

RESEARCH PROGRAM: MODELING OF MOTOR ABILITIES DEVELOPMENT AND TEACHING OF SCHOOLCHILDREN

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Abstract

The purpose of this study was to find methodological approaches to the development of a research program in modeling the process of teaching physical exercises, motor abilities development and pedagogical control in schoolchildren's physical education.

Materials and methods. The total number of schoolchildren involved in the experiment was: 6-10 years old – 465 (240 boys and 225 girls); 11-13 years old – 430 schoolchildren (205 boys and 225 girls); 14-16 years old – 221 schoolchildren (122 boys and 99 girls). To achieve the purpose set, the following research methods were used: modeling, systems approach, methods of theoretical analysis and generalization; pedagogical testing, methods of recording the respiratory system state, observation and pedagogical experiment; methods of mathematical analysis (logistic and asymptotic functions); mathematical methods of planning multifactorial experiments. Factor, discriminant, and regression analyses were performed.

Results. The research program of modeling schoolchildren's physical education includes the development of factor, discriminant, and regression models to obtain new information for planning and managing the processes of teaching physical exercises, motor abilities development, and pedagogical control in schoolchildren's physical education.

Conclusions. Modeling is an effective tool for studying the regularities of motor training and for developing physical education programs for children and adolescents.

In the program of modeling schoolchildren's physical education, initial data, study object, research methods must meet the following conditions: parametrical description (formulation of tasks, consideration of physical components, analysis of coefficients); initial data (information potential, reliability, accuracy, quantity); methods (similarity, accuracy, implementation time, coincidence with control criteria).

Keywords: physical education, children, adolescents, teaching, modeling.

Introduction

One of the conditions for improving the level of schoolchildren's motor fitness is pedagogical control in physical education (Bodnar, & Andres, 2016; Koryahin, & Blavt, 2016). The procedure of pedagogical control is a classification of the current state of motor and functional fitness, which influences decision making in managing children's and adolescents' physical education.

The main task of schoolchildren's physical training is to achieve a sufficient level of development necessary for effective teaching of physical exercises (Ivashchenko, Khudolii, Iermakov, & Harkusha, 2017). In the development of strength abilities in schoolchildren, it is important to select appropriate means and modes of strength exercises (Khudolii, Ivashchenko, Iermakov, Nosko, & Marchenko, 2019; Khudolii, Ivashchenko, Iermakov, Veremeenko, & Lopatiev (2019).

Physical activity, its appropriateness to age peculiarities and tasks of education are of primary importance both in mastering movements and motor abilities development (Ivashchenko, Khudolii, Iermakov, Chernenko, & Honcharenko, 2018; Ivashchenko, Khudolii, Iermakov, & Harkusha, 2017). Strength development in children depends on the assessment and control of strength loads (Cieślicka, Ivashchenko, 2017). The importance of assessing and managing the effects of training loads in schoolchildren's physical education is highlighted in papers by Kryvolapchuk (2008, 2009).

One of the effective methods of studying the results of teaching and training effects in physical education is modeling. The study of Lopatiev, Pityn, and Demichkovskiy (2017), Lopatiev, Ivashchenko, Khudolii, Pjanylo, Chernenko, and Yermakova (2017) systemizes and generalizes mathematical modeling procedures in physical education and sport. The study found that teaching and training based on information models make it possible to intensify the training process, to increase the effectiveness of learning management. Khudolii,

Ivashchenko, Iermakov, and Rumba (2016), Ivashchenko (2016) developed conceptual approaches to modeling the process of teaching and motor abilities development in physical education and sport. The researchers examined models of motor abilities development that can be used for current and final control of children's fitness. It was found that current control of the level of children's motor fitness can be carried out based on discriminant function analysis.

Thus, increasing schoolchildren's physical activity depends on their ability to respond adequately to physical loads during teaching physical exercises and motor abilities development, as well as on the planning and management of physical education. A necessary condition for this is to obtain objective information about the processes that take place. Modeling is one of the effective methods for obtaining such information.

The purpose of this study was to find methodological approaches to the development of a research program in modeling the process of teaching physical exercises, motor abilities development and pedagogical control in schoolchildren's physical education.

Materials and Methods

Study Participants

The total number of schoolchildren involved in the experiment was: 6–10 years old – 465 (240 boys and 225 girls); 11–13 years old – 430 schoolchildren (205 boys and 225 girls); 14–16 years old – 221 schoolchildren (122 boys and 99 girls). All the schoolchildren participating in the study were practically healthy and were supervised by a school doctor. The children and their parents were fully informed about all the features of the study and gave their consent to participate in the experiment.

Organization of the Study

The study substantiated the importance and necessity of using models of teaching physical exercises and motor abilities development in children, which ensure the effectiveness of the educational process in school.

