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Confirmatory factor analysis of the motor section of the UPDRS

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Introduction

This document is a detailed numerical report on the results of a search for a confirmatory factor analysis of the Motor Examination section of the Unified Parkinson’s Disease Rating Scale – UPDRS (Fahn and Elton, 1987). The analyses were carried out at the request of Dr. Glenn T. Stebbins and Sue Leurgans both of the Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois. Neither of the first authors of this report is trained in medicine so that the descriptions and interpretation will be primarily structural and not substantive. Wherever, we venture to make medical interpretational comments such comments should be seen as provisional until certified by our medically trained co-authors.

Aim

The central question addressed in this report is the following “Is it possible to find a common factorial structure for the three groups?" The idea behind this question is to describe within a common framework the differences between the three groups in their relationships between the items of the Motor Examination section of the UPDRS. A possible side effect of this question is that the model found to describe the three groups simultaneously might not necessarily be the most economical description for each group separately. The analyses will be guided by the results obtained by Stebbins and Goetz (1998) for the On-group.

Method

Data

Under the direction of Dr. Stebbins data were collected with the Motor Examination section for three groups of subjects: (1) 294 Parkinson’s disease subjects on medication while the medication is working well – On-group, (2) 200 Parkinson’s disease subjects on medication during an “off” time when medication is not helping them – Off group, and (3) 175 subjects with Progressive Supranuclear Palsy – PSP group.

Materials

The Motor Examination section consisted of the items which could be scored from 0 (normal) to 4 (terrible) and they are listed in abbreviated form in Table 1, while detailed descriptions taken from *http://www.mssm.edu/neurology/wemove/pdrscale.html* are contained in Appendix A.

Table 1 Descriptive information on the distribution of the variables for all three groups. Strongly deviating values have been printed in bold.

			On-group				Off-group				PSP-group		
		Mean	St. dev.	Skew ness	Kurto sis	Mean	St. dev.	Skew ness	Kurto sis	Mean	St. dev.	Skew ness	Kurtosis
1	Speech	1.40	.91	.37	-.06	1.72	.93	.33	.03	2.45	1.00	.07	-.92
2	Facial Expression	1.55	.89	.44	.11	2.15	.85	.06	-.25	2.67	1.02	-.33	-.58
3	Tremor at rest: H/N	.48	.73	1.42	1.45	.360	.76	2.24	**4.71**	**.02**	.24	**11.69**	**142.73**
4	RUE	.81	.93	.75	-.52	1.01	1.19	.80	-.58	**.10**	.42	**4.56**	**22.08**
5	RLE	.55	.76	1.15	.35	.65	1.01	1.28	.44	**.03**	.21	**6.86**	**51.53**
6	LUE	.69	.87	.91	-.38	.94	1.19	1.08	.10	**.10**	.41	**4.72**	**23.60**
7	LLE	.52	.73	1.24	.74	.65	1.10	1.60	1.52	**.03**	.25	**10.47**	**118.78**
8	Postural tremor R	.66	.68	.87	1.33	.93	.87	.69	.02	.34	.55	1.40	1.02
9	L	64	.63	.46	-.66	.98	.95	.69	-.28	.34	.57	1.65	2.69
10	Rigidity H/N	1.24	.80	.19	-.00	1.89	1.07	.03	-.55	2.40	1.19	-.22	-.91
11	RUE	1.68	.78	-.24	.16	1.84	.90	-.21	.07	1.70	.98	.30	.11
12	RLE	1.36	.80	.29	.29	1.58	1.06	.01	-.74	1.34	1.01	.35	-.69
13	LUE	1.63	.78	.26	.54	1.96	.91	-.25	-.01	1.61	1.03	.23	-.25
14	LLE	1.39	.82	.44	.60	1.68	1.11	.07	-.76	1.37	1.04	.26	-.83
15	Finger taps R	1.58	.78	.34	.55	2.20	.93	.17	-.46	1.54	1.04	.42	-.37
16	L	1.59	.82	.69	1.05	2.38	1.01	-.28	-.32	1.69	1.12	.40	-.59
17	Hand movements R	1.50	.83	.58	.57	1.72	.94	.48	-.04	1.59	.98	.61	-.04
18	L	1.51	.84	.79	1.07	1.98	1.00	.08	-.50	1.65	1.02	.55	-.22
19	Rapid Alt. Mov. R	1.45	.82	.35	.35	1.85	.97	.20	-.29	1.66	1.06	.43	-.32
20	L	1.50	.80	.71	1.14	2.21	1.04	-.16	-.48	1.76	1.15	.53	-.50
21	Leg agility R	1.44	.83	73	.91	2.05	1.03	.02	-.64	1.57	1.13	.42	-.47
22	L	1.50	.85	.81	1.03	2.25	1.03	-.17	-.55	1.72	1.18	.37	-.59
23	Arise from chair	1.23	1.05	1.07	.89	1.70	1.45	.33	-1.28	2.40	1.24	-.11	-1.20
24	Posture	1.35	.86	.67	.66	1.75	1.10	.26	-.56	1.47	1.14	.31	-.61
25	Gait	1.28	.91	.66	.29	2.12	1.13	.02	-.71	2.60	1.14	-.42	-.63
26	Postural stability	.89	1.01	1.17	.96	1.95	1.23	.09	-.97	2.67	1.12	-.28	-.93
27	Body bradykinesia	1.45	.97	.73	.14	2.46	1.05	-.15	-.69	2.39	.98	-.26	-.51

The numerical information in this table will be discussed later.

Analysis methods

After describing the general information on the data per group, as well as indicating some troublesome aspects of some variables, we will first report principal component analyses for each of the groups, then we discuss the search for a common confirmatory factor analysis model. With the model found, we have carried out several tests to establish whether certain factors were similar to one another and finally we pay some attention to the mean structures as well.

