Person. individ. Diff. Vol. 2, pp. 311 to 318, 1981
Printed in Great Britain.
0191-8869/81/040311-08$02.00/0

RADIAL PARCEL FACTOR ANALYSIS

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(*Received* 28 *April* 1981)

INTRODUCTION

In psychometrics, interest has focused on the type of variable that is most suitable for factoring. Eysenck (1971) and Howarth and Browne (1971) have denied the validity of any factoring not based upon items, while Comrey (1961, 1970), MacDonald and Ahlawat (1974) and Nunnally (1978) insist that items can never provide suitable results. The main arguments against using binary or trinary choice items are that they are too unreliable and their score range is so narrow that correlations computed from the responses may be seriously distorted given a small shift in response frequencies across choices. The solution proposed by Comrey is to use variables that are 'parcels' of homogenous single items; his factored homogenous item dimension (FHID) is the outcome of this proposal. The FHID as defined by Comrey (1970) is

"a total score variable calculated by summing scores over several (usually from two to six) items which must meet two criteria: (a) the items were specifically conceived and logically conceptualized as measures of the particular variable under consideration, and (b) in empirical studies, the items have been found to define an item factor in factor analyses of items. Through the satisfaction of this dual criterion, it is established that the items constituting an FHID have both conceptual and empirical homogeneity".

However, Cattell (1973) has criticized this approach claiming that invariably these homogenous parcels are partially defining primary factors in their own right, thus any factoring of the FHIDs will produce a mixture of 1st and 2nd order factors. From Comrey's (1961) detailed description of the technique, it would appear impossible for this to ever occur. The only conditions under which Cattell's statement would hold is if an item factor to be 'parcelled' was in fact a grounded secondary or that a final parcel factor scale consists of parcels from two or more item factors.

Another method of parcelling variables is that using a clustering algorithm that produces parcels of items which all intercorrelate above some fixed minimum. These parcels may be constrained to consist of equal quantities of items or to simply consist of the quantities that satisfy the minimum correlation bound. With regard to the unconstrained size solution, there is a very real danger that hyperplane item variables will tend to form large clusters yielding proportionately fewer parcels than the factor identification variables. Thus in any new rotation, the correct location of axes will be extremely difficult if not impossible to achieve. The diagram presented by Cattell (1973, Fig. 24) is slightly misleading in that it is unlikely that any parcelling of those variables would yield unequivocal interpretable results. The use of the constrained size solution would alleviate this problem. However, there is as yet no empirical evidence which would allow any assessment of the method.

Cattell (1973, 1974; Cattel and Burdsall, 1975) has presented his arguments concerning parcelling vs item factor analysis, concluding that either method will yield essentially the same results. However, the parcel analyses are based upon his own method of radial parcelling. This involves the parcelling of items that have large inter-item vector cosines in the item factor space. These parcels are limited in equal sizes to powers of 2, e.g. 2, 4, 8, 16. The cosines are given by computing congruence coefficients between all rows of an unrotated factor pattern matrix, choosing the highest coefficient as being indicative of the first item parcel. The only empirical results using this particular technique are those presented by Cattell (1974). However, these are most unsatisfactory in that little detail of the parcel solutions and structures is given and the final item vs parcel solution congruences are so very low as to suggest that there is little agreement whatsoever. Bell (1978) attempted a radial parcel analysis of 100 scholastic ability items but unfortunately did not use Cattell's radial parcelling technique. Having computed item vector cosines, he then proceeded to cluster these items into parcels of unequal size. Thus little can be said about the efficacy of the radial procedure from these results.

Finally, Friel and Nesselroade (1976) have used a variant of parcelling that builds parcel variables from the same factor scale items, the choice of variables with which to pair being made randomly. The parcels were semi-constrained in that they only consisted of 4, 3 and 2 items. The rescoring of the data and subsequent analysis yielded a factor pattern indicative of Cattell's original radial parcelling of the High School Personality Questionnaire. Unfortunately, the authors provided no information as to the deviations between their parcel components and those of Cattell.

