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Original Article

Non-invasive approach for assessing the functional condition of high-level sportsmen

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Abstract
Background. Non-invasive methods of express diagnostics using a hardware–software complex are of great value. The majority of such complexes are based on the analysis of heart rate variability and do not estimate functional and resource states of other systems, which are involved in the adaptation process.
Aim. The goal of this study was to estimate the functional and resource state of main body systems under heavy loads of high-level sportsmen using the hardware–software complex ROFES.
Methods. Twelve high-level athlete-swimmers were included in the study: six girls (13–25 years) and six young men (16–21 years). Medical and pedagogical control of the functional and resource condition of the athletes was carried out in two mesocycles (precompetitive and competitive) of one-year training and a competition stage. The common health level and the functional and resource state of body systems and organs were determined by the hardware–software complex ROFES on a five-point scale.
Results. Indices of functional and resource states of organs and organ systems as well as common health level were conformed to the normal level (4–5 points). Statistically significant differences in functional and resource parameters for 12 organs and organ systems were detected. The functional state of the cardiovascular system, lungs, and liver made it possible to differentiate athletes who improved the result. In the group of athletes without improving the result in competitions, the functional state of the liver was estimated at 5 points (m/Me), and the resource state on average was 4.5 (m/Me), unlike the improved-result athletes with scores of 4.59/5 and 4.07/4.0, respectively.
Conclusion. Indicators of the resource status of organs and systems can be used as criteria for monitoring and predicting changes of organ system conditions at the pre-nosological level. The same indicators can be considered as criteria of overwork and recovery of the athlete. They are especially important for diagnosing overtraining syndrome.
Keywords: pre-nosological diagnostics, organ resource state, hardware–software complex, functional state of the athlete

Introduction

Adaptation of a person to peak physical and psycho-emotional loads has essential value for medicine and biology of extreme conditions [12]. Changes in various systems of the organism under extreme loads have common mechanisms that apply to all types of human activity related to extraordinary influence factors [7]. Under extreme loads, adaptation resources are depleted, which is a prerequisite for the development of pathological changes in the organism [5]. It is known that in the trained athlete near or at the peak of his sports form (maximum sports preparedness), a resistance to damaging effects and unfavourable factors, including immunity, decreases [12]. In addition, there is a risk of admission to sports activities of a practically healthy person whose organism cannot adapt to stress, which can lead to the development of pathological conditions, leading to a lethal outcome. In the last decade, deaths of young (14–25 years old) athletes in sports grounds or stadiums during training or competitions have become more frequent in Russia and European countries. Therefore, the development and implementation of sufficiently simple but informative express methods for diagnosing the functions of athletes' organism systems reflecting their current adaptive state is topical.

Assessment of the functional and psycho-emotional condition of the athlete makes it possible to determine the degree of influence of the main factors of psychophysical, training, and competitive loads, as well as the level of resistance, adaptation, reserves, and health in general [5, 12]. The prognosis of professional reliability of top-qualified athletes can be either long-term or prompt. The length of the long-term forecast is months or years. Methods of assessing the health level, the decisive tasks of this forecast, are numerous and aimed at an integral estimation of the physical condition, professional health, and adaptive organism's capabilities, as well as the evaluation of functional reserves and polyparametric pre-nosological diagnostic and biological age calculation [4, 13].

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Adaptation criteria, norms for assessment and management of professional health, were developed as a result of the long-term studies by specialists working in the field of aerospace medicine and extreme physiology [14]. The prompt forecast is carried out just before heavy loads during training sessions on the day before an important competition. The length of the quick forecast is several hours.

For non-invasive rapid diagnostics of the functional state, the following hardware–software complexes (HSC) using heart rate variability (HRV) analysis are used in Russia: Varikad, Omega-M, Cardiovisor-6S, and SACR. These complexes, in one way or another, are aimed at screening the state of the cardiovascular, respiratory, and central nervous systems to comprehensively assess the athlete's health status. Although the HRV analysis technique is widespread and successfully applicable, many researchers recommend remembering the correct medical and physiological interpretation of the obtained results [1]. Indicators of HRV play only an alarm role in the diagnosis. Concrete signs of structural, metabolic, and energy changes, which are currently investigated by laboratory and instrumental methods, are crucial. Researching HRV when using stress tests on the cardiorespiratory system is relevant for the benefit of developing an easy, reliable, and widely used method of assessing functional reserves of vegetative regulation of the cardiorespiratory system [2]. However, this method cannot give ratings of other systems of the organism.