Principal component analyses

We will present the results of obliquely transformed component solutions for each group, and discuss the differences and similarities between these solutions. The analyses were carried with the software package SPSS Version 8 (SPSS, 1998). The oblique solutions were the starting point for confirmatory factor analyses.

Confirmatory factor analysis and its relation with principal component analysis

Principal component analysis is essentially a data reduction technique meant to find a number of new independent variables composed of the original ones so that the new ones explain as much variance as possible from the original ones. Another way of expression this is to say that one attempts to project the original variables into a lower dimensional space with as little loss of information as possible. With an oblique transformation like oblimin, one seeks to find relatively simple directions in this low dimensional space which are hopefully easier to interpret than the orthogonal components which were selected for maximum explained variance.

Factor analysis has a different aim, i.e. to seek those latent, underlying variables which can reconstruct the covariance or correlation matrix of the original variables. The idea is that the relationships between the observed variables is due to a number of underlying variables and after the influence of these variables has been partialled out, only two things remain. One is variance specific to each variable unconnected with the other variables and error covariance, i.e. relationships between the observed variables which is not explained by the latent variables and which is assumed to be due to random error.

The factor model only really makes sense if the latent variables influence some but not all observed variables; otherwise one cannot really speak of a "real" model for the observed variables and their relationships. Factor analysis in which some latent variables influence some observed variables but not all of them is generally referred to as confirmatory factor analysis because the model is restricted and given enough restrictions can be tested to see whether it fits the data or not. Thus confirmatory factor analysis takes us from the realm of exploratory analysis to that of model fitting. A certain amount of exploration is still in evidence as finding a model is a kind of exploratory undertaking, and the significance tests should not be taken in too absolute a sense as the significance level is influenced by multiple testing.

The confirmatory factor models used in this report have their origin in exploratory analysis and were adapted to find a suitable fitting model. One special aspect was that it was not only necessary to find a factor model which fitted one single covariance matrix, but this model had to fit three different covariance matrices at the same time. This was not always straightforward due to complicated and different patterns of similarity and differences between the factors for the three groups. Moreover, it turned out to be necessary for model fitting to assume that the left and right variants of the observed variables, for instance finger tapping, had correlated errors which is indicative of a certain amount of so-called method variance. This variance is due to the fact that the same kind of phenomenon is measured twice, once for the left-hand side of the body and once for the right-hand side of it.

In this present study, it was not straightforward to find an adequately fitting model, primarily due to differences between the Palsy and Parkinson’s groups, and some more technical aspects of the data, which we will discuss later. The effect of this was that there were several plausible models containing more or less parameters and with different interpretational details. The central results, however, were fairly robust.

The confirmatory factor analyses were estimated via the structural equation modelling program LISREL 8 developed by Jöreskog and Sörbom (1996) and distributed by Scientific Software International. Appendix E contains the LISREL scripts used to estimate the parameters of (some of) the models.

Results

Distributions and their properties

Variances. The main results of the distributions were given in Table 1. One of the most noticeable features in the table is the lack of variance for the tremor-at-rest variables for the Palsy group. This lack of variance is also evident in the extremely high values for the skewness and kurtosis of their distributions. Therefore, their distributions deviate very far from the Gaussian one and invalidate or hamper most analyses with these variables for this group. We will refer and comment on this situation later. The distributions of two of the variables as well as the subjects of the PSP-group, which had non-zero values on the tremor-at-rest variables, are given in Appendix B.

Skewness and kurtosis. Clearly, there are other skew distributions with a high kurtosis, but on the whole this is probably not very harmful for the analyses to be carried out. The basis for this belief is that all scales only have 5 different scale points so that values cannot really run out of hand. The high skewness and kurtosis is generally the result of a concentration of values at the lower end, indicating that few of the subjects deviate from the normal on those variables.

Mahalanobis distances. Another worry might be that some subjects have very unusual patterns for their groups. One way to investigate is to calculate their Mahalanobis distance from the multivariate mean. In Appendix B some information is presented for the Mahalanobis distance of the three groups, from which it is clear that there are some subjects in the PSP-group, which are very different from the other subjects in their group. This is probably related to the fact that they show some tremor-at-rest which is relatively unusual for persons with supranuclear palsy. In the other groups no very serious outliers could be discerned. At the moment we have left these subjects in the analysis, but at a later stage one could decide to eliminate them sample because it turns out from their raw data that their patterns are indeed unusual.

Discriminant analysis. Another way to evaluate group membership is to perform a discriminant analysis with group membership as categorical criterion variable and the 27 variables as predictors. The two discriminant axes are able to make a 74.3% correct classification with a cross-validation correct classification of 73.2%, which seems reasonable. On the other hand Figure 2 also shows that there are some subjects whose classification should be checked or at least it should be inspected to establish why they are so different from the other subjects in their group. Another way of looking at this plot is to observe that the measurements in themselves are insufficient to make an unequivocal allocation of subjects to one of the three disease groups. Overall from a statistical point of view the classification might be acceptable, but it is not quite accurate enough for clinical decisions. An interesting question might to investigate which additional variables could be used to improve the allocation. A further observation is that the variables are also insufficient to allocate patients on the basis of their scores to the On or Off group. Of course an alternative use for the plot might be to single out those subjects for which medicine is not working or subjects for which the Off period is not really affecting them all that much judging from their location in the On territory.