Thus, in order to clearly examine the similarities and efficacies of radial parcel vs item factor analysis, an exhaustive analysis is required. Presented below are the results from an investigation carried out using two samples of responses to the Eysenck Personality Questionnaire (EPQ; Eysenck and Eysenck, 1975). The issues upon which the results bear are:

(1) The comparison of item parcels found in two different data samples of the same questionnaire.
(2) The importance of factor extraction as a determiner of the parcel item and factor structure.
(3) The rescoring and analysis of one set of data on the basis of the item parcels generated from another set.
(4) The comparison of factors found from item and parcel factor analysis.

METHOD

Subjects

Two hundred and thirty-five male and 171 female undergraduates provided responses on the EPQ in addition to a Gallup quota sample of 600 male and 598 female English adults. This adult sample data was kindly loaned to us by Professor Eysenck. The details of these samples are given elsewhere (Barrett and Kline, 1980a; Eysenck, 1979).

Item factor analysis

The 2-item factor analyses were carried out using principal components analysis (PCA) on the Phi correlation matrices. Factor extraction was based upon the results from two tests, an automated scree test (AUTOSCREE; Barrett and Kline, 1980b) and the Velicer (1976) minimum average partial test (MAP). The factors thus retained were rotated using the direct oblimin procedure (Jennrich and Sampson, 1966) with the parameter δ swept from -30 to 0.5 in steps of 0.5, the convergence criterion set at 0.00001, with a maximum of 400 iterations per δ. The associated overall hyperplane count (HC) for each of these rotations was noted, the appropriate solution being given by the maximum HC and its associated δ. (The HC bound was set at ± 0.1). Then the rotation was again carried out around this δ value in steps of 0.1 to 'fix' the solution. Given that a sufficient number of factors had been extracted at this order, a 2nd order solution was undertaken. This involved principal component factoring of the 1st order factor correlation matrix, a Hendrickson–White (H–W; Hendrickson and White, 1966) grounding operation on the chosen unrotated 2nd order factors, then the same direct oblimin procedures as above to yield a maximized simple structure solution. This higher-order factoring procedure would continue as required. More specific detail of this factoring procedure is provided in Barrett and Kline (1980a).

Parcel factor analysis

The 2-item parcelling procedure was as follows: from an unrotated V_0 retained factor pattern matrix of item loadings congruences between each row (the item vector) and all others were computed. The highest absolute value congruence coefficient indicated the formation of the first 2-item radial parcel. These two items were then eliminated from any further searching. That is, all congruences computed using either of these two items were removed from the congruence matrix. This simple search procedure continued until all items were parcelled. Although the absolute congruence values were used in the search procedure, the sign of this value indicated a possible reflection of scoring for one of the variables in order to make the congruence positive. Thus, when rescoring the data prior to factor analysis, the addition of the values of two items was moderated by a reflection constant of -1 or $+1$ operating on one item's response. Having obtained the rescored 2-item parcel data, these 45 parcel variables were submitted to PCA, followed by AUTOSCREE and the MAP test, and subsequently the direct oblimin rotation procedure as indicated above.

In order to obtain 4-item parcels, one can either operate the above procedure on the unrotated 2-item parcel V_0 matrix, or proceed directly from the 2-item parcel identification stage operating on the unrotated V_0 item matrix. For the purpose of this analysis, the latter procedure was adopted. Having identified the 2-item parcel components, and having noted the sign of the congruences, the task is now of one generating a new composite V_0 matrix. By adding or subtracting the loadings across factors for each of the two items in a parcel, a new row in the composite V_0 is generated for that parcel variable. Table 1 provides an example of this procedure. If the congruence between rows was positive, add the row values, if negative subtract all values from one another. Thus a 45-parcel variable composite V_0 matrix is found. Now adopt the congruence and search procedure given above for 2-item parcel composition. In this particular case, a negative congruence indicates a reflection of a 2-item parcel score such that the possible score range for this 2-item parcel becomes -2, -1, 0, $+1$, $+2$. Thus in this way, the rescoring of the data was accomplished by adding item *a* (which is itself a 2-item parcel score) to item *b* (also a 2-item parcel score), moderating *a* or *b* by the reflection constant of $+1$ or -1. Having obtained the rescored data, the PCA and associated analyses were undertaken. Note here that whereas 45 2-item parcels were generated, only 22 4-item parcels were formed, thus two items were lost entirely to the analysis. The two items (1 parcel) are the least related in radial factor space to any other 2-item parcel. One can either include it in the PCA as hyperplane 'stuff' or discard it entirely. In this analysis, they were omitted from further examination.

