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A canonical analysis of the general variability and interrelationships among parameters of speed-strength fitness, circumferential, and longitudinal body dimensions in highly skilled wrestlers

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Abstract

Background and Study Aim Speed-strength fitness and body dimensions are components of athletic performance in combat sports. The interaction between speed-strength fitness parameters and anthropometric characteristics influences physical capabilities and competitive outcomes in wrestlers. Despite the application of various approaches to assessing these parameters, their interrelationships and general variability remain of practical interest. The aim of the study is to perform a canonical analysis of the general variability and interrelationships among parameters of speed-strength fitness (SSF), circumferential, and longitudinal body dimensions in highly skilled wrestlers.

Material and Methods The research was conducted on 44 combat athletes aged 18–31 who were members of the Ukrainian national teams in Greco-Roman wrestling, freestyle wrestling, and judo. The assessment of SSF was based on the results of motor tests that characterize the manifestation of anaerobic alactate work capacity, explosive strength, and speed-strength endurance in athletes. Circumferential (CBD) and longitudinal (LBD) body dimensions were considered indicators of physical development (PD). Canonical correlation, regression, and correlation analysis methods were used to process the research data.

Results The analysis of general variability and interrelationships between the canonical variables of PD and SSF in combat athletes revealed a high level of mutual influence ($R = 0.981$, $p = 0.0000$). Increases in CBD and LBD are accompanied by increases in SSF, and increases in SSF are associated with increases in CBD and LBD. The interaction between SSF and CBD parameters demonstrates approximately equal mutual influence (redundancy: 53.9% and 53.4%). In the relationships between LBD and CBD, a stronger influence of LBD parameters on CBD is observed (redundancy: 66.88% vs. 57.5%). CBD values are more dependent on changes in SSF parameters than on the group of LBD indicators (39.53% vs. 24.79%). The SSF level of athletes shows greater dependence on the group of CBD indicators than on that of LBD indicators (43.71% vs. 44.83% of total variability contribution across significant roots). LBD values are less dependent on CBD values and SSF level than CBD parameters are on LBD values and SSF level.

Conclusions The findings indicate that speed-strength fitness parameters are functionally related to circumferential and longitudinal body dimensions in highly skilled wrestlers. The structure of these relationships reflects the role of specific anthropometric characteristics in the manifestation of different forms of physical work capacity. The intergroup interactions between circumferential and longitudinal body dimensions form a structural basis associated with the development of speed-strength fitness. The identified patterns characterize the integration of morphofunctional and performance-related parameters within the physical state of combat athletes.

Keywords: wrestlers, physical development, physical fitness, work capacity, canonical analysis, interrelationships.

Introduction

Athletic performance in combat sports is determined by a combination of functional capacities and morphological characteristics. In wrestlers, speed-strength fitness is associated with the ability to generate force rapidly under conditions of short-term, high-intensity effort. At the same time, circumferential and longitudinal body dimensions reflect structural features that influence movement mechanics and load distribution during

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competitive activity. The relationships between these functional and morphological parameters form a complex system of interdependencies that affect the manifestation of physical qualities in highly skilled athletes.

In the process of long-term adaptation to training and competitive loads, a specific structure of physical state (PS) is formed in the bodies of combat athletes. It is characterized by a certain level of development, as well as by the ratios and interrelationships among parameters of physical development (PD), functional, physical, psychological, and technico-tactical fitness, and special physical work capacity (SPWC). The dynamics of changes in these parameters during long-term adaptation to strenuous muscular activity reflect the process of forming a specific profile of highly skilled athletes [1, 2, 3, 4].

The factors determining the morphofunctional profile of elite athletes include both individual and integral parameters of physical development, physical, functional, and psychological fitness, as well as special physical work capacity. The long-term process of adaptation to physical loads in combat athletes is characterized not only by morphofunctional and metabolic changes in the leading body systems, but also by changes in their ratios and interrelationships within the morphofunctional structure of fitness in highly skilled athletes [5]. However, most publications are dominated by a one-sided characterization of the morphofunctional profile of athletes.

Most authors describe the structure of the morphofunctional profile primarily according to individual criteria:

- anthropometric parameters [2, 6, 7];
- parameters of physical development (PD) [8, 9, 10];
- parameters of physical fitness (PF) [8, 11, 12];
- parameters of functional state [1, 11, 13, 14, 15];
- parameters of special physical work capacity (SPWC) [2, 5, 16, 17, 18].

Fewer studies have been devoted to the formation of the structural profile of combat athletes from a systems perspective, that is, from the standpoint of a comprehensive analysis of the relationships and interconnections among PS parameters during adaptation to specific training and competitive loads [5].

The level of development, as well as the ratios and interrelationships of PS parameters in combat athletes, are determined by the specificity of training loads and the nature of motor activity during a bout. These include the speed of response to an opponent's actions, the time required to perform single movements and series of movements of varying structure, their number and intensity, and the total duration of the bout. The variable character and intensity of a wrestling bout determine the activation of different energy systems: anaerobic alactate, anaerobic lactate, and aerobic. The degree of involvement and the balance among these energy systems are determined by the duration and intensity of both the bout as a whole and its individual segments [11, 19].

To assess the PS structure of combat athletes, a set of individual and integral parameters of PD, physical (PF), functional, psychological, and technico-tactical fitness is typically used.

The following are considered integral parameters of the PS structure in athletes: a) integral parameters of functional state: efficiency, stability, mobility of functional manifestations, aerobic and anaerobic power, and the general level of functional fitness [20, 21, 22, 23, 24]; b) integral parameters of PD: Quetelet index, volume of muscle, fat, and bone tissue, body surface area, body water content, and other parameters [8, 25]; c) integral parameters of PF: the level of development of motor qualities, as well as different forms of SPWC, including aerobic, anaerobic, speed, strength, and speed-strength [12, 16, 17, 19, 26].

One of the issues in systems physiology is the elucidation of the morphofunctional and metabolic mechanisms underlying the support of the SPWC of combat athletes from the standpoint of the relationships and interactions between both individual and integral parameters of the PS structure of wrestlers, including PD, PF, and functional state. Among the insufficiently studied aspects of the formation of the profile of highly skilled combat athletes are the mechanisms of interaction and integration of various components of the athletes' PS. These include the level of development, as well as the relationships and interconnections of individual and integral, intra- and intergroup parameters of the PS of combat athletes [5, 22]. Intra- and intergroup pairwise relationships of PS parameters in combat athletes are widely represented in the specialized literature [26, 27, 28, 29]. However, intergroup interactions among sets of interrelated variables belonging to different subsets of the PS structure of highly skilled combat athletes have been addressed to a lesser extent [5].

To analyze the structure of the PS and the morphofunctional profile of combat athletes, a number of authors have examined the interrelationships among parameters of PD, PF, functional state, and SPWC [30, 31, 32]. Several studies present evidence indicating the dependence of the SPWC level and wrestlers' endurance on anthropometric factors [26, 27, 29, 33], as well as on the level of development of motor abilities [17, 28, 33]. However, most publications are devoted to the analysis of pairwise relationships between parameters of the PS structure of athletes. These include relationships between body composition and aerobic work capacity, recovery after training loads [34, 35], body composition and anaerobic work capacity [29, 33], and body composition and the level of development of motor abilities [27, 28].

The diversity of factors, parameters, and mechanisms determining the morphofunctional and metabolic profile of combat athletes provides a basis for studying them from the standpoint of integrated and systems approaches. The methodological principles of the systems approach necessitate the use of comprehensive methods for the recording, processing, and analysis of various parameters of the PS of combat athletes. They also require the investigation of their relationships and interconnections, which collectively determine the morphofunctional and metabolic profile of elite athletes.

From a systems perspective, the level of special work capacity of combat athletes is a system-forming factor that determines the level of development, the partial contribution, and the relationships and interconnections among parameters of different components of the PS structure of athletes, including PD, PF, and functional state. At the same time, publications by various authors indicate that the partial role and influence of individual PS indicators on the level of SPWC in highly skilled combat athletes are determined both by the level of development and interrelationships of intragroup indicators and by intergroup relationships among parameters belonging to different subsets of the athletes' PS, including PD, PF, SPWC, and functional state.