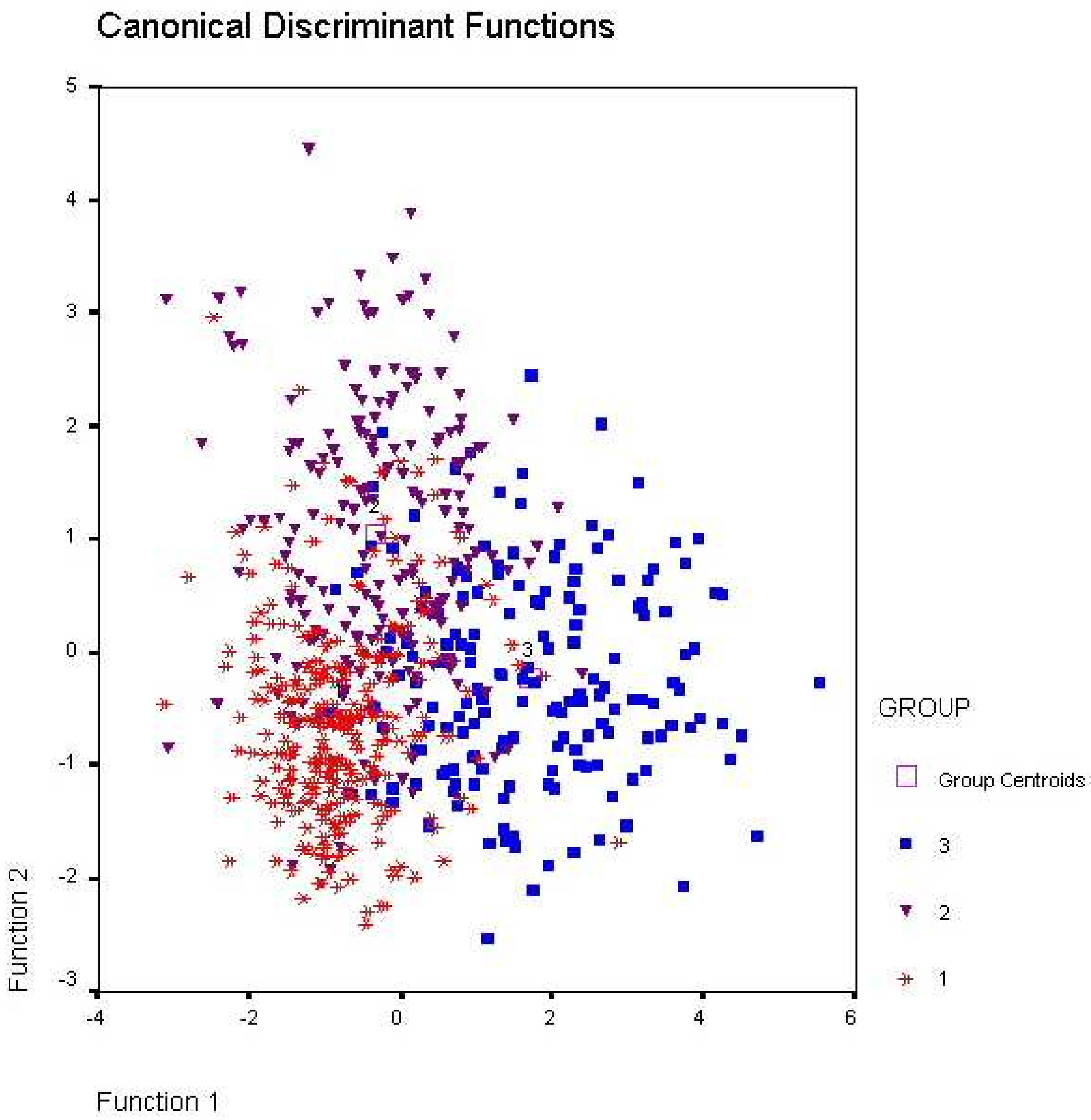

Figure 2 Discriminant analysis for the three groups of subjects (1 = On-subjects; 2 = Off-subjects; 3 = PSP subjects) with all 27 variables are predictors.

Separate component analyses

In Stebbins and Goetz (1998) the oblimin transformed six component[1] solution for the On-subjects is presented. We have performed similar six component solutions for each of the groups, the results of which are presented in Tables 2, 3 and 4. Note by the way that Table 1 in Stebbins and Goetz (1998, p. 635) incorrectly mentions the approximate percent variances. The values mentioned refer to the unrotated and orthogonal principal components. After an oblique transformation such independent explained variances are no longer available because of the correlations between the components. The term loadings in this “pattern matrix” is also slightly ambiguous because the values in the table are no longer variable-component correlations, but partial regression coefficients of the variables on the correlated components. The variable-component correlations are contained in the “structure matrix” which was not shown.

[1] In this report we will make an explicit distinction between (oblique) *components* resulting from a principal component analysis and *factors* resulting from a modelling procedure with confirmatory factor analysis.

Table 3 Oblique components for On-group

		1 Axial functioning	2 Tremor at rest	3 Rigidity	4 Brady-kinesia Left	5 Brady-kinesia Right	6 Postural Tremor	R^2
1	Speech	**.788**						.656
2	Facial Expression	**.719**						.618
3	Tremor at rest: H/N		**.816**					.717
4	RUE		**.809**			.221		.761
5	RLE		**.902**					.823
6	LUE		**.844**					.775
7	LLE		**.913**					.859
8	Postural tremor R						**.842**	.854
9	L						**.938**	.896
10	Rigidity H/N	.241		**.624**				.670
11	RUE			**.647**	-.215	.386		.754
12	RLE			**.796**		.205		.846
13	LUE			**.793**	.286			.786
14	LLE			**.855**				.885
15	Finger taps R					**.715**		.795
16	L				**.696**			.791
17	Hand movements R					**.770**		.846
18	L				**.697**	.228		.824
19	Rapid Alt. Mov. R					**.725**		.804
20	L			.238	**.636**			.789
21	Leg agility R	.223			.221	**.683**		.837
22	L	.282			**.653**	.223		.771
23	Arise from chair	**.775**						.731
24	Posture	**.756**						.725
25	Gait	**.909**						.814
26	Postural stability	**.832**						.719
27	Body bradykinesia	**.764**						.732

