HUMAN MOVEMENT
2010, vol. 11 (2), 124–131

THE HIERARCHICAL STRUCTURE OF SELECTED MORPHOLOGICAL AND MOTORIC VARIABLES IN SKI JUMPING

doi:10.2478/v10038-010-0016-0

BOJAN JOŠT
Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia

ABSTRACT
Purpose. The main purpose of the present research paper was to establish a hierarchical factor structure in a selected sample of morphological and motor variables of ski jumpers; such variables are base constituents of the potential performance model in ski jumping. Basic procedures. The subject sample was Slovene ski jumpers older than 15 years (*n* = 72), tested in May 2008. The research was done on a selection of 41 variables (12 basic morphological ones, seven from a special morphological index, 10 basic motoric ones and 12 special dynamic variables of take-off power). Main findings. Through factor analysis in the first phase, nine factors were excluded from the manifest variables of first orders: 1. Factor of velocity power (34.9% of variance); 2. Factor of longitudinal body dimensions (17.2% of variance); 3. Factor of morphological index of flight aerodynamics (12.2% of variance); 4. Factor of morphological index of take-off (7.3% of variance), 5. Factor of push-off explosive power (5.0% of variance), 6. Factor of informatic component of motorics (3.5% of variance); 7. Factor of specific morphological index of thigh dimensions (3.1% of variance), 8. Factor of transversal dimensions of body (2.4% of variance), 9. Factor of flexibility of hips (2.2% of variance). All nine factors of the first order explained 88% of variance of manifest variables. On the basis of configuration of nine factors of the first order in the second phase, four components were excluded from the second order with 62.7% of total variance. The first was component of specific take-off movement (22.9% of variance), followed by component of thigh dimension (14.5% of variance), then component of specific flight potential (13.0% of variance) and finally component of basic morphology (12.1% of variance). On the third level of factor analysis, two general factors of ski jumpers with 57.1% of total variance were found. The first was the general factor of specific movement of ski jumpers (29.8% of variance) and second the general factor of morphology (27.7% of variance). **Conclusions.** The research confirms the main hypothesis that hierarchical latent factor structures of manifest motor and morphological variables exist. The independent primary factors of the first order are crucial for understanding the latent dimensions of the potential performance model on the second and third level. This factor shows the structure between manifest dimensions more clearly and their relations are more understandable.

Key words: ski jumping, motor behavior, morphology, hierarchical factor analysis

Introduction

The main purpose of the present research paper was to establish a hierarchical factor structure in a selected sample of morphological and motor variables of ski jumpers; such variables are base constituents of the potential performance model in ski jumping [1]. The construction and supplementation of the potential model of athletic performance is especially productive if these are carried out by modeling of the optimal personal athletic profile in accordance with the theory of the "Champion" [2]. Many performance variables and characteristics are used to describe the model of the potential performance of elite athletes. A large number of model dimensions is the cause of many difficulties in managing such models. Often it is useful to reduce a large set of performance dimensions to a more manageable model structure. Athletes who are oriented towards competition, achievements and top-level sport must, in order to be able to attain top-level achievements, practice regularly, systematically and continuously for several years. This preparation period is characterized by intensive growth of sports performance and, as such, represents the most complex and demanding stage of their sports life. In today's competitive, achievement-oriented sport, success is not possible without a high level of knowledge, technological support, financial support, appropriate organization and successful management. A multitude of factors that affect achievement in sports requires that a corresponding treatment should be based on a permanent cybernetic systems approach.

In modeling athletic performance, smaller or larger problems are encountered. Larger problems occur in the study of complex fields, phenomena, objects, processes, events, whose inner workings are more or less inaccessible to us. We have only access to the observation of external behavior. We can draw conclusions about internal mechanisms, properties, characteristics only by means of external indicators.

In most cases, however, we are not able – due to the large number of variables and their mutual interactions

– to describe all of them and to place them into a coherent functional cause-and-effect whole [3]. For that reason, we attempt to form a model of potential performance that will be maximally predictable and easier to manage. The modeling of potential athletic performance is based on the model facts and rules with which we define the relations between the criterion of performance and individual constituents of the reduced potential performance model [4].

