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Intra- and intergroup interrelations of parameters of physical development structure and speed-strength fitness of highly skilled combat athletes

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Abstract

Background and Study Aim The objective of this work is to study intra- and intergroup interrelations of parameters of physical development (PD) structure and speed-strength fitness (SSF) of highly skilled combat athletes.

Material and Methods The research was conducted on 44 highly skilled athletes aged 18–30 years, members of the national teams of Ukraine in Greco-Roman and freestyle wrestling, and judo. Most of them were students. In the course of studies, 39 PD and 11 physical fitness (PF) indices were recorded. Of the PD parameters, the circumferential (CBD) and transverse body dimensions, and skinfold (SF) thickness were registered, whereas of the PF parameters — indices of SSF and special work capacity of combat athletes. The methods of factor, correlation, regression, and canonical analysis were used to process and analyze the experimental material.

Results Statistical analysis revealed three key factors determining the general structure of PD and PF of combat athletes: 1) the factor of CBD; 2) the factor of SSF; 3) the factor of SF thickness and the total level of the fat component. As a result of stepwise regression analysis, multiple regression models characterizing the influence of the key PD and SSF indices on the level of special work capacity of combat athletes were developed. Canonical analysis of interrelations between the parameters of SSF and CBD revealed a high interdependence, indicating that the increase in the CBD of combat athletes contributes to the increase in their SSF and vice versa—the increase in SSF contributes to the increase in CBD. A moderate interdependence was disclosed between the parameters of SF and SSF, explaining the variability of a relatively small part of one group's parameters when changing the parameters of the other group. The results of the interaction between SF and CBD indicate that the SF thickness indices show a low dependence on the changes in CBD, whereas the latter demonstrates a strong dependence on SF thickness.

Conclusions The key factors of the structure of PD and PF of combat athletes include CBD, SSF, and SF thickness. As a result of the canonical analysis: 1) the specificity of mutual influence and interrelations of the CBD, SSF, and SF indices was determined; 2) the key factors and indices determining the general variability (redundancy) of the parameters of each group under study were revealed; 3) strong, moderate, and weak intra- and intergroup paired interrelations of the CBD, SF thickness, and SSF indices were disclosed. The strongest intra-group interrelations are manifested between the CBD indices, whereas the strongest inter-group interrelations are between the CBD and SF thickness indices.

Keywords: physical development, physical fitness, interrelations, models, combat athletes

Introduction

Physical development (PD), physical, technical-tactical, and psychological fitness of skilled combat athletes are interrelated key components of the physical condition (PC) structure. Their level, ratio, and interrelations determine the competition form, qualification, and the level of special work capacity of combat athletes [1, 2, 3]. The complex of factors and indices determining the fitness structure of skilled athletes envisages comprehensive and systematic approaches to reveal the key mechanisms that ensure the competition form and the level of special work capacity of combat athletes.

Meanwhile, the works of most authors addressed, as a rule, separate aspects of combat athletes' fitness structure, including:

a) physical fitness [4];
b) physical development [5, 6, 7];
c) technical-tactical fitness [8, 9, 10];

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d) psychological fitness [11, 12];
e) functional state [13, 14, 15];
f) energy support of special work capacity [16].

The diverse material presented in publications reflects the variety of factors determining the structure of combat athletes' fitness, their competition form, and the level of special work capacity. This approach, however, methodologically does not allow us to study the PC structure of combat athletes as a set of interrelated components and qualities that determine the competition form, functional reserves, and the level of special work capacity [17].

In accordance with the principles of the system approach, the level of competition form, functional reserves, and physical work capacity are determined not only by the level of development of individual PC components but also by their ratio and interrelations in the overall fitness structure (FS) of athletes [17]. For instance, it was noted in the publications of Podrigalo et al. [18], Volodchenko et al. [19], and Pryimakov et al. [17] that the sports result and special work capacity of combat athletes are determined both by the level of development of individual morphological, functional, and metabolic components of the athletes' PC structure and by their interaction.

However, most comprehensive publications do not sufficiently analyze the interrelations of the PC structure components of highly skilled combat athletes, providing a high level of special work capacity. The use of system analysis methods allowed the authors of a few publications to study the interrelationships of individual components of the combat athletes' PC structure and the mechanisms of their integration in the dynamics of sports improvement.

In some publications, the interrelations of morphological and functional indices in the process of morphofunctional profile formation and provision of special work capacity of Greco-Roman wrestlers [20, 21, 22], athletes specializing in taekwondo [23], and judo [24] were analyzed. The studies by Durkalec-Michalski et al. [25] and Witkowski et al. [24] analyzed the relationship between body composition parameters and motor potential in individual weight categories of judokas.

In these publications, the authors noted that the development and improvement of physical, technical-tactical, and psychological fitness of combat athletes are interrelated and interdependent. It is characteristic that in the process of long-term adaptation to physical loads, a complex structural-functional multilevel organization of the body of combat athletes with a high level of special work capacity, technical-tactical and psychological fitness, and competitive activity efficiency is formed.

In our previous publications, it was noted that as a result of a long-term adaptation process, the FS of combat athletes is formed and improved as a set of interrelated hierarchically organized structural and functional components. Their interaction is organized according to the type of mutual interaction, ensuring the achievement of a high level of special work capacity and sports results [3, 17].

However, the issues of formation and improvement of combat athletes' FS, their morphofunctional, metabolic, psychological, and technical-tactical profiles are not sufficiently reflected in these and other works [22]. One cannot recognize the quantity and quality of publications, in which the FS of combat athletes would be covered from complex and systemic positions, as sufficient, and above all, from the positions of analyzing the ratios and interrelations of various components of the combat athletes' PC structure in the process of improving their competition form and special work capacity [20, 26].

The solution of such problems is possible by using the methods of complex and system approaches and comprehensive methods of experimental material mathematical processing [3, 17, 27].

In the publications of the majority of authors dealing with the structure of combat athletes' PF, the role of individual PC parameters in determining the level of athletes' special fitness was preferentially analyzed [4, 23, 26]. Some publications present a complex of heterogeneous indices that form the profile of highly skilled athletes [1, 20, 21, 22]. The interrelationships of PC structure parameters influencing the level of physical work capacity of combat athletes have been studied to a much lesser extent [28].