At the ascertaining stage of the pedagogical experiment, the schoolchildren's motor fitness was tested. Factor and discriminant analyses were conducted. The study determined informative indicators for pedagogical control of the current state and indicators for end-to-end control of motor fitness of elementary, middle, and high school students.

At the formative stage of the pedagogical experiment, a full factorial experiment was conducted in accordance with conditions and requirements of the pedagogical research program. In the process of 2^k FFE, the study examined the influence of the number of sets, the number of repetitions, rest interval on improving the level of proficiency in motor actions, on the probability of successful performance of the exercise; on the dynamics of strength abilities development in schoolchildren. The study developed regression models based on the results of 2^k FFE, discriminant analysis and logistic function, which included the calculation of regression coefficients and model verification.

At the control stage of the pedagogical experiment, the study determined the effectiveness of methodological approaches to the development of a research program in modeling the process of teaching physical exercises, motor abilities

development, and pedagogical control in schoolchildren's physical education.

To achieve the purpose of the study, the following research methods were used: modeling, systems approach, methods of theoretical analysis and generalization to reveal the essence, leading development trends of physical education, and to define theoretical prerequisites and methodological approaches to its further improvement; pedagogical testing, methods of recording the respiratory system state, observation and pedagogical experiment to find methodological approaches to modeling the process of teaching, motor abilities development and pedagogical control in children's physical education; methods of mathematical analysis (logistic and asymptotic functions) to determine the regularities of allocating the means of primary focus during motor abilities development, teaching physical exercises; mathematical methods of planning multifactorial experiments to study the regularities of motor abilities development and teaching physical exercises.

Testing Procedure

The study recorded the following:

elementary school students – One-leg static stance (sec); Walking along segments of hexagon (steps); Combined movements of arms, torso and legs (errors); Walking along straight line after 5 rotations, deviations (cm); Shuttle run 4×9 m (sec); 30 m run (sec); Frequency of arm movements (times); Catching a falling Dietrich's stick (cm); Standing long jump (cm); 300 m run (sec); Mixed hanging pull-ups on rope (times); One minute sit-ups (times); Seated forward bend (cm); Spine mobility test (bridge stand); Shoulder mobility test;

middle school students – Height (cm), Body weight (kg), Vital lung capacity (cm³), Handgrip strength, right hand (kg), Handgrip strength, left hand (kg), Extra distance jumps (times); Shuttle run 4×9 m (sec), Push-ups (times), Pull-ups (times), Bent arm hang (sec), Standing long jump (cm), Lying pull-ups (times), Hanging leg raise (times), L-sit on parallel bars (sec), One minute sit-ups (times), Seated forward bend, legs apart (cm), Bent arm hang (sec), Trunk lift in 30 sec (times), Throwing a stuffed ball (1 kg) from a sitting position (cm), Stange test (sec), Genchi test (sec), Serkin test (sec), Forward roll (level of proficiency), Backward roll (level of proficiency), Vault (level of proficiency), Rope climbing in three steps (level of proficiency), Bridge stand (level of proficiency), Inverted shoulder stand (level of proficiency).

The level of proficiency in gymnastic exercises during every class was assessed by the alternative method ("performed", "failed"), the probability of performing the exercise was calculated ($p = n/m$, where n is the number of successful attempts, m is the total number of attempts).

Statistical Analysis

The obtained experimental material was processed using statistical analysis software (SPSS 20). Factor, discriminant, and regression analyses were performed.

Results

The application of systems approach made it possible to reveal integrative, systemic characteristics of the study object; to identify modeling techniques that can be used in informa-

tion support of motor abilities development and teaching of children and adolescents.

Among the objects studied using mathematical modeling in physical education are: age dynamics of children's functional and motor fitness; physical exercises modes and their impact on performance; children's motor training. A 2k full factorial experiment (models of training effects), logistic function (determination of terms of teaching and motor abilities development), and discriminant function (pedagogical control of fitness level) can be used to obtain the models (Lopatiev, Ivashchenko, Khudolii, Pjanylo, Chernenko, & Yermakova, 2017; Ivashchenko, 2016; Khudolii, 2019).

In mathematical models of processes, initial data, study objects, research methods must meet the following conditions (Fig. 1):

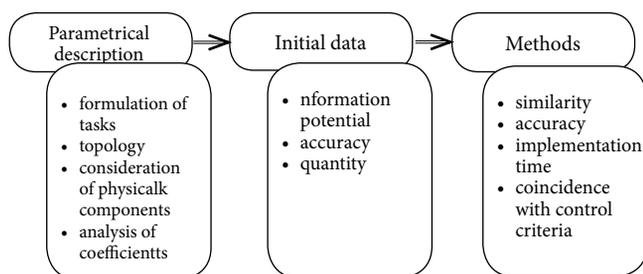


Fig. 1. Structural diagram of natural processes' mathematical modeling (Lopatiev, Ivashchenko, Khudolii, Pjanylo, Chernenko, & Yermakova, 2017)

A full factorial experiment method makes it possible to mathematically describe the process in some local area of the factorial space around the point with coordinates of the n-dimensional space and to verify the regression model.