A ski jumper's movement is a complex and difficult motor task, which (in terms of motor behavior terminology) requires high levels of strength, coordination, accuracy, balance, orientation in space and appropriate morphological structure of body. These abilities could be measured with many motoric tests; such tests are the input for the hypothetical model of special motor behavior of athletes. The realization of technique depends on the morphological characteristics of athletes. However, its manifest expression can only be shown through the variables of motor behavior; their interaction affects the performance of athletes. Especially in ski jumping, technique performance depends not only on the motor abilities of the athlete, but to a large extent on the aerodynamic features of the athlete's body and his equipment [5, 6]. Morphological features play a major role in competition success of ski jumpers. A guiding concept in the modeling of the morphology profile of athletes is morphological optimization, which occurs through two mechanisms: selection and adaptation. The performance of athletes in the flying phase has greater potential when they realize the two hypothetical components. The first energy component of movement represents the total component of mechanisms which within the athletes' motorics take care of the control and regulation of energy processes. In addition to this component, there is also presumed, from the aspect of motor behavior, the existence of the information component of movement that covers the coordinate action of those latent motor mechanisms that take care of the control and regulation of information processes. In ski jumping, it is hypothesized that both components have an equally important weight in the formation of the total motor regression function.

The research findings could be significant in improving the reduced potential performance model in ski jumping, which must become more and more specifically oriented according to the criteria of optimal technique realization. The relative importance of model characteristics depends on the specific demands of the sport discipline. The structure of the potential performance model in ski jumping could be built up in both horizontal and vertical directions.

In the vertical direction, it could constitute a hierarchic structure from more empirical and specialized categories to more abstract and general categories [7]. The main hypothesis of that research is that there exist a smaller independent number of latent or hidden variables on the first and higher order of the reduced potential performance model in ski jumping. This hypothesis will be tested by factor analysis. The goal of factor analysis is to discover the factors (underlying or hidden constructs) that best explain a group of manifest variables and describe the linear relation of each variable to the latent or hidden factor [8].

Material and methods

The research was conducted on a sample of 72 ski jumpers, members of the Slovene junior-men and senior-men team selections, tested in May 2008. The sample included almost all elite Slovene ski jumpers aged between 16 and 29 years. Table 1 contains the list of all the manifest variables applied in this study as well as the corresponding codes, which will be consistently used throughout the text. The research was done on sample of 41 elementary variables (12 basic morphological, 7 special morphological indexes, 10 basic motoric, and 12 special dynamic variables of special take-off power measured in laboratory conditions). Anthropometric measures were chosen and their measuring was carried out in accordance with the methodology presented in the International Biological Program recommendations (IBP). Ski jumpers executed a vertical jump from a specific in-run position on a Kistler Force Plate. Based on the achieved and calculated take-off parameters, the following variables were selected for the purpose of this research: push-off height, push-off time, ratio between push-off height and time (also called index of take-off explosive power) and acceleration of the first part of push-off (also called index of explosive power of the first part of take-off). Factorial analysis (principal component analysis) was used to determine the latent ski jumping motoric and morphological structure. The Guttman-Kaiser criterion was used to determine the significance of the extracted factors and components. The algorithm (Oblimin rotation method with Kaiser Normalization), consisted of Oblimin transformation of latent dimensions obtained by orthoblique transformation of the characteristic vectors (rotation converged in nine iterations) of the variable inter-correlation matrix. The component correlation analysis was done to determine the dependency between latent vectors. The matrices of orthogonal (a structure matrix) loadings were computed.

Results

The results of the factor analysis on the first order are shown in Table 1a and Table 1b.

Through factor analysis in the first phase, nine factors were excluded from the manifest variables of first order: 1. Factor of velocity power (34.9% of variance); 2. Factor of longitudinal body dimensions (17.2% of variance); 3. Factor of morphological index of flight aerodynamics (12.2% of variance); 4. Factor of morphological index of take-off (7.3% of variance); 5. Factor of push-off explosive power (5.0% of variance); 6. Factor of informatic component of motorics (3.5% of variance); 7. Factor of specific morphological index of thigh dimensions (3.1% of variance); 8. Factor of transversal dimensions of body (2.4% of variance); 9. Factor of flexibility of hips (2.2% of variance). All nine factors of the first order explained 88% of variance of manifest variables.