Note: Percentage total variance explained = 78%

Correlations among components

		1 Axial Functioning	2 Tremor at rest	3 Rigidity	4 Brady-kinesia Left	5 Brady-kinesia Right	6 Postural Tremor
1	Axial functioning						
2	Tremor at rest	.176					
3	Rigidity	**.499**	.238				
4	Bradykinesia Left	**.431**	.105	.324			
5	Bradykinesia Right	**.474**	.198	**.398**	.251		
6	Postural Tremor	.237	**.353**	.300	.097	.184	

Table 4 Oblique components for Off-group

		1 Axial Functioning	2 Tremor at rest	3 Rigidity	4 Brady-kinesia Left	5 Brady-kinesia Right	6 Postural Tremor	R^2
1	Speech	**.535**						.433
2	Facial Expression	.445		.201				.496
3	Tremor at rest: H/N		**.747**					.589
4	RUE		**.669**			.223	.250	.680
5	RLE		**.793**					.622
6	LUE		**.725**				.235	.732
7	LLE		**.844**					.749
8	Postural tremor R						**.875**	.857
9	L						**.805**	.803
10	Rigidity H/N			**.716**				.611
11	RUE			**.733**		.268		.661
12	RLE			**.854**				.793
13	LUE		.202	**.632**	.485			.740
14	LLE			**.836**				.789
15	Finger taps R				.218	**.691**		.676
16	L				**.822**			.782
17	Hand movements R				.239	**.736**		.772
18	L				**.841**			.844
19	Rapid Alt. Mov. R				.200	**.754**		.727
20	L		-.215		**.694**		.229	710
21	Leg agility R	.258				**.629**		.607
22	L	.355			.404	.223		.580
23	Arise from chair	**.848**						.732
24	Posture	**.815**						.708
25	Gait	**.901**						.755
26	Postural stability	**.852**						.685
27	Body bradykinesia	**.746**						.680

Note: Percentage total variance explained = 70%

Correlations among components

		1 Axial Functioning	2 Tremor at rest	3 Rigidity	4 Brady-kinesia Left	5 Brady-kinesia Right	6 Postural Tremor
1	Axial functioning						
2	Tremor at rest	.037					
3	Rigidity	.332	.096				
4	Bradykinesia Left	**.350**	.064	.284			
5	Bradykinesia Right	.320	.088	.259	.291		
6	Postural Tremor	.006	.329	.076	.083	.090	

Table 5 Oblique components for PSP-group

		1	2	3	4/5	6	R^2
		Axial functioning	Tremor at rest	Rigidity	Brady-kinesia R&L	Postural Tremor	
1	Speech	**.628**					.451
2	Facial Expression	**.590**		.336			.490
3	Tremor at rest: H/N						**.135**
4	RUE		**.638**				.539
5	RLE		**.600**	.216			.424
6	LUE		**.896**				.842
7	LLE		**.844**				.704
8	Postural tremor R					**.897**	.796
9	L	.468				**.874**	.765
10	Rigidity H/N			.486			.510
11	RUE			**.692**			.631
12	RLE			**.781**			.778
13	LUE			**.741**			.704
14	LLE			**.792**			.768
15	Finger taps R				**.853**		.722
16	L				**.871**		.720
17	Hand movements R				**.831**		.780
18	L				**.802**		.758
19	Rapid Alt. Mov. R				**.781**		.721
20	L				**.769**		.708
21	Leg agility R				**.728**		.657
22	L				**.704**		.623
23	Arise from chair	**.738**			.249		.702
24	Posture	.311			.260		**.241**
25	Gait	**.864**					.718
26	Postural stability	**.812**					.695
27	Body bradykinesia	**.616**					.580

Note: Percentage total variance explained = 64%

Correlations among components

		1	2	3	4/5	6
		Axial functioning	Tremor at rest	Rigidity	Brady-kinesia R&L	Postural Tremor
1	Axial functioning					
2	Tremor at rest	-.117				
3	Rigidity	.270	.053			
4/5	Bradykinesia R&L	.311	.050	**.419**		
6	Postural Tremor	.039	.123	-.026	-.025	

From the above three oblique component solutions we can see that there are both similarities and differences between the three groups with stronger similarity between the Parkinson's groups than between them and the palsy group. In particular, the left-right split, which is present in the former, is not present in the latter. Incidentally, a sixth component for the palsy subjects gives a component with only sizeable coefficients for Tremor at rest in head and neck and Posture. The main difference between the On-group and the Off-group is the correlations between the components that are higher for the On-group. In a sense the simplicity of the solutions is deceptive because all coefficient smaller than .200 have been eliminated. The effect of this is that the orientations of the components is not quite the same even though it might look this way by leaving out the small coefficients.

Confirmatory Factor Analyses: General model

To put the comparisons of the variable structure of the three groups on a more certain footing we have performed a series of confirmatory factor analyses to investigate the common parts and the differences within a unified framework. As we have seen above there are clear differences in the component structures finding a common factor model was not a straightforward job. The basic aim was to find one factor model for all groups, in which only the parameter estimates were different, so that similarities and differences could be expressed through differences in the values of the estimated parameters.

In a sense modelling a single factor structure for all groups was a bit artificial, because we had to accommodate the fact that the PSP-group had no tremor-at-rest factor, and this group only had a single Bradykinesia factor. We have solved this by specifying a special general bradykinesia factor together with two (orthogonal) left and right bradykinesia factors. The latter should have very little variance in the PSP-group. In addition, we fixed the parameters of the tremor-at-rest factor for the PSP-group so that the factor coefficients play no role in the estimation of the entire model. Due to the lack of variability in the original scores this factor should also have very little variability in the PSP-group.