As for the role of intergroup interactions of PC parameters in determining the level of special fitness of combat athletes, it has not been studied at all. The publications do not contain the analysis of the cumulative mutual impact of interrelated indices belonging to different groups of the PC structure. In particular, the specifics of the cumulative mutual impact of a set of indices of physical development (PD), physical fitness (PF), and special work capacity (SWC) of combat athletes of different skill levels, gender, fitness level, and weight categories are understudied.

The narrowness of analytical methods of research and the complexity of the problem of covering the FS of combat athletes served as a basis for applying in the research process the methods of factor, correlation, and regression analysis along with the methods of complex and system approaches [3, 5, 17, 27].

The use of complex methods of statistical processing allowed a number of authors to determine the key indices and their interrelations in the general FS of combat athletes and to develop mathematical models reflecting the partial contribution of individual morphofunctional

indices to the level of athletes' special work capacity [3]. However, the available publications do not fully disclose the PF structure of combat athletes. The developed models insufficiently reflect the mutual influence of the most interrelated indices belonging to different groups of combat athletes' PC - PD, PF, and SWC. The system approach implies the study of the PC structure in the dynamics of age growth and development, in the process of long-term adaptation to physical loads, and depending on various factors, such as gender, weight category, and skill level of athletes. The diversity of factors determining the formation of combat athletes' FS envisages complex and systemic approaches to its description.

Insufficient study of the integrative activity of the combat athlete's body and the importance of most of the considered issues for the theory and practice of sports preparation served as a basis for choosing the objective of this work: the study of intra- and intergroup interrelations of the parameters of physical development structure and speed-strength fitness of highly skilled combat athletes.

Material and Methods

Participants

The research was conducted on 44 highly skilled combat athletes aged 18–31 years, including members of the national teams of Ukraine in Greco-Roman and freestyle wrestling, and judo. Most of them were students. The study protocol was approved by the Ethics Committee of the University. The research was conducted in compliance with the WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects [29].

Study Design

The groups of PD and PF parameters were defined as components of the fitness structure of combat athletes. Of the PD parameters, the circumferential (CBD) body dimensions and skinfold (SF) thickness were registered, whereas of the PF parameters—indices of speed-strength fitness and special work capacity.

Of the CBD parameters, the circumference dimensions of the neck (CND), chest (CCD), abdomen (CAD), shoulder (CSD), forearm (CFD), tibia (CTD), and thigh (CThD) were recorded. Of the SF thickness indices, skinfolds were recorded on the chest (SFC), under the scapula (SFS), on the shoulder in front (SFShF) and behind (SFShB), on the hand (SFH), abdomen (SFA), and thigh (SFT).

Of the PF parameters, the indices of speed-strength fitness (SSF) of combat athletes were recorded: 30 m running time (30mRT), 4 m rope climbing time (RCT), maximum number of pull-ups in 10 s (10sPUN), maximum number of push-ups in 10 s (10sNPU), maximum number of squats with a partner of equal weight to failure (MNSP), time of performing 15 (TP15T) and 45 (TP45T) one-arm bending throws of a partner of equal weight at maximum pace.

The time of performing 15 and 45 throws at maximum pace was analyzed to evaluate the level of wrestlers' special work capacity. Wrestlers specialized for each type of combat sport performed throws of a partner of equal weight at maximum pace—15 throws in each of 3 performed series. During testing, the time spent on performing 15 throws in each series and the total time spent on performing 45 throws were analyzed. Anaerobic alactate (TP15T) and anaerobic lactate (TP45T) mechanisms play a key role in the energy supply of work capacity during such tests.

Statistical analysis

The package of statistical programs STATISTICA 13.5 [30] was used for experimental material processing. The methods of factor, correlation, regression, and canonical analysis were applied to assess the PC structure of wrestlers and to determine the key indices and interrelations in the structure of their fitness.

The method of factor analysis was used to determine the key factors and indices in the combined group of PD and PF parameters—two components of the PC structure of combat athletes. *Regression analysis* was used to determine the degree of influence of the key indices of the PD and PF structure of highly skilled combat athletes on the level of special work capacity. *Canonical analysis* was applied to investigate the relationships between the following groups of PD and PF variables of combat athletes:

1. Body circumference (7 indices) and speed-strength indices (5 indices);
2. Speed-strength indices (5 indices) and skinfolds (7 indices);
3. Skinfolds (7 indices) and body circumference (7 indices).

During canonical analysis, for each set of variables, linear combinations (called canonical variables) maximizing the correlation between the two sets were calculated [31]. The method of canonical correlations allowed us to determine the relationship of linear combinations of variables (canonical variables) from one set with those from another set. The method was applied to identify hidden dependencies between two groups of variables, maximum correlations, and to determine the total mutual impact of indices belonging to different groups.

Results

Factor analysis of PD and PF indices. Factor analysis of 44 indices of PD and PF of combat athletes revealed that the greatest partial weight in the fitness structure of highly skilled athletes belongs to the factor of circumferential and transverse

body dimensions (31.1% of the total dispersion of the studied indices). The key indices of this factor are defined as circumferential (neck, chest at rest, shoulder, forearm) and transverse (trunk, shoulder, forearm, thigh) body dimensions (Fig. 1).

The second factor included as key indices those characterizing speed-strength fitness and the level of special work capacity of wrestlers—TP15T, TP45T, MNSP. Their combined impact explains the variability of 13.65% of the total dispersion of the studied PC parameters.

The third factor included the parameters of SF on the chest and shoulder in front, as well as the total level of the fat component (11.29% of the total dispersion of the studied parameters).

Regression analysis results. The method of stepwise regression allowed us to identify the key indices of the wrestlers' PD structure, determining the result in performing the test of special work capacity (Table 1).