On the basis of configuration of nine factors of the first order in the second phase, four components were excluded from the second order with 62.7% of variance (see Tab. 2). The first was **component of specific take off movement** (22.9% of variance), followed by **component of thigh dimension** (14.5% of variance), then **component of specific flight potential** (13.0% of variance) and finally **component of basic morphology** (12.1% of variance).

On the third level of factor analysis, two general factors of ski jumpers with 57.1% of total variance was determined (see Tab. 3). The first was the **general factor of specific movement of ski jumpers** (29.8% of variance) and the second was the **general factor of morphology** (27.7% of variance). The results of this

Table 1a. Structure of factors of selected morphological and motoric variables of ski jumpers (*n* = 72), part one

Manifest variables	M	SD	Factor scores of the first order								
			F1	F2	F3	F4	F5	F6	F7	F8	F9
FACTOR 1			Factor of velocity power								
MOC – Power of take-off (W)	1842.3	301.0	**0.89**	0.31	–0.21	–0.07	–0.10	0.11	–0.04	–0.01	0.09
SMABAVO – Vertical push-off height (cm)	45.3	6.5	**0.86**	0.29	–0.09	0.33	0.52	**–0.61**	–0.21	–0.11	0.28
HODR – Velocity of take-off (m/s)	2.9	0.2	**0.86**	0.30	–0.10	0.34	0.52	**–0.61**	–0.19	–0.13	0.27
MMENSDM – Horizontal jump length (cm)	258.1	21.9	**0.62**	**0.58**	–0.11	0.43	0.44	**–0.71**	–0.22	–0.19	0.28
MMEN3SM – Elastic power in triple jump (cm)	805.3	70.7	**0.60**	**0.55**	–0.14	0.43	0.42	**–0.73**	–0.22	–0.23	0.28
SUN – Impulse of the push-off force (Ns)	187.8	30.6	**0.48**	**0.72**	**–0.58**	0.47	0.33	–0.41	–0.15	–0.23	0.22
FACTOR 2			Factor of longitudinal body dimensions								
ADV – Absolute body height (cm)	225.0	11.0	0.13	**0.97**	–0.21	0.28	–0.01	–0.26	–0.15	–0.21	0.28
ADN – Right leg length (cm)	90.4	4.5	0.06	**0.95**	–0.19	–0.07	–0.11	–0.14	–0.26	–0.11	13
AV – Body height (cm)	175.0	8.4	0.14	**0.95**	–0.28	0.37	0.02	–0.24	–0.19	–0.20	0.27
ADG – Right shank length (cm)	42.5	2.2	0.10	**0.93**	–0.19	–0.05	–0.08	–0.12	–0.06	–0.15	0.16
ADR – Right arm length (cm)	79.4	4.3	0.16	**0.92**	–0.26	0.17	0.04	–0.28	–0.10	–0.14	0.26
AT – Body mass (kg)	60.6	7.7	0.15	**0.78**	**–0.71**	0.43	0.16	–0.23	–0.06	–0.24	0.12
FACTOR 3			Factor of morphological index of flight aerodynamics								
INDPLOV – Aerodynamic index (I = (ASR+ASM)*AV/ 2 AT	1016.6	70.9	–0.06	–0.14	**0.94**	–0.22	–0.19	0.04	–0.06	–0.17	0.09
BMI – Body mass index (kg/m^2)	19.7	1.3	0.10	0.12	**–0.93**	0.30	0.30	–0.11	0.12	–0.20	–0.13
AOS – Right thigh girth (cm)	51.6	3.0	0.04	0.42	**–0.83**	0.33	0.21	–0.04	0.06	–0.14	–0.08
MORIND – Morphological index of rotation (I = ADT/ADS)	112.7	10.1	–0.08	**–0.63**	**0.83**	–0.12	–0.09	0.11	0.09	–0.07	–0.01
FACTOR 4			Factor of morphological index of take–off								
INDVZG – Morphological index of lift force (I = ADT/ADN)	59.9	3.8	0.15	0.07	–0.22	**0.96**	0.24	–0.17	0.10	–0.10	0.24
INDODSK – Ski-jumping morphological take-off index (I = AV/ADN)	193.6	4.8	0.15	–0.07	–0.17	**0.90**	0.28	–0.19	0.16	–0.16	0.25
ADT – Trunk length (cm)	54.2	4.0	0.17	**0.72**	–0.31	**0.76**	0.11	–0.25	–0.10	–0.17	0.30