Intra- and intergroup relationships among parameters of various PS components play a role in shaping the structure of the morphofunctional and metabolic profile of highly skilled combat athletes. However, most researchers have characterized this profile through the analysis of pairwise interactions among different PS components, using methods of pairwise correlation and regression [29, 33, 34, 35]. Multiple correlation and regression coefficients, reflecting the dependence of individual parameters on several determining variables, have been calculated to a lesser extent [5, 22].

Among the insufficiently explored aspects of the formation of the morphofunctional and metabolic profile of highly skilled combat athletes are the intergroup interactions of integral components of the PS. In this regard, one of the least studied areas of relationships among components of the PS structure in combat athletes is the combined intergroup mutual influence of parameters of PD, functional state, PF, SPWC, and others. Only a limited number of studies [28, 36] have addressed the intergroup interactions among PS parameters in highly skilled combat athletes. These studies served as a basis for developing regression models describing the dependence of wrestlers' SPWC level on a set of leading parameters from the studied PS groups. However, in analyzing intergroup interactions, researchers have primarily focused on the dependence of individual outcome PS variables on a set of determining factors.

In biological research, the method of canonical analysis, based on constructing linear combinations in two specified sets of variables, has been used less frequently to determine relationships between two sets of variables [37, 38, 39]. A number of authors have noted that the method of canonical correlations makes it possible to identify the maximum correlation between several outcome variables and several determining factors [38, 39]. However, the potential of this method for studying intergroup interactions among parameters belonging to different sets of the PS of highly skilled athletes has been insufficiently reflected in biological research.

Analysis of research findings has shown that the morphofunctional profile of combat athletes is determined by a combination of physical development, functional state, physical fitness, and special work capacity, as well as by the relationships among these parameters. Researchers emphasize that both individual indicators and their interconnections contribute to the structure of physical state in highly skilled athletes. At the same time, the complexity of intergroup interactions among different components of the PS structure complicates their comprehensive assessment within a unified analytical framework. This limitation constrains the interpretation of integrated relationships among parameters belonging to different subsets of the PS of combat athletes.

Given the limited coverage of intergroup interactions among parameters of the PS structure in highly skilled combat athletes, as well as its relevance for the theory and practice of wrestling, the aim of the present study was defined as follows: to perform a canonical analysis of the general variability and interrelationships among parameters of speed-strength fitness and circumferential and longitudinal body dimensions in highly skilled wrestlers.

Materials and Methods

Participants

The studies were conducted on members of the national teams of Ukraine in Greco-Roman wrestling, freestyle wrestling, and judo. A total of 44 combat athletes aged 18–31 years were examined. Among them were 10 Candidates for Master of Sport, 14 Masters of Sport, 17 Masters of Sport of International Class, and 3 Honored Masters of Sport. Most of them were students of higher education institutions in Ukraine.

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 [40].

Research Design

As parameters of PD and PF in highly skilled combat athletes at the stage of maximal realization of individual capacities, indicators of circumferential (CBD) and longitudinal (LBD) body dimensions and speed-strength fitness (SSF), including special physical work capacity (SPWC), were recorded.

Circumferential body dimension indicators in combat athletes included neck circumference (NC), chest circumference (CC), abdominal circumference (AC), relaxed shoulder circumference (ShC), forearm circumference (FC), calf circumference (CaC), and thigh circumference (TC).

Longitudinal body dimension indicators included the longitudinal dimensions of the trunk (LTD), upper extremity (LDUE), shoulder (LShD), forearm (LFD), lower extremity (LDLE), thigh (LThD), and calf (LCaD).

The SSF level of athletes was assessed according to the time of 30 m running (R30m), the time required to perform 15 partner throws of equal weight at maximal tempo (T15T), the standing long jump result (SLJ), the maximum number of pull-ups on a horizontal bar performed within 10 seconds (PU10s), and push-ups in a prone support position performed within 10 seconds (PPU10s).

The results of the studied motor tests reflect the level of development of motor abilities: speed (R30m), explosive strength (SLJ), and speed-strength endurance (PU10s, PPU10s, T15T). In addition, they reflect the power of the anaerobic alactate (creatine phosphate) system as one of the energy systems ensuring special physical work capacity in combat athletes.

The acyclic nature of a sporting bout is characterized by the execution of movements that vary in structure and intensity. These include accelerations, pushes, single throws, and series of throws of different types, performed during wrestling matches at varying speeds and durations and under conditions of opponent resistance. Such a character of a competitive bout indicates the manifestation of different forms of physical work capacity in wrestling.

If one proceeds from the criteria of energy supply for muscular activity, the following types of work capacity are manifested in a combat sports bout: anaerobic alactate (creatine phosphate), anaerobic lactate (glycolytic), and aerobic. Based on the criteria of manifestation of leading motor qualities, the following types of physical work capacity are distinguished: speed, strength, and speed-strength. From the standpoint of the mode of muscle contraction, both static and dynamic forms of physical work capacity are manifested during a bout.

The result of performing 15 throws of a partner of equal weight at maximal tempo (T15T) reflects the power of one of the forms of SPWC in combat athletes, namely the anaerobic alactate (creatine phosphate) type.

From these perspectives, the speed-strength motor tests performed by the athletes in this study characterize the manifestation of anaerobic alactate (creatine phosphate) work capacity in combat athletes, including speed, strength, and speed-strength forms of physical work capacity. These tests include a 30 m maximal run (R30m), the standing long jump (SLJ), the maximum number of pull-ups on a horizontal bar within 10 seconds (PU10s), push-ups in a prone support position within 10 seconds (PPU10s), and the time required to perform 15 throws of an equal-weight partner at maximal tempo (T15T).

Statistical Analysis

To determine intra- and intergroup relationships within the structure of the PS of combat athletes, methods of correlation, regression, and canonical analysis were employed. The processing of the experimental data was carried out using the STATISTICA 13.5 software package [41]. Pairwise and multiple coefficients of correlation and determination, multiple stepwise regression, and canonical analysis were calculated. In canonical analysis, linear combinations (referred to as canonical variables) are computed for each set of variables, which maximize the correlation between the two sets [37, 38]. The method of canonical correlations was applied to identify latent relationships between two sets of variables, determine maximal correlation links, as well as the partial and total mutual influence of indicators belonging to different groups of the PS of combat athletes. In particular, relationships were examined between the following pairs of variable sets: (1) CBD (7 indicators) and SSF (5 indicators); (2) LBD (7 indicators) and SSF (5 indicators); (3) LBD (7 indicators) and CBD (7 indicators).

Results

Table 1 presents the canonical correlation coefficients, extracted variance, and total variance, which characterize the degree of interaction and mutual variability between two sets of wrestlers' PS variables: five speed-strength indicators of PF and seven indicators of PD.

The results presented in Table 1 reflect different degrees of mutual variability between speed-strength indicators of PF and CBD in the group of highly skilled combat athletes.

An eigenvalue analysis of the PD and PF indicators identified five canonical roots, which account for 100% of the extracted variance in the PF indicator group and 90.9% in the PD indicator group. However, statistically significant mutual influences between the two sets of physical state variables are manifested in each group of subjects only for three of the five canonical roots. Therefore,

Table 1. Results of the canonical correlation analysis of the mutual influence of speed-strength indicators and indicators of body circumferential dimensions in highly skilled wrestlers.

Parameters	Speed-strength indicators	Body circumferential dimensions
Canonical correlation (R), χ^2	0.981, χ^2 (35) = 145.3, p = 0.0000	
Extracted variance	100.0%	90.88%
Total variability (redundancy)	53.896%	53.359%

further analysis was conducted using only these three statistically significant roots.

The values of total variability (redundancy) indicate (Table 1) that 53.9% ($p < 0.0000$) of the PF indicators in combat athletes are explained by the influence of the group of interrelated PD indicators, while 53.4% ($p < 0.0000$) of the variability in PD indicators is explained by the influence of the weighted PF variables.

The total contribution of the three statistically significant roots to the total variability of PF indicators amounted to 43.71% and to PD indicators 44.83%. This corresponds to 81.1% of the total contribution of all five roots to the overall variance of PF indicators and 84.02% for PD indicators.

