

Retaining principal components for discrete variables*

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The present study discusses retention criteria for principal components analysis (PCA) applied to Likert scale items typical in psychological questionnaires. The main aim is to recommend applied researchers to restrain from relying only on the eigenvalue-than-one criterion; alternative procedures are suggested for adjusting for sampling error. An additional objective is to add evidence on the consequences of applying this rule when PCA is used with discrete variables. The experimental conditions were studied by means of Monte Carlo sampling including several sample sizes, different number of variables and answer alternatives, and four non-normal distributions. The results suggest that even when all the items and thus the underlying dimensions are independent, eigenvalues greater than one are frequent and they can explain up to 80% of the variance in data, meeting the empirical criterion. The consequences of using Kaiser's rule are illustrated with a clinical psychology example. The size of the eigenvalues resulted to be a function of the sample size and the number of variables, which is also the case for parallel analysis as previous research shows. To enhance the application of alternative criteria, an R package was developed for deciding the number of principal components to retain by means of confidence intervals constructed about the eigenvalues corresponding to lack of relationship between discrete variables.

Keywords: principal components analysis, eigenvalues, parallel analysis, discrete items.

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Retención de componentes principales para variables discretas

El presente estudio trata sobre diferentes criterios para la retención de componentes en el análisis de componentes principales (PCA) aplicado a escalas tipo Likert, que son comunes en los cuestionarios psicológicos. El principal objetivo del estudio es recomendar a los investigadores no confiar en el criterio de extracción fundamentado en criterio del autovalor mayor que uno, sugiriendo procedimientos alternativos que se ajusten al error muestral. Un objetivo adicional consiste en añadir evidencia sobre las consecuencias de utilizar el criterio antes mencionado cuando el PCA se usa con variables discretas. Las condiciones experimentales se estudiaron por medio de remuestreo Monte Carlo, incluyendo distintos tamaños de muestra, diversas cantidades de reactivos y alternativas de respuesta y, finalmente, diferentes distribuciones de probabilidad para las opciones de respuesta. Los resultados sugieren que, incluso cuando todos los ítems y las dimensiones subyacentes son independientes, los autovalores mayores que uno son frecuentes y pueden dar cuenta de hasta el 80% de la varianza de los datos, alcanzándose el criterio empírico. Las consecuencias de utilizar el criterio de Kaiser se ilustran con un ejemplo propio de la Psicología clínica. Se halló que el tamaño de los autovalores es una función del tamaño de la muestra y del número de variables, que se corresponde con lo encontrado previamente para el parallel analysis. Para potenciar la aplicación de criterios alternativos, un paquete en R fue desarrollado para decidir el número de componentes principales que deben retenerse y recurriendo a intervalos de confianza fundamentados en los autovalores asociados a la inexistencia de asociación entre las variables discretas.

Palabras clave: análisis de componentes principales, autovalores, parallel analysis, reactivos discretos.

Introduction

Psychological research often deals with understanding the structure of correlations among measured variables and even obtaining indirect measurements of underlying dimensions for applied and theoretical purposes. For instance, a psychological test assesses anxiety as a construct (or latent variable) by means of observable variables such as the items of a questionnaire referring to physiological measurements, cognitive aspects, etc. Regarding the identification of constructs, it has been argued that exploratory factor analysis (EFA) is the proper statistical procedure for such an aim (Fabrigar, Wegener, MacCallum & Strahan, 1999), at least if there is not enough foundation to specify an *a priori* model. According to Preacher and MacCallum (2003), an often followed routine in applied and theoretical research consists of using a variation of EFA wherein researchers carry out principal components analysis (PCA), retaining components with eigenvalues greater than 1.0, and obtaining new orthogonal dimensions by varimax rotation, a bundle of procedures termed “Little Jiffy”. However, although PCA has been applied in many psychological studies, it is not a reasonable substitute of EFA (Fabrigar *et al.*, 1999; Preacher & MacCallum, 2003). In fact, PCA does not seem

to be a suitable statistical method to identify latent structures since principal components are linear composites of the measured variables and, thus, include common and unique variance. That is, PCA and EFA have different mathematical models and conceptual meanings and the choice among the two should be based on researcher's aims and on the characteristics of the techniques. The present study focuses on the use of PCA due to the wide use of this statistical technique in applied and theoretical research, although it is not an appropriate substitute of EFA.