To get proper fitting factor models, scores obtained in a similar manner for the right and left side of the body had to have correlated error terms. These correlated error terms indicate that there is a comparatively higher correlation between these variables than could be explained from their coefficients on the common factors. For example, the left and right finger tapping variables had an additional covariation of .12, .16, and .24 in the three groups respectively, indicating that these measures were more correlated than could be modelled by the three bradykinesia factors. One might call this method variance, some people are simply better and others worse at this kind of exercise, independent of other influences.

A final characteristic of the factor model is that we decided to split on purely heuristic grounds the Facial and Speech variables from the Gait, Posture, Postural stability and general bradykinesia, calling the former (for lack of a better term) facial control. This is not statistically very important but it seemed to us that this would make more substantive sense

Below we first present the factor solutions for all three groups, the values of the correlated error variances , and the variances and the correlations between factors (in the model fitting, covariances are estimated but for interpretational purposes correlations are easier – f or completeness sake the covariance matrices are given in Appendix C).

The overall model for all three groups together has a chi-square of 1761 with 872 df, which gives an acceptable lack of fit per degree of freedom (2.0) .The RMSEA is 0.067, which is generally considered a reasonable fit (see Browne and Cudeck, 1992). The contributions of the groups to the overall chi-square are 707, 536 and 518, or 2.4, 2.7 and 3.0 per subject showing that comparatively per subject in the group the fit was best for the On-group and worst for the PSP-group, but in addition that these differences were not large. In other words, the model fitted reasonably for all groups and overall. Which, considering the discrepancies noted above, is quite pleasing. This means that we can use the parameters to describe what the differences are within a unified framework.

Table 6 Factor loadings for ON-group - based on a simultaneous analysis for all groups

		1a	1b	2	3	4	5/6	7	8	
		Facial Control	Axial Functioning	Tremor at rest	Postural Tremor	Rigidity	Bradykinesia General	Brady-kinesia Right	Brady-kinesia Left	Residual variance
1	Speech	1								.20
2	Facial Expression	0.96								.21
3	Tremor at rest: H/N			1						.15
4	RUE			1.08						.42
5	RLE			1.00						.21
6	LUE			1.14						.27
7	LLE			1.05						.13
8	Postural tremor R				1					.06
9	L				0.82					.14
10	Rigidity H/N					1				.21
11	RUE					.0.86				.30
12	RLE					1.01				.22
13	LUE					0.86				.30
14	LLE					1.05				.20
15	Finger taps R						1	1		.17
16	L						1.04		1	.21
17	Hand movements R						1.07	1.14		.12
18	L						1.10		1.26	.13
19	Rapid Alt. Mov. R						1.05	1.10		.16
20	L						1.08		1.07	.14
21	Leg agility R						1.11	0.93		.18
22	L						1.07		0.72	.28
23	Arise from chair		1							.32
24	Posture		0.82							.22
25	Gait		0.92							.16
26	Postural stability		0.93							.35
27	Body bradykinesia		0.88							.33

Note: N = 294; Contribution to Chi-Square = 707.15

Residual covariations

	Right Up/Low	Left Up/Low	Upper Right/Left	Lower Right/Left	Right/Left
Tremor at rest	.11	.04	.11	.08	
Rigidity	.08	.10	.06	.12	
Finger taps					.12
Hand movements					.11
Rapid Alt. Mov.					.08
Leg agility					.13

Variances of Factors (Diagonal) and Correlations among Factors (Off-diagonal)-- On-Group

		1a	1b	2	3	4	5/6	5	6
		Facial Control	Axial Functioning	Tremor at rest	Postural Tremor	Rigidity	Brady-kinesia General	Brady-kinesia Right	Brady-kinesia Left
1a	Facial Control	(0.63)							
1b	Axial functioning	**.78**	(0.79)						
2	Tremor at rest	.24	.24	(0.37)					
3	Postural Tremor	.28	.31	.51	(0.39)				
4	Rigidity	.65	.69	.38	.45	(0.42)			
5/6	Bradykinesia General	.71	**.83**	.33	.35	**.83**	(0.32)		
5	Bradykinesia Right	0	0	0	0	0	0	(0.13)	
6	Bradykinesia Left	0	0	0	0	0	0	0	(0.12)

Table 7 Factor loadings for OFF-group - based on a simultaneous analysis for all groups

		1a Facial Control	1b Axial Functioning	2 Tremor at rest	3 Postural Tremor	4 Rigidity	5/6 Bradykinesia General	7 Brady-kinesia Right	8 Brady-kinesia Left	Residual variance
1	Speech	1								.42
2	Facial Expression	1.03								.26
3	Tremor at rest: H/N			1						.31
4	RUE			1.79						.57
5	RLE			1.12						.69
6	LUE			1.88						.48
7	LLE			1.45						.67
8	Postural tremor R				1					.28
9	L				1.14					.27
10	Rigidity H/N					1				.54
11	RUE					0.75				.48
12	RLE					1.05				.46
13	LUE					0.71				.52
14	LLE					1.15				.47
15	Finger taps R						1	1		.34
16	L						1.10		1	.36
17	Hand movements R						1.05	1.07		.25
18	L						1.13		1.26	.17
19	Rapid Alt. Mov. R						0.89	1.20		.41
20	L						1.12		0.92	.44
21	Leg agility R						0.97	0.98		.59
22	L						1.32		0.27	.47
23	Arise from chair		1							.56
24	Posture		0.69							.46
25	Gait		0.76							.37
26	Postural stability		0.78							.56
27	Body bradykinesia		0.66							.41