The study revealed the effectiveness and reliability of 22 factorial designs in determining the effects of different training modes on the change in children's functional state and the ability to learn movements (Khudolii, Ivashchenko, Iermakov, & Rumba, 2016; Ivashchenko, 2016).

The analysis of change in learning outcomes and pulse rate in each lesson of the plan showed that both processes can be described by a dependence (model) (Lopatiev et al., 2017; Ivashchenko, 2016)

$$Y = A / (1 + 10^{(a_m + bx)}) + C,$$

where Y (heart rate/level of proficiency) is the function result, depending on the number of sets x , A , C , a_m , b are the coefficients of the so-called logistic function.

The logistic function regression equation coefficients vary significantly depending on exercises modes and rest at the design points.

This dependence can be described by the following type of equations:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2,$$

where x_1 is the amount of movements in the lesson, x_2 is the rest interval.

It was found that the relationship between the change in learning outcomes and pulse rate during the lesson can be described by the following nonlinear dependence

$$Y = a + b\eta + b\eta^2,$$

where Y is the learning outcome, η is the pulse rate.

At the point $\eta = -b_1/2b^2$, the maximum level of assessment is observed, and the pulse rate becomes a boundary between the work aimed at learning and endurance development.

Thus, modeling is an effective method for obtaining new knowledge about the regularities of the process of teaching physical exercises.

The analysis of scientific and methodological literature shows that strength development is a process of adaptation that combines immediate and long-term stages of implementation (Verkhoshanskij, 1985; Khudolii, 2005). The study conducted under the 2² FFE program allowed to identify the models of immediate and delayed training effects of strength loads. Based on regression equations, two types of strength loads were calculated: a) concentrated strength load ($M - s$) (mode "A"), b) strength load favorable for maximum effort ($M + s$) (mode "D") (Khudolii, 2005; Khudolii, et al., 2016).

Verification of models of strength change under the influence of training loads showed that the equations describe the experimental data quite accurately ($p < 0.01$) (Khudolii, Ivashchenko, Iermakov, Nosko, & Marchenko, 2019).

Thus, modeling of strength training makes it possible to obtain information about the amount of load and the number of training sessions required to achieve the optimal level of strength development in children and adolescents.

To determine the transition of the system from one state to another, a discriminant function was used, since pedagogical control of schoolchildren's functional and motor fitness is aimed at identifying minimal changes that characterize this process.

Based on the canonical discriminant function coefficients, the children were classified by their motor fitness level according to age, which is of practical importance for developing effective programs of their motor training. Verification of functions indicates their high discriminative ability and value in interpreting the general population (Tables 1, 2).

Table 1. Canonical discriminant function. Eigenvalues

Function	Eigenvalues	% of explained dispersion	Cumulative %	Canonical correlation
1	16.161	95.2	95.2	0.970
2	0.579	3.4	98.6	0.605
3	0.136	0.8	99.4	0.346
4	0.096	0.6	100.0	0.296

Table 2. Canonical discriminant function. Wilks' lambda

Function verification	Wilks' lambda	Chi-square	Degrees of freedom	P
From 1 to 4	0.030	805.684	60	0.000
From 2 to 4	0.509	154.721	42	0.000
From 3 to 4	0.803	50.142	26	0.003
4	0.913	20.958	12	0.051

The first canonical function explains 95.2 % of the results variation, the second one 3.4 %, which indicates their high informative value (see Table 1). The correlation coefficient between the calculated values of the discriminant function and group membership indicators is $r = 0.970$ and shows a high predictive value of the first canonical function. The eigenvalue of the first canonical function indicates that its coefficients are well-chosen.

Table 2 presents material of the analysis of canonical functions. The first line contains the value $\lambda = 0.030$ and the

Table 3. Unstandardized canonical discriminant function coefficients. Boys aged 6–10 years

No	Test	Function			
		1	2	3	4
1	One-leg static stance (sec)	.000	.031	-.031	-.022
2	Walking along segments of hexagon (steps)	-.053	.148	-.300	.269
3	Combined movements of arms, torso and legs (errors)	.031	.053	.019	-.129
4	Walking along straight line after 5 rotations, deviations (cm)	.001	.001	-.003	-.009
5	Shuttle run 4×9 m (sec)	-.084	-.437	-.128	.244
6	30 m run (sec)	-.083	.242	1.168	-.453
7	Frequency of arm movements (times)	-.014	-.009	.041	.008
8	Catching a falling Dietrich's stick (cm)	.005	-.043	.005	-.007
9	Standing long jump (cm)	-.004	.034	.004	.005
10	300 m run (sec)	.075	.021	-.004	.006
11	Mixed hanging pull-ups on rope (times)	.070	-.054	.069	.044
12	One minute sit-ups (times)	-.001	.038	.022	-.005
13	Seated forward bend (cm)	.002	-.040	.057	.074
14	Spine mobility test (bridge stand)	.007	.053	.064	.002
15	Shoulder mobility test	.473	-.585	.358	.918
	(Constant)	-4.935	-1.661	-11.119	-3.421

statistical significance $p = 0.001$ for the entire set of canonical functions, the second line contains data after excluding the first function, etc. The first and second functions have a high discriminative ability and value in interpreting the general population.