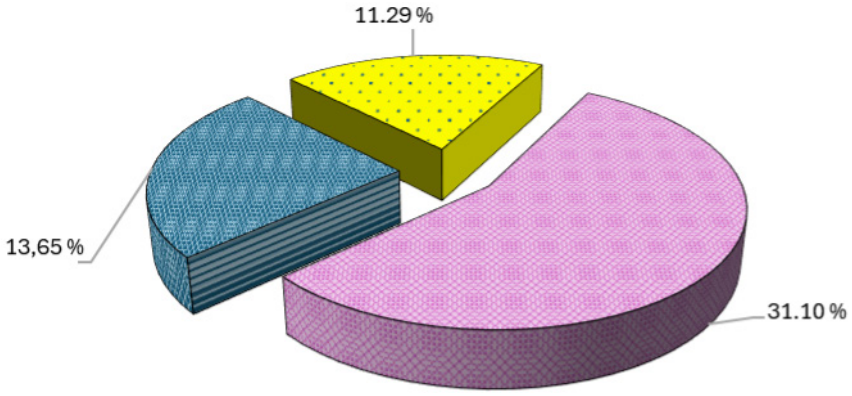


Figure 1. Key factors of the general structure of PD and PF of highly skilled wrestlers (% of total dispersion): - Circumferential, longitudinal, and transverse body dimensions; - speed-strength fitness (speed-strength qualities, special work capacity); - skinfolds)

Table 1. Regression model of the result dependence in the test of special work capacity on the key indices of the wrestlers' PD structure

N=43		**Regression information for the dependent variable (time of performing 45 throws): R= 0.996; R^2= 0.986 F(19.2)=153.0 p<0.0000.. Standard error of estimate: ±2.7**			
		Coefficient (b)	**Std.Err.**	**t(23)**	**p-value**
Intercept		222.36	50.15	4.4	0.000191
Anteroposterior diameter of the chest, cm		5.04	0.35	**14.3**	0.000000
Circumference	neck, cm	-6.76	1.22	5.6	0.000012
	chest at rest, cm	2.85	0.34	8.4	0.000000
	abdomen, cm	0.45	0.04	11.2	0.000000
	relaxed shoulder, cm	169.24	6.76	**25.0**	0.000000
	tensed shoulder, cm	-139.60	6.63	**21.1**	0.000000
	forearm, cm	-13.28	1.75	7.6	0.000000
	tibia, cm	3.16	0.96	3.3	0.003080
	thigh, cm	-3.59	0.92	3.9	0.000714
Skinfolds	on the chest, cm	-14.24	0.52	**27.6**	0.000000
	under scapular, mm	3.73	0.68	5.5	0.000014
	on the shoulder in front, mm	6.73	0.67	**10.1**	0.000000
	on the hand, mm	5.94	1.09	5.4	0.000016
	on abdomen, mm	1.83	0.47	3.9	0.000725
	on the thigh, mm	4.74	0.38	**12.6**	0.000000
Muscle component, %		-6.38	1.24	5.2	0.000032
Fat component, %		-6.32	0.65	9.7	0.000000
Quetelet index, c.u.		-0.90	0.06	15.8	0.000000
Muscle development index, c.u.		44.57	1.97	**22.7**	0.000000

The coefficients presented in Table 1 (b) indicate that out of 39 morphometric indices recorded in the experiment, the highest influence on the level of special work capacity is exerted by 8 indices of body circumference dimensions, 6 indices of skin folds, anteroposterior diameter of the chest, muscle development and Quetelet indices, muscle and fat components.

The values of multiple correlation coefficients (R = 0.996, p = 0.00001) and determination coefficients (R^2 = 0.986, p = 0.00001) are indicative of a high informative value and prognostic significance of the presented model.

The method of stepwise regression enabled the identification of the key indices of the speed-strength component of the wrestlers' PF structure, determining the result in the test of special work capacity (equation 1).

$$Y = (35.9x_1 + 3.64x_2 + 0.577x_3 - 0.967x_4 - 0.75x_5 - 0.285x_6 - 4.23) \pm 16.5 \quad (1),$$

where:

Y – index of special work capacity (total time spent to perform 45 throws, s);

x_1 – 30 m running time, s;

x_2 – number of pull-ups in 10 s;

x_3 – left hand strength, kg;

x_4 – number of squats with a partner in 10 s;

x_5 – number of push-ups in 10 s;

x_6 – number of push-ups in lying support to failure.

Correlation coefficients (R = 0.724, p = 0.0001) and determination coefficients (R^2 = 0.525, p = 0.0001) indicate a statistically significant dependence of the result during the specialized test with throws: 3 series of 15 bending hip-rolls of a partner of equal weight.

The model parameters explain the variability of 52.5% of the dispersion of wrestlers' special work capacity indices. Of the 6 indices of the regression model, the following parameters have the highest impact on the result of the specialized test: the result in 30 m running (x_1), the maximum number of squats with a partner in 10 s (x_4), and the maximum number of push-ups in 10 s (x_5).

This indicates their high informative value and the important role of speed-strength fitness and strength endurance in determining the physical work capacity of combat athletes with the dominance of anaerobic alactate and anaerobic lactate energy mechanisms [13, 16].

The developed multiple regression models reflect the specificity of the impact of the most informative parameters of the PD and PF structure on the result when performing the test with bending hip-rolls of a partner of equal weight (45 throws in 3 series), physical work capacity – time.

At the same time, regression analysis did not allow us to study the impact of interacting indices of one set of PC on indices of another set. For this purpose, canonical analysis was further conducted.

The method of canonical analysis was applied to analyze the hidden dependencies between the three groups of the most interrelated variables of combat athletes' PC. It allowed us to study the mutual influence of canonical variables of 3 groups of combat athletes' physical condition: 1) body circumference dimensions (CBD); 2) speed-strength indices (SSI); 3) skin fold thickness (SF).

Canonical analysis of the mutual influence of SSF and CBD. The canonical analysis parameters reflecting the relationship between the variables of the SSF group and those of the CBD group are presented in Table 2.

It follows from the data presented in Table 1 that a strong, positive significant relationship exists between the groups of variables under consideration. The values of canonical correlation (R = 0.975, p = 0.0000...) and Chi-square criterion (χ^2 = 168.27, df = 35, p = 0.0000...) indicate a strong interdependence between the weighted sums of the first pair of canonical variables (root 1).

The analysis of the eigenvalues of SSF and CBD revealed five statistically significant canonical roots explaining 100% and 96% of the dispersion of the SSF and CBD group, respectively.

The values of the total variability (redundancy) indicate that 69.95% of the SSF dispersion is explained by the influence of the group of interrelated CBD indices. On the other hand, 66.39% of the dispersion of the CBD indices of combat athletes is due to the impact of the canonical variables of their strength and speed-strength fitness (Table 2).