Note: N = 200; Contribution to Chi-Square = 536.38

Residual covariations

	Right Up/Low	Left Up/Low	Upper Right/Left	Lower Right/Left	Right/Left
Tremor at rest	.10	.21	-.03	.28	
Rigidity	.07	.10	.20	.26	
Finger taps					.16
Hand movements					.18
Rapid Alt. Mov.					.22
Leg agility					.34

Variances of Factors (Diagonal) and Correlations among Factors (Off-diagonal)-- Off-Group

		1a	1b	2	3	4	5/6	5	6
		Facial Control	Axial Functioning	Tremor at rest	Postural Tremor	Rigidity	Brady-kinesia General	Brady-kinesia Right	Brady-kinesia Left
1a	Facial Control	(0.44)							
1b	Axial functioning	.70	(1.55)						
2	Tremor at rest	.16	.02	(0.26)					
3	Postural Tremor	.12	.00	.65	(0.48)				
4	Rigidity	.60	.48	.09	.16	(0.59)			
5/6	Bradykinesia General	.73	.67	.17	.23	.61	(0.33)		
5	Bradykinesia Right	0	0	0	0	0	0	(0.19)	
6	Bradykinesia Left	0	0	0	0	0	0	0	(0.25)

Table 8 Factor loadings for Palsy-group - based on a simultaneous analysis for all groups

		1a	1b	2	3	4	5/6	7	8	
		Facial Control	Axial Functioning	Tremor at rest	Postural Tremor	Rigidity	Bradykinesia General	Brady-kinesia Right	Brady-kinesia Left	Residual variance
1	Speech	1								.49
2	Facial Expression	1.03								.49
3	Tremor at rest: H/N			1						.05
4	RUE			1						.16
5	RLE			1						.04
6	LUE			1						.14
7	LLE			1						.05
8	Postural tremor R				1					.08
9	L				1					.10
10	Rigidity H/N					1				1.07
11	RUE					1.18				.48
12	RLE					1.34				.41
13	LUE					1.37				.40
14	LLE					1.32				.46
15	Finger taps R						1	1		.35
16	L						1.04		1	.38
17	Hand movements R						1.05	1.35		.13
18	L						1.09		0.77	.18
19	Rapid Alt. Mov. R						1.05	1.17		.34
20	L						1.14		0.86	.35
21	Leg agility R						1.04	0.54		.60
22	L						1.06		0.38	.67
23	Arise from chair		1							.44
24	Posture		0.40							1.12
25	Gait		0.82							.58
26	Postural stability		0.81							.53
27	Body bradykinesia		0.65							.48

Note: N = 175; Contribution to Chi-Square = 517.86

Residual covariations

	Right Up/Low	Left Up/Low	Upper Right/Left	Lower Right/Left	Right/Left
Tremor at rest	0.00	0.05	0.08	0.01	
Rigidity	0.05	0.03	0.15	0.31	
Finger taps					0.24
Hand movements					0.11
Rapid Alt. Mov.					0.25
Leg agility					0.48

Variances of Factors (Diagonal) and Correlations among Factors (Off-diagonal)-- PSP-Group

		1a	1b	2	3	4	5/6	5	6
		Facial control	Axial Functioning	Tremor at rest	Postural Tremor	Rigidity	Brady-kinesia General	Brady-kinesia Right	Brady-kinesia Left
1a	Facial control	(0.52)							
1b	Axial functioning	.70	(1.10)						
2	Tremor at rest	-.18	-.23	(0.01)					
3	Postural Tremor	-.04	-.03	.23	(0.22)				
4	Rigidity	.52	.46	.05	-.01	(0.35)			
5/6	Bradykinesia General	.43	.51	.01	-.12	.76	(0.61)		
5	Bradykinesia Right	0	0	0	0	0	0	(0.09)	
6	Bradykinesia Left	0	0	0	0	0	0	0	(0.22)

Table
Goodness of Fit Statistics (as supplied by LISREL8) for Basic CFA model for all three groups

Minimum Fit Function Value	2.64
Population Discrepancy Function Value (F0)	1.31
Root Mean Square Error of Approximation (RMSEA)	**0.067**
Expected Cross-Validation Index (ECVI)	3.41
ECVI for saturated Model	1.14
ECVI for Independence Model	22.41
Chi-Square for Independence Model with 1053 Degrees of Freedom	**14873.55**
Independence AIC	15035.55
Model AIC	2269.68
Saturated AIC	2268.00
Independence CAIC	15481.52
Model CAIC	3712.20
Saturated CAIC	8511.56
Root Mean Square Residual (RMR)	0.077
Standardised RMR	**0.082**
Goodness of Fit Index (GFI)	0.83
Parsimony Goodness of Fit Index (PGFI)	1.91
Normed Fit Index (NFI)	0.88
Non-Normed Fit Index (NNFI)	**0.92**
Parsimony Normed Fit Index (PNFI)	0.73
Comparative Fit Index (CFI)	0.94
Incremental Fit Index (IFI)	0.94
Relative Fit Index (RFI)	0.86
Critical N (CN)	368.56

Confirmatory Factor Analyses: Model refinement

In this section we will discuss our attempts to test a series of hypotheses about the equality of factors between groups. Such tests are every time tests of the entire model across all three groups, but in each case a different restriction is placed on some aspect of the model. For instance, one such restriction was that the factor Axial functioning had the same coefficients in each of the three groups.

Differences in means

[An options to supplement the story is by presented a series of MANOVAs analysing the variables which load on a single factor in a single analysis to control the experiment-wise error rate. We also hope to look into the possibility of estimating the factor means and their differences between groups. This is the logical extension of the structural model. If one intends to work with the factors, one might as well use the means of the factors rather than the means of the original variables.]

