LINEAR AND NON-LINEAR MORPHOLOGY STRUCTURE MODELS

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LINEARNI IN NELINEARNI MODELI STRUKTURE MORFOLOGIJE

Abstract

All studies trying to find the structure of morphology till now used the linear correlation model. This work compares the classic linear approach with a non-linear one. A sample of 686 adult males was measured with 23 anthropometric measures. The obtained data was analysed with the SAS statistical package, using Hotelling's principal component factor analysis method (procedure PRINCOMP) and the MTV method of data transformation (procedure PRINQUAL). The linear and non-linear latent factor solutions (Kaiser-Guttman criterion was used for the number of factors) were rotated to an oblique solution with the PROMAX method. Comparison of the two solutions showed unexpectedly small differences. The latent structures are practically identical, the non-linear solution is somewhat cleaner and more in accord with the theoretical model. The question remains, however, if the same holds for younger or older males, females and other subspaces of the psychosomatic status.

Keywords: morphology, models, non-linearity, factor analysis, adults, males

Izvleček

Vse dosedanje študije o strukturi morfologije so bile osnovane na linearnem korelacijskem modelu. V tem delu primerjamo klasični linearni pristop z nelinearnim. Vzorec 686 odraslih moških je bil izmerjen s 23. antropometričnimi merami. Dobljene podatke smo analizirali s statističnim paketom SAS, uporabljajoč Hotellingovo metodo glavnih komponent (procedura PRINCOMP) in MTV metodo transformacije podatkov (procedura PRINQUAL). Linearno in nelinearno latentno faktorsko strukturo (število faktorjev je bilo določeno s Kaiser-Guttmanovim kriterijem) smo zavrteli v poševnokotno rešitev s PROMAX metodo. Primerjava obeh rešitev je pokazala nepričakovano majhne razlike. Latentni strukturi sta praktično enaki, nelinearna je malce čistejša in bolj v skladu s teoretičnim modelom. Ostaja pa vprašanje, če enako velja tudi za mlajše ali starejše moške, ženske in druge podprostore psihosomatičnega statusa.

Ključne besede: morfologija, model, nelinearnost, faktorska analiza, odrasli, moški

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Introduction

The characteristics of the body in connection with sports have been the object of interest for a long time. Research in the past went mainly in three directions: first, by comparing sportsmen of various sports with the general population and competitors of other sports; second, searching for distinct subgroups - morphologic types or somatotypes; and third, finding the latent structure of morphology. One the most comprehensive reviews of this research is given in the monograph »Struktura i razvoj morfoloških i motoričkih dimenzija omladine« (Structure and Development of Morphologic and Motor Dimensions of Youth) (12).

The theoretical model of morphology was conceptualised with four latent dimensions - longitudinal dimensionality, transversal dimensionality, voluminosity and subcutaneous fat. Research on general samples of the male population did not always confirm this model; sometimes the transversal factor did not appear (16) or joined with voluminosity (17). Transformation into image metrics or partialisation of social status did not give a different solution (10). Female samples showed very different solutions (9); a study on seventeen-year-old girls gave even six latent dimensions (2). Differing solutions were obtained also with samples of PE students (13, 14), the exception was a study on several university centres (students) in Yugoslavia, where the theoretical model was fully confirmed (11). The morphological structure of children usually changes with age, the four latent dimensions merge and separate in various periods, so that two-factor, as well as four factor solutions are known (18).

In light of this great instability of structure some authors warned of the problems of classical approaches and methods (3). Gredelj (7) for instance states that the obtained and theoretical structures differ too much for the measures to define human morphology well, he feels that the reason is the complexity of the anthropometric measures. A group of authors (6) criticises in their work the existent methods of computing »ideal weight« indices and proposes the quadratic polynomial regression model. This model gave better results on a sample of adult males than the classic approach. Polynomial regression was used also by another group of authors (5) in analysing changes in morphological structure between sixteen and twenty years of age. All this clearly shows a need for verifying one of the most basic suppositions in kinesiology till now - the linearity of correlation between variables and the linear factor structure model based on them.

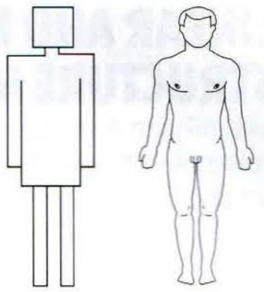

Figure 1: Linear and non-linear morphology structure models

Figure 1 clearly shows that the non-linear model resembles the human body much better, but finding that out from the gathered data is much more difficult. Interested readers, who would like to learn more about the problem theoretically or at the level of variable pairs, are referred to preceding studies by this author or sources given therein (1). In this article we shall present only some methods dealing with analysing latent structures (both the linear and non-linear component analysis methods are described in some detail in one of the reference books of the SAS statistical package -15).