M – mean value, SD – standard deviation, F1 to F9 – orthogonal loadings, the values typed in bold are the extracted factor saturation scores which determine the theoretical mean of the factors

Table 1b. Structure of factors of selected morphological and motoric variables of ski jumpers of the first order (*n* = 72), part two

Manifest variables	M	SD	Factor scores of the first order								
			F1	F2	F3	F4	F5	F6	F7	F8	F9
FACTOR 5			Factor of push-off explosive power								
SMABATO – Push-off time in vertical take-off (s/1000)	422.5	43.0	–0.22	0.06	0.18	–0.22	**–0.96**	0.27	–0.01	–0.06	0.08
EKSPLO – Index of explosive power of take-off	72.1	11.0	**0.55**	0.05	–0.19	0.31	**0.91**	–0.46	–0.07	–0.01	0.07
EKSPLO1 – Index of explosive power of take-off in the first phase	5.8	1.1	0.26	0.06	–0.04	0.31	**0.91**	–0.44	–0.01	–0.21	0.28
POSP – Acceleration of take-off (m/s^2)	7.1	1.0	**0.55**	0.05	–0.19	0.30	**0.91**	–0.46	–0.06	–0.01	0.07
STMOR – Starting acceleration in push-off (m/s^2)	1.4	0.8	0.15	0.14	–0.05	0.20	**0.81**	–0.29	–0.06	–0.24	0.31
FPOPR – Acceleration in take-off in the second part (m/s^2)	6.9	1.0	**0.63**	–0.20	–0.11	–0.15	**0.68**	–0.25	–0.00	0.24	–0.26
MGGOLS – Ankle flexibility (angle degrees)	42.3	4.6	0.31	0.05	0.27	–0.16	**–0.40**	–0.15	0.03	–0.28	0.25
FACTOR 6			Factor of informative component of motorics								
MHFNTL – Speed of left leg frequency (rep.)	34.2	3.1	0.39	0.10	0.03	0.15	0.29	**–0.87**	–0.12	0.01	0.31
MHFNTD – Speed of right leg frequency (rep.)	35.3	3.3	0.33	0.00	0.01	0.08	0.28	**–0.79**	–0.06	0.02	0.38
MKPOLN – Co-ordination of atypical movement (s/10)	6.8	1.1	–0.44	–0.17	–0.04	–0.23	–0.20	**0.79**	0.00	0.24	–0.43
MMRNPK3 – Repetitive leg power (rep.)	101.7	14.8	0.38	0.28	–0.14	0.43	0.26	**–0.77**	–0.07	–0.43	0.38
MFE50 – Co-ordination in jumping (s/10)	5.0	0.5	–0.35	–0.38	–0.04	–0.44	–0.23	**0.75**	0.09	0.17	–0.38
MRSAGIT – Balance in sagittal plane (s/10)	9.5	7.8	0.29	0.32	0.21	0.16	0.19	**–0.69**	–0.21	0.23	0.38
MRFRONT – Balance in frontal plane (s/10)	7.9	7.8	0.21	0.38	0.25	0.13	0.20	**–0.56**	–0.21	0.21	0.49
MKKROSP – Coordination in an “eight” (s/10)	15.5	0.7	–0.30	–0.17	–0.00	–0.16	–0.26	**0.74**	0.08	0.05	–0.04
MMRTDT45 – Repetitive power of abdominal muscles (rep.)	18.8	20.5	0.23	0.14	–0.12	0.02	0.30	**–0.55**	–0.06	–0.18	–0.25
FACTOR 7			Factor of specific morphological index of thigh dimension								
INDSTEG – Index of thigh length	130.1	11.1	0.04	0.09	–0.27	**0.79**	0.19	–0.12	**0.64**	–0.11	0.16
ADS – Right thigh length (cm)	41.7	2.7	0.12	**0.70**	–0.04	–0.12	–0.09	–0.12	**–0.78**	–0.05	0.12
FACTOR 8			Factor of transversal dimensions of body								
ASR – Shoulder width (cm)	380.9	2,4	0.28	**0.70**	–0.12	0.36	0.03	–0.28	–0.04	**–0.60**	0.15
ASM – Pelvis width (cm)	30.9	10.9	0.00	**0.71**	–0.30	0.41	0.24	–0.26	–0.09	**–0.55**	0.20
FACTOR 9			Factor of flexibility of hips								
MGGTPKR – Relative index of flexibility	252.0	21.4	0.20	0.30	0.05	0.32	0.13	–0.38	–0.09	–0.13	**0.86**
MGGTPK – Flexibility of hips (cm)	62.8	5.8	0.21	0.26	0.03	0.48	0.17	–0.40	–0.02	–0.16	**0.85**
SPZ – Force ratio in the first and second parts of push-off (in %)	122.8	20.9	0.22	0.25	–0.03	–0.28	**–0.45**	0.27	–0.09	**0.51**	**–0.57**
% OF VARIANCE			**34.9**	**17.2**	**12.2**	**7.3**	**5.0**	**3.5**	**3.1**	**2.4**	**2.2**