The next size radial parcel is now one of 8 items, the combining of two 4-item parcels. This procedure continues in exactly the same way as the 4-item parcelling, yielding 11 8-item parcels. This is obviously the limit in that any factors identified by the parcels will only be expected to have a maximum of three parcels loading. For most practical purposes, 8-item parcels are simply too large, approaching scale length. However, in this analysis they were utilized in order to demonstrate the parcelling technique and the simplicity of results provided. Note that all scales in the EPQ are composed of more than 20 items, thus reasonable parcel coverage would be expected.

One final issue concerns the comparison of parcel factor patterns with those of item factor patterns. Cattell (1973, 1974) utilizes Dwyer's (1937) extension analysis to calculate the item loadings from the parcels so as to obtain estimated individual item loadings. However, as the results below indicate, this procedure was unnecessary in this particular

Table 1. The generation of the composite V_0 matrix (assuming no item reflections)

	Item factor V_0				Composite 2-item parcel V_0				
Item	Fac 1	Fac 2	Fac 3	Fac 4	Parcel item	Fac 1	Fac 2	Fac 3	Fac 4
1	0.7	0.16	−0.1	0.2	(1, 4)	1.45	0.31	−0.15	0.3
2	0.1	0.8	0.2	0.1	(2, 3)	0.25	1.51	0.3	0.15
3	0.15	0.71	0.1	0.05					
4	0.75	0.15	−0.05	0.1					

analysis as all parcel solutions were so clear as to obviate any use of extension analysis with its concommitant problems (Horn, 1973). Furthermore, Cattell's use of Dwyer's extension is necessitated due to the vast majority of his parcels being composed of items from different item factor scales (Cattell and Burdsall, 1975). An example of this problem is given in Cattell (1974) for a set of 4-item parcels of the 16PF questionnaire items.

RESULTS

The detailed results of the 2-item factor analyses are given in Barrett and Kline (1980a), thus only the relevant aspects of these results will be given here. For the student (N = 406) data, AUTOSCREE and the MAP test both indicated six factors (accounting for 28% of the solution variance) for extraction and rotation at the 1st order. These six factors were then taken to 2nd order analysis where four factors corresponding to E, N, L and P were extracted (accounting for 23% of primary solution variance). All items keyed for the E scale loaded >0.3 on the E factor. All items keyed for the N scale loaded >0.3 on the N factor. Seventeen items keyed for the L scale loaded >0.3 on the L factor, the four 'missing' items were L28, L55, L69 and L73. Fourteen items keyed for the P scale loaded >0.3 on the P factor, the 11 missing items were P30, P43, P50, P57, P61, P65, P76, P79, P83, P87 and P90. Four non-scale items loaded on this P factor >0.3 but <0.4, −N12, +E36, −N72 and −N80.

For the Gallup sample (N = 1198) adult data, AUTOSCREE indicated nine factors while the MAP test indicated five. On the basis of the student item factor results, and previous (Barrett and Kline, 1980a) subsample factorings, nine factors (accounting for 34% of the solution variance) were rotated to simple structure at the 1st order. These nine were then taken to 2nd order, yielding the four factors (accounting for 24% of the primary solution variance) E, N, P and L at this level. All but one item keyed for the E scale loaded >0.3 on the E factor; the missing item was E64 (0.298). All items keyed for the N scale loaded >0.3 on the N factor. All but one item keyed for the L scale loaded >0.3 on the N factor; the missing item was L55 (0.293). All but three items keyed on the P scale loaded >0.3 on the P factor; the missing items were: P2, P74 and P79 (all three loadings >0.25).

However, ignoring all the methodology above and simply extracting and rotating the first four factors at the 1st order level, practically the same results are achieved between these 1st order factors and the 2nd order factors. Simply, there is a very slight overall increase in all loadings on the 1st order set compared to the 2nd order set. This is exemplified by the small increase in solution variance explained, the four 1st order factors accounting for 24.8% in the Gallup sample, the same four factors at the 2nd order accounting for 24.1%. Having replicated this result on both the student sample and on a Thai student sample (Kline *et al.*, 1980) it is obvious that the four factors are self evident at the 1st order. Thus for the parcel factor analyses, this knowledge was directly used when interpreting the outputs from the AUTOSCREE and MAP tests. Additionally, three of the four parcel analyses utilized this information when parcelling was begun from the unrotated item factor V_0 matrix.