PCA is a statistical technique applied to a set of measured variables when researchers are concerned with identifying which variables in the set form coherent subsets that are independent among them. Hence, if the number of measured variables equals p , the specific goal of PCA is to summarise patterns of covariances or correlations among variables to a usually smaller number q of underlying dimensions. One of the most difficult decisions that analysts have to make is to choose the number of principal components to retain. In general, researchers using PCA decide on the basis of the absolute and relative size of eigenvalues, although there are other rules such as including enough principal components to account for, say, 80 percent of the total variance (i.e., the "empirical criterion") or basing the decision on the graph called "scree plot" (Cattell, 1966). Accordingly, and as a rule-of-thumb, many statistical packages specify a default option in which the number of retained principal components is equal to the quantity of eigenvalues greater than one. This rule, suggested by Kaiser (1960), states that the number of reliable principal components is as large as the number of the existing eigenvalues greater than one. That is, an eigenvalue less than one implies that the scores on the principal component would have negative reliability, although Kaiser's reasoning has been shown to be unsuitable (Cliff, 1988). Additionally, the eigenvalues-greater-than-one rule also means that only principal components that account for a greater variance than measured variables do have some summarizing power. These rules can be used and specifically adapted when either correlation or covariance matrices are used to obtain the eigenvalues.

The eigenvalues-greater-than-one rule may, however, be unsuitable since sampling effects may often lead to increasing the number of eigenvalues greater than one. That is, measured variables that are independent among themselves frequently lead to retaining a principal component, although it may not be useful to understand the meaning of the global phenomenon. Zwick and Velicer (1982) studied 48 population correlation matrices and systematically varied the number of measured continuous variables, number of components, sample size, and component saturation. The study showed that the eigenvalues-greater-than-one rule consistently overestimates the number of principal components retained. Interestingly, the number of principal components retained often fell between one-third and one-fifth of the number of measured variables included in the correlation matrix for low saturation and it increased as the number of measured variables became larger. Hence, it can be argued that in general, the use of the eigenvalues-greater-than-one rule cannot be recommended.

As a potential solution to the overestimation of the number of principal components, Horn (1965) proposed a statistical procedure, called *parallel analysis*, for determining the number of principal components to retain. According to this criterion, the eigenvalues of a population correlation matrix of independent measured variables are all equal to 1.0 . However, if random samples are obtained from such a population correlation matrix, most initial eigenvalues will probably exceed 1.0 whereas the last eigenvalues will be lower than 1.0 . Hence, eigenvalues of empirical correlation matrices of p observed variables and n participants should be compared with those obtained from correlation matrices on uncorrelated random data, given that the population matrix corresponds to the identity matrix. Thus, principal components of empirical correlation matrices for which eigenvalues are significantly greater than those of random correlation matrices would be retained. It should be noted that applying this rule means that researchers are not interested in principal components that do not account for more variance than the corresponding components from distributions of random and independent numbers. Also note that the rationale can be extended to covariance matrices. It should be mentioned that specific and free software for carrying out parallel analysis in PCA and even EFA is easily available on internet (Patil, Singh, Mishra & Donavan, 2008) and it can be also obtained by well-known computer programs (Ledesma & Valero-Mora, 2007).

It has been found that parallel analysis commonly leads to accurate decisions when applied to PCA (Zwick & Velicer, 1986). Parallel analysis has been studied assuming multinormal distributions or other continuous distribution functions (Dinno, 2009), but Likert scales need to be considered due to their frequent use in applied psychology. Accordingly, recent research has focused on both studying the performance of parallel analysis for binary data (Weng & Cheng, 2005) and adapting it to deal with items with categorical responses (Liu & Rijmen, 2008). Hence, although parallel analysis has also been used for analysing Likert scales (Hayton, Allen & Scarpello, 2004), systematic research on the parallel analysis technique with PCA has to be conducted for this kind of scales, as it is a common procedure in analysing questionnaires.

Statistical descriptive analysis is not sufficient for making inferences to populations when psychological scales are developed and inferential procedures are needed to obtain statistical significance for eigenvalues. However, in studies where psychological questionnaires require participants to answer items choosing one alternative among the k available and ordered options, the discrete nature of these Likert scales does not allow assuming the observed variables follow a p -variate normal distribution and probably leads to floor and ceiling effects (Nanna & Sawilowsky, 1998). Hence, the asymptotic confidence intervals for eigenvalues and hypothesis testing methods proposed for making statistical decisions are not suitable for most psychological research involving psychometric data analysis. Moreover, asymptotic probability distributions have been mainly derived for the eigenvalues and eigenvectors of a sample covariance matrix (Flury, 1988; Jolliffe,

1986). Regarding correlation matrices, asymptotic distribution theory of the characteristic roots and vectors is more complicated than that of covariance matrices (Morrison, 1976). Due to the reasons mentioned above, it seems that specific statistical tests should be developed to assign statistical significance to eigenvalues and, thus, make decisions regarding eigenvalues for discrete random variables.

