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The Relationship Between Physical Performance Indicators, Metabolic Characteristics, and Body Composition of Young Athletes

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ABSTRACT

BACKGROUND: Adequate supply of nutrients, water, minerals, and micronutrients is required to maintain energy-yielding and constructive metabolism and support the body in the context of intense exercise load. This is especially important for young, physically and socially active individuals such as athletes, military personnel, rescuers, police officers, and other adventure and action professionals.

AIM: To find relationships between Bioelectrical Impedance parameters of body composition of multi-event athletes and their key physical performance indicators determined by cardiopulmonary exercise testing with maximum exercise load.

MATERIALS AND METHODS: Nine men (a multi-event team) aged 18 to 22 voluntarily participated in the study. We used anthropometry, Bioelectrical Impedance Analysis, skinfold caliper measurement, and cardiopulmonary exercise testing with VO_2max measurement at peak exercise load. Due to small sample sizes, the Spearman nonparametric rank correlation method was used to analyze the relationship between the studied variables. Statistical analysis of the data was carried out using Microsoft Excel and Statistica 10.0 software.

RESULTS: We found significant and strong correlations between the lean body mass, including muscle mass; water, protein and mineral content and the exercise efficiency and muscle energy supply during intense exercise load measured by cardiopulmonary exercise testing.

CONCLUSION: It has been experimentally verified that during intense exercise load, most metabolic loading in the human body is borne by its lean body mass, including skeletal muscles, and their unimpaired functioning requires sufficient supply of both energy and proteins to maintain muscle volume and restore muscle mass. A reasonable way to increase the supply of proteins to the athlete's body is to introduce functional foods with given ingredients and optimal content of high-quality and easily digestible protein into the diet.

Keywords: bioelectrical impedance analysis; cardiopulmonary exercise testing; multi-event team; athletes; nutritional status; physical activity; physical performance.

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Взаимосвязь показателей физической работоспособности, метаболических особенностей и состава тела молодых спортсменов

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АННОТАЦИЯ

Актуальность. Для обеспечения деятельности связанной с интенсивными физическими нагрузками необходимо адекватное поступление питательных веществ, воды, минералов и микроэлементов, обеспечивающих энергетический и пластический метаболизм. Это особенно важно для лиц молодого возраста, активных физически и социально, таких как спортсмены, военнослужащие, спасатели, полицейские и прочие специалисты экстремальных видов деятельности.

Цель — поиск взаимосвязей между биоимпедансометрическими параметрами состава тела спортсменов-многоборцев и их основными показателями физической работоспособности, оцененными в кардиореспираторном тесте с максимальной физической нагрузкой.

Материалы и методы. В исследовании приняли добровольное участие 9 мужчин (сборная спортивная команда по многоборью) от 18 до 22 лет. Использованы следующие методы: антропометрия, биоимпедансометрия, калиперометрия, кардиореспираторный тест с определением максимального потребления кислорода на пике физической нагрузки. Для анализа взаимосвязи между исследуемыми переменными с учетом малых размеров выборок был использован метод непараметрической ранговой корреляции Спирмена. Статистический анализ данных проведен с использованием программных продуктов Microsoft Excel и Statistica 10.0.

Результаты. Выявлены статистически значимые сильные корреляционные связи показателей безжировой, в том числе мышечной, массы тела, а также значений содержания воды, протеина и минеральных веществ с показателями эффективности мышечной работы и ее энергообеспечения при интенсивных физических нагрузках, оцененных с применением кардиореспираторного теста.

Заключение. Экспериментально подтверждено, что при выполнении интенсивной физической работы главную метаболическую нагрузку в организме человека несет его тощая масса тела, включая скелетную мускулатуру, для полноценной деятельности которой необходимо достаточное обеспечение не только энергией, но и протеинами для поддержания мышечных объемов, восстановления мышечной массы. Одним из доступных способов увеличения поступления протеинов в организм спортсмена является введение в рацион функциональных продуктов питания с заданным составом и оптимальным содержанием высококачественного легкоусвояемого белка.