M – mean value, SD – standard deviation, F1 to F9 – orthogonal loadings, the values typed in bold are the extracted factor saturation scores which determine the theoretical mean of the factors

research showed the hierarchical structure of manifest dimensions of the potential model of performance in ski jumping.

Discussion and conclusions

Through factor analysis in the first order, nine factors were excluded out of 42 manifest variables, which explained 88% of the total variance of manifest variables (see Tab. 1a and 1b).

The first dominant was **factor of velocity power**, accounting for 34.9% of the total explained variance. The highest projection was discovered in the power of take-off (0.89) which was strongly connected to the variables of vertical push-off height and push-off velocity [9]. The success rate in ski jumping is strongly affected by this factor [10].

Table 2. Factor structure of selected morphological and motoric variables of ski jumpers of the second order (*n* = 72)

Factor analysis of the second order	C1	C2	C3	C4	Cum.
Component 1	Component of specific take-off movement				
F4 – Factor of morphological index of take-off	**–0.73**	–0.12	0.31	0.20	0.64
F5 – Factor of push-off explosive power	**0.70**	–0.24	0.03	0.18	0.60
F9 – Factor of flexibility of hips	**0.70**	0.04	–0.02	–0.20	0.52
Component 2	Component of thigh dimension				
F7 – Factor of specific morphological index of thigh dimension	–0.06	**0.88**	0.05	–0.04	0.79
Component 3	Component of specific flight potential				
F1 – Factor of velocity power	0.23	0.35	**–0.67**	–0.09	0.64
F3 – Factor of morphological index of flight aerodynamic	0.03	0.14	**0.63**	–0.04	0.43
F6 – Factor of informatic component of motorics	0.42	–0.38	**–0.50**	0.27	0.56
Component 4	Component of basic morphology				
F2 – Factor of longitudinal body dimensions	–0.12	–0.12	–0.12	**0.82**	0.71
F8 – Factor of transversal dimensions of body	0.12	–0.36	**–0.53**	**–0.57**	0.73
% OF VARIANCE	**22.9**	**14.5**	**13.0**	**12.1**	**62.7**

C1, C2, C3, C4 – orthogonal loadings of components, Cum. – cumulative loadings of components, the values typed in bold are the extracted factor saturation scores which determine the theoretical mean of the factors

Table 3. Structure of factors of selected morphological and motoric variables of ski jumpers of the third order (*n* = 72)

Factor analysis of the third order	GF1	GF2	Cum.
General factor of specific movement of ski jumpers			
C3 – Component of specific flight potential	**0.72**	–0.09	0.52
C1 – Component of specific take-off movement	**–0.70**	–0.07	0.51
General factor of morphology			
C4 – Component of basic morphology	0.26	**0.75**	0.64
C2 – Component of thigh dimension	0.31	**–0.71**	0.59
% OF VARIANCE	**29.8**	**27.3**	**57.1**

GF1, GF2 – orthogonal loadings of general factors, Cum. – cumulative loadings of general factors, the values typed in bold are the extracted factor saturation scores which determine the theoretical mean of the factors

The second was determined to be the **factor of longitudinal body dimensions,** which explained 17.2% of variance. With this factor, the basic projections of morphological variables of body were primarily defined by high projections of longitudinality (body height and total arm & body height and tibia length, leg length), projections of transversality (bicristal diameter and biacromial diameter) and projection of body mass (body weight). The success rate in ski jumps is only in one part affected by the general morphological factor. Other specific morphological factors of ski jumpers have a strong impact on the success of ski jumping technique [11].