The present investigation focuses on studying the eigenvalues-greater-than-one rule, as we expected that this rule may improperly lead to extract a number of irrelevant principal components for spherical population matrices. This effect can be explained by sampling error if sample correlation matrices are analysed. In addition, the research was also intended to study how that rule may lead to flawed statistical conclusions since its use may suggest retaining an only and artificial principal component for independent observable variables. This fact becomes problematic in those studies in which researchers try to develop one-dimensional scales and are interested in obtaining some empirical support. As applied psychometric data are often ordinal level Likert scale data, the simulation study focuses on this sort of measured variables since we were interested in finding some useful results for applied psychological research. Several multivariate techniques, including dimensionality reduction procedures, have already been investigated in relation to non-quantitative variables (Bernaards & Sijtsma, 1999; Ferrando & Lorenzo-Seva, 2001; Jöreskog & Moustaki, 2000; Lee, Song & Lu, 2007; Linting, Meulman, Groenen & van der Kooij, 2007; Meara, Robin & Sireci, 2000; Millsap & Yun-Tein, 2004) and thus the research on such variables is relevant.

Method

Data generation

Given that the objective of the present study was to examine the functioning of PCA applied to psychological measurements, the simulated data consisted of participants by items matrices. Several characteristics of empirical studies were investigated, including the common values available in applied studies. In order to select matrix size simulation values, we carried out a non-systematic review of applied studies¹ and also considered the findings of previous and more extensive studies (Fabrigar *et al.*, 1999; Henson & Roberts, 2006; Weng & Cheng, 2005). Thus, the sample sizes included in the simulation study were 100, 300, 500, 700, and 1000. Our review allowed us to set the number of items to be explored (i.e., 10, 30, 50, 70, and 100 items). Items were supposed to be answered according to k -point ordinal scales, whose values ranged from 1 to k . Several values were inves-

¹ The articles consulted for the non-systematic review are marked with an asterisk in the References section.

tigated for k (3, 4, 5, 6, and 7), representing different intensities of disagreement/agreement to the items' statements, as it could have an effect on the decision rules.

For all experimental conditions, data were generated from a population in which the correlation matrix among observed variables was set equal to the identity matrix. That is, the observed variables, which represent items of psychological scales, were supposed to be orthogonal. For each experimental condition defined by the combinations of the abovementioned conditions, data were generated to represent four patterns of items' mass probability distributions: discrete uniform, discrete triangular, discrete skewed, and mixed. A total of 500 experimental conditions were specified, generating 100,000 data matrices for each of them. A mathematical model was developed to establish the specific probabilities for the discrete distribution functions in order to guarantee some objective criterion. Previous studies were also taken into consideration to determine the mass probability functions to be included in the simulation study (Micceri, 1989; Nanna & Sawilowsky, 1998; Sawilowsky & Blair, 1992).

A discrete uniform distribution of answers represents the case where all alternatives are equally attractive to the participants and the mass probability value of each alternative is equal to $1/k$, where k denotes the number of answer options. The mass probability distribution for skewed conditions (figure 1) represents those cases in which alternatives of one extreme are more attractive to the participants. An example of such a distribution is the case in which each mass probability is equal to twice the previous one when moving towards the heavier tail. For instance, considering the black bars of figure 1, the mass probability of rating 6 is .0159, for rating 5 is twice .0159 and so on until rating 1 where the mass probability is 32 times .0159. For the white bars representing a negatively skewed distribution, the probabilities are the mirror image of the ones for the positively skewed distribution.

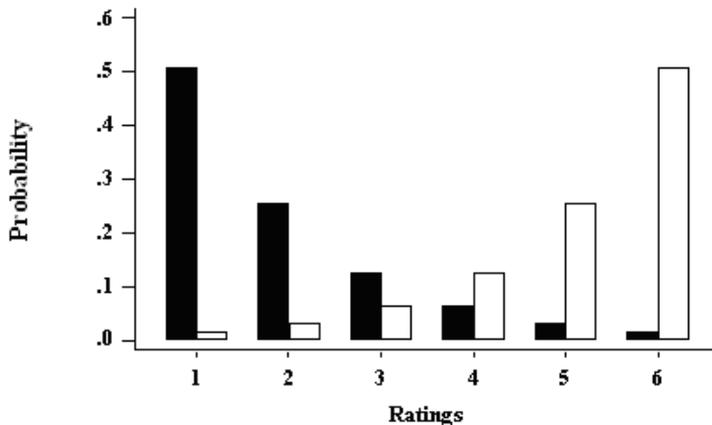


Figure 1. Two mass probability functions illustrating positively and negatively skewed distributions.