Parkinson disease only: On-Group and Off- Group.

Factors as in Table 6 ParkReport1, except 1a and 1b together (=Axial). To create sensible models it is necessary to allow correlated errors between Facial and Speech, i.e. they are more correlated than can be captured in the general Axial factor.

Model[1]		χ^2	**df**	**RMSEA**	**95% Confidence Interval RMSEA**	**Comments**
Park1	no constraints; as Table 6 - 1 axial factor; 3 Bradykinesia	1278	586	.069		
Park2	Simplification: Bradykinesia - only correlated left and right factor; no general one	1318	592	.071	**.0645 - .0767**	**BASE MODEL**
Park3[2]	As Park2: Per factor **all** loadings equal	1578	634	.078		outside interval Park2; too simple
Park4	As Park2: Loadings On = Loadings Off	1377	613	.071		Simpler model than Park2
Park6	As Park4: Also Factor COVARIANCE matrices equal	1450	634	.072		Very simple; easy interpretation; **Preferred model**
Park7	As Park6: Also Error variances and error covariances equal	2497	674	.100		Rejected: Oversimplification

[1]The name of the model corresponds with out file names. They should be changed to something more sensible.
[2]It would have been possible to take the factors one by one and check whether there would be a good fitting model with equal loadings on that factors. We felt it was a bit too much after the fact and a fishing expedition. You might differ, though.
[Park5 was model Park4 with equal intercepts across groups, which was rejected in the same way as Park3. We prefer not to mention this as it unnecessarily complicates explanations.]

The result of the analyses is that a model with equal loadings and covariances between the factors is a reasonably fitting model which cannot be further simplified in a systematic and obvious manner without significant loss. It is always possible to let the model estimate additional individual parameters but without real serious theory for this, it seems to us that this would be bad policy and a fishing expedition.

I will not go into the contents of the factors, because that can be done together with the PSP group. First some structural comments on model Park4. The fact that both the loadings of the factors and their covariances are equal is rather satisfactory in a sense that being ON or OFF has no serious influence on the structure or relationships between the items of the questionnaire. In other words the differences show up in the *level* of the responses (a model with equal intercepts had to be rejected, so that the hypothesis referring to factor means could not be tested) and the mean structure is such that for the OFF group all means are larger except one case where it marginally smaller (see Table 1). The other difference is that especially the residual variances (and covariances to a much lesser extent) are larger for the

OFF group. As the most extreme case let us take Tremor at rest for the left lower extremities (RTLLE):

Variances	**ON**	**OFF**
Total (in the original covariance matrix)	0.54	1.21
Common (equal in Park6)	0.35	0.35
Specific (independently estimated in Park6)	0.12	0.69

Note: The variances do not add up, because of the complexity of the model

The model modification indices in model Park7 indicated that the change in the chi-square likelihood if the specific variances are allowed to be estimated is 130, which is very large as the modification index is roughly chi-square with 1 df. The result is thus that tremor variance specific to RTLLE is not the same in both groups. In fact the specific variances are systematically larger in the OFF group than the ON group for all items suggesting that taking patients off medicine enlarges the specific variability. Thus it is specific to an item (not related to the factor to which the item belongs) and it is different for the items as it cannot be accommodated in the common part (the model modification index in Park4 for estimating the common variance of RTLLE in each of the groups separately rather than jointly was only .11; compare this with 130!).

Parkinson & PSP.

Starting point is the Park2 model from the Parkinson only analyses.

		χ^2	df	RMSEA	95% Confidence Interval RMSEA	Comments
ParkPSP2	Same model as Park2 (BradyK -R and BradyK-L. Thus different from those in ParkReport1	--	--	--	--	**Empirically not identified**[1]
ParkPSP4	As ParkPSP2: Loadings On = Loadings Off = Loadings PSP[2]	1949	930	0.070	**0.065 - 0.075**	**Base Model.** acceptable fit
ParkPSP6	As ParkPSP4: Also Factor Correlation matrices equal	2376	972	0.081		Outside confidence limits ParkPSP4
ParkPSP6a	As ParkPSP6: in PSP all factor (co)variances related to the factor Tremor estimated rather than set equal to those of the PD groups.[3]	2049	966	0.073		Within confidence limits of ParkPSP4 **Preferred model**

[1]This model is empirically not identified, because very small to no variability in tremor at rest factor for the PSP group. A zero variance estimate implies that the loadings can become arbitrary large. The model did not converge.

[2]By fixing the loadings across groups, the (near null) factor variance just shaved past the abyss of zero factor variance (0.01) and non-identifiability.

[3]In the PSP group the model modification index of the factor variance for Tremor at Rest was large (70) indicating that the common value was not very accurate for this variance. Furthermore, also the same factor variances for the other groups were not small (On - 19 and OFF- 12). As it is known that Tremor at rest does not really occur in PSP (confirmed in Table 1), it was felt justified to have separate independent estimates for these parameters in the PSP group (ON and OFF estimates still equal to each other). One has to be careful with ad-hoc adaptations of this kind, but we felt this was justified. The largest model modification index in Park6a (47) implied that Gait and Postural Stability in the PSP group have more in common than one could model via the common factor they load on. Even though this might be considered an easily explainable phenomenon after the fact, we felt that this was taking us down the ad-hoc road too far. In particular, because such relationships were not formulated in advance, but only were thought off after the results had been inspected, and the modification index might have been the result of a statistical fluke. Furthermore, we already had a model which was well within the confidence bounds of the base model.

Conclusion of model search.

