The use of Factor Analysis in Measuring Psychomotor Behaviour

因子分析法測試心理肌動行為的應用

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摘要

一般使用因子分析法的教育研究，多集中於在認知和情感範疇。本文章以簡易的電腦程式，說明如何使用因子分析法來量度心理肌動行為，並作出實際例子給讀者參考。

Abstract

With the aid of today's computer software, the use of factor analysis becomes popular in educational setting, especially in cognitive and affective domain. However, the factor-analytic technique has been extensively used by researchers in the psychomotor domain since 1970s. The present paper attempts to illustrate the basic theories and assumption of utilizing factor analysis and to demonstrate the user friendly procedures in order to measure psychomotor behaviour.

Background

The term 'Factor Analysis' stands for a broad category of approaches to conceptualizing groups (or clustering) of variables and an even broader collection of mathematical procedures for determining which variables belong to which group (Nunnally, 1978). The birth of factor analysis was generally ascribed to Spearman (1904) who was considered to be the 'father' of the method. Traditionally, factor analysis was utilized by researchers in cognitive and affective domain to measure specific behaviour. McCloy (1940, 1941) was the pioneer in utilizing factor analysis in the psychomotor domain. With the aid of today's computer technology, there has been extensive use of factor analysis by many physical educators in analysing various components of psychomotor functions (Baumgartner & Zuidema, 1974; Disch, 1973; Gaunt, 1979; Hensley, 1979; Hopkins, 1976; Louie, 1990).

Factor analysis is a multivariate method intended to explain the relationships among several difficult-to-interpret, correlated variables in terms of a few conceptually meaningful, relatively independent factors (Kleinbaum, Kupper, & Muller, 1988). It is also a technique of multivariate analysis that attempts to account for the correlation pattern in a set of observable random variables in terms of a minimal number of unobservable or latent random variables called 'factors'. Then the first step can be used in a sequence of investigations which aims at developing insight into the relationships among variables. The second step may involve more direct input-response analysis of the data or confirmatory factor analysis (Press, 1982).

As mentioned by Bernstein, Garbin, and Teng (1988), factor analysis may be used for the following purposes: (a) orthogonalization of a set of variables; (b) reduction in size of a set of variables; (c) dimensional analysis of latent dimensions; (d) generation of factor scores; and (e) statistical control. Gorsuch (1983) further stated some common purposes for which factor analysis can be utilized: (a) through factor-analytic techniques, the number of variables for further research can be minimized while also maximizing the amount of information in the analysis. The original set of variables is reduced to a much smaller set that accounts for most of the reliable variance of the initial variable pool. The smaller set of variables can be used as operational representatives of the constructs underlying the complete set of variables; (b) factor analysis can be used to search data for possible qualitative and quantitative distinctions, and is particularly useful when the sheer amount of available data exceeds comprehensibility. Out of this exploratory work can arise new constructs and hypotheses for future theory and research; (c) if a domain of data can be hypothesized to have certain qualitative and quantitative distinctions, then this hypothesis can be tested by factor analysis. If the hypotheses are tenable, the various factors will represent the theoretically derived qualitative distinctions. If one variable is hypothesized to be more related to one factor than another, this quantitative distinction can also be checked.

When factor analysis is used as a method of hypothesis-testing, it is said to be confirmatory factor analysis. Confirmatory factor analysis is analogous to the planned comparisons approach (Disch, 1989). In contrast, the method of analysis may be guided by some questions about the number and kinds of factors which may be derivable from a collection of variables. This technique in studying factors underlying a broad collection of tests concerning reasoning is called exploratory factor analysis (Nunnally, 1978). The users can choose either of these approaches that will best suit their needs. With the help of the modern User Friendly computer software, the exploratory factor analysis can easily be accessed through the SPSS windows whereas the confirmatory factor analysis can also be obtained from the LISREL software (Joreskog & Sorbom, 1993).

Methodological Steps in Factor Analysis

Statistics are the tools for us to conduct research. Thus, students or researchers may not need to fully understand the mathematical bases of the advanced statistics provided that most of the computer software can produce user friendly procedures. The most important concept is whether you are using the right tool to do the right things. The reliability and validity coefficients can always tell you the appropriateness of your instrument.