For discrete triangular distributions, which correspond to symmetric distributions, all items' mass probability values linearly increased from the extremes to the centre rates (as the white bars show on figure 2). This condition was studied since individuals may avoid extreme answers in favour of more moderate ones. An example of such a distribution is the case in which each mass probability is equal to twice the previous one when moving towards the centre. For instance, considering the white bars of Figure 2, the mass probability of ratings 1 and 6 is approximately .0714285, for rating 2 and 5 it doubles that value and for ratings 3 and 4 it is four times the same value. It is also possible to consider a distribution which is bimodal at the extremes (see the black bars of figure 2). For this distribution, the mass probabilities for rating 1 and 6, on one hand, and for ratings 3 and 4, on the other hand, are inverted with respect to the ones mentioned above.

The mixed condition was defined as a combination of discrete uniform, discrete triangular, and discrete skewed items' mass probability functions, different types of items being represented as far as possible by a third of each sort of distribution. For questionnaires consisting of 10, 70, and 100 items, the number of them following a discrete uniform distribution was set equal to $\text{int}(p/3) + 1$, where p denotes the number of items. In the case of 50 items, the amount of them which are uniformly and triangularly distributed equalled $\text{int}(p/3) + 1$.

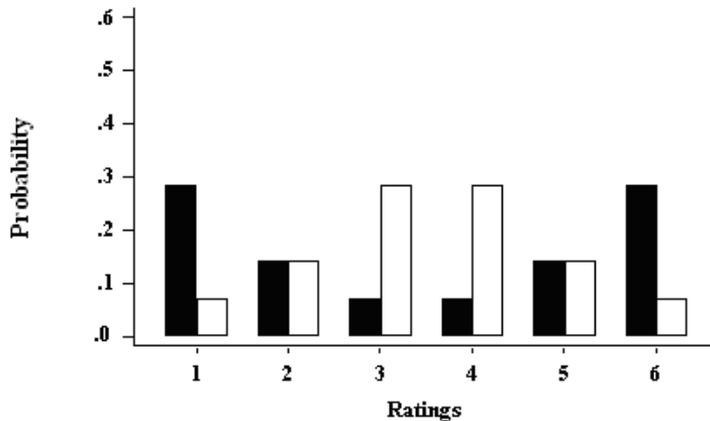


Figure 2. Two mass probability functions showing bimodal at extremes and triangular distributions.

Data analysis

Given that the eigenvalues of population matrices were equal to 1 and the eigenvalues obtained in simulated samples were expected to be close to 1, the empirical eigenvalues were compared to the expected ones. In fact, departures from sphericity were expected due to sampling error.

The fact the items are independent means that the percentage of variance accounted for by each principal component should theoretically be equal to 100 divided by the number of items. Hence, the expected variance accounted for by each principal component was compared to the values obtained in the simulation study.

R and C codes were developed for generating data matrices according to the mass probability functions abovementioned (using the *runif* R function), to specify correlation matrices, and to obtain eigenvalues (by means of the *dsyev* Lapack routine). All computations were verified comparing the results to the output provided by common statistical software.

Results

Data features' influence on eigenvalues

Out of the four factors studied (n , p , k , and type of distribution) only sample size and the number of variables proved to affect eigenvalues. The estimates corresponding to different number of alternatives only diverge at third decimal, which was also observed in the four distributions studied. Accordingly, the results presented are applicable to all values of k and to all the discrete distribution functions studied. As shown on figure 3, a greater number of items are associated with larger first principal component (PC#1) eigenvalues. In contrast, for larger n the eigenvalues corresponding to PC#1 are smaller. The average eigenvalues obtained for each combination of n and p studied are presented in table 1.

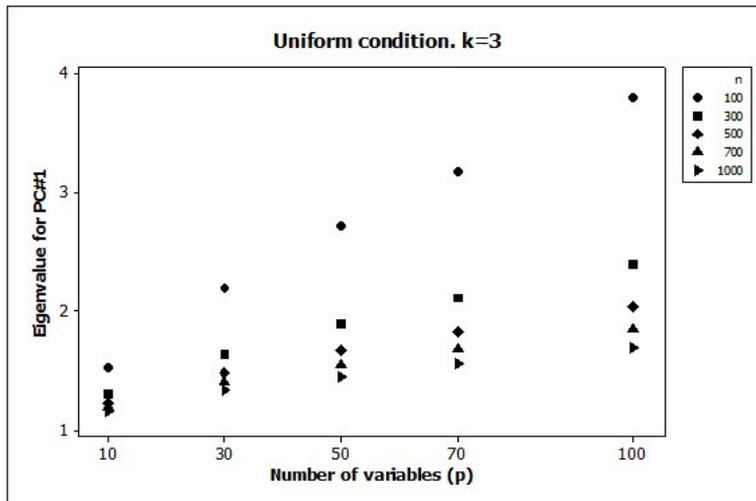


Figure 3. Mean eigenvalues for the first principal component (PC#1) for different sample sizes (n) and questionnaire sizes (p). The case of $k = 3$ alternatives and a uniform distribution is represented.