Ключевые слова: биоимпедансометрия; кардиореспираторный тест; многоборье; спортсмены; статус питания; физическая нагрузка; физическая работоспособность.

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ЭКО • ВЕКТОР

BACKGROUND

Optimal human functioning depends on the adequate intake of essential nutrients, water, minerals, and micronutrients that support energy metabolism and constructive processes. Adequate nutrient intake is critical for young individuals, especially those who are physically and socially active and are regularly exposed to physical and psychosocial stressors during professional activities, including extreme conditions (athletes, military personnel, emergency responders, law enforcement officers, and other professionals engaged in high-risk occupations) [1–3]. Currently, various methodological approaches for developing dietary strategies for such populations have been proposed; however, many of these approaches are contradictory [4, 5]. Therefore, when designing optimal dietary regimens for individuals engaged in moderate to high levels of physical activity, their nutritional status should be considered. A pilot study was conducted to explore potential associations between physical performance indicators and nutritional status in young male athlete–soldiers engaged in multi-event training, as decathlon resembles the physical demands encountered in military professions. A larger-scale study involving a statistically adequate sample will be conducted to assess the effects of intense physical exercise on body composition.

MATERIALS AND METHODS

Nine male military personnel (members of a multi-event sports team) aged 18–22 years voluntarily participated in the study. The sample size was determined by the number of team members. Anthropometric measurements (stadiometer and medical scales) and bioelectrical impedance analysis (InBody770 body composition analyzer, Biospace Co., Korea) were used to assess the following parameters: height (cm), body weight (kg), total body water (L), intracellular water (L), extracellular or interstitial water (L), protein (kg), minerals (kg), body fat mass (BFM; kg), soft lean mass (kg), lean body mass (kg), skeletal muscle mass (kg), body mass index (kg/m^2), percent body fat (PBF;%), ideal body weight (kg), basal metabolic rate (kcal), waist-to-hip ratio (WHR; unitless), visceral fat area (VFA; cm^2), degree of obesity (unitless), and active cell mass (kg).

In assessing physical performance and endurance, the participants (in a fasted state) underwent a cardiopulmonary exercise test to determine the maximal oxygen consumption (VO$_2$max) at peak physical exertion. The test was conducted using an ergoline bicycle ergometer connected to the ergospirometry system MetaLyzer 3B (Cortex, Germany), following the protocol: rest for 1.5 minutes and then free pedaling for 1.5 minutes, followed by incremental loading starting at 20 W and increasing by 20 W/min until the participant refused to continue, followed by a 3-minute recovery period. The following parameters were measured: heart rate (HR; bpm), respiratory rate (RR; cycle/min), minute ventilation (L/min), oxygen consumption (V'O$_2$/kg, mL/min/kg), respiratory exchange ratio (RER; unitless), and maximal work rate at VO$_2$max (WR; W). The parameters at rest, moderate physical activity corresponding to approximately 50% of VO$_2$max, and maximal physical activity upon reaching VO$_2$max were recorded.

A correlational study design was employed, with physical performance indicators as the independent variables and metabolic and body composition parameters as the dependent variables. The statistical hypothesis posited a relationship between physical performance metrics and metabolic and body composition characteristics.

Data were statistically analyzed using Microsoft Excel, Statistica 10.0, and SPSS23. The critical value for statistical significance in testing null hypotheses was 0.05. In analyzing the relationship between the variables, considering the small sample sizes, Spearman’s rank correlation method was used [6, 7].

RESULTS AND DISCUSSION

Table 1 presents the statistical data obtained from the anthropometric and bioelectrical impedance measurements of the study participants.

The main results of the cardiopulmonary exercise test, conducted at rest and under various levels of physical load, are summarized in Table 2 as medians, along with the corresponding maximum and minimum values. In this context, the use of the median is preferred than the mean, as not all values follow a normal distribution, and in small samples, outlier correction is challenging, and the median is not sensitive to outliers.