Norusis (1988) suggested that there may be four steps in factor analytic procedures. Firstly, the researcher should compute the correlation matrix for all variables. Secondly, the technique of factor extraction is examined which refers to the determination of number of factors necessary to represent the data and the method of computing them. Thirdly, rotation of the computed factors is required so as to help make the interpretation more understandable. Lastly, factor scores for each factor will be computed for each case. These factor scores can then be used in a variety of other analyses. Prior to the data analysis, the correlation matrix for all variables must be checked. The goal of the factor analysis is to obtain 'factor' that help explain these correlations, the variables must be related to each other for the factor model to be appropriate. If the correlations between variables are low, it is unlikely that they will share some common factors. In addition, Bartlett's test of sphericity is the common test to evaluate the hypothesis that the correlation matrix is an identity matrix (ones on the diagonals and zeros on the off diagonals). The Bartlett's test requires that the data be a sample from a multivariate normal distribution. On the other hand, Safrit and Wood (1989) identify six steps to follow in order to conduct a factor analysis study: (a) identify theoretical dimensions and marker variables; (b) collect data and analyze the correlation matrix; (c) determining the initial factor structure; (d) determining simple structure and the patterns of factors; (e) the question of rotation; and (f) interpreting the results of the factor analysis.

Determining the number of factors used in further analysis is very important at the beginning stage. Generally using the eigenvalue greater or equal to one is the common method. Users can select the criterion at the SPSS window software before actual analysis. Another common method to choose the number of factors is the graphical technique called the 'scree' plot. Norusis (1988) explained that the plot shows a distinct break between the steep slope of the large factors and the gradual trailing off of the rest of the factors. This gradual trailing off is called the scree because it resembles the rubble that forms at the foot of a mountain. Gorsuch (1983) summarized that any of the common factor statistical tests can be used provided one remembers that they are unidirectional indicators.

Another major step in factor analysis is to find out how many factors can adequately explain the observed correlations among the variables. For the users not quite familiar with all of the solution, the plan is to choose the default function in the software which is mostly the Principal Component analysis. The goal of principal components analysis is to extract maximum variance from the data set with each component. The solution is mathematically unique and, if all components are retained, will then reproduce exactly the observed correlation matrix. It will facilitate the interpretation of the results because the components are orthogonal. The principal components analysis can reveal a great deal about the probable number and nature of common factors even though it may not provide the solution that is finally interpreted. It also satisfies the primary interest of the researchers because it can reduce a large number of variables down to a smaller number at earlier stage (Tabachnick & Fidell, 1983). Users may also select other extraction methods, such as Maximum-likelihood, Alpha Factoring, Image Factoring, or Least Squares method to have comparisons (Kim & Mueller, 1978).

After the extraction of initial factors, rotation of the factors is needed in order to form a 'simple structure'. The criteria of simple structure were described by Thurstone (1947) as follows: (a) each variable should have at least one zero loading; (b) each factor should have a set of linearly independent variables whose factor loadings are zero; (c) for every pair of factors, there should be several variables whose loadings are zero for one factor but not for the other; (d) for every pair of columns of the factor matrix, a large proportion of the variables should have vanishing entries in both columns when there are four or more factors; and (e) for every pair of columns of the factor matrix, there should be only a small number of variables with non-zero loadings on both columns. It is suggested users should utilize both the orthogonal and oblique rotation techniques and compare these results until meaningful factors have been formed.

Application of Factor Analysis in Psychomotor Domain

The use of factor analysis in cognitive and affective domain is very popular in educational and other academic disciplines. Owing to the widely availability of various powerful computer package, the implementation of factor analysis in the psychomotor domain became popular since 1970s. Many physical educators have successfully utilized this technique in analysing and identifying the components of different sport skills, such as basketball, tennis, football, and badminton.

Hopkins (1976) examined the factor structure of the basketball skill domain using 21 different basketball skill tests administered to high school boys. The selected 21 test items represented 5 theorized dimensions of basketball skills including jumping, passing, shooting, movement with the ball, and movement without the ball. The researcher utilized four factor analytic models: principal component analysis, alpha factor analysis, canonical factor analysis, and image factor analysis, together with orthogonal and oblique rotational methods to interpret the data. The hypothesized dimension of 'jumping' was identified and found to be best measured by the Jump and Reach Test. The hypothesized dimensions of 'movement with the ball' and 'movement without the ball' were found to consolidate into one dimension. The best measures of this factor were the Zig Zag Run and the Zig Zag Dribble Test. The hypothesized dimension of 'passing' was also identified and was best evaluated by Wall Pass Test. The last component of 'shooting' was identified and found to be measured by Front Shot Test and the Free Throw Test. Gaunt (1979) replicated the study by utilizing high school girls as subjects. The researcher hypothesized the same dimensions as Hopkins' study. A multidimensional model was obtained including dribbling, explosive leg strength, lay-up shooting, and passing.