These results, presented in Table 1, reflect an approximately equal mutual influence between SSF and CBD variables in the studied group of highly skilled combat athletes. An increase in CBD contributes to an increase in SSF level. Conversely, an increase in SSF in wrestlers contributes to an increase in CBD.

The analysis of the factor structure allowed determining the partial variability of individual CBD and SSF indicators within the overall variability of each set under the influence of the group of canonical variables from the other set.

As a result, it was found that across the three statistically significant canonical roots, the highest partial weight in the overall variability of SSF parameters belongs to indicators of explosive strength (PU10s – 14.41%), speed-strength endurance (PPU10s – 10.67%), and anaerobic alactate work capacity (T15T – 9.50%).

Their combined contribution to the total variability (redundancy) of SSF across the three statistically significant roots amounts to 34.57%. This constitutes 79.1% of the total contribution of all studied variables to the overall variability of SSF parameters.

The largest specific weight in the overall variability of PD variables (CBD) in combat athletes belongs to the indicators of chest circumference (CC – 7.12%), shoulder circumference (ShC – 7.28%), and calf circumference (CaC – 10.93%). Their combined contribution to the total variability of PD parameters across the three statistically significant roots is 44.8%. This contribution of the three PD indicators accounts for 84.02% of the total contribution of all studied variables to the overall variability of the CBD indicator group.

This also indicates that CC, ShC, and CaC indicators are the most variable parameters under the influence of the SSF group of indicators in combat athletes. Conversely, indicators of explosive strength (PU10s), speed-strength endurance (PPU10s), and anaerobic alactate work capacity (T15T) are the most variable under the influence of the CBD group of indicators.

Correlation analysis made it possible to determine the magnitude and direction of intra- and intergroup relationships between SSF and CBD indicators. The analysis of pairwise correlation coefficients showed that intragroup relationships among CBD indicators are higher than those within the SSF group and the intergroup relationships between CBD and SSF. Specifically, the mean correlation coefficient among CBD indicators was 0.617 ± 0.07 ($p < 0.001$), within the speed-strength group 0.256 ± 0.06 ($p < 0.05$), and for intergroup relationships 0.224 ± 0.03 ($p < 0.05$).

The averaged pairwise correlation coefficients indicate that among CBD indicators, the strongest relationships with other variables in the set are demonstrated by TC (0.750 ± 0.12), FC (0.738 ± 0.13), CC (0.729 ± 0.14), and NC (0.712 ± 0.11).

Among the individual indicators of SSF, the strongest pairwise relationships with other variables in the complex are demonstrated by two indicators: PPU10s (r = 0.329 ± 0.10) and SLJ (r = 0.365 ± 0.10).

Among intergroup pairwise interactions, the strongest relationships were identified between the indicator of anaerobic alactate work capacity (T15T) and the indicators of CBD. The average value of the pairwise correlation coefficients between T15T and all examined CBD indicators was −0.410 ± 0.09.

However, pairwise intergroup correlations reflect only the relationships between individual pairs of PD and SSF indicators in combat athletes, as well as their averaged intergroup values.

In this regard, to reveal the dependence of individual key indicators in each set (CBD and SSF) on the combined influence of a group of key indicators from the other set, multiple correlation analysis and stepwise multiple regression analysis were performed (Table 2).

Table 2 presents the equations of stepwise multiple regression, as well as the coefficients of multiple correlation and determination. They reflect statistically significant effects of the group of CBD indicators on individual SSF indicators and of

Table 2. Model characteristics of the dependence of individual SSF indicators on the combined influence of a number of key PD indicators (Y_1–Y_5), and of individual PD indicators on the influence of key SSF indicators in wrestlers (Y_5–Y_9).

Regression equations*	r	d	F	p
$Y_1 = (16.36 + 1.144x_1 + 0.115x_2 + 0.337x_3 - 0.216x_4 - 0.244x_5 - 0.765x_6) \pm 0.98$	0.834	0.696	11.07	< 0.00000
$Y_2 = (5.54 + 0.0927x_7 + 0.040x_8 - 0.013x_5 - 0.121x_6 - 0.004x_5 - 0.011x_1) \pm 0.18$	0.634	0.402	4.14	< 0.003
$Y_3 = (3.83 + 0.3495x_6 + 0.1124x_4 - 0.1422x_5) \pm 0.92$	0.572	0.327	6.45	< 0.001
$Y_4 = (47.81 + 2.68x_6 + 0.61x_5 + 1.005x_7 - 2.71x_9 - 0.91x_8 - 0.31x_3) \pm 3.99$	0.642	0.412	5.03	< 0.0006
$Y_5 = (129.98 + 0.02x_{10} - 0.760x_{11} - 0.720x_{12}) \pm 7.22$	0.423	0.179	3.26	< 0.029
$Y_6 = (52.05 - 0.23x_{12} - 0.50x_{13}) \pm 2.74$	0.400	0.160	4.18	< 0.02
$Y_7 = (46.59 - 0.242x_{12} - 0.730x_{13}) \pm 2.74$	0.377	0.142	3.8	< 0.03
$Y_8 = (50.46 - 0.305x_{12} - 0.678x_{13}) \pm 3.4$	0.424	0.180	3.4	< 0.01
$Y_9 = (112.51 + 0.045x_{10} - 0.521x_{12} - 11.24x_{14} - 1.11x_{11}) \pm 8.7$	0.750	0.562	8.7	< 0.0002

* where: Y_1 – PPU10s; Y_2 – R30m; Y_3 – PU10s; Y_4 – T15T; Y_5 – CC; Y_6 – NC; Y_7 – TC; Y_8 – ShC; Y_9 – tense shoulder circumference; x_1 – chest excursion, cm; x_2 – AC, cm; x_3 – CC, cm; x_4 – CaC, cm; x_5 – TC, cm; x_6 – FC, cm; x_7 – ShC, cm; x_8 – NC, cm; x_9 – tense shoulder circumference, cm; x_{10} – SLJ, cm; x_{11} – PPU10s, number; x_{12} – BR15s, s; x_{13} – PU10s, s; x_{14} – R30m, s.; ** r – correlation coefficient; d – determination coefficient; F – Fisher's coefficient.

the SSF group on individual CBD indicators.

The coefficients of determination reflect a stronger influence of the group of leading CBD indicators on individual SSF indicators than the influence of SSF indicators on individual CBD parameters.

In the regression models describing the dependence of individual SSF indicators on the group of CBD indicators, the CBD variables that entered the models with the highest correlation and determination coefficients included CC, TC, CaC, FC, ShC, and NC (Table 2, Y_1–Y_4). Different combinations of PD indicators exert varying degrees of influence on the manifestation of speed, strength, and speed-strength (anaerobic alactate) work capacity in wrestlers during motor tests.

It was found that among the individual parameters of SSF, the strongest dependence on the group of CBD parameters is demonstrated by the indicator of speed-strength (anaerobic alactate) work capacity, PPU10s (Table 2, Y_1). High coefficients of multiple correlation ($r = 0.834$, $p = 0.0000$) and determination ($d = 0.696$, $p = 0.0000$) reflect a strong dependence of the speed-strength work capacity parameter on the group of interrelated PD indicators: AC, CC, CaC, TC, FC, and chest excursion.

The parameters of the first model (Y_1) indicate that with an increase in chest circumference, its excursion, and abdominal circumference, the maximum number of push-ups from the prone support position (PPU10s) increases, that is, the level of speed-strength anaerobic work capacity increases. Conversely, with an increase in the circumference of the calf, thigh, and forearm, the number of push-ups decreases. This reflects a decrease in the level of speed-strength anaerobic work capacity.

The signs of the coefficients in regression model Y_4 indicate that with an increase in neck circumference, tensed shoulder circumference, and chest circumference at rest, the time required to complete the test involving throws of a partner of equal weight (T15T) decreases. That is, the level of special work capacity increases. Conversely, with an increase in thigh, forearm, and relaxed shoulder circumferences, the time required to complete the special test (T15T) increases. This indicates a decrease in the level of special work capacity.

Among the individual parameters of CBD, the strongest dependence on the SSF group is demonstrated by shoulder circumference in a flexed (contracted) state ($r = 0.750$, $p = 0.0000$, $d = 0.696$, $p = 0.0000$). The coefficients of multiple correlation and determination indicate a high dependence of shoulder circumference in a flexed state on the following group of SSF indicators: SLJ, PPU10s, T15T, and R30m.