These results reflect a strong, approximately equal, mutual influence of two groups of variables of the combat athletes' physical condition - the values of the CBD and SSF. The increase in the level of wrestlers' CBD contributes to the improvement of their speed-strength fitness and vice versa - the improvement of speed-strength fitness results in

Table 2. Results of the canonical correlation analysis of the mutual impact of the group of speed-strength fitness indices and the group of circumferential body dimension indices

Parameters	Speed-strength indices	Circumferential body dimensions
Canonical correlation (R), χ^2	0.975, χ^2 (35) =168.3, p=0.0000	
Extracted dispersion	100.0%	95.995%
Total variability (redundancy)	69.95%	66.39%

the increase of their CBD.

The analysis of the factor structure allowed the determination of the value and direction of intragroup and intergroup interrelations of CBD and SSF indices.

The strongest positive correlation in the SSF group was between the index of speed-strength work capacity (TP15T) and that of speed-strength endurance (TP45N) – $r = 0.852$ ($p < 0.01$).

In the group of CBD variables, the strongest correlations were revealed between CND and CThD ($r = 0.914$, $p < 0.01$), CCD and CSD ($r = 0.921$, $p < 0.01$), CCD and CFD ($r = 0.940$, $p < 0.01$), and CCD and CThD ($r = 0.952$, $p < 0.01$). The positive sign of correlation coefficients indicates that the increase in some parameters of CBD is associated with an increase in other parameters.

Among the intergroup interrelations, the greatest number of statistically significant correlations was revealed between the index of speed-strength work capacity of wrestlers (TP15T) and indices of circumferential body dimensions: CCD ($r = -0.623$, $p < 0.01$), CND ($r = -0.513$, $p < 0.01$), CSD ($r = -0.512$, $p < 0.01$), CFD ($r = -0.458$, $p < 0.05$), and CThD ($r = -0.416$, $p < 0.05$). The strongest relationship among the intergroup ones is that of the variables TP15T and CCD ($r = -0.623$, $p < 0.01$).

The negative sign of the correlation coefficients indicates that the increase in the circumference dimensions of the neck, shoulder, forearm, and thigh is accompanied by a decrease in the time of performing a series of 15 throws, i.e. an increase in the intensity of their execution. An increase in the intensity of performing 15 specialized throws is an important criterion of the increase of anaerobic alactate (speed-strength) work capacity of wrestlers.

The values of correlation coefficients are indicative of a closer integration of intragroup indices in comparison with intergroup ones. Of the intragroup indices, the CBD indices are the most closely interrelated.

Subsequent analysis of the factor structure and redundancy of the indices of the two groups permitted determination the loads of canonical factors (being correlations between the canonical and the initial variables of each group), the share of extracted dispersion, explained by the corresponding root for each set (each canonical variable), as well as the values of the total variation (redundancy) of the SSF group and CBD indices across all roots.

The analysis of loads of the canonical factors showed that the extracted dispersion of the SSF (100%) was distributed across the roots as follows: first root 14.29%, second root 26.03%, third root 17.68%, fourth root 24.23%, fifth root 17.77%. In the CBD indices, the first root explains 8.12% of the extracted dispersion (out of 96%), the second root explains 18.23%, the third root explains 26.87%, the fourth root explains 31.02%, and the fifth root explains 11.76%.

The total variability (redundancy) of the SSF (69.95%) was distributed among the individual indices as follows: TP15T (16.59%), PUN10s (15.91%), TP45T (15.8%), NPU10s (13.3%), 30mRT (8.51%). The greatest partial contribution to the total variation of the SSF group belongs to three parameters - TP15T, PUN10s, and TP45T. Their combined share in the total variability of the SSF parameters constitutes 48.3% (out of 69.95%).

The total variability (redundancy) of CBD parameters (66.39%) was distributed among the individual parameters as follows: CCD (10.6%), CTD (10.4%), CAD (8.50%), CND (8.61%), CSD (9.34%), CFD (9.71%), CThD (9.2%). The highest contribution to the variability of the CBD parameter group is made by the following parameters—CCD (10.6%), CTD (10.4%), and CFD (9.7%). Their combined contribution to the total variability of the CBD parameters constitutes 30.7%.

The results indicate that the greatest variability in the SSF indices under the influence of the group of CBD indicators is manifested in three parameters—TP15T, PUN10s, TP45T. Their total variability constitutes 48.3% (out of 69.95% for all parameters of the SSF group). On the other hand, the greatest variability in the CBD indices under the impact of the SSF group of indicators is manifested in the parameters CCD, CTD, and CFD—30.7% (out of 66.4% for all indices of the PD group).

These results can be interpreted in the following way: the most dependent and informative speed-strength indices (SSI), which change to a greater extent under the influence of CBD, are TP15T, PUN10s, and TP45T. The most dependent indices of the CBD group, which change to a greater extent during the alteration of the SSI, are the indices of CCD, CTD, and CFD.

The redundancy indices confirm the strong relationship between the CBD indices and SSI. It is noteworthy that the informative value of the indices of the two groups is close to each other.

The calculations of canonical weights of normalized variables of each set demonstrated that in the SSI group, the greatest contribution to the value of the first canonical variable is made by the TP45T index (-1.506), to the value of the second canonical variable - TP15T (-1.165), the third - NPU10s (-0.841), the fourth - TP45T (1.106), and the fifth - 30mRT (-0.998).

In the group of CBD parameters, the highest contribution to the value of the first canonical variable is made by the CFD variable (4.05), to the value of the second canonical variable - CCD (2.216), the third - CThD (-2.25), the fourth - CFD (1.974), and the fifth - CThD (2.575).

The canonical weights are regression coefficients in which the responses are the canonical variables of the corresponding root and the predictors are the

SSI and CBD variables, respectively.

The canonical weights can be used to make regression equations reflecting the contribution of each of the SSI and CBD indices to the value formation of canonical variables of statistically reliable roots.

Below are presented the regression equations reflecting the contribution of individual variables of the SSI and CBD to the formation of the values of the canonical variable of the 1st root (equations 2-3):

$$\text{Root } 1_{PF} = 0.078RT30m-0.44PUN10s-0.336NPU10s+1.291TP15T-1.506TP45T \quad (2)$$

$$\text{Root } 1_{PD}=-0.957CND+0.676CCD-0.860CSD+1.492CAD+4.05CFD-0.772CTD-3.16CThD \quad (3)$$

The graphical and generalized regression models of the interrelations of the canonical variables of root 1 are presented in Figure 2.