TABLE 1. AVERAGE EIGENVALUE AND PERCENTAGE OF VARIANCE ACCOUNTED FOR BY THE FIRST PRINCIPAL COMPONENT FOR EACH COMBINATION OF N (NUMBER OF PARTICIPANTS) AND P (NUMBER OF VARIABLES).

n	$p = 10$	$p = 30$	$p = 50$	$p = 70$	$p = 100$	cell content
100	1.530	2.199	2.716	3.172	3.79	eigenvalue
	15.30%	7.33%	5.43%	4.53%	3.79%	variance accounted for
300	1.295	1.640	1.893	2.111	2.399	eigenvalue
	12.95%	5.47%	3.79%	3.02%	2.40%	variance accounted for
500	1.226	1.483	1.669	1.827	2.034	eigenvalue
	12.26%	4.94%	3.33%	2.61%	2.03%	variance accounted for
700	1.190	1.403	1.555	1.683	1.850	eigenvalue
	11.19%	4.67%	3.11%	2.40%	1.85%	variance accounted for
1000	1.158	1.333	1.457	1.560	1.695	eigenvalue
	11.58%	4.44%	2.91%	2.22%	1.69%	variance accounted for

Complementarily, the results show that even when the variables are independent, as much as 50% of the principal components have eigenvalues greater than one (see table 2). In general, it can be seen that an eigenvalue greater than one does not necessarily imply that there is a relationship between the variables and that they can be reasonably summarised by principal components.

TABLE 2. PROPORTION OF PRINCIPAL COMPONENTS HAVING AN EIGENVALUE GREATER THAN ONE ($\lambda > 1$) AND VARIANCE ACCOUNTED FOR BY THOSE COMPONENTS FOR EACH COMBINATION OF N (NUMBER OF PARTICIPANTS) AND P (NUMBER OF VARIABLES).

n	$p = 10$	$p = 30$	$p = 50$	$p = 70$	$p = 100$	cell content
100	.5000	.4333	.4200	.4143	.3900	proportion $\lambda > 1$
	62.60%	66.09%	71.48%	76.26%	80.40%	variance accounted for
300	.5000	.4667	.4600	.4429	.4400	proportion $\lambda > 1$
	57.27%	59.82%	63.09%	64.54%	68.22%	variance accounted for
500	.5000	.4667	.4600	.4571	.4500	proportion $\lambda > 1$
	55.62%	56.85%	59.25%	61.43%	63.80%	variance accounted for
700	.5000	.4667	.4800	.4714	.4600	proportion $\lambda > 1$
	54.75%	55.27%	59.20%	60.43%	61.91%	variance accounted for
1000	.5000	.4667	.4800	.4714	.4700	proportion $\lambda > 1$
	53.98%	53.86%	57.37%	58.27%	60.32%	variance accounted for

Data features' influence on the amount of variance accounted for

Since the amount of variance accounted for is related to eigenvalues, it varies only as a function of n and p . The amount of variance accounted for by the principal components decreases both for larger samples and for questionnaires with more items, as illustrated on figure 4. For instance, in the case of PC#1 as much as 15% of the information contained in the data can be accounted for when the questionnaire is short (see Table 1). Therefore, the fact that a principal component explains more than $100/p$ % of the variance should not be taken as an indicator that it has to be retained, since such values can be obtained in presence of random fluctuation. In addition, the amount of variability accounted for by the principal components with $\lambda > 1$ ranges from 53% to 80% (table 2), values that can be found frequently in applied studies justifying the principal components retained. In summary, the percentage of variance accounted for may also indicate relevant principal components in presence of independent items.