The model equations indicate that the provision of athletes' anaerobic physical work capacity may be based on different combinations within a complex of PD variables. Stepwise analysis selected a set of variables for the regression models. Their combination provides the best prediction of the result characterizing the level of wrestlers' SPWC.

The values of the canonical factor loadings indicate that among SSF indicators, the strongest relationship with the canonical variable of the first root is shown by the parameter PU10s (−0.732), of the second root by T15T (−0.739), and of the third root by PPU10s (0.807). Among CBD indicators, the strongest relationship with the canonical variable of the first root is shown by CaC (−0.769), of the second root by CC (0.570), and of the third root by FC (−0.711).

The values of the canonical weights of SSF indicators indicate that the greatest contribution to the formation of the canonical variable of the first root is made by the PU10s parameter (−1.201), of the second root by T15T (−0.878), and of the third root by PPU10s (1.103).

The values of the canonical weights of PD variables indicate that the greatest contribution to the first canonical variable is made by FC (2.913), to the second canonical variable by TC (−2.632), and to the third by FC (−3.239).

The magnitudes of the canonical factor loadings and canonical weights indicate that among SSF indicators, the PU10s parameter, having the strongest relationship with the canonical variable, makes the greatest contribution to the formation of the canonical variable of the first root. Among CBD indicators, the strongest relationship with the canonical variable is demonstrated by the CaC parameter; however, the greatest contribution to the formation of the canonical variable of the first root is made by FC and ShC.

Canonical weights were used to construct multiple regression equations. These equations reflect the contribution of each of the PD (CBD) and PF (SSF) indicators to the formation of the canonical variable values.

Thus, the regression equations reflecting the contribution of individual PD (CBD) and PF (SSF) variables of combat athletes to the formation of the canonical variable of the first root (Equations 1–2) are presented below:

$$\text{Root } 1_{PD} = 0.191CC_1 + 0.705AC_2 + 2.913FC_3 - 1.047NC_4 - 1.442ShC_5 - 1.327CaC_6 - 0.404TC_7 \quad (1)$$

$$\text{Root } 1_{PF} = 0.843PPU10s + 0.139T15T - 0.014R30m - 1.002SLJ - 1.201PU10s \quad (2)$$

The results reflect different patterns of mutual variability between the indicators of PD (CBD) and PF (SSF) in the group of highly skilled combat athletes.

Graphical and generalized regression models, as well as the coefficients of correlation and determination reflecting the relationships between the canonical variables of SSF and CBD for root 1, are presented in Figure 1.

The scatter plot of canonical variables for the first root reflects the linear relationship between the weighted sums of variables from two canonical sets, CBD and SSF. Each point on the graph represents an integral parameter of the weighted sums of the initial variables of SSF (five variables) and CBD (seven variables) for each subject. The X-axis corresponds to the scale of weighted sums of CBD, while the Y-axis corresponds to the scale of weighted sums of SSF indicators.

A strong positive linear relationship between the canonical variables of SSF and CBD for the first root ($r = 0.981$, $p < 0.0000$) indicates that an increase in CBD in combat athletes is accompanied by an increase in SSF parameters, including speed-strength work capacity, and vice versa. The distribution of

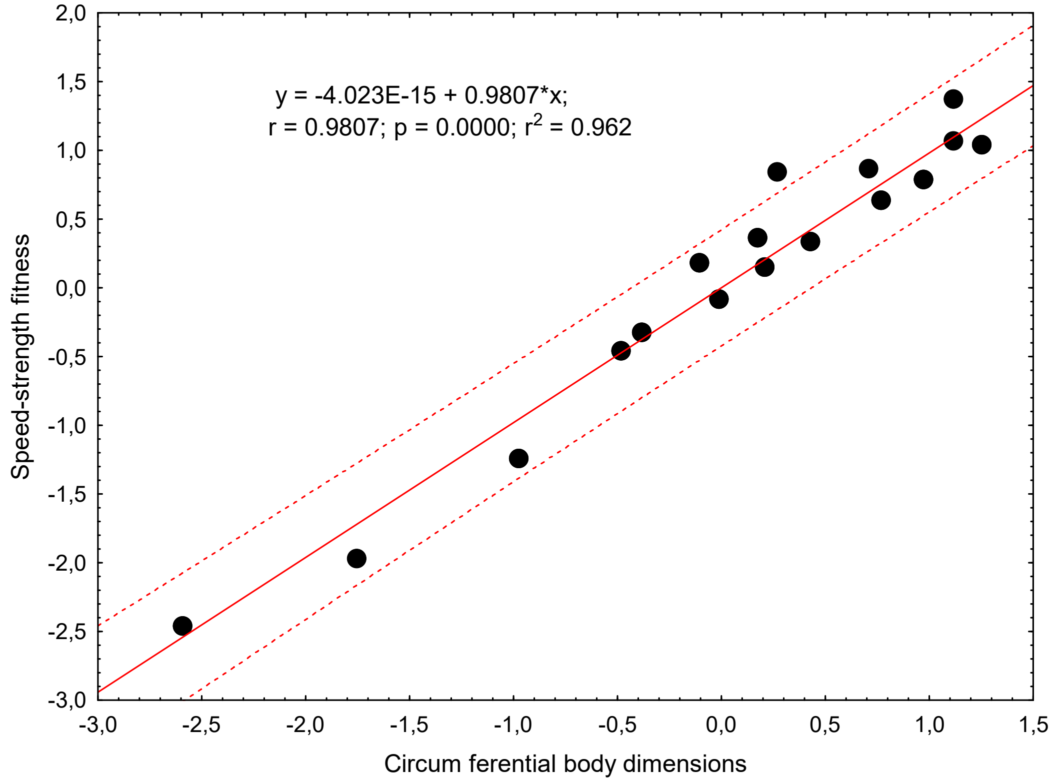

Figure 1. Graphical and regression models of the relationships between the weighted variables of PD (CBD) and the indicators of SSF for the first canonical root.

individual points on the graph, as well as the values of the correlation and determination coefficients, indicate that variables from one group are predicted by variables from the other group.

Below are presented the results of the canonical analysis of the interaction between variables of speed-strength fitness (five variables: R30m, SLJ, PU10s, PPU10s, T15T) and variables of longitudinal body dimensions (seven variables: LTrD, LDUE, LShD, LDLE, LTD, LCaD) (Table 3).

The results of the canonical analysis presented in Table 3 indicate a high level of canonical correlation between the two sets of variables, SSF and LBD ($R = 0.900$, $p = 0.0000$). The chi-square values ($\chi^2 = 82.75$, $p = 0.00001$) reflect a statistically significant interdependence between the set of canonical variables of SSF and the set of variables of LBD (Table 3).

The indicators of total variability (redundancy) demonstrate different mutual influences between the two analyzed groups of variables. Specifically, 39.53% of the variability of the canonical SSF variables is determined by the influence of the canonical LBD variables of combat athletes, while 24.79% of the total variability of the LBD group is explained by the influence of the SSF indicators.

The analysis of the factor structure and redundancy made it possible to determine the loadings of canonical factors for variables in both groups, the proportion of extracted variance explained by the corresponding root for each set, as well as the values of total variability of individual parameters across all roots.

Canonical factor loadings indicate that five roots account for 100% of the total variance of SSF indicators and 70.5% of the variance in the LBD group. Since only two out of the five roots were statistically significant, further analysis was conducted primarily based on these roots.

The analysis of intra- and intergroup relationships between canonical variables of SSF and LBD showed that the strongest relationships are the intragroup correlations among LBD indicators ($r = 0.470 \pm 0.04$). The relationships among speed-strength indicators (SSF) are lower ($r = 0.159 \pm 0.02$). The average level of intergroup relationships between canonical variables of SSF and LBD is also low ($r = 0.199 \pm 0.04$).

Among the LBD variables, the strongest intragroup relationships with all indicators in the set are demonstrated by two variables: LDUE ($r = 0.546 \pm 0.06$) and LDLE ($r = 0.638 \pm 0.05$).