The scatter diagram of the canonical variables on root 1 has a shape characteristic of a linear relationship in the graph. The correlation between the values of the canonical variables of SSF and CBD constitutes 0.975 ($p<0.0000$). The strong correlation between the canonical variables of SSF and CBD indicates their high informative value.

Canonical analysis of the interaction between SF thickness and SSF. In this analysis, the interrelations of SF thickness on the chest, under scapular, on the shoulder, hand, abdomen, and thigh with the indices of speed-strength fitness (SSF) of athletes - the maximum number of pull-ups and push-ups (within 15 s), the time of performing 15 specialized throws with maximum speed, the time of 4 m rope climbing, and 30 m running time.

The data presented in Table 3 indicate that a high level of canonical correlation (R=0.991, p=0.0000.) was found between the groups of variables under consideration. The values of the correlation coefficient and Chi-square ($\chi2=123.1$, p=0.0000...) reflect a strong mutual dependence between the first canonical variables of SF thickness and SSF indices.

The results presented in Table 1 show that 43.95% of the dispersion of the *SF* thickness indices is determined by the influence of the canonical variables of the *SSF* group of combat athletes, whereas 44.97% of the dispersion of the *SSF* group - by the impact of the group of *SF* thickness indices.

The data indicate equal interdependence of the two analyzed groups of variables in combat athletes.

The factor structure analysis allowed us to determine the value and direction of intragroup and intergroup interrelations of the studied indices.

It was revealed that the most interrelated are the indices of the SF thickness (R = 0.524 ± 0.025). The correlations of speed-strength indices (SSI) are significantly lower (R = 0.227 ± 0.05). The average correlation between the indices of different groups (SF and SSI) is also low (R = 0.220 ± 0.01).

The strongest correlation among the variables of SF thickness exists between the SF thickness under the scapula, on the shoulder, abdomen, and thigh, whereas among the variables of the SSF group - between the number of pull-ups in 10 s, push-ups

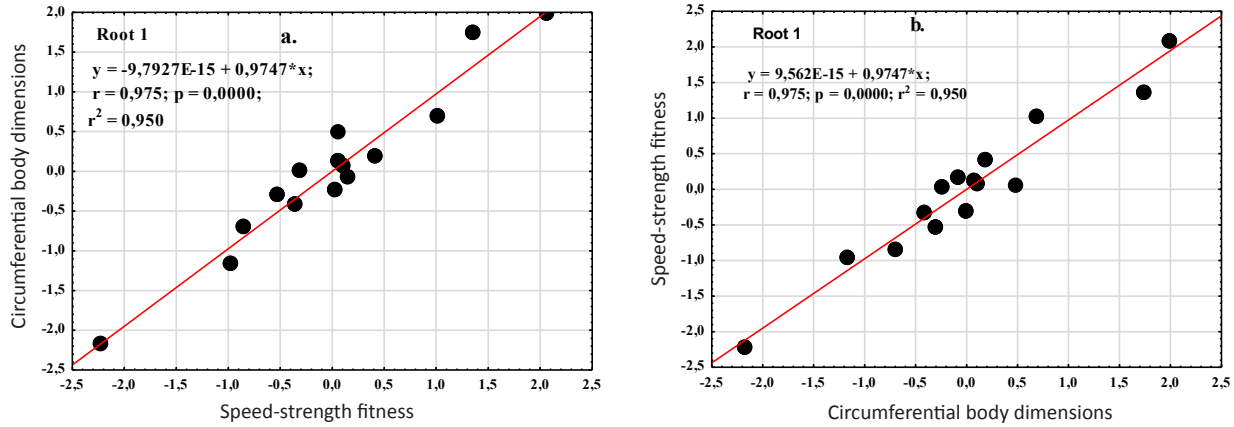


Figure 2. Graphical and regression models of interrelations of canonical variables (CBD and SSI) of the first canonical root.

Table 3. Results of the canonical correlation analysis of the mutual impact of skin fold thickness indices and those of speed-strength fitness (N=35)

Parameters	Skinfolds	Speed-strength indices
Canonical correlation, $\chi2$	Canonical R: 0.991 $\chi2(35)$ =123.1 p=0.0000	
Extracted dispersion	85.94%	100.0%
Total variability	43.95%	44.97%

in 10 s, and the time of 4 m rope climbing with the help of hands.

As for variables from different sets, the strongest correlation is manifested between the result in the 30 m running and the SF thickness on the thigh (r=-0.514, p<0.01), between the SF thickness on the abdomen and the number of push-ups in 10 s (r=-0.537, p<0.005).

Eigenvalue analysis of the indices of the two groups manifested 5 canonical roots, two of which are statistically significant.

The factor structure and redundancy analysis allowed us to determine the loads of canonical factors for the variables of both groups, the proportion of extracted dispersion, explained by the corresponding root for each set, as well as the values of the total variability of the studied parameters for all roots.

Loads of canonical factors indicate that the five roots extract 86 % of the total dispersion of the parameters of the SF thickness and 100 % - of the SSF group.

Analysis of redundancy (variability) on two statistically significant roots showed that the highest variability in the SSF group under the influence of the parameters of the SF thickness group is manifested in the parameters of TP15T (40.2% of the total dispersion of root 1 indices) and 30mRT (55.6% of the total dispersion of root 2 indices). The highest degree of variability in the group of SF thickness parameters under the impact of SSF is manifested in the parameters of SFA (61.1% of the total dispersion of root 1) and SFShF (23.4% - root 2).

The analysis of canonical weights of normalized variables of each set showed that in the group of SSF, the greatest contribution to the value of the first and the second canonical variable is made by the variable TP15T (0.683) and variable RCT (-0.741), respectively.

In the group of SF parameters, the greatest contribution to the value of the first and the second canonical variable is made by the variable SFA (-2.048) and SFShF (-1.119), respectively.