Changes in physiological parameters in response to physical load remained within normal limits. No pathological symptoms were observed, including on ECG monitoring. At the point of voluntary test termination, all the athletes attained VO$_2$max, which was indicated by the oxygen uptake curve reaching a plateau and the RER exceeding 1.0 [8]. A correlation analysis was performed to identify potential correlations between the cardiopulmonary and metabolic parameters and bioelectrical impedance-derived nutritional status indicators of the examined athletes. The results are shown in Tables 3–5.

Table 3 reveals a positive rank correlation ($rS \geqslant 0.698$) between resting RR and body fat-related parameters, namely, BFM, PBF, VFA, and WHR. Additionally, a negative correlation was observed between WHR and RER. No significant correlations were found between minute ventilation, HR, and V'O$_2$ with these body composition parameters.

Table 1. Anthropometric and Bioelectrical Impedance Analysis of the multi-event team members

Таблица 1. Данные антропометрии и биоимпедансометрии членов спортивной команды по многоборью

Parameters	Quartile 1	Median, *Me*	Quartile 3	Maximum value	Minimum value
Age, years	20.00	20.00	21.00	22.00	17.80
H, cm	172.50	176.75	181.38	186.00	169.00
BW, kg	72.08	74.90	77.50	87.60	65.60
TBW, L	46.95	49.60	51.65	56.10	42.70
ICW, L	29.48	31.25	32.38	35.00	26.60
ECW, L	17.38	18.55	19.28	21.10	16.10
Pr, kg	12.68	13.50	14.03	15.10	11.50
Min, kg	4.32	4.67	4.92	5.52	4.00
BFM, kg	5.45	6.60	8.85	10.90	4.10
SLM, kg	60.45	66.05	66.90	70.10	54.90
LBM, kg	63.98	67.80	70.53	76.70	58.20
SMM, kg	36.38	38.75	40.30	43.70	32.70
BMI, kg/m^2	22.93	23.90	24.98	26.30	21.30
PBF, %	7.35	9.80	12.20	12.60	5.20
IBW, kg	72.08	76.05	77.50	87.60	65.60
BMR, kcal	1751.75	1835.00	1893.75	2026.00	1627.00
WHR, unitless	0.76	0.77	0.80	0.83	0.74
VFA, cm^2	18.78	24.05	33.40	48.10	8.10
DO, unitless	104.50	109.50	114.50	120.00	97.00
ACM, kg	42.15	44.75	46.40	50.10	38.10

Table 2. Cardiopulmonary exercise test results at rest and exercise load

Таблица 2. Результаты выполнения кардиореспираторного теста в покое и с физической нагрузкой

Parameters	Resting state			Moderate intensity load at 50% VO_2max			Maximal intensity load at 100% VO_2max		
	Me	max	min	*Me*	max	min	*Me*	max	min
HR, 1/min	80.0	99.0	72.0	116	151	101	176	191	159
RR, 1/min	16.0	20.0	7.0	18	30	10	38	53	31
V'E, L/min	12.4	16.8	9.8	30.1	47.3	22	112.2	160.3	85.7
$V'O_2$/kg, mL/min/kg	5.0	8.0	4.0	20	28	12	44	48	40
RER, unitless	0.86	1.0	0.76	0.88	0.99	0.74	1.11	1.26	1.05
WR, W	0.0	0.0	0.0	98	146	73	270	291	213

Table 4 presents the correlation data between the studied parameters under moderate load.

The trend observed at rest was maintained during moderate physical exertion. For the VFA parameter, the significance level was $p < 0.05$, and for the other relevant parameters—BFM, PBF, and VFA — the significance level was $p < 0.1$ (Table 4). Notably, none of the participants demonstrated increased BFM and PBF. The ideal body weight obtained through bioelectrical impedance analysis was almost identical to the actual body weight. Therefore, whether the amount of fat stored in tissue depots could be a mechanical barrier to external respiration function was unclear; however, the influence of other mechanisms cannot be excluded. Additionally, a negative correlation was observed ($p < 0.05$) between the WHR, which characterizes the degree of visceral obesity, and respiratory exchange ratio at rest (Table 3). This relationship indicates that an increased role of lipids in energy supply during physical rest may occur in individuals with increased body fat content.