Classic principal component analysis is a well-known method (8), therefore we shall not present it here. The procedure PRINQUAL is another matter, so here is some basic information. This procedure is a data transformation method and comes from the works of Kruskal & Shepard, Young, Takane & DeLeeuw , Winsberg & Ramsay. It can also be used as a generalisation of the classic method of principal components to non-numerical variables or for finding non-linear relations between numeric and non-numeric variables. It contains three methods for data transformation: MTV, MGV and MAC. All these attempt with certain transformations to reduce the rank of the covariance matrix of the transformed variables. The MAC method can be used only if all the correlations between the variables are positive, in our case this is not so, therefore this method cannot be used. Of the remaining two we chose MTV because it is based on the principal components model, which was the one used as the reference (comparison) model. We are fully aware of the still present controversies and possible doubts on the choice of the principal components method and not one of the factor analysis methods (for a comprehensive overview see Borg & Mohler - 4), it is a conscious choice. It is a fact namely, that practically without exception all the studies of the latent structure of morphology have been made using the principal components method. Since the purpose of this study is to compare the linear model with the non-linear one, the choice of principal components method was completely logical.

All the variables to be analysed are at least interval (for nominal and ordinal variables other transformations are used), therefore we can use linear or nonlinear transformations; optimal, such as splines and monotonous splines; or non-optimal, such as exponential, power, logarithmic and other functions. Since we have no previous information about which function best linearises a certain variable and because we are not sure that linear (splines with knots) or monotonous splines would lead to an optimal solution, we decided on non-monotonous splines without knots – polynom of order three (higher order polynoms could of course also have been used), the method SPLINE. This procedure is also iterative and is supposed to converge to a global optimal solution. There were no missing data in our case, so we did not have to decide how the programme should treat them.

Aim of the study

The principal purpose of this study was to find if the linear structure model (based on the Pearson correlation coefficient) describes sufficiently well the nature of the structure of morphology of adult males.

METHODS

Subject sample

The subject sample comprised of 686 adult males between 18 and 27 years of age, taken from the population of clinically healthy adult males, without manifest morphological or motor disorders - the base for sampling were all military draftees of the former Yugoslavia, serving in 1973/74. The sample was a two-level group sample with optimal allocation, more details are given in one of the articles of the research group (16).

Variable sample

The morphological sub-space is represented in this study by 23 anthropometric measures, chosen on the basis of the works of Pogačnik and Momirović and other authors. This sample includes all measures proposed in the International Biologic Programme, with the addition of the variable: hand length. A complete description of the measurement procedures is given in the previously cited work (16). All the variables are given by their original name in order to make comparison with the original study easier.

Longitudinal dimensionality:
(VISINA) - body height,
(DUZIRU) - arm length,
(DUZISA) - hand length,
(DUZINO) - leg length,
(DUZIST) - foot length;

Transversal dimensionality:
(BIAKRO) - shoulder width,
(DILAKT) - elbow diameter,
(DIRUZG) - wrist diameter,
(SIRISA) - hand width,
(BIKRIS) - pelvic width,
(DIKOLJ) - knee diameter,
(SISTOP) - foot width;

Voluminosity:
(TEZINA) - body weight,
(OPGRUD) - mean chest circumference,
(OPNADL) - circumference of relaxed upper arm,
(OPPODL) - lower arm circumference,
(OPNATK) - subgluteal thigh circumference,
(OPPOTK) - calf circumference.

Subcutaneous fat:
(NAPAZU) - chest skin-fold,
(NANALE) - back skin-fold,
(NATRBU) - stomach skin-fold,
(NANADL)- upper-arm skin-fold,
(NABPOT) - thigh skin-fold;

All the variables were measured three times, with the exception of skin-folds and mean chest circumference, which were measured six times.

Data analysis

The data was pre-processed at the Faculty of Physical Culture in Zagreb, Croatia. The original measured items were condensed to the first principal component, obtained from the covariance matrix of the original results, rescaled to antiimage metrics. This procedure enhanced the reliability of the data and also gives no information on the real distributional parameters of the variables, which was in this case mandatory.