Among the variables of the SSF group, the strongest intragroup relationships with all variables in this group are shown by the indicators SLJ ($r = 0.234 \pm 0.02$) and PU10s ($r = -0.218 \pm 0.05$).

Among variables from different sets, the strongest intergroup relationships are observed between indicators of PU10s and LDUE ($r = -0.453$, $p < 0.05$), as well as between PPU10s and LDUE ($r = -0.456$, $p < 0.05$).

To identify the dependence of individual indicators of each set (LBD and SSF) on the group of leading indicators of the other set, multiple correlation and stepwise multiple regression analyses were performed.

Table 4 presents the dependencies of individual SSF indicators (Y_1–Y_6) on the combined influence of the leading LBD variables.

The parameters of the regression equations, as well as the coefficients of multiple correlation and determination, reflect the combined influence of the group of leading LBD indicators on individual SSF indicators (Table 4, Y_1–Y_6). The coefficients of determination indicate that the degree of influence of different combinations of LBD parameters on individual SSF parameters in wrestlers ranges from 29.2% (result in the SLJ, equation Y_3) to 53.6% (result in the PPU10s, equation Y_2).

Table 5 presents the dependencies of individual LBD indicators (Y_1–Y_5) on the combined influence of the leading SSF variables.

The parameters of the regression equations, along with the coefficients of multiple correlation and determination, indicate that the degree of variability of individual LBD indicators in response to changes in SSF parameters in wrestlers ranges from 18.1% ($p < 0.004$; equation Y_3) to 44.1% ($p < 0.004$; LDUE, equation Y_2) (Table 5). Statistically significant regression coefficients reflect the magnitude, proportion, and interaction of various SSF parameters influencing the values of individual LBD indicators.

The results suggest that in the process of long-term adaptation, a model of speed-strength indicators is formed, associated with a specific number and ratio of LBD parameters. Each LBD parameter is determined by the level, proportion,

Table 3. Results of the canonical correlation analysis of the mutual influence between speed-strength fitness parameters and longitudinal body dimensions in highly skilled wrestlers (N = 35).

Parameters	Indicators of speed-strength fitness	Indicators of longitudinal body dimensions
Canonical correlation (R), χ^2	0.900, χ^2 (35) = 82.75, p = 0.00001	
Extracted variance	100.0%	70.5%
Total variability (redundancy)	39.53%	24.79%

Table 4. Model characteristics of the dependence of individual SSF indicators on the leading LBD variables (Y_1–Y_6).

Regression equations*	r	d	F	p
$Y_1 = (18.73 + 0.194x_1 - 0.120x_2) \pm 1.37$	0.628	0.395	11.09	< 0.0002
$Y_2 = (15.20 + 0.235x_1 + 0.136x_3 - 0.125x_2 - 0.294x_4) \pm 1.23$	0.733	0.536	9.23	< 0.00004
$Y_3 = (7.77x_1 + 13.09x_5 - 4.17x_3 - 135.2) \pm 89.6$	0.541	0.292	4.55	< 0.009
$Y_4 = (47.16 + 0.945x_4 + 0.236x_6 - 0.640x_3) \pm 4.2$	0.578	0.334	5.36	< 0.004
$Y_5 = (5.012 + 0.009x_7 + 0.012x_1 - 0.036x_4 - 0.021x_5) \pm 0.14$	0.578	0.335	3.65	< 0.015
$Y_6 = (9.75 + 0.093x_8 - 0.088x_7 - 0.044x_1) \pm 0.88$	0.560	0.313	5.01	< 0.006

* where: Y_1–Y_2 – PPU10s, number; Y_3 – SLJ, cm; Y_4 – T15T, s; Y_5 – R30m, s; Y_6 – PU10s; x_1 – LTD, cm; x_2 – LDUE, cm; x_3 – LTrD, cm; x_4 – LShD, cm; x_5 – LFD, cm; x_6 – LCaD, cm; x_7 – LDUE, cm; x_8 – LDLE, cm.; ** r – correlation coefficient; d – determination coefficient; F – Fisher's coefficient.

Table 5. Model characteristics of the dependence of individual LBD indicators on the combined influence of the leading SSF variables (Y_1–Y_5) in wrestlers.

Regression equations*	r	d	F	p
$Y_1 = (261.5 + 0.979x_1 - 0.637x_2 - 27.63x_3 - 3.85x_4 - 3.39x_5) \pm 6.1$	0.629	0.396	3.7	< 0.01
$Y_2 = (165.3 + 0.039x_6 - 2.51x_1 - 3.23x_5 - 0.331x_2 - 1.996x_4) \pm 7.2$	0.664	0.441	4.41	< 0.004
$Y_3 = (48.41 + 0.012x_6 + 0.662x_1 - 1.11x_5 - 0.17x_2) \pm 4.0$	0.426	0.181	4.29	< 0.004
$Y_4 = (34.2 + 0.016x_6 - 0.467x_1 - 0.135x_2) \pm 2.45$	0.463	0.214	3.3	< 0.06
$Y_5 = (94.59 + 0.013x_6 - 1.446x_1 - 2.2x_4 - 5.37x_3) \pm 4.48$	0.534	0.285	2.88	< 0.04

* where: Y_1 – LBD, cm; Y_2 – LDUE, cm; Y_3 – LTD, cm; Y_4 – LFD, cm; Y_5 – LCaD, cm; x_1 – PPU10s, number; x_2 – T15T, s; x_3 – R30m, s; x_4 – 4 m rope climb time, s; x_5 – PU10s, s; x_6 – SLJ, cm.; ** r – correlation coefficient; d – determination coefficient; F – Fisher's coefficient.

and interrelationships of certain SSF parameters within each regression model.

The analysis of variability across two statistically significant roots demonstrated that the greatest variability in the SSF group under the influence of canonical LBD variables is observed in the parameters PPU10s (52.8% of the total variance of root 1 indicators) and R30m (28.7% of the total variance of root 2 indicators). At the same time, the greatest variability in the LBD group under the influence of SSF is observed in the parameters LDUE (33.04%, root 1) and LShD (24.73%, root 2).

The analysis of canonical weights of normalized variables in each set showed that within the SSF group, the greatest contribution to the first canonical variable is made by the 10 s maximal anaerobic power test (−0.785), while the second canonical variable is primarily determined by the 30 m sprint (−0.982).

In the LBD parameter group, the greatest contribution to the first canonical variable is made by the LTrD variable (−1.338), and to the second canonical variable by LShD (1.626).

The canonical weights of root 1 individual indicators were used to construct regression equations reflecting the partial and combined contributions of SSF and LBD indicators to the formation of the values of the first canonical variable (Equations 3, 4):

$$\text{Root } 1_{SSF} = 0.092\text{R30m} + 0.070\text{SLJ} + 0.434\text{T15T} - 0.275\text{PU10s} - 0.785\text{PPU10s} \quad (3)$$

$$\text{Root } 1_{LBD} = 0.827\text{LDUE} + 1.014\text{LShD} + 0.071\text{LFD} + 0.781\text{LDLE} - 0.992\text{LTD} - 0.744\text{LCaD} - 1.338\text{LTrD} \quad (4)$$

Figure 2 presents graphical and regression models of the relationship between the canonical variables of LBD and SSF for the first canonical root in highly skilled combat athletes.

The squared correlation (r^2) of the canonical variable pairs indicates that 81.1% ($p = 0.0000$) of the variation in the weighted LBD and SSF variables for the first canonical root is explained by their mutual influence. The magnitude and direction of the correlation and determination coefficients indicate a strong positive linear relationship between the weighted variables of LBD and SSF.

Table 6 presents an analysis of the relationships between two sets of PD variables, longitudinal (LBD) and circumferential (CBD) body dimensions.