The third was the more specific **factor of morphological index of flight aerodynamics** which explained 12.2% of variance, the projection of morphological aerodynamic index (0.94) was prevalent. A high factor saturation was also seen in body mass (–0.67) and body mass index (–0.93). From the point of view of aerodynamics, the existence of independent specific morphological factors has to be taken into account. These factors have a strong impact on the execution of ski jumping technique. The morphological aerodynamic index plays an important aerodynamic role in the central phase of flight. Ski jumpers with higher aerodynamic indexes show higher potential capacity for successful execution of a jump in the flight phase. This finding is of great importance in selection of talented jumpers and their training. In that factor, the body mass index (BMI) is important. It is defined as the individual's body weight divided by the square of their height. In ski jumping, from the aspect of aerodynamics, lower values of BMI are much better than higher ones [12]. A BMI of 18.5 to 25 indicates optimal weight in the general population. The best ski jumpers have BMI near to the value of 18.5, i.e., on the border of the underweight [13]. The Fédération Internationale de Ski (FIS) has regulated this extremely negative BMI trend with the shortening of ski lengths.

The fourth was the **factor of morphological index of take-off**, accounting for 7.3% of variance. The morphological take-off index plays an important role in achieving rapid transition to flight. With this factor, there was dominant projection of morphological index of take off (0.90). Morphological index of the take-off expresses a relation between the height of a ski jumper and the lower limb length. Ski jumpers with relatively shorter legs according to their body height have hypothetically better torque of the body weight force. This torque acts before and during the take-off in a negative way in the knee joint, where the muscular force action at the take-off is the highest. The result of the vertical velocity of the take-off does not only depend on the muscular force of the take-off, but predominantly on the torque, at which this force acts. This factor is responsible for potential performance of the ski jumper in take-off phase. It plays an important role in achieving rapid transition to flight from the aspect of aerodynamics (minimization of the air resistance and maximization of the lift force during the take-off).

With the fifth **factor of push-off explosive power**, accounting for 5.0% of variance, there were dominant variables of starting acceleration in push-off. The variables of the push-off explosive power formed a homogeneous structure. In analyzing the push-off power in a ski jumper's take-off, one has to consider the factor of explosive push-off power. Explosiveness of take-off is particularly important in the first phase of ski jumper's push-off [13]. In ski jumping, take-off action is the most important factor for having ascent force. Ascent force acts on the ground and is required for a jumper to obtain initial velocity and angular momentum [14].

The projection of the basic motoric variable was strongly prevalent in the sixth **factor of the informative component of motorics,** representing 3.5% of variance. The information component of movement covers the coordinated actions of those latent motor mechanisms that take care of the control and regulation of information processes. Coordination may be defined as the concerted action of the muscles in producing the movement. As such, it is ultimately determined by timing, sequencing and amplitude of muscle activation [15]. The coordination was represented by three manifest variables indicating three typical forms of coordination. For all three forms, characteristic is the requirement for the fastest possible execution of motor tasks, which are complex in some way. Of course, the manifestation of the coordination abilities depends on the plasticity of the mechanism for the regulation of the synergistic and antagonistic muscle groups. On the phenomenological level, a domination of the ability of the speed of alternative movements of lower extremities was discovered. However, the sixth factor also obtained quite considerable orthogonal loadings of the balance tests in the sagittal plane and balance in the frontal plane.

The seventh factor was the **factor of specific morphological index of thigh dimensions**, accounting for 3.1% of the total explained variance. This factor defines the potential performance from the aspect of knee angular velocity in the take-off phase in ski jumping technique. Take-off force is produced by joint movement [16]; most of the power from initial action until take-off is produced by two joints, the hip and the knee [17]. The knee joint power is important for achievement of the optimum level of angular momentum in the forward direction [18]. There are two important factors that determine how much knee inertia a rotating ski jumper will have: the mass of the ski jumper and the radial distribution of body mass. The term "radial distribution of body mass" refers to how the mass of a ski jumper is distributed, or positioned, relative to the knee axis about which it is rotated. The ski jumpers with the high level of morphological factor of knee angular velocity have better potential to reach higher knee extension velocity, which is a proven factor for successful ski jumping technique.