The canonical weights of the statistically significant canonical root 1 were used to make regression equations reflecting the partial contribution of each of the PF and PD indices to the formation of the values of the canonical variables of the 1st root (Equations 4-5):

$$\text{Root } 1_{PF} = 0.012RT30m+0.293RCT+0.236PUN10s+0.648NPU10s+0.683TP15T \quad (4)$$

$$\text{Root } 1_{PD} = -0.65SFC-0.697SFS+0.485SFShF+0,749SFShB+0.67SFH -2,05SFA+1,181SFT \quad (5)$$

Figure 3 shows the graphical and regression models of the relationship between canonical variables of canonical root 1 in highly skilled combat athletes.

The square of interrelations (r2) of the canonical pairs of variables indicates that 98.2% (p = 0.0000) of the variation of weighted variables of SSF and SF by the first canonical root is explained by their mutual influence. The values and direction of the correlation and determination coefficients are indicative of a strong positive and linear dependence between the weighted variables of SSF and SF thickness.

Canonical analysis of the interaction between CBD and SF thickness indices. The interactions of two sets of PD variables - CBD indices (7 indices) and SF thickness (7 indices) are analyzed below.

The first set of variables consisted of indices of circumference dimensions of the neck, chest, shoulder, forearm, abdomen, tibia, and thigh. The second set of variables included indices of the thickness of skin folds on the chest, under the scapula, on the shoulder front and back, on the hand, thigh, and abdomen.

The canonical analysis of eigenvalues, as well as

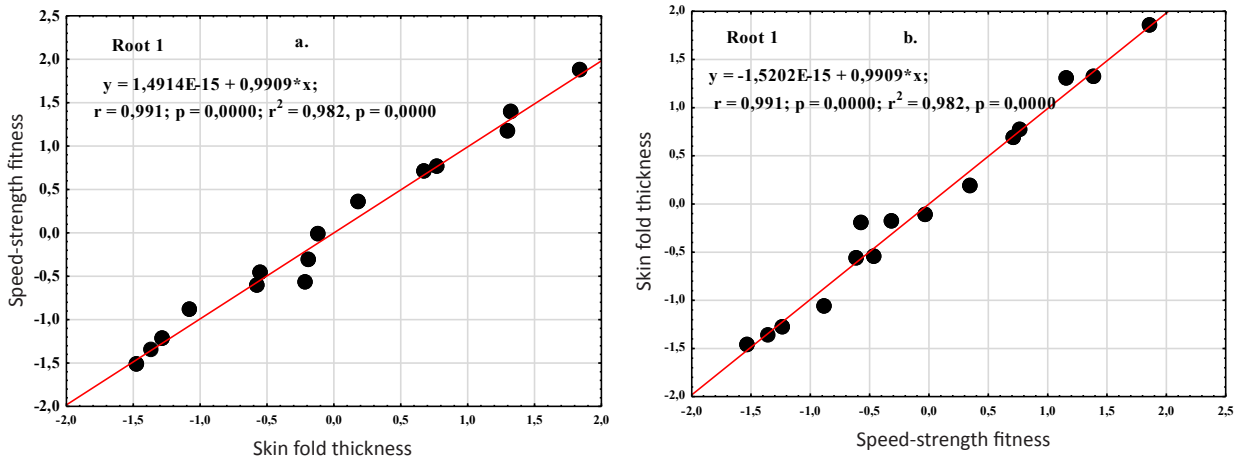


Figure 3. Graphical and regression models of the interrelations of weighted variables of SSF and SF thickness by the first canonical root.

the results of the χ2 test revealed 7 canonical roots explaining 100% of the dispersion of the groups of CBD and SF indices (Table 4). Of these, the first 3 canonical roots were statistically significant.

A high level of canonical correlation (R=0.994, p=0.0000...) was revealed between the considered groups of variables. Its value and that of chi-square (χ2=214.5, df = 49, p=0.0000...) reflect a strong mutual dependence between the first canonical variables of the CBD and SF group.

The results presented in Table 4 indicate that 41.5% of the total variability of the *SF* thickness indices is determined by the influence of the canonical variables of combat athletes' *CBD*, whereas 68.5% of the total variability of the *CBD* indices is due to the impact of the group of *SF* thickness indices. This result, as well as the results of the correlation analysis presented below, indicate that *the increase in the CBD of combat athletes contributes to the increase of SF thickness, and vice versa - SF thickness increase contributes to the increase in the CBD.*

It is characteristic that the *SF* thickness indices manifest a lower dependence on the CBD value, while the changes in CBD demonstrate a greater dependence on the *SF* thickness.

The factor structure analysis enabled the study of correlations between indices within each group and between groups and the determination of canonical factor loads and redundancy for both groups of variables across all roots.

The average values of the correlations indicate that the CBD indices are the most interrelated (*R = 0.620 ± 0.07*). The interrelations of *SF thickness indices were significantly lower (R = 0.524 ± 0.06)*. The intergroup correlations between the indices of the SF and CBD groups were the lowest (R = 0.431 ± 0.04).

Of the variables of the CBD group, the strongest correlations are manifested between the indices of CCD, CThD, CSD, and CFD. Of the variables of the SF group, the strongest correlations were observed between subscapular, shoulder, thigh, and abdomen SF thickness.

For the variables from the different sets, the strongest correlations were found between the abdomen SF thickness index and the following CBD indices: CND (r=0.721, p<0.005), CCD (r=0.793, p<0.005), CSD (r=0.812, p<0.005), CFD (r=0.857, p<0.005), and CThD (r=0.833, p<0.005).

The redundancy analysis by three statistically significant roots showed that in the parameters of root 1, the greatest variability of CBD under the influence of SF thickness is manifested by the indices of CFD (84.7%), CThD (67.8%), and CSD (65.06%), whereas in the parameters of root 2 - by CND (14.44%), and root 3 - by CSD (17.57%). In the group of SF thickness variables, the greatest variability under the impact of the CBD group of indices is manifested in the parameters of root 1 by the SFA index (70.5%), in the parameters of root 2 - by the SFC index (9.58%), and root 3 - by the SFH index (21.66%).

The analysis of canonical weights of normalized variables of each set has shown that in the group of CBD parameters, the greatest contribution to the value of the first canonical variable is made by the CFD variable (2.807), to the value of the second canonical variable - CND (3.135), and the third - CFD (4.947).