The first set of PD variables, presented in Table 6, consists of seven indicators of LBD: the longitudinal dimensions of the upper extremity (LDUE), lower extremity (LDLE), trunk (LTrD), shoulder (LShD), forearm (LFD), thigh (LTD), and calf (LCaD). The second group of PD variables, also presented in Table 6, includes seven indicators of CBD: neck circumference (NC), chest circumference (CC), shoulder circumference (ShC), forearm circumference (FC), abdominal circumference (AC),

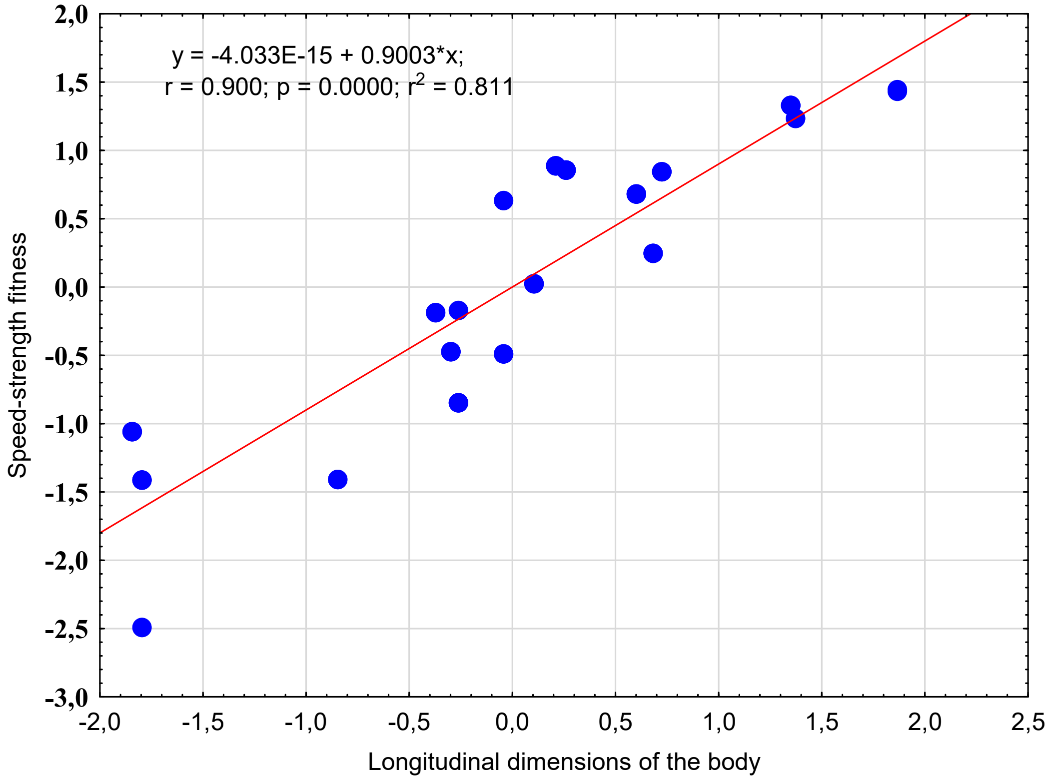

Figure 2. Graphical and regression models of the relationships between the weighted variables of LBD and SSF for the first canonical root.

Table 6. Results of the canonical correlation analysis of the mutual influence between the group of longitudinal body dimensions and the group of circumferential body dimensions (N = 35).

Statistical parameters	Longitudinal body dimensions	Circumferential body dimensions
Canonical correlation (R), χ^2	R = 0.968, χ^2 (49) = 163.9, p = 0.0000	
Extracted variance	100.0%	100.0%
Total variability (redundancy)	57.61%	66.877%

calf circumference (CaC), and thigh circumference (TC).

A high level of canonical correlation was found between the examined groups of variables (Table 6: R = 0.969, p = 0.0000). Its value and that of the chi-square (χ^2 = 163.9, df = 49, p = 0.0000) reflect a strong interdependence between the first canonical variables of the two PD groups, LBD and CBD.

The canonical analysis of eigenvalues revealed seven canonical roots explaining 100% of the extracted variance in the LBD group and 100% in the CBD group. Of the seven roots, the first four are statistically significant.

The results of total variance across all seven roots, presented in Table 6, indicate that 57.5% of the extracted variance in LBD indicators is due to the influence of the CBD canonical variables in combat athletes, while 66.88% of the total variance in CBD indicators is explained by the influence of the LBD variable group.

Redundancy analysis for the four statistically significant roots showed that 54.84% of the total variance in LBD indicators is determined by the influence of the CBD canonical variables, while 65.23% of the total variance in CBD indicators is determined by the influence of the LBD variable group. Relative to the combined effect of all variables across the seven roots, these values amount to 95.2% for LBD indicators and 97.5% for CBD indicators.

High values of the canonical correlation coefficient (R = 0.969, p = 0.0000) and the coefficient of determination (d = 0.938, p = 0.0000) for the first root indicate a strong relationship and mutual influence between the two sets of PD variables: an increase in LBD in combat athletes is accompanied by an increase in CBD, and conversely, an increase in CBD is associated with an increase in LBD. The variability of LBD indicators under the influence of CBD is less pronounced than the variability of CBD indicators under the influence of LBD.

Analysis of the factor structure of the four statistically significant roots made it possible to determine the proportional variability of individual CBD and LBD indicators in the total variability of their respective sets under the influence of the canonical variables of the other set. As a result, it was found that the greatest partial weight in the total variability of CBD indicators belongs to chest circumference (CC – 11.01%), neck circumference (NC – 11.51%), forearm circumference (FC – 10.62%), and thigh circumference (TC – 10.95%). Their combined weight in the total variability of CBD parameters across the four statistically significant roots constitutes 67.6%. This contribution of these four PD indicators accounts for 69.3% of the total contribution of all studied variables to the overall variability of the CBD group under the influence of the LBD canonical variables.

The greatest partial contribution to the total variability of LBD indicators across the four canonical roots belongs to indicators of LTrD (11.25%), LDLE (10.01%), LFD (9.2%), and LShD (9.04%). Their combined contribution to the total variability of LBD parameters across the four roots is 72.0%. This corresponds to 75.6% of the total contribution of all studied variables to the overall variability of the LBD group.

The findings indicate that the most variable CBD indicators under the influence of LBD in combat athletes are chest circumference (CC), neck circumference (NC), forearm circumference (FC), and thigh circumference (TC). The most variable LBD indicators under the influence of CBD are the longitudinal dimensions of the trunk (LTrD), lower extremity (LDLE), forearm (LFD), and shoulder (LShD).

Analysis of the canonical weights of standardized variables for each set showed that within the CBD parameter group, the greatest contribution to the value of the first canonical variable is made by the TC variable (−1.114); to the second canonical variable by CC (3.088); to the third by ShC (1.678); and to the fourth by FC (3.219).

In the LBD parameter group, the greatest contribution to the value of the first canonical variable is made by LFD (−0.721); to the second canonical variable by LTrD (1.28); to the third by LDLE (1.614); and to the fourth by ShC (1.2).

Canonical weights were used to construct regression equations reflecting the contribution of each CBD and LBD indicator to the formation of the canonical variables of the first root (Equations 5–6):

$$Root\ 1_{LBD} = 0.371LDUE + 0.232LTD - 0.237LTrD - 0.491LShD - 0.721LFD - 0.058LDLE - 0.271LTrD \quad (5)$$

$$Root\ 1_{CBD} = 0.632CC + 0.149AC + 0.132ShC + 0.537FC - 1.114TC - 0.41CaC - 0.915NC \quad (6)$$

Figure 3 presents graphical and regression models of the relationships between the weighted CBD and LBD variables for the first canonical root.

The squared canonical correlation (r^2), presented in Figure 3, indicates that 93.8% of the variance in the weighted LBD and CBD variables for the first canonical root is explained by their mutual influence.