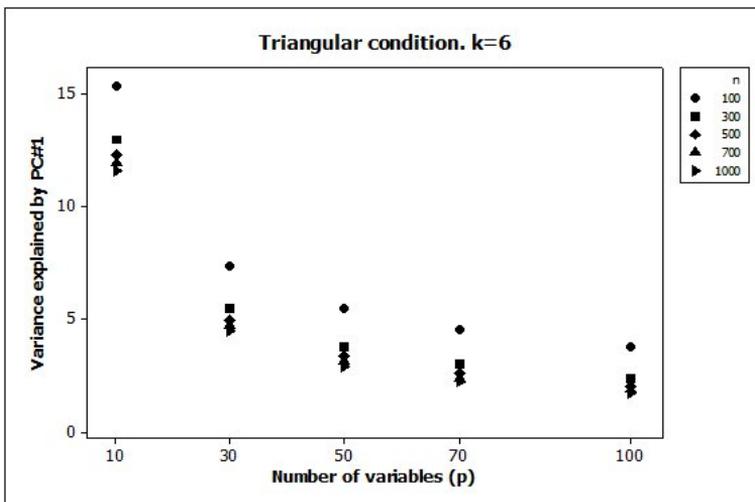


Figure 4. Variance accounted for by the first principal component (PC#1) for different sample sizes (n) and questionnaire sizes (p). The case of $k = 6$ alternatives and a triangular distribution is represented.

R code for making decisions on the number of principal components to retain

In order to offer applied psychologists a user-friendly procedure that yields both critical values and confidence intervals, an R package was constructed (*discrete_pca*, available upon request). Efforts have been made to develop specific

software incorporating the findings of recent research on multivariate techniques (e.g., Kaufman & Dunlap, 2000; Lorenzo-Seva & Ferrando, 2006; O'Connor, 2000). The procedure developed consists of the following steps:

1. Compute the proportions of answers given to each alternative.
2. Generate data matrices of the same size as the original one using the proportions obtained in the previous step as mass probability.
3. Compute eigenvalues in the original and the simulated data matrices.
4. Compute the mean and standard deviation of the sampling distribution obtained in the previous step.
5. Print the critical eigenvalue and its corresponding confidence intervals at a specified confidence level.

Therefore, the output of the program helps applied researchers to decide whether to retain a principal component or not, considering the eigenvalues that could have been obtained solely by chance. Regarding the use of the package, once it is installed and loaded in the R working session, it can be used following the steps presented in the Appendix.

An illustrative example of the effects of sampling error

In order to illustrate the inappropriateness of the eigenvalue-greater-than-one rule, the previously presented evidence gathered via simulation will be summarised in a contextualised example. Suppose that the psychological inventory of interest is the World Health Organization Disability Assessment Schedule II (WHO-DAS II; World Health Organization, 2000), specifically the shorter 12-item version, which has not been tested as extensively as the original 36-item instrument. The 12 questions that participants need to answer using a five-point scale (from 1 = none disability during the previous 30 days to 5 = extreme disability) are: 1. Standing for long periods such as 30 minutes? 2. Taking care of your household responsibilities? 3. Learning a new task, for example, learning how to get to a new place? 4. How much of a problem did you have in joining in community activities (for example, festivities, religious or other activities) in the same way as anyone else can? 5. How much have you been emotionally affected by your health condition? 6. Concentrating on doing something for ten minutes? 7. Walking a long distance such as a kilometre or equivalent? 8. Washing your whole body? 9. Getting dressed? 10. Dealing with people you do not know? 11. Maintaining a friendship? 12. Your day to day work/school?

Although the items have been chosen to represent evenly six different domains, it is possible to study how the items group in an exploratory manner until further evidence is available. In fact, there is a recent study (Luciano *et al.*, 2010)

in which exploratory Principal Components Analysis (PCA) followed with an improper oblique rotation is applied to the instrument. Suppose that the results obtained from a sample of 100 participants were the following: 5 eigenvalues greater than one (2.15, 1.53, 1.22, 1.17, and 1.03) with 17.92%, 12.75%, 10.17%, 9.71% and 8.66% variance accounted for, respectively (adding up to a total of 59.21%). Now, suppose that researchers may wish to follow Kaiser's rule and to additionally retain a sixth component (whose eigenvalue is .93) given the expectation of the items belonging to 6 subscales (i.e., Understanding and communicating, Getting around, Self-care, Getting along with people, Life activities, and Participation in society). In that case, the amount of variance accounted for is almost 67%, which could be used as another justification for retaining as many factors.

At that moment, the reader should assess the previous decision on the number of components to retain and their interpretation from the perspective that the 12 variables were actually simulated to be unrelated to each other and, thus, the eigenvalues greater than one are only due to sampling error. In the study previously referenced, among the retaining criteria used, Luciano et al. (2010) mention the interpretability of the components, Kaiser's criterion, and the scree plot. In their study, the PCA yielded two factors with eigenvalues greater than 1.0 (5.54 and 1.22), that accounted for 46.15% and 10.20% of the total variance, respectively. Note that the combined variance accounted for is lower than the one of the five components to be retained (due to sampling error) in the example. The scree plot, however, suggested retaining a single factor, which, in this case, apparently served as a filter for any possible overestimation of the initial eigenvalues, especially for the second principal component (whose eigenvalue in this case coincidentally is equal to the one of the third component in the simulated example).