Table 3 shows the canonical discriminant function coefficients (unstandardized), which act as multipliers of the fixed values of variables included in discriminant functions. Based on the comparison of the obtained data with the centroids of functions (see Table 4), we classify each case separately. The

Table 4. Functions at group centroids. Boys aged 6–10 years

Boys' age	Function			
	1	2	3	4
6 years	3.574	-1.218	-.247	.104
7 years	3.554	.364	.240	-.519
8 years	2.038	.852	.021	.369
9 years	-5.203	-.478	.506	.079
10 years	-5.231	.336	-.599	-.188

classification results shown in Table 5 indicate that 78.3% of the original grouped observations are correctly classified.

The graphic material given in Fig. 2 shows the density of objects in each class and a distinct boundary between the classes, which indicates the possibility of classifying the boys aged 6-10 years using the above-mentioned battery of tests.

During the analysis, the study calculated the canonical discriminant function coefficients (unstandardized), which act as multipliers of the fixed values of variables included in discriminant functions. It is possible to use them to classify the boys by their motor fitness level according to their age, which is of practical significance.

Thus, the discriminant analysis made it possible to answer the question: how reliably one class can be separated

from another by a set of suggested variables; which of these variables most significantly influence the differentiation of classes; what class the object belongs to based on the values of discriminant variables.

Consequently, the suggested methodological approaches to modeling are the basis of information support of the learning process and provide new information about the impact of fitness level, loads and focus of lessons on the effectiveness of motor skills formation and motor abilities development in children.

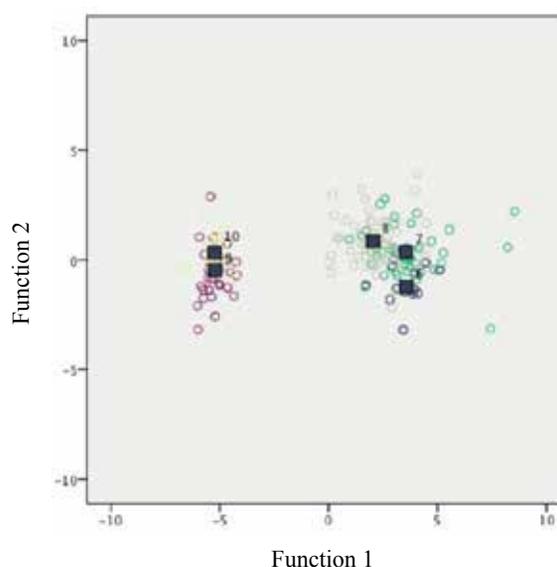


Fig. 2. Canonical discriminant functions. Graphic representation of the results of classification of boys aged 6–10 years by the level of motor fitness: ■ – centroids for groups 6, 7, 8, 9, 10 years (Ivashchenko, 2016)

Table 5. Results of group classification. Boys aged 6–10 years

	Boys' age	Predicted group membership					Total
		6 years	7 years	8 years	9 years	10 years	
Frequency	6 years	38	6	4	0	0	48
	7 years	9	25	11	0	0	45
	8 years	4	3	53	0	0	60
	9 years	0	0	0	38	9	47
	10 років	0	0	0	6	34	40
%	6 years	79.2	12.5	8.3	.0	.0	100.0
	7 years	20.0	55.6	24.4	.0	.0	100.0
	8 years	6.7	5.0	88.3	.0	.0	100.0
	9 years	.0	.0	.0	80.9	19.1	100.0
	10 years	.0	.0	.0	15.0	85.0	100.0

The obtained materials confirm the effectiveness of the suggested approaches to modeling when studying the regularities of pedagogical control, motor abilities development and teaching of schoolchildren.

In pedagogical control of motor abilities development, there are two vectors. The first vector is the assessment of a current state, the second is the assessment of a state dynamics. It is essential to choose an appropriate informative indicator and assessment scale. To assess the current state, factor analysis, which determines informative indicators, and a sigma assessment scale are used. To assess the state dynamics, discriminant analysis is used, which allows to determine informative indicators for end-to-end control and to decide what class of fitness the pupil belongs to based on discriminant functions.

As an example, let us consider the results of factor and discriminant analyses as a methodological basis for pedagogical control of motor and functional fitness of girls aged 12–14.