Table 3. Correlation between the cardiopulmonary exercise test, metabolic parameters, and Bioelectrical Impedance Analysis of athletes at rest (Spearman rank correlation)

Таблица 3. Корреляционная связь между кардиореспираторными, метаболическими параметрами и показателями биоимпедансометрии у спортсменов в покое (ранговая корреляция Спирмена)

Parameters	RR, 1/min		RER, unitless	
	rS	*p*	*rS*	*p*
BFM, kg	0.698	0.037	–	–
PBF, %	0.778	0.014	–	–
WHR, unitless	0.725	0.027	–0.855	0.003
VFA, cm^2	0.724	0.028	–	–

Note. The Table shows only significant correlations (rS=0.67, p <0.05; rS=0.83, p <0.01; rS=0.91, p <0.001).
Примечание. В таблице указаны только значимые корреляционные связи при rS=0,67 — p <0,05; rS=0,83 — p <0,01; rS=0,91 — p <0,001.

Table 4. Correlation between the cardiopulmonary exercise test, metabolic parameters, and Bioelectrical Impedance Analysis of athletes at moderate exercise load (Spearman rank correlation)

Таблица 4. Корреляционная связь между кардиореспираторными, метаболическими параметрами и показателями биоимпедансометрии у спортсменов при умеренной нагрузке (ранговая корреляция Спирмена)

Parameters	RR, 1/min		RR, 1/min		RER, unitless	
	rS	*p*	*rS*	*p*	*rS*	*p*
BW, kg	–	–	–	–	–0.686*	0.041
TBW, L	–	–	–	–	–0.678*	0.045
ICW, L	–	–	–	–	–0.678*	0.045
Pr, kg	–	–	–	–	–0.678*	0.045
Min, kg	–	–	–	–	–0.703*	0.035
LBM, kg	–	–	–	–	–0.678*	0.045
SMM, kg	–	–	–	–	–0.678*	0.045
BMR, kcal	–	–	–	–	–0.678*	0.045
WHR, unitless	–	–	–	–	–0.700*	0.036
VFA, cm^2	–	–	0.672*	0.047	–	–
DO, unitless	–0.717*	0.030	–	–	–	–
ACM, kg	–	–	–	–	–0.678*	0.045

Note. The Table shows only significant correlations (* rS=0.67, p <0.05; ** rS=0.83, p <0.01).
Примечание. В таблице указаны только значимые корреляционные связи при * — rS=0,67 — p <0,05; ** — rS=0,83 — p <0,01.

Table 5. Correlation between the cardiopulmonary exercise test, metabolic parameters, and Bioelectrical Impedance Analysis of athletes at peak exercise load (Spearman rank correlation)

Таблица 5. Корреляционная связь между кардиореспираторными, метаболическими параметрами и показателями биоимпедансометрии у спортсменов при максимальной нагрузке (ранговая корреляция Спирмена)

Parameters	RR, 1/min		V'E, L/min		$V'O_2$/kg, mL/min/kg		WR, W	
	rS	*p*	*rS*	*p*	*rS*	*p*	*rS*	*p*
BW, kg	–	–	0.917**	0.001	0.653	0.057	0.717*	0.030
TBW, L	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005
ICW, L	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005
ECW, L	0.800**	0.010	0.950**	0.000	0.787*	0.012	0.850**	0.004
Pr, kg	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005
Min, kg	0.683*	0.042	0.950**	0.000	0.728*	0.026	0.767*	0.016
SLM, kg	–	–	0.932**	0.000	0.732*	0.025	0.661	0.053
LBM, kg	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005
SMM, kg	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005
IBW, kg	–	–	0.917**	0.001	0.653	0.057	0.717*	0.030
BMR, kcal	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005
ACM, kg	0.767*	0.016	0.967**	0.000	0.728*	0.026	0.833**	0.005

Note. The Table shows only significant correlations (* rS=0.67, p <0.05; ** rS=0.83, p <0.01).
Примечание. В таблице указаны только значимые корреляционные связи при * — rS=0,67 — p <0,05; ** — rS=0,83 — p <0,01.