Further analysis was performed at the Faculty of Sport - University of Ljubljana, on a PC with the statistical package SAS. The procedures PRINCOMP and PRINQUAL were used. The number of factors in the linear case was determined with the Kaiser-Guttman criterion and the initial solution rotated with the PROMAX method to an oblique solution. In the nonlinear factor procedure (PRINQUAL) the data was transformed by the MTV method using nonmonotonous splines without knots (method SPLINE) and the extracted number of factors fixed to the number of factors obtained in the linear solution to make comparison easier.

RESULTS

Analysis of factor structures usually starts by taking a look at the correlation matrix and trying to see if the correlation coefficients between variables of the same expected subspace are higher than their correlations with variables of other subspaces. This analysis was already made in a previous work by this author (1) which led to this one, since the non-linear correlations differed sufficiently from the linear ones, promising at least to some extent a somewhat changed structure. Consequently, we shall bypass this analysis of the correlation matrix here, interested readers are referred to the cited work.

In order to make a comparison of the classic method with the non-linear one simpler, we executed both in the SAS statistical package. The purpose of this work was mainly to ascertain the appropriateness of the linear model and not the »real structure« of morphology, therefore we did not attempt to analyse the data with various transformations, starting values or rotations - we just wish to find the concordance of the two models. To make comparison easier, we extracted the same number of latent dimensions in both cases, which might not be the best idea, since it is possible that the non-linear procedure would extract less latent dimensions – this has been left to further studies.

We present the eigen values and percentage of explained variance in the linear and the non-linear solution (after transformation of variables). Also the initial solution, the factor pattern matrix and the correlations between the factors are shown.

The first information on the suitability of the linear model in finding the latent structure of a space is the difference between the common variance of this

Table 1: Comparison of the linear and non-linear solution – basic data

	PRINQUAL MTV – iteration procedure			
Iteration	Average change	Largest change	Percentage of variance	Change in variance
1	0.03703	2.46444	**0.70288**	0.00000
2	0.01152	0.63491	0.70669	0.00381
3	0.00517	0.39289	0.70719	0.00050
4	0.00307	0.26465	0.70732	0.00013
5	0.00215	0.18624	0.70737	0.00005
27	0.00001	0.00054	**0.70744**	0.00000
	Factor1	Factor2	Factor3	Factor4
Eigen value	9.2349	4.0255	1.7680	1.1378
% variance	0.4015	0.1750	0.0769	0.0495
Eigen value	9.2627	4.0859	1.7938	1.1287
% variance	0.4027	0.1776	0.0780	0.0491

Legend: the upper two lines show the linear solution, lower two the non-linear one (first 4 factors)

space with the supposition of linearity of correlation between the variables and without it. In table 1 we can notice that the final value of the iterative process (0.70744) is only slightly higher than the starting value (0.70288). This means that the use of a non-linear model did not increase significantly the common variance. This does not necessarily mean that the latent structure will be the same, but it is a sign that the

Table 2: Comparison of linear and non-linear initial solution

	F1	F2	F3	F4	NF1	NF2	NF3	NF4
VISINA	0.68712	-0.52125	0.31174	0.05422	0.68336	-0.52319	0.31930	0.06136
DUZIRU	0.62577	-0.55516	0.34379	0.03122	0.62365	-0.55234	0.35081	0.04416
DUZISA	0.59277	-0.50170	-0.00051	0.34304	0.59062	-0.50304	0.01676	0.33912
DUZINO	0.63335	-0.50751	0.42842	0.09333	0.63076	-0.50409	0.43229	0.10461
DUZIST	0.66918	-0.50830	0.19826	0.11354	0.66690	-0.50634	0.21032	0.10343
BIAKRO	0.58761	-0.21629	-0.09452	-0.04762	0.58909	-0.22572	-0.07600	-0.07867
DILAKT	0.66310	-0.16182	-0.16027	0.05572	0.66545	-0.16387	-0.16919	0.07314
DIRUZG	0.39922	-0.27011	-0.36025	0.56516	0.36690	-0.27205	-0.41547	0.56863
SIRISA	0.60076	-0.22892	-0.33480	0.11295	0.59920	-0.23507	-0.32402	0.11428
BIKRIS	0.59875	-0.29955	0.19694	-0.38010	0.60119	-0.29406	0.20048	-0.36710
DIKOLJ	0.52876	0.04067	0.41173	-0.35053	0.55289	0.04131	0.40191	-0.35753
SISTOP	0.53366	-0.31212	-0.26389	-0.16372	0.53757	-0.33562	-0.27144	-0.15232
NAPAZU	0.47677	0.67921	0.29984	0.19347	0.48262	0.68588	0.28012	0.19127
NANALE	0.51494	0.68502	0.27903	0.09920	0.51699	0.68547	0.26521	0.07646
NATRBU	0.44477	0.53199	-0.05464	0.40418	0.45261	0.56363	0.00517	0.38878
NANADL	0.42481	0.59177	0.45183	0.07328	0.43112	0.60333	0.43136	0.07192
NAPOTK	0.42866	0.55690	0.23204	0.15119	0.43458	0.55849	0.22066	0.18020
TEZINA	0.95928	0.03989	-0.09266	-0.03704	0.95969	0.02711	-0.09911	-0.03400
OPGRUD	0.79054	0.15169	-0.21205	-0.17921	0.79089	0.13880	-0.22201	-0.18068
OPNADL	0.73223	0.43243	-0.29194	-0.14049	0.73560	0.42908	-0.29695	-0.14391
OPPODL	0.79005	0.21683	-0.29836	-0.21832	0.79030	0.21123	-0.30626	-0.22126
OPNATK	0.78872	0.34728	-0.20341	-0.09385	0.78848	0.34513	-0.20511	-0.08618
OPPOTK	0.74875	0.19414	-0.27829	-0.11998	0.74970	0.18405	-0.28849	-0.10249