In the group of SF parameters, the variable SFA (1.267) contributes the most to the value of the first canonical variable, whereas SFS (-1.742) to the value of the second canonical variable, and SFShF (2.206) to the value of the third canonical variable.

The canonical weights were used to make regression equations reflecting the contribution of each of the CBD and SF indices to the formation of the values of canonical variables of the 1st root (Equations 6-7):

$$Root\ 1_{SF} = -0.873SFC-0.168SFS+0.562SFShF-0,431SFShB+0.138SFH+1,267SFA-0,164SFT \quad (6)$$

$$Root\ 1_{CBD} = -0.378CND-0.115CCD+0.259CAD-0,683CSD+2.807CFD+0,038CTD-0,895CThD \quad (7)$$

The graphical and regression models of the relationships between the weighted CBD and SF thickness variables by the first canonical root are presented in Fig.4.

The square of the values of canonical pairs of variables indicates that 98.9% of the variations of weighted CBD and SF variables by the first canonical root are explained by their mutual influence.

This confirms their informative value. It is characteristic that changes in CBD indices at the alteration of those of SF thickness are more pronounced than changes of SF thickness depending on the alteration of CBD indices.

Table 4. Results of canonical correlation analysis of the mutual influence of skin fold thickness indices and the group of indices of body circumferential dimensions (N=49).

Parameters	Circumferential body dimensions	Skin folds
Canonical correlation (R), χ^2	R: 0.994, R^2: 0.989, χ^2 (49) =214.5 p=0.0000	
Extracted dispersion	100.0%	100.0%
Total variability (redundancy)	68.5%	41.5%

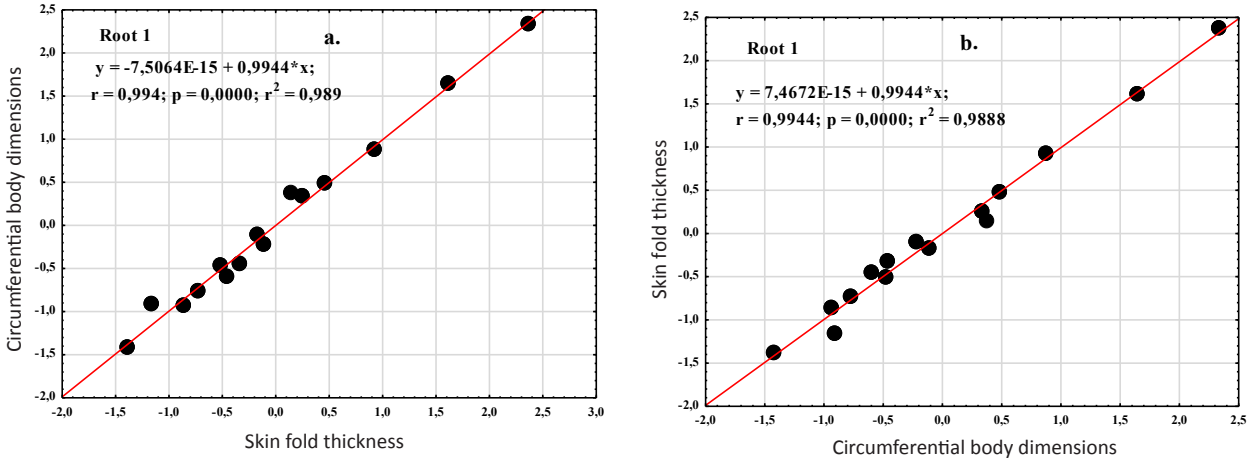


Figure 4. Graphical and mathematical models of interrelations of weighted CBD and SF thickness variables by the first canonical root.

Discussion

Insufficient state of knowledge about the PC structure of combat athletes from the standpoint of the system approach served as a basis for setting the objective, tasks, and organization of the present study, determining the methodological approach, selecting research methods, and processing the experimental material.

In the basis of the methodological approach in the course of the research were laid the principles of system analysis, in accordance with which the PF structure of combat athletes is determined not only by a set of parameters of PD, speed-strength, technical-tactical, and psychological fitness, but their ratio and interrelations as well. This conditions the necessity of using for its study both methods of registration of different indices and various methods of statistical processing and analysis.

Computerized methods of factor, correlation, regression, and canonical analysis were used for processing, analysis, and interpretation of the obtained experimental material, [30, 31, 32].

System and complex approaches, multiple methods of experimental material statistical processing and analysis allowed to:

1) study the generalized structure of combat athletes' PF and PD as constituent and interrelated components of physical condition structure;

2) determine intra- and intergroup interrelations of the studied indices;

3) develop multiple regression models of dependence of special work capacity indices on the key SSF and PD indicators of highly skilled combat athletes;

4) investigate the specificity and strength of mutual influence of canonical variables of 3 groups of combat athletes' PC - CBD, SSF, SF.

The factor analysis of 44 indices of combat athletes' PC resulted in determining the key factors and indices of the generalized structure of PD and SSF:

1) the factor of circumferential body dimensions;

2) the factor of speed-strength fitness;

3) the factor of skin fold thickness and the total level of the fat component.

As a result of stepwise multiple regression analysis, regression models reflecting the impact of the key PD and SSF indices on the level of special work capacity of wrestlers were developed.

The regression analysis revealed that of PD indices the greatest influence on the level of wrestlers' special work capacity is exerted by the complex of parameters consisting of 8 indices of circumferential body dimensions, 6 indices of skin folds, indices of anteroposterior diameter of the chest, index of muscular development, muscle and fat components - a total of 21 indices.

Of the PF indices, the greatest impact on the result of the special work capacity test is due to the parameters characterizing the level of manifestation of speed-strength qualities - speed, explosive power, and strength endurance.

The correlation and determination coefficients reflect the high prognostic informative value of the models presented above. The statistical significance of each model parameter coefficient is the basis for modeling different variants of the ratio of the model indices and determining the partial contribution of each of them to the manifestation of wrestlers' special work capacity.

The multiple regression models present indices with statistically significant coefficients reflecting the partial contribution of each PD and PF index to the result of work capacity.

The models developed by us confirm the studies of several authors, which reflect the role of a number of PD and PF indices in the formation of morphological and functional profiles of combat athletes [5, 20, 33].

However, the publications of various authors lack the analysis of the dependence of combat

athletes' morphofunctional profile on the ratio and interaction of the indices of various sets of their fitness structure - physical development, physical, technical-tactical, and psychological fitness, etc.