The parcel factor results are reported with regard to the four analyses undertaken:

Analysis 1

The radial parcelling of the student sample item V_0 with four factors retained.

Analysis 2

The radial parcelling of the Gallup sample item V_0 with four factors retained.

Analysis 3

The radial parcelling of the Gallup sample item V_0 with nine factors retained.

Analysis 4

The rescoring and analysis of the student sample data using the radial parcels generated from Analysis 2.

Table 2. MAP and AUTOSCREE factor extraction results

Parcel sizes		MAP	AUTOSCREE	Var %
	2	4	8	36
Analysis 1	4	4	4	53
	8	2	4	70
	2	4	8	38
Analysis 2	4	4	4:7	55
	8	3	4	73
	2	4	9	36
Analysis 3	4	4	4	52
	8	2	2:5	68
	2	4	6	35
Analysis 4	4	4	4	52
	8	3	4:6	71

Each Analysis was taken over three parcel sizes. Var % is the amount of variance explained by the 1st four factors in each parcel solution.

Thus Analyses 1, 2 and 4 used parcels generated over 4-item factors, in accordance with the results noted above. Analysis 3 was a direct test to ascertain whether parcel and factor structure computed from an item V_0 is dependent upon the number of initial retained item factors in the V_0. All analyses were concerned with factors from parcels of 2, 4 and 8 items. Table 2 presents the results of the MAP and AUTOSCREE factor extraction tests in addition to the variance accounted for by each solution over four factors. For all analyses, four factors were rotated to a maximum simple structure, this number being the consistent value given by both tests of factor extraction.

It is obviously impossible to present here the factor patterns and parcel structures for every analysis, however, the 8-item parcel structures and factor loadings for each analysis will be presented. From the particular notation used, the reader can easily see how the 8-item parcel was composed of 4- and 2-item parcels. This notation itself is simplified, leaving out all information as to reflection of items and parcels. Figure 1 presents the full parcelling notation in addition to the reduced notation to be used below.

Full Notated Size 8 Parcel Variable

$$\text{Parcel score} = \underbrace{\overbrace{(E1 + E2*1)}^{\text{2-Item parcel}} + [(E3 + E4*1)*1]}_{\text{4-Item parcel}} + \{(E5 + E6*1) + [(P7 + N8* - 1)*1]* - 1\}$$

Where: E1, E2, P7 etc. are the individual keyed items.
*1 and * −1 are the reflection constants applied to the appropriate values within brackets (the action is one of multiplication)

Reduced Notation Adopted

$$\text{Parcel score} = \underbrace{\overbrace{(E1,E2)}^{\text{2-Item parcel}}(E3,E4)}_{\text{4-Item parcel}}(E5,E6)(P7,N8)$$

Fig. 1.

Table 3 presents the parcel structures and loadings for the four sets of 8-item parcels. Each pair of identified items in brackets indicates a 2-item parcel. The first and last pair of bracketed parcels indicate the 4-item structures.

From Table 3, only Analysis 3 yields results that are mildly incongruous. Parcels 8 and 11 produce loadings that are inconsistent with the direction of keyed loading structure,

Table 3.