Legend: F1 - F4 mark the factors of the linear model, NF1 - NF4 of the non-linear model

Table 3: Comparison of the pattern matrices of both models

	F1	F2	F3	F4	NF1	NF2	NF3	NF4
VISINA	0.00163	0.91232	0.03618	0.02656	-0.00329	0.91784	0.03219	0.01470
DUZIRU	-0.05299	0.92788	0.00258	-0.00853	-0.05909	0.93118	0.00305	-0.01501
DUZISA	0.03716	0.67592	0.00040	0.41712	0.03136	0.69251	0.02039	0.39728
DUZINO	-0.15850	0.97457	0.12826	0.01014	-0.16183	0.97715	0.12546	-0.00052
DUZIST	0.05552	0.82095	0.00461	0.12616	0.05928	0.82504	0.00265	0.09881
BIAKRO	0.42513	0.33142	-0.08803	0.05758	0.43299	0.34130	-0.09978	0.02015
DILAKT	0.46786	0.29806	-0.00976	0.18049	0.46845	0.29564	0.00617	0.19843
DIRUZG	0.13583	0.20072	0.02028	0.73451	0.16833	0.15598	0.01845	0.76070
SIRISA	0.53932	0.19511	-0.14935	0.30912	0.53130	0.20503	-0.12712	0.30953
BIKRIS	0.37875	0.55007	-0.15811	-0.36387	0.37498	0.54097	-0.16591	-0.35958
DIKOLJ	0.17940	0.45339	0.21775	-0.46683	0.20686	0.44794	0.18565	-0.48183
SISTOP	0.60812	0.22248	-0.34514	0.02538	0.61232	0.22731	-0.35326	0.04865
NAPAZU	-0.01229	0.01192	0.90968	0.01478	-0.00081	0.00683	0.90448	-0.00107
NANALE	0.09260	-0.00883	0.85496	-0.06311	0.10949	-0.01409	0.83198	-0.09847
NATRBU	0.12320	-0.12905	0.69891	0.37215	0.07922	-0.09041	0.77271	0.31544
NANADL	-0.11274	0.14046	0.85824	-0.15413	-0.09862	0.12911	0.84483	-0.17126
NAPOTK	0.02931	0.01482	0.74265	0.01335	0.01393	0.02387	0.75863	0.02729
TEZINA	0.67404	0.32583	0.19841	0.06325	0.67611	0.32783	0.19437	0.06248
OPGRUD	0.79566	0.05570	0.07493	-0.04465	0.80209	0.05052	0.06490	-0.04098
OPNADL	0.85222	-0.21611	0.23210	-0.01055	0.85371	-0.22020	0.23758	-0.01104
OPPODL	0.90940	-0.06205	0.04385	-0.05309	0.91493	-0.07210	0.04163	-0.04971
OPNATK	0.76093	-0.05636	0.26942	0.01001	0.75146	-0.05680	0.28175	0.01440
OPPOTK	0.79795	-0.03089	0.08769	0.03059	0.79185	-0.03221	0.09688	0.05297

Legend: values in bold show the factor-defining variables and the underlined values those where the greatest differences between the two models exist

Table 4: Comparison between the factor correlation matrices of both models

	F1	F2	F3	F4	NF1	NF2	NF3	NF4
	1.00000	0.44133	0.42928	0.13677	1.00000	0.44727	0.42922	0.10263
	0.44133	1.00000	0.04753	0.11015	0.44727	1.00000	0.04883	0.10353
	0.42928	0.04753	1.00000	-0.12478	0.42922	0.04883	1.00000	-0.15562
	0.13677	0.11015	-0.12478	1.00000	0.10263	0.10353	-0.15562	1.00000

linear model is not too bad (in this case). A similar situation can be seen from the eigen values and the percentage of explained variance of the individual factors – in both cases we have the solution given by four latent dimensions, if we use the Kaiser-Guttman criterion ($l > 1$). The eigen values and explained variance in the non-linear model (after the optimal transformation of the original variables) are only slightly higher than in the linear model. Let us see what happened with the latent structure of morphology.