Hensley (1979) conducted a factor analysis of selected tennis skill tests. The researcher attempted to investigate the factor structure of human performance in the sport skill domain of tennis and to identify robust factors in that domain by utilizing the following steps: (a) a task analysis of tennis playing ability was conducted in order to identify the critical components of tennis skills; (b) a theoretical model of tennis playing ability was hypothesized based upon the identified components including 'forehand motion', 'backhand motion', and 'overhead motion'; and (c) alpha factor analysis, canonical factor analysis, and maximum likelihood factor analysis with both orthogonal and oblique rotations were performed to testify the proposed factor model. Fourteen selected tennis skill tests were administered to 80 college students. The following findings were obtained by researchers: (a) a variance of 62% of tennis playing ability as delineated in the study could be essentially explained by three robust factors; (b) the hypothesized dimensions of 'forehand motion' and backhand motion' did not develop as distinct factors. The skill tests representing these hypothesized factors clustered together across all solutions into one group factor named 'stroking'; and (c) the hypothesized dimension of 'overhead motion' was identified as 'serving' factor; and (d) a robust factor named 'volleying' emerged across the solutions. Moreover, Hensley mentioned that the oblique solutions more closely satisfied Thurstone's simple structure criteria and provided for a more meaningful interpretation of the data than the solutions from orthogonal models.

Factor Analysis Example

The following example was conducted by Louie (1990), which was an exploratory approach in analysing the factor structure of selected badminton skill tests. The efforts of the researcher were directed at investigating the factor components of badminton skills for college students. A theoretical model of the hypothesized dimensions of badminton skill was initially defined as follows: long serve, short serve, overhead strokes, and underarm strokes. It was being tested by four factor-analytic models including principal components analysis, unweighed least squares analysis, alpha factor analysis, and maximum-likelihood factor analysis. Both orthogonal and oblique rotations were performed with each of these four factor-analytic models. The subjects were 105 college students enrolled in the badminton skill subjects, including 58 males and 47 females. Data were collected on the last week of the 7-week long classes.

Table 1 demonstrated the hypothesized factors and the selected badminton skill tests. Each selected test item possessed acceptable reliability and validity in measuring specific skills. Both the order for the testing stations and students were randomly assigned. All subjects had sufficient amount of practice period in order to minimize the 'warm-up' effect during testing. Table 2 shows the intercorrelations among all test items. Most of the variables correlated reasonably high with at least one of the other variables in the set. Moreover, two common tests of basic assumptions were also utilized: Bartlett's test of sphericity and the Kaiser-Meyer-Olkin measure of sampling adequacy (Norusis, 1988). The Bartlett's test of sphericity was computed to test the hypothesis that the correlation matrix was an identity matrix. The value for this study was 394.765 (p=.000) which indicated that the correlation matrix for the data was significantly different from an identity matrix. Thus, there were sufficient intercorrelations among the set of the 10 badminton skill tests. According to Kaiser (1974), the Kaiser-Meyer-Olkin measure of sampling adequacy was developed to compare the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients in order to establish a criterion of justifying the assumption of factor analysis. The Kaiser-Meyer-Olkin measure of sampling adequacy for the present data returned a value of .81369, which Kaiser described as a 'meritorious' situation. Therefore, a sufficient degree of common variance is shared by the set of the 10 badminton skill tests. From the results of the above assumption tests, the researcher could comfortably proceed with the factor analysis.

Table 1. Hypothesized Factors and Selected Badminton Skill Tests.

Hypothesized Factors	Selected Skill Tests
I. Short Serve:	French Short Serve Test Sebolt Short Serve Test
II. Long Serve:	Scott & Fox Long Serve Test Poole Long Serve Test
III. Overhead Strokes:	Poole Forehand Clear Test Poole Backhand Clear Test Miller Wall Volley Test Poole Smash Test
IV. Underarm Strokes:	Lockhart-McPherson Wall Volley Test Drive Test for Distance

Table 2. Intercorrelations among the 10 Badminton Skill Tests.