The eighth was the **factor of transversal dimensions of body**, accounting for 2.4% of variance. The last, ninth factor was the **factor of flexibility of hips,** accounting for 2.2% of variance. This factor is important for good realization of ski jumping technique in the inrun phase and especially in take-off phase. This factor is connected to the force ratio in the first and second parts of push-off. The jumpers with better flexibility of hips could hypothetically produce more power in the first part of take-off phase.

Hoteling's method of principal components, according to the Guttman-Kaiser criterion, resulted in extraction of 9 principal factors of the manifest motor and morphological measure correlation matrix. The number of the principal factors corresponds to the hypothesis according to which the manifest variables were selected. The results were very similar as in study [19] where eight principal factors were ruled out (factor of velocity power, factor of morphological lengthiness, factor of morphological aerodynamics, factor of flexibility of ski jumpers, factor of explosive power of take-off, factor of ski jumping morphological take-off index, factor of balance of ski jumpers, factor of coordination and motor velocity).

The factor analysis made on factors of the first order produced four components on the second order. From Table 2 it is obvious that 62.7% of the total variability was explained by four components. The results are interesting primarily because they reflect more generality in expressing specific factors of the first order. The first **component of specific take-off movement** obtained quite considerable orthogonal loadings of the factors of specific motor behavior of ski jumpers especially in take-off phase. The second **component of thigh dimension** is strongly connected to the factor of specific morphological index of thigh dimension (0.88). The third isolated component can be interpreted as **component of specific flight potential** with dominant projection of factor of morphological index of flight aerodynamic. This factor has opposite projections to other two factors belonging to motor variables. In the last **component of basic morphology** the projections of two basic morphological factors dominated. The factor of longitudinal body dimensions has positive projection (0.82). On the other hand, the factor of transversal dimensions of body has negative projection (–0.53). The structure of components on second level is very interesting for ski jumping training theory. Today, it is more and more important to know specific factors which determine the successfulness in ski jumping. The combination of those specific factors significantly influence the whole performance in ski jumping competitions. The specific motor and morphological features or components play a major, arguably critical, role in competition success of ski jumpers. And this is an important fact for the specific motor & morphological optimization of the ski jumper's personal profile. This optimization occurs through two mechanisms: selection and adaptation. Adaptation refers to the physique-modeling of ski jumping performance.

At the third, highest level, the hypothetical statement that there exist two independent general factors could be defined (see Tab. 3): the first one **general factor of specific movement of ski jumpers** is regulated by motoric actions or behavior and the second one **general factor of morphology** is regulated by morphological processes. Both general factors explained only 57.1% of the total variance. The structure of the first general factor is very interesting for development of the performance theory in ski jumping. The general personality profile of ski jumper is influenced by technique nature of ski jumping. Some dimensions are more connected to the take-off phase and some to the flight phase of ski jumping. A reduced potential performance model (RPPM) for ski jumpers was set up on the concept of multidimensionality of psychosomatic status. The number of performance model dimensions depends on the level of hierarchic structure. The bigger number of elementary dimensions could be condensed to a smaller number of derived dimensions at a higher level. The results of research have shown the need for a new concept of modeling performance in ski jumping. With nine primary factors 88% of total variance manifest variables could be explained. The independent primary factors of the first order are crucial in understanding the latent dimensions of the potential performance model at the second and third levels. This primary factor shows the structure between manifest dimensions more clearly and their relations are more understandable.

At the second level the number of factors and the percentage of total variance falls down rapidly. The interpretation of derived factors at the higher level of the hierarchic factor model is difficult. At the higher level, we do not have the possibility of recognizing the realistic nature of latent variables. The relationships between latent dimensions at the second and third levels are complex, and behave in different and often contradictory ways [20]. Therefore we can look in the latent dimensions of hierarchic model of reduced potential performance only over empirical manifest dimensions. These manifest and latent motorical and morphological model dimensions have to be explored further from the point of view of biomechanics, physiology and other special sciences.