A comparison of both orthogonal solutions (table 2) shows unexpectedly small differences, the largest difference in the projections on the first principal component is only 0.03232 (wrist diameter) and in other factors 0.05522 (same variable). The latent structures are practically identical, without doubt the same variables define the latent dimensions before and after transformation. An orthogonal solution is not the best one in our case, since we know that human characteristics, properties and abilities are inter-correlated, therefore we usually perform some kind of oblique rotation where the latent space allows also correlations between the factors. In our case we used the PROMAX rotation, only the pattern matrix is presented since the possible differences between the linear and non-linear model will be there more evident than in the structure matrix.

It is quite obvious that no large differences exist between the two models also in the obliquely rotated factor solution (table 3). The same variables again define the factors, maybe we could say that the non-linear structure is somewhat »cleaner« since the projections are a little higher. The first latent dimension is a combination of voluminosity (circumferences and body weight) and transversal dimensionality (diameters), the second is longitudinal dimensionality and the third a very clear component of subcutaneous fat. The existence of the fourth dimension is quite questionable, since it is actually defined by just one variable (wrist diameter) and could be proclaimed a »single« factor even if it does contain some »addition« of transversal dimensionality (knee diameter, pelvic width and hand width).

Differences can be noted in just three variables: wrist diameter, knee diameter and stomach skin fold; which is not surprising since these variables are precisely the ones that had the most non-linear relations with the others (1). If we take a closer look at what happened, we see that the variable wrist diameter migrated from the second latent component (longitudinal dimensionality) to the first (voluminosity) and the fourth (transversal dimensionality), which is more logical since theory puts it there. The same thing happened with knee diameter and the variable stomach skin fold migrated from all the other components to the third (subcutaneous fat) where it belongs. We can therefore say that the latent structure under the non-linear model is practically identical to that under the linear model, only that it is even more in accord with the theoretical model.

Finally, let us look also at the correlations between the components (table 4), showing the association between the latent dimensions. The only difference we can see is the correlation of the fourth component with the others. The strength of association with the first and second weakened, while it increased with the third.

DISCUSSION

Let us try to explain the obtained results. In studies where they used the linear model, the transversal dimensionality component was obtained quite seldom, usually it merged with voluminosity or longitudinal dimensionality or the variables divided themselves between the two. Maybe the answer is actually in the non-linearity of some of the relations between the variables. In our (non-linear) example, the fourth component is defined by the variables wrist diameter, knee diameter and pelvic width. The other variables – foot width, hand width, elbow diameter and shoulder width, which theory puts in the same component – correlate most with voluminosity. Since we have allowed also non-linear associations the fourth component is cleaner and in consequence has a weaker correlation with voluminosity. It would be probably worth thinking about strengthening this sub-space with some additional variables, to define it better.

A comparison of both models of finding latent structure showed a much greater congruence between the factors than is shown by the pairs of variables defining morphology. This is good, because it means that we do not need to revise the already established latent structures and that the selection of variables representing a particular sub-space is not problematic. However, we feel that it is premature at this moment to consider it a fact, since this is the finding of one study, one sub-space of the psychosomatic status, one gender and one age category. It is namely questionable if these findings will be confirmed also in other cases. It will be very interesting to see if the inclusion of a non-linear model will – at least to some extent – abolish the great variability of the latent structure in connection with gender and the age of the subjects in the sample used. This study does, however, confirm the findings of R.Joreskog (1967-78, also Balderjahn (1989), Chou (1991), Hu (1992), Muthen and Kaplan (1985, 1992), Tanaka (1984), Amemiya (1985), Browne (1985), Mooijaart and Bentler (1991), Satorra and Bentler (1990, 1991); all in: Borg & Mohler - 4), who tested the stability (robustness) of factor analysis methods. He found namely that the obtained latent structure is quite stable, without regard to different methods, suppositions and procedures used. If we may be so bold as to add to these tolerances also tolerance to (non)linearity of the associations between the manifest variables, then this is another »feather in the hat« for factor analysis.

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