Relying solely on the frequently used eigenvalue-greater-than-one criterion would have led to retaining a second component whose contribution is not undoubtedly beyond chance levels. In the present simulated example a scree plot can be consulted on figure 5. The original eigenvalues are the unadjusted ones and, in this case, there is no evidence of such drastic difference between the components' eigenvalues as in the study by Luciano *et al.* (2010) and so the scree plot would not be as useful.

However, parallel analysis can be used, assessing whether the original eigenvalues are greater than the ones expected only by chance. An analyst can proceed in two equivalent ways: a) to retain the components whose unadjusted eigenvalue is greater than the random eigenvalue for the corresponding rank; or b) to retain the components whose adjusted eigenvalue is greater than 1.0. Such decisions can be made via the scree plot on figure 5. In this case, parallel analysis would indicate that two components are to be retained instead of five, as the original PCA suggested. The fact that not all the overestimation of the eigenvalues is corrected may be due to the example being an extreme case.

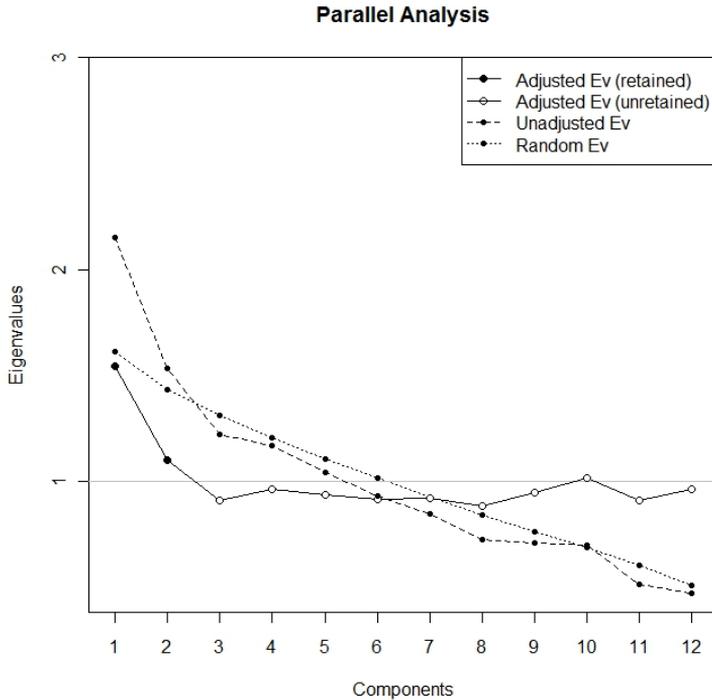


Figure 5. Results obtained via principal components analysis (unadjusted eigenvalues) and parallel analysis (random and adjusted eigenvalues) as applied on a data matrix with 100 participants and 12 items with 5 alternatives each. The R package paran (Dinno, 2009) was used to produce the results and the graph.

Another alternative is to base the decision on confidence intervals instead of the mean of the random eigenvalues. The limits for the confidence interval for a nominal significance of .05 are represented on figure 6, along with the observed unadjusted eigenvalues. As it can be seen, only the first component's eigenvalue is clearly beyond what is expected by chance, but the remaining ones are filtered as not significantly different from what is expected for unrelated items. That is, the effects of sampling error are reduced, with the exception of the first eigenvalue, which is apparently an extreme result. To summarize, it is preferable to use the alternative adjusting for sampling error (i.e., comparing the obtained eigenvalues to the expected ones at random or to confidence intervals) rather than the original eigenvalue-greater-than-one rule.