The analysis of test results revealed that the girls aged 12–14 show a positive statistically significant dynamics in the following tests: Test 2 Shuttle run 4×9 m (sec), Test 3 Push-ups (times), Test 4 Pull-ups (times), Test 6 Standing long jump (cm). The girls aged 12–14 show a consistent statistically significant dynamics of results in functional tests, the girls aged 14 are evaluated as healthy trained. With age, the results in differentiation of spatial characteristics of movement statistically significantly deteriorate (Test 1 “Extra distance jumps, times”).

In the factor model of motor and functional fitness of the girls aged 12, the priority components are functional fitness of respiratory and cardiovascular systems, coordination and strength fitness, speed and strength fitness; for the girls aged 13 – coordination and strength fitness, functional fitness of respiratory and cardiovascular systems, differentiation of spatial characteristics of movement; for the girls aged 14 – functional fitness of respiratory and cardiovascular systems, strength fitness, strength endurance.

For pedagogical control of motor and functional fitness of the girls aged 12–14, the most informative tests are the following:

- for the girls aged 12: Serkin test (sec) (0.854), Shuttle run 4×9 m (sec) (0.833), Genchi test (sec) (0.814), Push-ups (times) (0.762);

Table 6. Canonical discriminant function. Eigenvalues. Girls aged 12–14 years

Function	Eigenvalues	% of explained dispersion	Cumulative %	Canonical correlation
1	11.447	86.8	86.8	.959
2	1.736	13.2	100.0	.797

- for the girls aged 13: Bent arm hang (sec) (0.967), Extra distance jumps (times) (0.964), Serkin test (sec) (0.928), Stange test (sec) (0.927);
- for the girls aged 14: Extra distance jumps (times) (0.959), Standing long jump (cm); (0.959), Genchi test (sec) (0.945), Stange test (sec) (0.938).

To clarify the possibility of assessing the state of motor and functional fitness of the girls aged 12–14, a discriminant analysis was conducted (see Table 6).

The first canonical function explains 86.8 % of the results variation, the second 13.2 %, which shows their high informative value. Verification of the functions indicates statistical significance for both the entire set and after excluding the first function ($p < 0.001$; $\lambda_{12} = 0.029$; $\lambda_2 = 0.365$).

Table 7 shows standardized canonical discriminant function coefficients that allow to determine the ratio of contribution of the variables to the function result. Variables of Tests 2, 1, and 6 make the greatest contribution to the first canonical function: the larger the values of these variables, the larger the value of the function. Variables of Tests 5, 4, and 8 contribute most to the second canonical function: the larger the values of these variables, the larger the value of the function. The first function explains 86.8% ($p < 0.001$) of the results variation, the second function 13.2% ($p < 0.001$). The above shows that it is possible to classify age differences of the girls aged 12–14 based on functional, strength, and coordination fitness tests.

Table 7 shows structure coefficients of the first canonical discriminant function, which are the coefficients of correlation between the variables and the function. Thus, the function is most closely connected with variables in Tests 2, 6, 7, 1: hence, a significant difference between the girls aged 12 and 13–14 is observed in the development level of motor coordination, speed strength, and the Stange test results. The

Table 7. Results of discriminant analysis of the level of functional and motor fitness of girls aged 12–14

N	Test	Standardized coefficients		Structure coefficients		Function coefficients for classification of girls		
		Function		Function		Age		
		1	2	1	2	12	13	14
1	Extra distance jumps (times)	.420	.354	.306	.001	9.618	5.922	6.249
2	Shuttle run 4×9 m (sec)	.697	.453	.514	.334	60.009	51.143	51.224
3	Push-ups (times)	.311	.557	-.177	.071	2.945	2.452	2.638
4	Pull-ups (times)	.324	-1.046	-.079	-.191	-4.892	-4.591	-6.787
5	Bent arm hang (sec)	-.006	.988	-.125	.503	-.121	-.367	-.019
6	Standing long jump (cm)	-.837	.136	-.465	.205	1.522	1.941	2.138
7	Stange test (sec)	-.342	-.116	-.310	-.072	.626	.801	.826
8	Genchi test (sec)	-.370	.658	-.265	.115	.375	.442	.754
9	Serkin test (sec)			-.214	.086			
	(Constant)					-573.744	-516.379	-567.189

Table 8. Results of group classification. Girls aged 12–14 years

Results of group classification					Functions at group centroids			
	Classifier (age, years)	Predicted group membership (age, years)			Age, years	Function		
		12	13	14		1	2	
		Original	Frequency	12		31	0	0
13	0			24	2	13	-1.416	-1.870
14	0			1	27	14	-3.401	1.287
%	12		100.0	.0	0			
	13		.0	92.3	7.7			
	14		.0	3.6	96.4			

structure coefficients of the second canonical discriminant function indicate that the function is most closely connected with variables of Tests 5 and 4. Hence, a significant difference between the girls aged 13 and 14 is observed in the development level of static and relative strength of arm muscles.