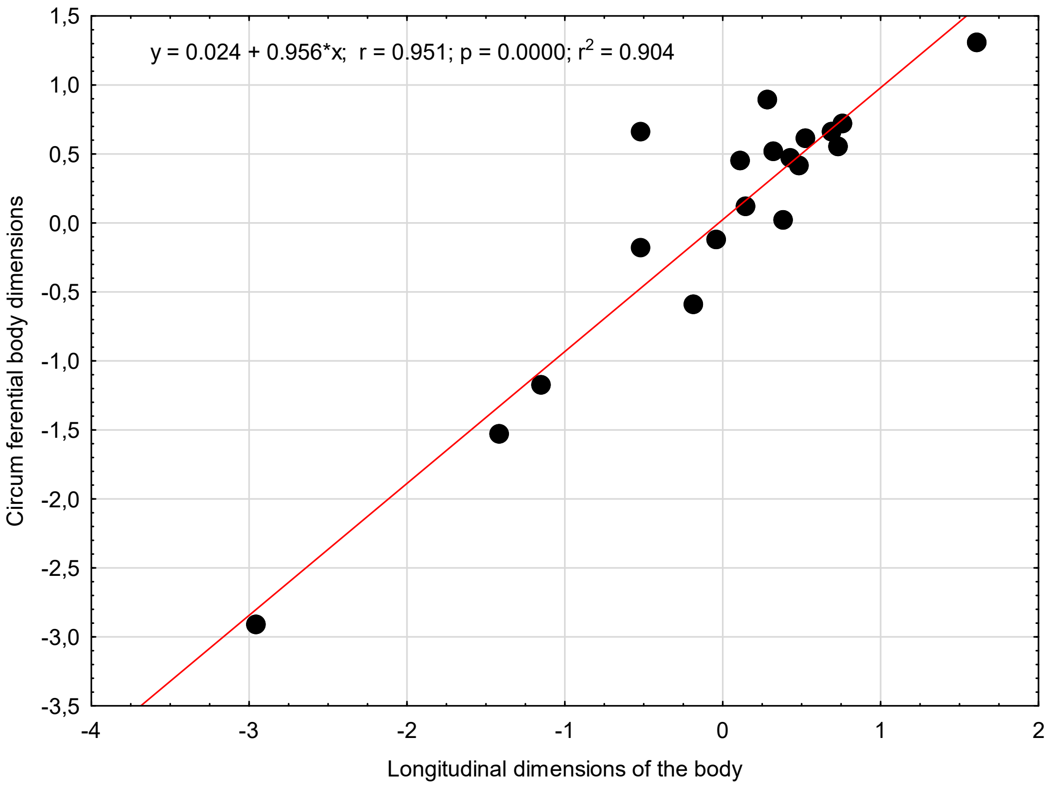

Figure 3. Graphical and mathematical models of the relationships between the weighted LBD and CBD variables for the first canonical root.

Discussion

The aim of the study was to perform a canonical analysis of the general variability and interrelationships among parameters of speed-strength fitness, as well as circumferential and longitudinal body dimensions in highly skilled wrestlers. The results showed the presence of statistically significant interrelationships between the studied groups of variables, reflecting their mutual influence. The analysis demonstrated that changes in speed-strength fitness parameters are associated with changes in circumferential and longitudinal body dimensions. It was also found that the degree of influence differs depending on the specific group of indicators and their combinations.

Long-term adaptation of combat athletes to physical loads is characterized by the formation of a complex of morphological, functional, and metabolic rearrangements. These reflect the structure of physical state (PS) and the reserve capacities of athletes.

The level of development, ratios, and interrelationships among parameters of PD, physical, functional, psychological, and technico-tactical fitness, as well as SPWC, determine the multilevel, hierarchically organized structure of the PS of combat athletes. They also determine their specific profile and the effectiveness of competitive activity [18, 24, 42, 43].

The complex and interconnected nature of adaptive changes in the bodies of combat athletes necessitates comprehensive studies of the level of development, proportions, and interrelationships of PS parameters. These depend on various determinants such as age, weight category, qualification, sex, training period, and the orientation of the training process.

The methodological principles of the systems approach form the basis for studying complex adaptive transformations in hierarchically organized biological systems during long-term adaptation to physical loads.

The principles of the systems approach necessitate conducting synchronous investigations of the level of development, proportions, and interrelationships among various PS components of combat athletes. They also involve identifying the most informative indicators and their partial contribution to the overall variability of the group of interacting parameters.

Systemic and comprehensive approaches also require the use of an appropriate set of statistical programs to determine the specificity of interrelationships and mutual influences, as well as the degree of integration of parameters representing different components of the PS of combat athletes. This applies both to the process of improving athletic mastery and shaping the morphofunctional and metabolic profile, and to the development of various forms of SPWC, including anaerobic, aerobic, mixed, strength, speed, speed-strength, static, and dynamic.

In accordance with the main aim and objectives of the present study, the processing of experimental data was carried out using methods of correlation, regression, and canonical analysis [41].

An analysis of scientific publications has shown that the method of canonical analysis is still insufficiently used for assessing the morphological, psychological, metabolic, functional, and technico-tactical profiles of athletes. At the same time, the specific profile and effectiveness of competitive activity are largely determined by intergroup interactions among various components of the PS structure of athletes [5]. The method of canonical correlation is one of the appropriate tools for studying such intergroup interactions [37, 44].

Only a limited number of studies [8, 37, 39], as well as our previous works [5, 45], have demonstrated that the canonical correlation method is one of the suitable methods for:

a) identifying latent relationships between groups of interacting parameters;

b) determining the maximum correlation between several output (resultant) indicators and a large number of input (determinant) factors;

c) assessing the partial role of individual parameters in the overall variability of the canonical variables of each group under the influence of the canonical variables of another group;

d) identifying the most variable output (resultant) indicators and the most variable input (determinant) factors.

However, the use of the canonical correlation method to assess intergroup interactions and mutual influences among indicators from different sets of the PS of combat athletes is insufficiently represented in the specialized literature.

The experimental material presented in our previous studies confirms the effectiveness of this method for identifying maximum relationships and the specific nature of mutual influences among parameters of different PS sets in combat athletes, including functional state, SSF, integral indicators of functional fitness, CBD, skinfold thickness (SFT), and other sets [5, 45].

In the present study, the canonical correlation method was used to evaluate both the combined and partial mutual influence of indicators from the following PS sets in combat athletes: CBD and SSF; LBD and SSF; CBD and LBD.

The SSF parameter group included indicators of speed and speed-strength work capacity, strength endurance, and explosive strength. The intensity and duration of the tests performed indicated the predominance of the anaerobic alactate (creatine phosphate) mechanism in the energy supply of

SPWC in combat athletes, along with contributions from anaerobic glycolytic (lactate) or aerobic mechanisms [46].

The assessment of other forms of SPWC manifestation, in which anaerobic (glycolytic) or aerobic energy systems play a significant role, was not within the scope of the present study.

The results obtained in this study confirm and extend the findings of our previous research devoted to the application of the canonical correlation method for evaluating interactions among parameters of different PS sets in combat athletes [45, 47].

While our previous studies analyzed intra- and intergroup correlations of CBD parameters, SFT, and integral functional parameters with a set of SSF parameters in combat athletes [45, 47], the present study examined intra- and intergroup relationships between CBD and SSF parameters, CBD and LBD, and LBD and SSF.

The results of the present study confirm the findings of our earlier research, which indicate close intergroup correlations between CBD and SSF parameters in combat athletes [45].

However, while our previous studies analyzed the correlations between CBD parameters and SSF test results, in which the anaerobic lactate mechanism played a role in energy supply, the present study analyzed the correlations between CBD and SSF test results, in which the anaerobic alactate (creatine phosphate) mechanism played a role in energy supply [20, 24, 46].

This methodological approach made it possible to obtain results that complement our previous studies conducted in this area [45].

The novelty of the present study lies in the fact that in highly skilled combat athletes, canonical analysis revealed latent intergroup interactions among the sets of variables of SSF, CBD, and LBD. The partial role of individual parameters in the mutual influence of the studied sets of the athletes' PS was also determined.

The analysis of intergroup interactions showed that increases in CBD and LBD contribute to increases in SSF, while increases in SSF parameters are accompanied by increases in CBD and LBD. In the interaction between SSF and CBD variables, an approximately equal mutual influence was identified. In contrast, in the interaction between CBD and LBD variables, a more pronounced influence of LBD variables on CBD was observed than the reverse effect of CBD parameters on LBD. It was also found that CBD parameters exert a stronger influence on the level of SSF in combat athletes than LBD parameters. Moreover, CBD parameters are more dependent on the level of SSF than on LBD.

The analysis of pairwise intragroup relationships revealed a higher degree of integration among CBD parameters than the intragroup integration of SSF and LBD parameters. The weakest intragroup integration was observed among SSF parameters.

Among the individual CBD variables, the strongest intragroup relationships with all variables in the set are exhibited by the circumferential dimensions of the neck, forearm, and chest. Among the individual LBD variables, the strongest intragroup relationships with all indicators in the set are shown by the longitudinal dimensions of the upper and lower extremities. Among the SSF variables, the strongest intragroup relationships with all other indicators of the analyzed group are demonstrated by the standing long jump and the number of pull-ups on the bar performed within 10 seconds.