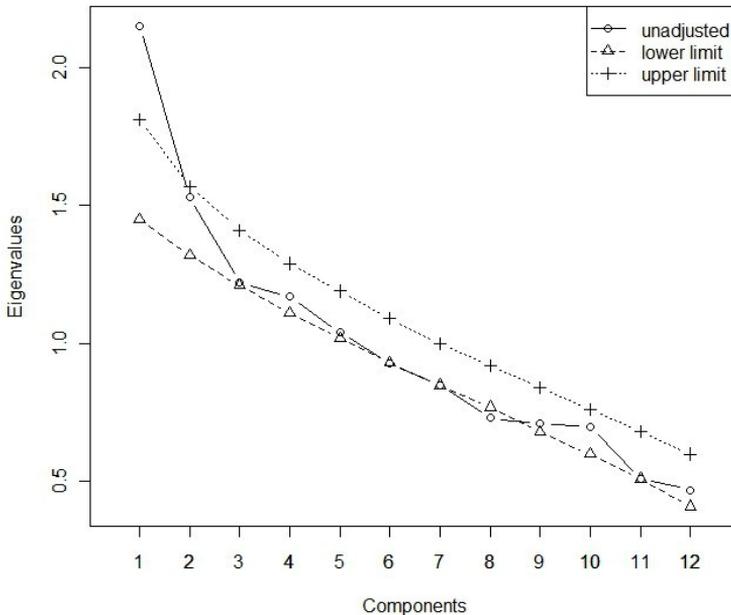


Figure 6. Results obtained via principal components analysis (unadjusted eigenvalues) and confidence interval upper and lower limits obtained through the proposed method based on Monte Carlo sampling generating 99,999 samples for data matrices with 100 participants and 12 independent items with 5 alternatives each. The R package `discrete_pca` was used to produce the results.

Conclusions

The present study focused on the eigenvalue-greater-than-one rule for retaining principal components, as the most frequently used criterion (Henson & Roberts, 2006). A related indicator, the percentage of variance accounted for by the principal components, was also assessed. Both criteria are applied to discrete data representing participants' answers to Likert scale psychological questionnaires. The results show that even unrelated variables may lead to eigenvalues and variance accounted for percentages suggestive of retainable principal components. Therefore, alternatives should be considered for retaining components, for instance, comparing the observed eigenvalues with the ones expected by chance and with confidence intervals about these chance values.

The procedure based on confidence intervals that is proposed can be applied through the `discrete_pca` R package to decide the number of principal compo-

nents to retain which is available upon request from the authors. Confidence intervals, as an interval estimator, ensure to a greater extent than point estimators (i.e., the eigenvalues themselves) that the summary variables reflect something more than random fluctuations. Concurring, for parallel analysis it has been found that the 95th- and 99th-percentile eigenvalues lead to better solutions than mean eigenvalues (Weng & Cheng, 2005). Nevertheless, the eigenvalue criterion can and should be complemented by other decision rules (Thompson & Daniel, 1996), taking into consideration especially the interpretability of the principal components. It is important not to use solely the default options of common statistical packages (e.g., the matrix of association used for extraction, the rule for components retention) without a reasonable justification.

Most studies regarding the number of principal components to be retained are concerned with continuous random variables for representing observed measurements, as normal and exponential distributions (e.g., Bernstein & Teng, 1998; Peres-Neto, Jackson & Somers, 2005), although psychologists often apply PCA for analysing ordinal data. Hence, the present simulation study focussed on questionnaires in which items are answered by Likert scales. The main result obtained shows that using the eigenvalue-greater-than-one rule may often lead to retain trivial axes, that is, underlying dimensions from a set of uncorrelated items. The most important explanation stems from the fact that principal components are also subjected to sampling error (Larsen & Warne, 2010). Therefore, as it has been previously suggested (Horn, 1965), parallel analysis should be used to prevent from retaining a number of trivial principal components. As regards, applied research can attain some benefit from applying parallel analysis to guarantee that psychological dimensions obtained are not statistical artefacts. However, it must be highlighted that PCA is not an adequate statistical technique if psychological researchers are concerned with extracting underlying psychological dimensions, as EFA is the proper statistical method.

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APPENDIX

The first required step is to specify the input matrix according a predefined format. If this matrix is in a text file (<filename>), it can be loaded in the working session as follows:

```
X <- matrix(<filename>,nrow=<number>,ncol=<number>)
```

where *nrow* is the number of individuals and *ncol* is the number of items.

Users have to specify the number of alternatives of the items of the questionnaire (*maxinterv*) and the number of iterations for the Monte Carlo sampling (*rep*) as follows:

```
maxinterv = <number of alternatives>
rep = <number between 1 and 10000000>
```

Researchers can decide whether the program show results for the eigenvectors:

```
eigenvectors = <TRUE or FALSE>
```

Finally, the probability of the confidence interval $(1 - \alpha)$ for the eigenvalues has to be chosen (*q*):

```
q = <proportion greater than .0 and smaller than 1.>
```

The function *mcpca* carries out a Monte Carlo sampling in order to estimate mean and variance for all eigenvalues and the variance accounted for by them. The function calls a C routine included in *discrete_pca* that generates *rep* matrices according to the estimates of probability masses computed by means of the original matrix **X**:

```
mcpca(X,maxinterv,rep,eigenvectors,q)
```