References

1. Ulaga M., Čoh M., Jošt B., Validity of the dimensional configuration of the reduced potential performance model in ski jumping. *Kinesiology*, 2006, 38 (2), 185–192.
2. Virmavirta M., Komi P.V., Take-off analysis of a champion ski jumper. *Coaching and Sport Science Journal*, 1994, 1, 23–27.
3. Blahuš P., Hruby J., Kvapil J., Paichl, J., Systems theory approach to using statistics in social sciences. Charles University, Prague 1988.
4. Jost B., Tušak M., The structure of reduced potential performance model in ski jumping. *J Hum Kinetics*, 2002, 8, 3–15.
5. Schmölzer B., Müller W., The importance of being light: aerodynamic forces and weight in ski jumping. *J Biomech*, 2002, 35, 1059–1069.
6. Müller W., Determinants of ski-jump performance and implications for health, safety and fairness. *Sports Med*, 2009, 39 (2), 85–106.
7. Gredelj M., Metikoš D., Hošek A., Momirović K., A model of hierarchic structure of motoric abilities [in Croatian]. *Kineziologija*, 1975, 5 (2), 8–84.
8. Thomas J.R., Nelson J.K., Research methods in physical activity. 3rd edition, Human Kinetics, Champaign 1996.
9. Vaverka F., Biomechanics of Ski jumping [in Czech] Univerzita Palackeho, Olomouc 1987.
10. Virmavirta M., Komi P.V., The take-off forces in Ski jumping. *Int J Sport Biomech*, 1989, 5, 248– 257.
11. Jost S., The factor structure of selected morphological variables in Ski jumpers. In: Milanović D., Prot F. (eds.), Proceedings book of the 5th International Scientific Conference on Kinesiology "Kinesiology research trends and applications", September 10–14, 2008. Faculty of Kinesiology, Zagreb 2008, 929–932.

12. Müller W., Gröschl W., Müller R., Sudi K., Underweight in Ski jumping: The Solution of the Problem. *Int Sports Med*, 2006, 27 (11), 926–934. doi:10.1055/s-2006-923844.
13. Komi P.V., Virmavirta M., Ski-jumping take-off performance: Determining factors and methodological advances. In: Müller E., Schwameder H., Kornexl E., Rascher C. (eds.), Science and skiing. E & FN Spon, London 1997, 3–26.
14. Virmavirta M., Komi P.V., Measurement of take-off forces in ski jumping – part I. *Scand J Med Sci Sports*, 1993, 3, 229–236. doi:10.1111/j.1600-0838.1993.tb00387.x.
15. Bobbert F.M., Schenau G., Coordination in vertical jumping. *J Biomech*, 1988, 21 (3), 249–262.
16. Sasaki T., Tsunoda K., Uchida E., The relation of muscle activity and joint power during ski jump takeoff action. In: Häkkinen K., Keskinen K.L., Komi P.V., Mero A. (eds.), Proceedings Book of abstracts, the XVth Congress of the International Society of Biomechanics, July 3–6, 1995 Jyväskyla. Department of Biology of Physical Activity, University of Jyväskyla, Jyväskyla, 1995, 800–801.
17. Sasaki T., Tsunoda K., Uchida E., Hoshino H., Ono M., Joint power production in take-off action during ski-jumping. In: Müller E., Schwameder H., Kornexl E., Rascher C. (eds.), Science and skiing. E & FN Spon, London 1997, 49–60.
18. Virmavirta M., Komi P.V., Measurement of take-off forces in ski jumping – part II. *Scand J Med Sci Sports*, 1993, 3, 237–243. doi:10.1111/j.1600-0838.1993.tb00388.x.
19. Jošt B., Pustovrh J., Ulaga M., Jošt P., The latent dimensions of selected morphological and motor variables in ski jumpers. *Studies in Physical Culture & Tourism*, 2006, 13 (suppl.), 137–140.
20. O'Connor H., Olds T., Maughan J.R., Physique and performance for track and field events. *J Sports Sci*, 2007, 25 (S1), S49–S60. doi:10.1080/02640410701607296.

Paper received by the Editors: January 22, 2010.
Paper accepted for publication: April 12, 2010.

Address for correspondence
Prof. Dr Bojan Jošt
Faculty of Sport
University of Ljubljana
Gortanova 22, 1000 Ljubljana, Slovenia
e-mail: bojan.jost@fsp.uni-lj.si