Table 8 shows the results of classification of groups, 96.5% of the original grouped observations were classified correctly. Thus, the canonical discriminant function can be used to classify age peculiarities of functional and motor fitness of the girls aged 12–14. The obtained centroid coordinates for the three groups allow to interpret the canonical function in terms of the role in classification. At the positive pole, there is a centroid for the girls aged 12, at the negative one a centroid for the girls aged 13 and 14, which reveals a significant difference in the fitness level of the girls aged 12–14 years.

The graphic material (see Fig. 3) shows the density of objects in each class and a distinct boundary between the classes, which indicates the possibility of classifying the girls aged 12–14 years using the above-mentioned battery of tests. Table 7 shows function coefficients for classifying the girls aged 12–14 by their level of functional and motor fitness.

The study’s findings point to the need for structural and functional analysis of children’s motor fitness. The performed analysis confirms that the girls aged 12 can be separated from

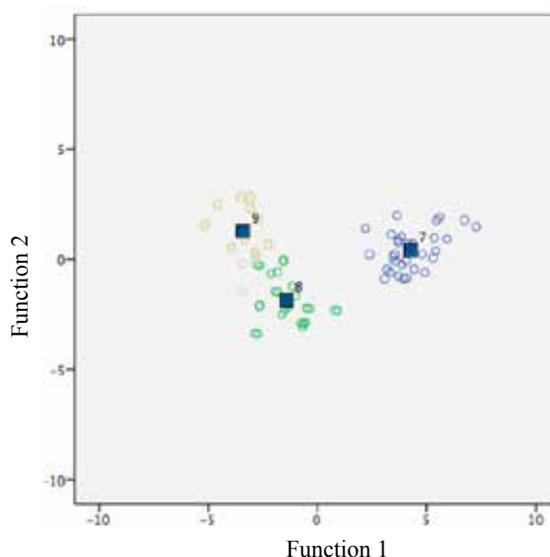


Fig. 3. Canonical discriminant functions. Graphic representation of the results of classification of girls aged 12–14 years: ■ – centroids for groups of girls 12 (7), 13(8), 14(9) years

Table 9. Canonical discriminant function. Eigenvalues. Girls aged 11–13 years

Function	Eigenvalues	% of explained dispersion	Cumulative %	Canonical correlation
1	5.430	76.7	76.7	.919
2	1.645	23.3	100.0	.789

Table 10. Canonical discriminant function. Wilks' lambda. Girls aged 11–13 years

Function verification	Wilks' lambda	Chi-square	Degrees of freedom	p
від 1 до 2	.059	437.819	44	.000
2	.378	150.297	21	.000

Table 11. Canonical discriminant function coefficients. Girls aged 11–13 years

No	Measurement	Structure coefficients function	
		1	2
1	Height (cm)	.444	-.022
2	Body weight (kg)	.262	-.011
3	Vital lung capacity (cm3)	.258	-.056
4	Handgrip strength, right hand (kg)	.316	-.080
5	Handgrip strength, left hand (kg)	.268	-.130
6	Push-ups (times)	.222	-.092
7	Lying pull-ups (times)	.436	-.085
8	Hanging leg raise (times)	.213	.049
9	L-sit on parallel bars (sec)	-.070	-.200
10	One minute sit-ups (times)	.298	-.234
11	Seated forward bend, legs apart (cm)	-.017	.362
12	Bent arm hang (sec)	.390	.050
13	Trunk lift in 30 sec (times)	.405	-.271
14	Standing long jump (cm)	.369	.343
15	Throwing a stuffed ball (1 kg) from a sitting position (cm)	.519	.243
16	Shuttle run 4x9 m (sec)	-.231	.249
17	Forward roll (level of proficiency)	.198	-.052
18	Backward roll (level of proficiency)	.260	-.162
19	Vault (level of proficiency)	.288	-.023
20	Rope climbing in three steps (level of proficiency)	.224	-.078
21	Bridge stand (level of proficiency)	-.016	-.109
22	Inverted shoulder stand (level of proficiency)	.249	-.300

those aged 13 and 14 years using the above-mentioned set of suggested variables with emphasis on functional tests and results of speed and strength fitness.

Motor abilities development in children is considered from the standpoint of improving the educational process effectiveness. Strength development in schoolchildren, in

contrast to elite sports, is viewed as a necessary condition for improving the process of teaching and motor abilities development.

The effectiveness of strength development is significantly influenced by strength exercises modes, as well as the interaction of training effects. Strength development programming is based on the assessment of training effects and determination of the optimal number of strength training sessions.