The multiple regression models presented in this, as well as in our earlier articles [3, 17], allow modeling and predicting with rather high accuracy the level of physical work capacity of combat athletes depending on the ratio and interrelations of a set of parameters characterizing morphological, functional, or morphofunctional profile.

The number of morphological and functional parameters, their ratio and partial role in determining physical work capacity in the presented multiple regression models complement our previous studies [3, 17] and those of a number of authors addressing the formation of morphological [7, 20, 21] and functional [13, 16; 19, 34] profiles of combat athletes.

However, the methods of multiple correlation and regression enable us to study the influence of one set of random variables on only one random variable [30, 35]. They do not allow us to examine the influence of one set of random variables on the indices of another set of random variables and vice versa.

Therefore, the method of canonical analysis was applied in this study to quantify the relationships between two sets of variables.

The method of canonical correlations is effective for detecting hidden dependencies between two sets of variables [32, 35].

During canonical analysis, linear combinations maximizing the correlation between two sets of variables were calculated, and the total mutual influence of indices belonging to different groups of random variables was determined.

It is noteworthy that canonical analysis is relatively little used for processing and analyzing experimental data in medicine, biology, physical education, and sports.

Only some publications substantiate the efficiency of the canonical analysis method in processing and analyzing medical [31] and biological [36, 37] experimental material.

The application of canonical analysis methods in the processing of the experimental material presented in this work allowed us to determine the mutual influence specificity of 3 sets of PC indices: 1) circumferential body dimensions; 2) speed-strength fitness; 3) skin fold thickness. The method of canonical analysis enabled to identify the key factors and indices determining the total variability of indices of each of the studied groups of PC - CBD, SSF, and SF.

The analysis of the interaction between the parameters of SSF and CVD revealed their strong, approximately equal, interdependence: 69.95% of the total variability of SSF parameters is determined by the influence of the group of interrelated CBD indices, whereas 66.39% of the total variability of CBD indices - by the indicators of speed-strength fitness.

The greatest variability in the SSF parameters under the influence of the group of CBD indices is manifested by the TP15T, TP45T, and PUN10s indices, which characterize the level of special (speed-strength) work capacity and explosive power of combat athletes. In the course of the experiment, it was revealed that the increase in the circumferential dimensions of the neck, shoulder, forearm, and thigh is accompanied by a decrease in the time of performing a series of 15 throws, i.e. an increase in the level of anaerobic alactate work capacity of combat athletes.

It is characteristic that the energy supply of such exercises is dominated by two mechanisms - anaerobic alactate and anaerobic lactate [13].

The greatest variability in the CBD indices under the influence of the group of SSF indices is manifested by the CCD, CTD, and CFD indices. The SSF and CBD indices manifesting the greatest variability in the process of the two sets of the PC structure interaction should be interpreted as the most informative.

The analysis of the mutual influence of the canonical variables of the SF thickness and the SSF indicates an equal, statistically significant, and relatively low degree of mutual influence of the parameters of the two sets of combat athletes' PF.

The greatest degree of SF thickness variability under the influence of the SSF parameters is manifested in the SFA and SFShF indices. The greatest degree of variability in the group of SSF parameters under the influence of the SF variables is manifested in the indices of 30mRT and TP15T, reflecting speed and speed-strength capacities. The energy supply of such tests is based on the anaerobic alactate mechanism [13].

The results of SF and CBD interaction indicate that the increase in the CBD of combat athletes contributes to SF thickness increase and vice versa - the increase in SF thickness contributes to the increase in CBD. At the same time, the SF thickness indices show less dependence on the CBD value, whereas the CBD indices change under the influence of the SF thickness indices to a greater extent.

Determining canonical weights of normalized variables of statistically significant canonical roots allowed us to make regression models that reflect the contribution of each of the canonical indices of one set to the formation of values of canonical variables of the other set. This paper presents regression and graphical models reflecting the degree and nature of the mutual influence of canonical variables by the first strongest root of each set - SSF and CBD, SF and SSF, SF and CBD.

Conclusions

1. The key factors of PD and PF general structure of highly skilled combat athletes include: 1) the factor of circumferential and longitudinal body dimensions; 2) the factor of special work capacity and speed-strength qualities; 3) the factor of skin folds thickness and the total level of fat component.
2. The canonical analysis enabled to: 1) determine the specificity of mutual influence and interrelations of the indices of CBD, SSF, and SF; 2) identify the key factors and indices determining the total variability (redundancy) of the parameters of each group under study; 3) reveal strong, moderate, and weak intra- and intergroup interrelations of the indices of CBD, SF thickness, and SSF. The strongest intragroup interrelations are manifested between the CBD indices, whereas the strongest intergroup interrelations - between the indices of CBD and SF thickness.
3. A high interdependence was revealed between the parameters of SSF and CBD, indicating that the increase in the CBD of combat athletes contributes to the increase in their SSF and vice versa - the increase in the SSF contributes to the increase in CBD. A moderate interdependence was noted between the parameters of SF and SSF, explaining the variation of a relatively small part of the variability of the parameters of one group during the change of the parameters of the other group. The results of SF and CBD interaction indicate that the SF thickness indices manifest a low dependence on the changes in CBD, whereas the CBD indices show a strong dependence on the SF thickness.
4. The most variable indices of combat athletes' SSF when changing the CBD and SF thickness are the time of performing 15 and 45 specialized throws, the number of pull-ups at the maximum pace in 10 s, and the 30m running time. The most variable CBD indices at changing the parameters of the SSF and SF thickness are the circumference dimensions of the chest, tibia, forearm, thigh, and shoulder. The most variable indices of SF thickness during alteration of the CBD and the level of combat athletes' SSF are the indices of the abdomen, tibia, hand, and front shoulder SF thickness. The most variable parameters are the most informative, explaining the variation of the most of the dispersion of the indices of one set depending on the influence of the indicators of the other set.
5. Regression equations reflecting linear interrelations of canonical variables of the physical fitness structure of highly skilled wrestlers are the basis for modeling different ratios of model parameters and determining the partial contribution of each of them to the manifestation of combat athletes' special fitness.

Conflict of interests

The authors declare that there is no conflict of interests.

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