A very much simpler model than suggested in the ParkReport1 could be found using the knowledge of the Chicago experts. Note that the original model had a RMSEA of 0.067 (better than the present one), but that model contained a general and two specific orthogonal bradykinesia factors, and a split axial factor. The present model has two factors less and postulates equality of factor loadings and factor correlations and variances across groups, a very powerful interpretational gain. The most satisfying aspect was the ability to enforce the equality of the loading structure on all groups as well as the equality of factor correlations except for Tremor at Rest.

The differences between the groups thus show up in the means and in the specific variances and correlations over and above the common factors. And of course, the tremor at rest. With respect to the latter one might say that from the present data the lack of a tremor at rest factor or tremor at rest in general is the most distinguishing feature between the Parkinson and PSP groups in terms of structure.

Nature of the model (Parameter estimates)

Factor loadings for all groups jointly

		1	2	3	4	5	6	Specific Variances		
		Axial Functioning	Tremor at rest	Postural Tremor	Rigidity	Brady-kinesia Right	Brady-kinesia Left	ON	OFF	PSP
3	Tremor at rest: H/N		1					0.16	0.26	*0.05*
4	RUE		1.25					0.41	0.70	*0.15*
6	LUE		1.30					0.25	0.67	*0.13*
5	RLE		1.07					0.21	0.62	*0.04*
7	LLE		1.13					0.12	0.69	*0.05*
8	Postural tremor R			1				0.06	0.21	*0.02*
9	L			0.84				0.14	0.41	*0.16*
10	Rigidity H/N				1			0.22	0.64	**1.02**
11	RUE				0.88			0.30	0.47	0.52
13	LUE				0.92			0.29	0.46	0.51
12	RLE				1.06			0.21	0.56	0.43
14	LLE				1.11			0.18	0.59	0.46
17	Hand movements R					1.11		0.12	0.24	0.15
18	L						1.10	0.13	0.25	0.16
19	Rapid Alt. Mov. R					1.05		0.16	0.42	0.34
20	L						1.04	0.14	0.42	0.38
15	Finger taps R					1		0.17	0.36	0.36
16	L						1	0.20	0.35	0.42
21	Leg agility R					0.93		0.19	0.60	0.63
22	L						0.85	0.29	0.60	0.74
23	Arise from chair	1.28						0.32	0.66	0.49
26	Postural stability	1.10						0.35	0.60	0.60

25	Gait	1.09		0.16	0.41	0.65
27	Body bradykinesia	1		0.33	0.39	0.44
24	Posture	0.95		0.22	0.46	**1.12**
1	Speech	0.73		0.45	0.61	0.71
2	Facial Expression	0.70		0.44	0.47	0.76

Note: The order of the items has been rearranged to show some patterns more clearly.

All specific variances for the OFF-group are larger than those for the ON group; those for the PSP group except tremor at rest are generally closer to the OFF group that the ON. Notable high values for the PSP group are Posture and Head & Neck Rigidity.

Residual covariances

		Right Up/Low	Left Up/Low	Upper Right/Left	Lower Right/Left	Right/Left	Facial
Tremor at rest	ON	.11	.03	.10	.08		
	OFF	.07	.29	.09	.24		
	PSP	.00	.05	.07	.01		
Rigidity	ON	.08	.10	.07	.11		
	OFF	.08	.10	.16	.37		
	PSP	.06	.03	.22	.32		
Finger taps	ON					.11	
	OFF					.17	
	PSP					.26	
Hand movements	ON					.12	
	OFF					.17	
	PSP					.26	
Rapid Alt. Mov.	ON					.08	
	OFF					.21	
	PSP					.26	
Leg agility	ON					.15	
	OFF					.38	
	PSP					.51	
Speech	ON						.24
	OFF						.20
	PSP						.25

Note: Except for Tremor at Rest, the residual covariances between left and right are for the Palsy group generally higher than in the other two groups indicating less lateralisation in that group compared to the Parkinson groups. Note that this is particularly true for leg agility.

The residual covariances indicate what left/right or upper and lower extremities have in common that could not be captured in the common factors. Thus a high covariances between left and right indicates that the activity had a higher correlation than could be predicted on the basis of the common factors alone. It is comparable to the situation that some people are better at making multiple choice exams irrespective of the contents (math or languages) and ability, while some others are always worse at them again irrespective content and ability.

Variances of Factors (Diagonal) and Correlations among Factors (Off-diagonal)

		2 PD	3	1	4	5	6	2 PSP
		Tremor at rest	Postural Tremor	Axial Functioning	Rigidity	Brady-kinesia Right	Brady-kinesia Left	Tremor at Rest
2	Tremor at rest	(0.33)						**(0.01)**
3	Postural Tremor	0.19/**.52**	(0.40)					0.01/.13
1	Axial functioning	0.06/.13	0.07/.14	(0.61)				-0.01/-.13
4	Rigidity	0.10/.26	0.11/.26	0.32/**.62**	(0.44)			0.00/.00
5	Bradykinesia Right	0.09/.21	0.08/.17	0.34/**.60**	0.32/**.66**	(0.53)		0.00/.00
6	Bradykinesia Left	0.08/.18	0.07/.14	0.36/**.59**	0.35/**.68**	0.42/**.71**	(0.60)	0.00/.00

Note: Except last column: Standard errors between 0.02 and 0.05; t-statistics all larger than 2.76; in the cells the first number is the covariance, the second the correlation. In the paper the latter should be reported.

The factor covariance/correlation matrix shows (1)The need for separate estimates of the Tremor at rest correlations for the PD and PSP groups. (2)The factors form two blocks: (a) Tremor factors, i.e. tremor at rest and postural tremor; (b) Bradykinesia factors (correct name?) consisting of axial functioning, rigidity and left & right bradykinesia. There is only a low correlation between the two groups.

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