315	315	315	280	353	393	393	353	353	393	393	353	315	353	315	353	353	315	315	315	353	353	353	393	315	315	315	436	436	436
20			912	684	796	529	579	100	529	631	529	529	529	631	353	315	190	165	089	123	190	123	123	105	089	165	052	075	075	123	075	063
30				315	393	218	315	529	247	218	218	190	190	190	165	143	105	105	089	105	123	075	089	089	105	123	063	075	075	075	105	089
40					853	684	912	796	579	853	481	529	353	280	218	143	123	123	123	123	123	089	143	123	123	123	089	063	075	123	123	123
50						529	971	853	436	684	353	529	190	165	247	143	052	034	052	075	105	105	105	035	052	075	075	052	035	023	023	023
60							796	353	971	912	912	100	912	912	796	739	529	436	247	315	481	436	436	218	218	393	190	190	247	353	165	123
70								739	739	912	631	796	393	436	529	247	165	143	089	190	143	165	105	105	165	218	143	105	063	075	075	089
80									315	529	247	280	105	089	123	052	011	004	009	011	023	019	019	004	005	009	009	005	005	002	002	002
90										971	796	971	739	796	579	353	280	247	218	353	280	165	165	123	190	315	089	089	105	105	143	218
100											739	796	481	481	315	315	218	190	165	190	218	143	165	218	143	247	123	143	105	218	190	143
110												971	796	853	529	481	315	315	247	247	280	165	190	247	165	280	105	143	143	165	165	143
120													579	684	739	315	190	105	105	315	190	315	075	063	143	247	089	089	035	035	052	075
130														631	971	971	631	529	123	190	436	353	280	105	105	481	105	123	247	165	075	023
140															853	739	481	315	143	143	247	353	247	052	075	123	123	105	075	023	043	023
150																579	280	190	218	353	280	436	190	165	247	393	218	190	075	075	075	089
160																	529	280	190	393	436	529	631	143	315	529	315	280	105	075	123	123
170																		631	315	796	912	971	100	436	739	912	739	579	436	280	436	315
180																			393	739	971	912	853	579	631	853	796	631	393	353	353	165
190																				971	739	684	631	631	912	353	796	796	796	853	971	796
200																					912	853	971	912	912	579	631	796	912	796	912	631
210																						100	100	631	684	853	739	631	579	579	579	481
220																							853	796	971	631	912	796	631	579	796	912
230																								796	971	684	100	739	481	912	739	684
240																									796	529	739	739	853	912	579	393
250																										529	971	684	796	971	971	853
260																											393	353	218	280	165	105
270																												796	739	912	912	971
280																													971	971	971	912
290																														971	912	529
300																															912	684
310																																481
320																																

Table-4.4: Significance level (p values× 10^{-3}) in comparison of Ω reliability coefficients according to different sample sizes using Mann-Whitney U test for the scale with 30 items (α*=0.0016).

n	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320
10		000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
20			052	002	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
30				023	002	002	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
40					089	009	007	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
50						123	105	011	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
60							853	123	011	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
70								280	023	005	003	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
80									218	019	015	005	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
90										353	247	089	009	005	001	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
100											853	481	075	035	007	004	001	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000
110												579	075	063	009	005	000	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000
120													165	165	019	011	005	004	000	000	000	000	000	000	000	000	000	000	000	000	000	000
130														912	315	247	105	052	009	005	005	004	001	000	002	002	000	000	000	000	000	000
140															353	190	052	029	007	004	004	003	001	001	001	002	000	000	000	000	000	000
150																684	190	143	052	015	015	009	004	005	004	007	000	000	000	000	000	000
160																	436	218	075	035	035	019	007	004	009	007	001	000	000	000	000	000
170																		247	123	165	105	123	043	023	075	052	007	004	004	002	003	003
180																			436	393	393	315	123	123	247	218	063	035	007	019	023	023
190																				739	853	971	579	393	579	579	315	143	075	105	123	123
200																					971	912	739	853	684	684	280	190	143	143	029	029
210																						971	796	631	912	739	315	165	190	143	075	063
220																							631	684	100	912	436	190	165	123	123	123
230																								971	912	912	529	247	143	063	043	105
240																									100	971	481	165	105	075	035	075
250																										100	218	165	052	035	011	029
260																											353	165	105	105	052	075
270																												393	280	280	353	481
280																													631	853	739	100
290																														971	912	971
300																															853	100
310																																912
320																																