Tests	2	3	4	5	6	7	8	9	10
1. SLONG -	.07	.23	.30	.38	.39	.45	.75	.11	.17
2. FSHORT	1.00	.31	.16	.26	.17	.22	.03	.54	.27
3. FCLEAR		1.00	.52	.41	.32	.52	.32	.31	.57
4. BCLEAR			1.00	.39	.30	.55	.44	.24	.49
5. LWALL				1.00	.46	.50	.36	.23	.34
6. MWALL					1.00	.42	.37	.26	.31
7. DRIVE						1.00	.53	.23	.39
8. PLONG							1.00	.21	.30
9. SSHORT								1.00	.38
10. SMASH									1.00

N = 105

Table 3 shows the final statistics generated by the SPSS programme. The three factors accounted for 67.1% of the total variance. The eigenvalues serve as the criteria for the selection of number of factors for further analysis. There were four factor-analytic model for this data. Each model was being rotated by both orthogonal and oblique techniques until simple structures were formed which allowed easy interpretation of the retained factors. For easier explanation of the common factors, no loadings less than .40 in the absolute values were displayed in the table. Table 4 displayed the final simple structure derived from the Principal Component Analysis with Orthogonal Rotation for the identified three factors.

Table 3. Final Statistics for the Variables by Principal Components Analysis

Variables	Communality	* Factor	Eigenvalue	% Var	Cum %
SLONG	.82293	* 1	4.16253	41.6	41.6
FSHORT	.76653	* 2	1.60428	16.0	57.6
FCLEAR	.70588	* 3	.95499	9.5	67.1
BCLEAR	.68776	*			
LWALL	.48448	*			
MWALL	.49138	*			
DRIVE	.63858	*			
PLONG	.75234	*			
SSHORT	.72018	*			
SMASH	.65166	*			

Table 4. Factor Loadings of the Selected Badminton Skill Tests

Tests	Rotated Factors		
	1	2	3
SLONG	.899		
PLONG	.824		
FCLEAR		.795	
BCLEAR		.779	
SMASH		.758	
FSHORT			.857
SSHORT			.819

Once the factors were extracted, the researcher had to identify them with appropriate names. In this example, common Factor 1 showed solid and consistent loadings for both long serve tests across all rotations in all four factor models. All factor loadings between Factor 1 and these two tests were greater than .70. Thus, common Factor 1 was identified as 'long serve' and was best measured by the Scott and Fox Long Serve Test (Scott & French, 1959) and the Poole Long Serve Test (Poole& Nelson, 1970). Of the variables which loaded on Factor 2, three tests including the Poole Forehand Clear Test, Poole Backhand Clear Test, and the Poole Smash Test (Poole & Nelson, 1970) were found to have significant loadings greater than .60 across the rotations. The forehand and backhand clear tests were purported to measure the ability to hit the overhead clear shot from the player's back court high and deep into opponent's back court. The smash was designed to evaluate the overhead smash ability to hit the shuttle down on either side of the opponent's court. Consequently, Factor 2 was referred to as 'overhead strokes' and was best evaluated by the above three skill tests. The factor loadings obtained in Factor 3 associated only with the Sebolt Short Serve test (Sobolt, 1968) and French Short Serve test (Scott,Carpenter, French & Kuhl, 1941) in all solutions. Thus, this factor was named 'short serve'. The hypothesize dimension of 'underarm strokes' did not emerge across any factor-analytic solution. This hypothesized factor was expected to be measured by two wall-volley test and the drive test. In fact, these tests were often doubly loaded on more than one factor and did not form another distinct factor. Only 7 out of the 10 selected badminton skill tests were able to form three distinctly clear factors which could be used to evaluate the playing abilities for college students.

To conclude, understanding the components of badminton skill could enhance the teaching, coaching, and evaluation process. Physical educators and coaches can accurately evaluate their students and players for various purposes. Researchers can apply this kind of factor-analytic technique to measure different sport skills. Once the factor structure of a particular sport is identified, it is much convenient for diagnosis, classification, motivation, practice, as well as prediction purposes.

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