The study made an assumption that the system of children's physical education has a hierarchical structure where motor abilities development is subordinated to the process of motor skills formation. To accept this hypothesis, the study classified motor fitness of the girls aged 11–13 years, taking into account the level of proficiency in physical exercises (see Table 9).

The first canonical function explains 76.7 % of the results variation, the second one 23.3 %, which indicates a high informative value of the first and second canonical functions ($r_1 = 0.919$; $r_2 = 0.789$) (see Table 9). Table 10 presents material of the analysis of canonical functions. The first line contains the value $\lambda = 0.059$ and the statistical significance $p = 0.001$ for the entire set of canonical functions; the second line contains data after excluding the first function ($\lambda = 0.378$; $p = 0.001$). The first and second functions have a high discriminative ability and value in interpreting the general population.

The standardized canonical discriminant function coefficients indicate that the greatest contribution to the first canonical function is made by variables that characterize physical development, dynamic and static relative strength. The largest contribution to the second canonical function is made by variables that characterize speed, dynamic and static strength, motor coordination, the level of proficiency in acrobatic exercises.

The structure coefficients of the first discriminant function show that the function is most closely connected with variables that characterize physical development, speed, dynamic and static strength, the level of proficiency in physical exercises. The structure coefficients of the second discriminant function show that the function is most closely

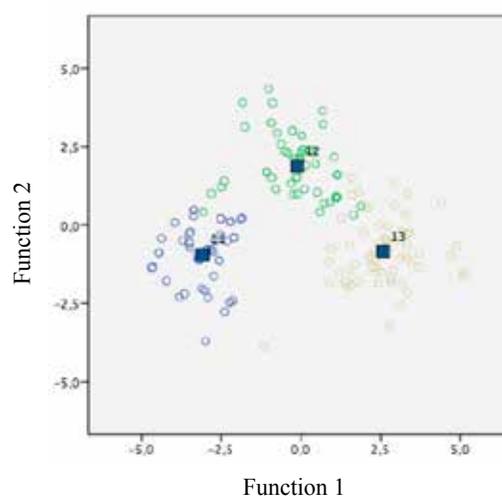


Fig. 4. Canonical discriminant functions. Graphic representation of the results of classification of motor fitness of girls aged 11–13 years, taking into account the level of proficiency in physical exercises: ■ – centroids for groups 11, 12, 13 years

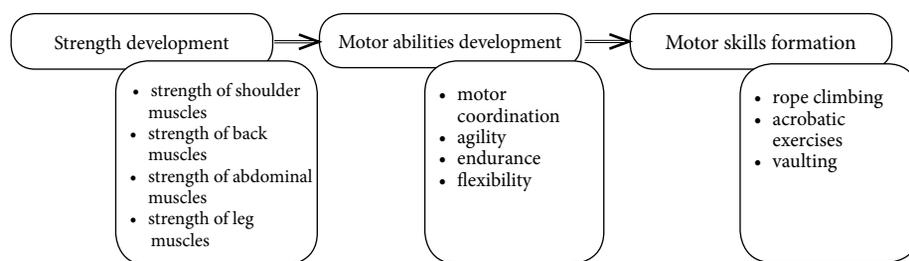


Fig. 5. Scheme of motor abilities development and motor skills formation in girls aged 11–13 years

connected with flexibility and the level of proficiency in Inverted shoulder stand (Table 11).

In the classification of motor fitness results of the girls aged 11–13, taking into account the level of proficiency in physical exercises, 95.8% of the original grouped observations are correctly classified. Thus, the canonical discriminant function can be used to determine the peculiarities of managing the process of teaching and motor abilities development in children.

The graphic material given in Fig. 4 shows the density of objects in each class and a distinct boundary between the classes. At the positive pole of the first function, there are centroids of the state of the girls aged 13, at the negative one centroids of the state of the girls aged 11. This suggests that the classification of motor fitness of girls aged 11–13, taking into account the level of proficiency in physical exercises makes it possible to consider the system of children's physical education as a hierarchical system where motor abilities development is subordinated to the process of motor skills formation.

The findings characterize development links and show that children's physical education has a hierarchical structure where motor abilities development is subordinated to the process of motor skills formation: strength development – development of motor coordination, agility, endurance, and flexibility – motor skills formation (Fig. 5).

Discussion

The paper assumed that the research program in modeling schoolchildren's physical education involves the development of factor, discriminant, and regression models to obtain new information for planning and managing the processes of teaching physical exercises, motor abilities development, and pedagogical control in physical education of schoolchildren.

With regard to biological and natural objects and processes, the models should include the characteristics of the environment itself (Lopatiev, Pityn, & Demichkovskiy, 2017) and the influence and typical response of the system to perturbation (Lopatiev, et al., 2017).