The results of comparisons α, θ and Ω coefficients according to different sample sizes are given in Table 4.5, 4.6, 4.7 for the scale with 34 items.

Table-4.5: The homogeneity test results for the scale with 34 items

	Levene Statistic	Degree of freedom 1	Degree of freedom 2	Significance level (p)
α	11.003	22	207	<0.001
θ	10.477	22	207	<0.001
Ω	3.238	22	207	<0.001

Table-4.6: Significance level in comparison of α, θ and Ω reliability coefficients according to different sample sizes using Kruskal-Wallis test for the scale with 34 items

	α	θ	Ω
χ^2	6.329	8.960	176.741
Degree of freedom	22	22	22
Significance level (p)	1.000	0.994	<0.001

Bonferroni correction: $\alpha^* = 1-(1-\alpha)^{1/k}$

$$\alpha^* = 1-(1-0.05)^{1/23} = 0.0022$$

Table-4.7: Significance level (p values× 10^{-3}) in comparison of Ω reliability coefficients according to different sample sizes using Mann-Whitney U test for the scale with 34 items (α*=0.0022)

n	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
10		000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
20			004	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
30				280	043	007	001	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
40					247	043	009	004	002	000	000	000	000	000	000	000	000	000	000	000	000	000	000
50						481	143	063	023	003	000	000	000	000	000	000	000	000	000	000	000	000	000
60							280	143	052	009	001	000	000	000	000	000	000	000	000	000	000	000	000
70								853	353	143	052	075	015	009	000	000	000	000	000	000	000	000	000
80									579	247	075	089	043	029	004	011	001	002	000	000	000	000	000
90										739	315	247	123	123	023	015	007	005	002	001	002	001	002
100											684	739	247	218	075	052	043	009	005	003	002	001	002
110												971	579	315	052	105	035	011	005	003	002	001	002
120													436	280	063	075	023	011	002	001	002	001	015
130														912	218	190	075	035	005	003	003	002	015
140															247	123	043	019	002	001	002	001	002
150																971	315	218	015	003	009	003	015
160																	218	280	011	004	005	002	002
170																		912	280	075	052	019	019
180																			280	123	089	052	105
190																				436	353	218	796
200																					912	631	684
210																						631	280
220																							165
230																							

The results of comparisons α, θ and Ω coefficients according to different sample sizes are given in Table 4.8, 4.9, 4.10, 4.11 for the scale with 39 items.

Table-4.8 : The homogeneity test results for the scale with 39 items

	Levene Statistic	Degree of freedom 1	Degree of freedom 2	Significance level (p)
α	10.692	23	216	<0.001
θ	12.048	23	216	<0.001
Ω	1.418	23	216	0.104

Table-4.9: Significance level in comparison of α and θ reliability coefficients according to different sample sizes using Kruskal-Wallis test for the scale with 39 items

	α	θ
χ^2	7.206	8.702
Degree of freedom	23	23
Significance level (p)	0.999	0.997

Table-4.10: Significance level in comparison of Ω reliability coefficients according to different sample sizes by analysis of variance for the scale with 39 items

	Sum of Squares	Degrees of freedom	Sum of Squares	F	Significance level (p)
Between groups	0.00536	23	0.0002329	142.881	<0.001
Within groups	0.000352	216	0.00000163		
Total	0.00571	239			