	Parcel structure	Loading	
Analysis 1 Students $N = 406$ 4 factors	1 (E14,E17)(E1,E29)(E32,E52)(E25,E49)	0.869(E)	
	2 (E40,E82)(E21,E42)(E45,E70)(E64,E86)	0.878(E)	
	3 (P22,P83)(P26,P90)(P37,P46)(P2,P71)	0.754(P)	
	4 (L51,L63)(L4,L59)(L35,L39)(L44,L73)	0.801(L)	
	5 (N23,N77)(N41,N54)(N31,N75)(N34,N38)	0.838(N)	
	6 (N62,P76)(P50,N68)(N15,N58)(P43,P61)	0.752(N)	0.382(P)
	7 (L24,L81)(L28,P79)(L20,L85)(L13,L69)	0.701(L)	0.307(P)
	8 (N3,N47)(N7,N27)(N19,N88)(N12,N72)	0.789(N)	
	9 (P57,P74)(P33,L55)(P18,P67)(P6,P9)	0.737(P)	
	10 (L8,L48)(L78,L89)(P11,N80)(L16,N66)	0.768(L)	
	11 (E36,E60)(P53,E56)(P30,P65)(N84,P87)	0.493(E)	0.555(P)
Analysis 2 Adults $N = 1198$ 4 factors	1 (N19,N34)(N12,N58)(N72,N80)(N38,N47)	0.858(N)	
	2 (L48,L73)(L20,L44)(L39,L51)(L78,L85)	0.915(L)	
	3 (P18,P61)(P26,P83)(P11,P90)(P43,P67)	0.853(P)	
	4 (E29,E52)(E10,E17)(E1,E32)(E49,E64)	0.880(E)	
	5 (L59,L63)(L55,L69)(L4,L13)(L16,L28)	0.785(L)	
	6 (E14,E42)(E21,E56)(E25,E82)(E40,E86)	0.903(E)	
	7 (P74,P79)(P2,P46)(P33,P71)(P22,P57)	0.746(P)	
	8 (N23,N27)(N3,N7)(N62,N77)(N15,N68)	0.784(N)	
	9 (P65,P76)(P30,P87)(P9,P37)(P50,L89)	0.752(P)	
	10 (N41,N75)(N31,N54)(N84,N88)(P6,P53)	0.875(N)	
	11 (L24,L81)(L8,L35)(E45,E70)(E36,E60)	0.415(L)	0.547(E)
Analysis 3 Adults 9 factors	1 (E17,E52)(E14,E29)(E25,E82)(E32,E36)	0.822(E)	
	2 (L39,L63)(L8,L24)(L44,L48)(E49,L59)	0.796(L)	
	3 (N72,N80)(N19,N34)(N38,N47)(N27, N88)	0.847(N)	
	4 (N3,N23)(N7,N58)(N68,N77)(N15, N62)	0.802(N)	
	5 (E21,E42)(E5,E40)(E10,E86)(E45,E70)	0.878(E)	
	6 (P11,P61)(P26,P90)(P33,P71)(P46,P83)	0.800(P)	
	7 (P9,P22)(P37,P43)(P18,P67)(N54,P74)	0.759(P)	
	8 (L4,L89)(L13,L16)(L28,L55)(P2,L85)	0.691(L)	−0.330(P)
	9 (L35,L51)(L69,L81)(L20,L78)(L73,L84)	0.839(L)	
	10 (N41,N75)(N31,N54)(P65,P76)(P30,P87)	0.786(N)	
	11 (E56,E60)(E1,E64)(P6,N12)(P50,P53)	0.541(E)	−0.403(P)
Analysis 4 Student rescored using adult parcels	1 (N19,N34)(N12,N58)(N72,N80)(N38,N47)	0.835(N)	
	2 (L48,L73)(L20,L44)(L39,L51)(L78,L85)	0.859(L)	
	3 (P18,P61)(P26,P83)(P11,P90)(P43,P67)	0.853(P)	
	4 (E29,E52)(E10,E17)(E1,E32)(E49,E64)	0.908(E)	
	5 (L59,L63)(L55,L69)(L4,L13)(L16,L28)	0.813(L)	
	6 (E14,E42)(E21,E56)(E25,E82)(E40,E86)	0.894(E)	
	7 (P74,P79)(P2,P46)(P33,P71)(P22,P57)	0.624(P)	
	8 (N23,N27)(N3,N7)(N62,N77)(N15,N68)	0.800(N)	
	9 (P65,P76)(P30,P87)(P9,P37)(P50,L89)	0.674(P)	
	10 (N41,N75)(N31,N54)(N84,N88)(P6,P53)	0.842(N)	
	11 (L24,L81)(L8,L35)(E45,E70)(E36,E60)	0.396(L)	0.575(E)

'Loading' column provides the factor loadings >0.3 and the identified factors (E, N, P & L) on which they appear. Where two loadings are given for the same parcel, this indicates that the mixed keyed items within the parcel are loading differentially on each factor.

e.g. Parcel 8, comprised primarily of L keyed items, loads negatively on P (−0.330) and Parcel 11, containing four P items, also loads negatively on P (−0.403). Otherwise, the results are extremely clear.