Furthermore, correlation (p <0.05) was observed between the RER obtained under moderate load and bioelectrical impedance parameters (Table 3) and was divided into three conditional groups:

1. Correlations between RER and total body water, intracellular water, protein, and mineral content
2. Correlations between RER and lean body mass, skeletal muscle mass, and cell mass (but not with parameters related to body fat content)
3. Correlations between RER and basal metabolic rate

RER is known to indicate which substrate (lipids or carbohydrates) is used for energy during athletic activity [9–11]. At the point of anaerobic threshold, there is a shift from predominantly lipid aerobic catabolism to a mixed aerobic-anaerobic process, leading to an increase of RER values to levels comparable to those observed at rest (Table 2).

Thus, it can be assumed that the athletes exhibiting higher values in the three conditional groups abovementioned had lower RER values. This may demonstrate a probable predominance of lipid-based energy supply during exercises leading to anaerobic threshold in individuals with higher levels of water content and hydrophilic fat-free body mass and more intense basal metabolism [9, 12, 13]. As lipid catabolism requires the presence of oxygen, it can be hypothesized that these individuals have a more efficient energy supply for moderate or prolonged (long-distance) physical activities. This is supported by findings of increased lipid metabolites in calf muscles, more pronounced expression of genes involved in fat metabolism, and higher insulin sensitivity in endurance athletes than in sprinters and untrained healthy individuals [14, 15]. Considering that the study participants are engaged in multi-sport disciplines involving substantial endurance training, the results of this study are consistent with published data. Adipose tissue serves as an energy depot; however, primary catabolic processes occur in the cells of soft fat-free tissues, particularly in actively working muscles. Muscle activity requires more than energy alone. For anabolic processes that maintain muscle function, proteins, amino acids, and minerals are required, which are obtained through diet like energy sources. Therefore, the negative correlation between RER values and fat-free and cell mass parameters, water, protein, and mineral content highlights the need for continuous replenishment of nutrients involved in anabolic metabolism for individuals whose activities are consistently associated with physical exertion (particularly athletes).

Table 5 presents the positive correlation (p <0.05; p <0.01; p <0.001) between the same three conditional groups of bioelectrical impedance parameters and RR, ventilation, relative VO_2max, and the achieved workload WR.

Increased RR and ventilation during maximal physical exertion is associated with intense respiratory muscle activity, which, in turn, elevates their metabolic rate, potentially influencing parameters such as lean body mass, cell mass, water, protein, mineral content, and basal metabolic rate [16–20]. Active work requires an adequate supply of substrate and oxygen; thus, relative VO_2max also positively correlates with these nutritional status indicators of the athletes in the group. Because VO_2max is an indicator of human performance, and the achieved power during peak physical exertion is the result of this performance, the correlation between WR and lean body mass, cell mass, water, protein, and mineral content is also understandable.

CONCLUSION

Significant strong correlations were found between the indicators of muscle work efficiency and its energy supply during intense physical exertion and parameters of lean body mass, including skeletal muscle mass, and water, protein, and mineral levels in the body. Thus, the study confirmed that the primary metabolic load in the human body during physical activity is borne by its lean (fat-free) component, including skeletal muscle, and its full functionality requires adequate energy and proteins to maintain muscle volume and facilitate muscle mass recovery. An accessible method to increase peptide intake in athletes during intense physical exertion is incorporating functional foods with optimal protein content in bioavailable form into their diet, supplemented with vitamin and mineral complexes. Therefore, the development of protein-enriched functional foods for individuals exposed to intensive physical loads in their professional activities is highly relevant in import substitution.

ADDITIONAL INFO

Authors' contribution. All authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study. Personal contribution of each author: V.O. Matytsin, concept and design of research, search and analytical work, collection and processing of materials, analysis of the received data, writing of the text; G.A. Smirnova, concept and design of research, search and analytical work, collection and processing of materials, analysis of the received data, writing of the text, making final edits; E.V. Kravchenko, the concept and design of the study, search and analytical work, collection and processing of materials, analysis of the data obtained, writing the text, making final corrections; O.G. Korosteleva, laboratory research; D.V. Raguzina, laboratory research.

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