The analysis of pairwise intergroup relationships showed that the strongest associations between SSF and CBD indicators are observed between the parameter of anaerobic alactate work capacity (T15T) and all indicators of the CBD group.

Among the intergroup interactions between SSF and LBD parameters, the strongest relationships were identified between the indicator of speed-strength work capacity (PPU10s) and all LBD indicators.

The analysis of the factor structure and canonical weights made it possible to determine the shared variability of individual indicators in the overall variability of each set (CBD and LBD, SSF) under the influence of the group of canonical variables from the other set.

The redundancy analysis revealed that among CBD indicators, the most variable under the influence of LBD in combat athletes are the circumferential dimensions of the neck, chest, forearm, and thigh. Among LBD indicators, the most variable under the influence of CBD are the longitudinal dimensions of the trunk, lower extremity, forearm, and shoulder. Among SSF indicators, the most variable under the influence of the canonical variables of LBD are the maximum number of push-ups performed in the prone support position within 10 seconds and the result in 30 m running.

The greatest variability within the LBD group under the influence of SSF is observed in the parameters of the longitudinal dimensions of the upper extremity and the shoulder. The most variable SSF parameters under the influence of CBD variables are indicators of speed-strength endurance, anaerobic alactate work capacity, and explosive strength. The highest degree of variability within the CBD group under the influence of SSF is observed in the circumferential dimensions of the calf, shoulder, and chest.

The canonical regression equations reflect the partial contribution of the leading indicators of the wrestlers' PS to the formation of the values of the first canonical root variables for each of the studied sets (Equations 1–6).

High values of canonical correlations, coefficients of determination, and χ^2 between the three interacting groups of PS parameters in combat athletes indicate a strong interdependence of the parameters of the studied sets. They also show that the variables of one group of indicators are predicted by the variables of another group.

The results of the stepwise multiple regression analysis showed that the level of speed-strength work capacity in combat athletes can be provided by different combinations and interactions of variables from two groups of PD parameters (CBD and LBD). The calculated models indicate that the total influence of the leading CBD indicators of wrestlers on individual SSF parameters ranges from 32.7% to 69.6%. The total influence of different combinations of leading SSF indicators on individual CBD parameters ranges from 14.2% to 56.2%. The total influence of different combinations of leading LBD indicators on individual SSF parameters ranges from 29.2% to 53.6%. The total influence of different combinations of leading SSF indicators on individual LBD parameters ranges from 8.2% to 44.02%.

The coefficients of canonical correlation, multiple regression, and determination indicate a stronger influence of the CBD parameter group on individual SSF parameters than the reverse influence of the SSF indicators on individual CBD parameters.

The regression models also showed that an increase in chest, neck, and tensed shoulder circumference is associated with an increase in the level of special (anaerobic alactate) work capacity. An increase in chest circumference, chest excursion, and abdominal circumference is associated with an increase in speed-strength anaerobic endurance. At the same time, an increase in the circumferential dimensions of the thigh, forearm, and shoulder is associated with a decrease in special anaerobic (alactate) work capacity. It should be noted that the values of TC, FC, and ShC are higher in combat athletes of heavier weight categories. These athletes also demonstrate a lower level of SPWC than athletes in middle and lightweight categories [22]. Therefore, for an adequate interpretation of the obtained results, it is necessary to take into account the weight categories of combat athletes.

Limitations and Future Research Directions

The present study has several limitations that should be considered when interpreting the findings. The analysis was based on a selected set of morphofunctional and performance indicators corresponding to the study aim, which defines the scope of the obtained results and limits their extension to other components of physical state. The assessment of speed-strength fitness was focused on motor tests reflecting predominantly anaerobic alactate work capacity, which determines the specificity of the identified relationships among the studied parameters. The cross-sectional design of the study does not allow establishing the direction of causal relationships between variables and does not reflect potential changes in their interactions over time. In addition, the applied multivariate statistical methods, including canonical analysis, are based on the structure of the selected variables and their linear relationships, which should be considered when interpreting the identified patterns of intergroup interaction.

Future research may focus on examining the relationships among PS parameters in more homogeneous groups with respect to sport specialization, qualification level, and weight categories in order to уточнить структуру выявленных взаимодействий. It is also appropriate to analyze the dynamics of these relationships at different stages of training and competitive activity using longitudinal designs. Further studies may expand the set of analyzed indicators within the framework of the studied components of physical state to уточнить характер межгрупповых взаимосвязей.

Conclusions

As a result of the canonical analysis of the interaction between physical development parameters and speed-strength fitness of combat athletes, the following were determined: a) the leading parameters of the overall variability of the indicators of the interacting groups; b) the partial role of individual indicators in the mutual influence of the parameters of the studied sets; c) the specifics of mutual influences among the sets of variables of speed-strength fitness and circumferential and longitudinal body dimensions; d) the most variable determining indicators and the most variable outcome indicators; e) latent intra- and intergroup relationships among the parameters of the physical state of combat athletes.

The indicators of overall variability of the canonical variables of physical development and speed-strength fitness of combat athletes, as well as the values of canonical correlations, coefficients of determination, and χ^2, reflect a high level of interdependence among the parameters of the studied sets. Increases in circumferential and longitudinal body dimensions contribute to increases in speed-strength fitness, while increases in speed-strength fitness are associated with increases in circumferential and longitudinal body dimensions of athletes. The strongest intergroup relationships are observed between the indicators of circumferential and longitudinal body dimensions, whereas the strongest intragroup relationships are found among the indicators of circumferential body dimensions.

In the interaction between circumferential and longitudinal body dimensions, a stronger influence of longitudinal dimensions on circumferential ones is observed. In the interaction between circumferential body dimensions and speed-strength fitness variables, their mutual influence is approximately equal. In the interaction between longitudinal body dimensions and speed-strength fitness variables, a stronger influence of longitudinal dimensions is observed. The level of speed-strength fitness in combat athletes is more dependent on circumferential than on longitudinal body dimensions. Variables of circumferential body dimensions demonstrate a greater dependence on speed-strength fitness variables than on longitudinal body dimension variables.

The speed-strength fitness parameters most dependent on circumferential body dimensions are indicators of explosive strength, speed-strength endurance, and anaerobic alactate work capacity. The circumferential body dimension parameters most dependent on the level of speed-strength fitness in combat athletes are the circumferences of the chest, shoulder, and calf. The speed-strength fitness parameters most dependent on longitudinal body dimensions are indicators of anaerobic alactate work capacity and speed-strength endurance. The longitudinal body dimension parameters most dependent on the level of speed-strength fitness are the longitudinal dimensions of the upper extremity and the shoulder. The circumferential body dimension parameters most dependent on changes in longitudinal body dimensions are the circumferences of the chest, neck, forearm, and thigh. The longitudinal body dimension parameters most dependent on changes in circumferential body dimensions are the longitudinal dimensions of the trunk, shoulder, forearm, and lower extremity.

The results of the multiple regression analysis indicate that the total influence of different combinations of leading indicators of wrestlers' circumferential body dimensions on individual parameters of longitudinal body dimensions ranges from 8.2% to 44.02%, and on individual parameters of speed-strength fitness from 32.7% to 69.6%. The total influence of different combinations of leading indicators of longitudinal body dimensions on individual parameters of circumferential body dimensions ranges from 14.2% to 56.2%, and on individual parameters of speed-strength fitness ranges from 29.2% to 53.6%. The total influence of different combinations of speed-strength fitness indicators on individual parameters of circumferential body dimensions ranges from 14.2% to 56.2%, and on individual parameters of longitudinal body dimensions ranges from 8.2% to 44.02%.

An increase in the circumference of the neck, tensed shoulder, chest, and abdomen is associated with an increase in the level of special work capacity and speed-strength endurance in combat athletes. Conversely, an increase in the circumferential dimensions of the thigh, calf, forearm, and shoulder, in parallel with an increase in athletes' weight categories, is associated with a decrease in the level of anaerobic work capacity.

Conflict of interest

The authors declare that there is no conflict of interest.

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