The findings clarify the conceptual approaches to experimental planning in studying the learning process effectiveness and the development of learning models in children (Ivashchenko, 2016); regression models provide an opportunity to choose the best option for teaching every exercise and supplement the conclusions on the effectiveness of using FFE in physical education and sport research (Khudolii, et al., 2016; Khudoli, Ivashchenko, & Chernenko, 2015).

The findings supplement the data on the use of factor and discriminant analyses in determining the structure of motor fitness of children and adolescents (de Bruijn, G.-J., & Gardner, B., 2011; Dorita Du Toit, Anita E. Pienaar, & Leani

Truter, 2011). Similarly to papers by Geoffrey D. Broadhead And Gabie E. Church (1982), we observed a high predictive ability of factor analysis in determining the model and informative indicators of schoolchildren's motor fitness.

The data obtained testify to a sufficient effectiveness of a discriminant function in assessing training effects of strength loads in children and add up to the results of research on age peculiarities of strength development in children and adolescents (Ivashchenko, & Cieślicka, 2016).

These findings supplement those of Xu, X., & Ke, F. (2014) about the influence of physical peculiarities on motor skills formation in elementary-school-aged children, and those of Khudolii, Ivashchenko, and Chernenko (2015), Kapkan, Khudolii, and Bartik (2019) about the factors that influence the effectiveness of teaching gymnastic exercises.

The performed discriminant analysis allowed to consider motor abilities development and teaching as a whole. The analysis of standardized and structure canonical discriminant function coefficients made it possible to define the role of any given indicator in the structure of the process under study, which points to the necessity of using multidimensional methods of mathematical statistics to study the regularities of physical education of children and adolescents.

Thus, the research program includes:

- determination of an object, subject of study, formulation of research hypothesis;
- setting of the following procedural tasks:
- development of a structural model of schoolchildren's motor fitness separately for each class;
- development of a discriminant model of motor fitness of elementary, middle, and high school students;
- development of regression and discriminant models of motor abilities development separately for each class;
- development of regression and discriminant models of teaching physical exercises to elementary, middle, and high school students;
- organization and performance of a pedagogical experiment.

Conclusions

Modeling is an effective tool for studying the regularities of motor training and for developing physical education programs for children and adolescents. The research program of modeling schoolchildren's physical education includes the development of factor, discriminant, and regression models to obtain new information for planning and managing the processes of teaching physical exercises, motor abilities development, and pedagogical control in schoolchildren's physical education.

In the program of modeling schoolchildren's physical education, initial data, study object, research methods must meet the following conditions: parametrical description (formulation of tasks, consideration of physical components, analysis of coefficients); initial data (information potential, reliability, accuracy, quantity); methods (similarity, accuracy, implementation time, coincidence with control criteria).

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Conflict of Interest

The author declares no conflict of interest.

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ПРОГРАМА ДОСЛІДЖЕННЯ: МОДЕЛЮВАННЯ ПРОЦЕСУ РОЗВИТКУ РУХОВИХ ЗДІБНОСТЕЙ І НАВЧАННЯ ШКОЛЯРІВ

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Реферат. Стаття: 10 с., 11 табл., 5 рис., 23 джерела.

Мета дослідження – визначити методологічні підходи до розробки програми дослідження у моделюванні процесу навчання фізичних вправ, розвитку рухових здібностей і педагогічного контролю у фізичному вихованні школярів.

Матеріали і методи. Загальна кількість учнів охоплених експериментом: 6–10 років – 465 (240 хлопчиків та 225 дівчаток); 11–13 років – 430 учнів (205 хлопців та 225 дівчат); 14–16 років – 221 учень (122 хлопців та 99 дівчат). Для досягнення поставленої мети у роботі були використані такі методи дослідження: моделювання, системний підхід, методи теоретичного аналізу та узагальнення; педагогічне тестування, методи реєстрації стану дихальної системи, спостереження і педагогічний експеримент; методи математичного аналізу (логістична і асимптотична функції); математичні методи планування багатфакторних експериментів. Здійснювався факторний, дискримінантний і регресійний аналіз.

Результати. Програма дослідження моделювання процесу фізичного виховання школярів включає в себе

розробку факторних, дискримінантних і регресійних моделей для отримання нової інформації для планування і управління процесами навчання фізичних вправ, розвитку рухових здібностей і здійснення педагогічного контролю у фізичному вихованні школярів.

Висновки. Метод моделювання є ефективним інструментом для вивчення закономірностей процесу рухової підготовки та розробки програм фізичного виховання дітей і підлітків.

У побудові програми моделювання процесу фізичного виховання школярів вхідна інформація, об'єкт дослідження, методи дослідження повинні задовольняти таким умовам: параметричний опис (формулювання завдань, врахування фізичних складових, аналіз коефіцієнтів); вхідні дані (інформативність, надійність, точність, кількість); методи (збіжність, точність, час реалізації, узгодження точності з критеріями керування).

Ключові слова: фізичне виховання, діти, підлітки, навчання, моделювання.

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