Bonferroni correction: $\alpha^* = 1-(1-\alpha)^{1/k}$

$$\alpha^* = 1-(1-0.05)^{1/24} = 0.0021$$

Table-4.11: Significance level (p values × 10^{-3}) in comparison of Ω reliability coefficients according to different sample sizes using Tukey's HSD post-hoc comparison test for the scale with 39 items (α*=0.0021).

n	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
10		000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
20			002	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
30				031	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
40					729	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
50						899	003	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
60							781	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
70								100	972	322	029	000	000	000	000	000	000	000	000	000	000	000	000	000
80									100	986	561	035	005	002	000	000	000	000	000	000	000	000	000	000
90										100	947	227	051	021	004	000	000	000	000	000	000	000	000	000
100											100	934	617	411	159	021	001	000	000	000	000	000	000	000
110												100	991	953	749	264	035	001	000	000	000	000	000	000
120													100	100	100	963	558	086	011	003	008	000	000	000
130														100	100	100	908	330	069	020	055	001	001	000
140															100	100	977	525	147	049	119	002	002	000
150																100	999	836	388	170	335	012	010	001
160																	100	996	863	610	821	104	091	018
170																		100	999	975	997	514	479	171
180																			100	100	100	975	967	750
190																				100	100	100	100	984
200																					100	100	100	999
210																						100	100	991
220																							100	100
230																								100
240																								

The results of comparisons α, θ and Ω coefficients according to different sample sizes are given in Table 4.12, 4.13, 4.14 for the scale with 43 items.

Table-4.12: The homogeneity test results for the scale with 43 items

	Levene Statistic	Degree of freedom 1	Degree of freedom 2	Significance level (p)
α	6.313	16	153	<0.001
θ	7.654	16	153	<0.001
Ω	2.463	16	153	0.002

Table-4.13: Significance level in comparison of α, θ and Ω reliability coefficients according to different sample sizes using Kruskal-Wallis test for the scale with 43 items

	α	θ	Ω
χ^2	11.248	7.026	141.750
Degree of freedom	16	16	16
Significance level (p)	0.794	0.973	<0.001

Bonferroni correction: $\alpha^* = 1-(1-\alpha)^{1/k}$

$$\alpha^* = 1-(1-0.05)^{1/17} = 0.003$$

Table-4.14: Significance level (p values$\times 10^{-3}$) in comparison of Ω reliability coefficients according to different sample sizes using Mann-Whitney U test for the scale with 39 items (α*=0.003)

n	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
10		000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
20			000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
30				143	000	000	000	000	000	000	000	000	000	000	000	000	000
40					001	000	000	000	000	000	000	000	000	000	000	000	000
50						353	015	002	000	000	000	000	000	000	000	000	000
60							123	011	003	000	000	000	000	000	000	000	000
70								218	089	009	003	000	000	000	000	000	000
80									353	105	105	005	001	000	000	000	000
90										393	315	035	015	009	002	001	002
100											912	280	190	089	035	029	023
110												280	165	105	035	029	009
120													631	481	190	075	023
130														912	579	123	043
140															436	218	063
150																481	165
160																	481
170																	

Conclusion

The answer to the question of sample size in this context is important. The accuracy of reliability coefficients changes according to the sample size. There is high positive correlation between number of items and reliability coefficient as mentioned in Carmines and Zeller (1982). Also, the difference in number of items must be taken into account.

Significant differences are not observed due to the sample size in the commonly used Cronbach Alpha, and with the Theta coefficient which is based on principal components. However, with the Omega coefficient, based on factor analysis, large differences were observed due to the sample size. With an increase in item numbers, however, the Omega coefficient is stabilized even for smaller sample sizes.

Ozdamar (1999a) mentioned that the sample size should be more than 50 in reliability analysis applications. According to the results of this study, that sample size is not important for the Cronbach alpha or theta coefficients, and is stable even for a small number of items (although of course an increase in the number of items will increase the magnitude.) However, in order to estimate the population parameter with Omega coefficient, the item number is important. With an increase in item number, either the consistency of estimation or the reliability level increases.

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