The two missing items from each Analyses 1, 2 and 3 are: (1) item E5 and item E10; (2) item E5 and N66; (3) item N66 and item P79. As expected, the size of the factor loadings increases dramatically as the size of the parcel composition increases. This is simply due to item error variance being in part cancelled out. The common part in each item now is more clearly expressed in the parcel variable. Cattell (1974) provides a mathematical treatment of this fact. This boosting of the commonality is also reflected in the proportion of variance accounted for by each parcelling solution (Table 2).

DISCUSSION

Looking at the results presented in Table 3, Analyses 1 and 2 have different parcel structures but this difference is confined only to the combinatorial construction of parcels from the same key items. Obviously the parcels of Analysis 1 are not quite as scale pure as those of Analysis 2, but this is a function of the sample size. Overall, there is little difference in the quality of factor structure. For this reason alone, Dwyer's extension analysis is not required, to all intents and purposes the factors E, N, L and P are identified clearly in these analyses. The 2- and 4-item parcel factor patterns reflect this clarity to a greater extent such that mixed 8-item parcels are comprised of uniscale 2- and 4-item parcels.

Analysis 3 was a direct examination of the effects of parcelling over more than four factors using the Gallup sample adult data. Once again good parcel structure is found yielding four clear factors (see Table 2). However, there is no doubt that some deterioration of the parcel structure has taken place producing some odd results such as those for Parcels 8 and 11. This would appear to indicate that some form of factor extraction test is required to ensure reasonable parcel structure. Note that nine factors was the value yielded by AUTOSCREE, although four factors produces optimum results for this data. It is also of interest to note that in all analyses, using 4-item parcel solutions, MAP and AUTOSCREE tests both yielded four factors regardless of the number of factors over which the parcels were originally computed. Intuitively, the 4-item radial parcel would be the optimum size for these scales.

Analysis 4 presented the results of the student data rescored and analysed using the parcels identified from the adult Gallup sample data. This had the effect of producing slightly clearer factors than those of Analysis 1. However, the difference is minimal especially with regard to the values of Table 2. The important point is that rescoring data using an independently assigned criterion does not produce 'peculiar' results. This statement may perhaps be moderated by the fact that both sets of parcels from the student and adult samples are really quite similar. Unlike Cattell's (1975) parcels, very few multiscale parcels are formed. Those that are formed represent the 'dregs' of the associative congruence matrix.

With regard to the clarity of the item factor and parcel factor patterns, it is clear that the radial parcelling factor results are little more than a reflection of the item factors. The student sample item factors are less 'clean' than the Gallup sample factors, this being reflected in the resultant parcel analyses. This result has also been confirmed in a factor study of the 16PF (Barrett and Kline, 1980c), the radial parcels reflecting a very poor item factor pattern. Thus it can be seen that radial parcels *per se* do not produce any startling revelations that cannot be revealed by careful item factor analysis.

Radial parcelling, therefore, is viewed as a method of examining data so as to obtain from them the most commonality among variables. For example, if any exploratory analysis is undertaken of some set of data, it is advised to item factor the data continuously until the researcher is reasonably satisfied that the items load consistently upon the same factors. Having achieved this, radial parcelling would then be undertaken to assess the best possible structure for the variables. If necessary, Dwyer's extension analysis will ultimately be undertaken in the case of mixed item parcels. However, the accuracy of the extension estimation procedure is, as yet, unknown. This whole procedure is what Cattell has often referred to as progressive rectification. Of course, if the item factor solution is already accounting for upwards of 60% of the solution variance, then little might be gained from parcel analysis. However, there are not many such item factor solutions reported accounting for this proportion of variance. Given the clarity and replicability of item factor solutions for the data presented here, the variance accounted for by these solutions is relatively low ($\sim$21%). It is this type of solution (accounting for relatively little variance) which is most likely to benefit from parcelling. In addition, for small samples of data, the results above indicate that the rescoring of the data using a set of 'master parcels' will offset statistical measurement error due to the low number of observations. Also, the resultant number of variables to be factored is now at least one half of the original set. Thus, a simple way now exists to maintain a factorial check on the structures of test instruments without having to resort to large samples.

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