One of the examples of modern HSC for carrying out non-invasive screening diagnostics, which allows assessment of the functional and resource status of the main organs and systems, is the HSC ROFES. In ROFES, several key technical and diagnostic characteristics are of interest to specialists in the field of elite sports. Firstly, it is a mobile portable device that can be connected to both personal and tablet computers that have the ability to install software from the Internet; remote access technology to survey results is implemented in this device. Secondly, an intuitive and user-friendly interface displays a variety of indicators. Thirdly, there is simplicity of design and use, which does not require special training, as well as a numerical score evaluation.

For obtaining more accurate results of online diagnostics of the functional and resource status of 17 organs and systems of the athlete's organism, several ROFES-grams (rofogram) must be taken daily during the training process: the first after awakening, the second after the first training, the third before the second training, the fourth after the second training, and the fifth before going to bed. It is crucial that the decrease in the parameters of the rofogram, which is usually observed after training, is absent in the morning, which would indicate full post-training recovery of the organism.

The goal of this study is to assess the functional and resource status of the basic organism's systems in high-level athlete-swimmers under heavy loads using ROFES technology.

Material and methods

Both the research and the publication of the experimental data were approved by the Ethics Committee of the College of the Olympic Reserve N1 (chairperson – Sergey V. Stepanov, protocol no. 1-MD-09-2016, date of approval 12.09.2016).

Participants

The study group included swimmers (mean age 17.5 years) — six girls (from 13 to 25 years old) and six boys (from 16 to 21 years old) — who are trained at the Yekaterinburg School of Olympic Reserve in the group of high-level athletes.

The medical and pedagogical control of the functional and resource status of the athletes was carried out in two mesocycles (pre-competitive and competitive) of the yearly training and competition cycle, during which the athletes were under considerable and heavy loads. Based on the theory and methodology of sports training, the load intensity is characterised by the degree of fatigue it causes.

According to the degree of fatigue, heavy, significant, medium, and low loads are distinguished (Table 1) [8]. But the training effect through super-compensation is achieved only under the influence of considerable and heavy loads, during which it is important to control the resource status of the organs and systems of the athlete's organism. Since the presented study is a pilot, randomisation of the group by sex and age was not carried out in order to identify the most common patterns of the examined indicators' changes in the health status of athletes. Health status parameters at different stages of the training process were determined doubly at least.

Table 1. Training results in correspondence with load intensity

The value of loads in training	Brief characteristics of loads	Training effects of loads and their recovery period. Current tasks
Heavy loading (H)	Characterised by explicit (uncompensated) fatigue. An external criterion is decreased efficiency and inability to continue the implementation of the ordered work in terms of volume or intensity.	It causes the training, developing effect. Recovery period is 48–72 hours. Increase in qualification.
Significant loading (S)	Characterised by latent (compensated) fatigue. It is not accompanied by decreased efficiency of the athlete due to the use of compensatory mechanisms, but it is accompanied by de-economisation of the work. These constitute 70–80% of the heavy loads.	It has a training, developing effect, but to a lesser degree than after heavy loads. Recovery period is 24–48 hours. Stabilisation and further improvement of qualification.
Medium	The second phase of stable efficiency. It is	Stabilising, supporting effect. Recovery

loading (M)	characterised by a relatively stable state of the athlete's organism. The energy request for the performance of the training work and its satisfaction are balanced. It is 40–60% of the heavy loads.	period is 12–24 hours. Maintenance of the achieved training level, the solution of specific training tasks.
Low loading (L)	The first phase of stable efficiency. It is 25–30% of the heavy loads.	Acceleration of recovery processes, and low loads have a supporting effect. The recovery period is 6 hours.

Procedure

Determination of the common health level (CHL) and functional and resource conditions of organs and systems of organs was carried out with the help of ROFES. The method is based on the effect of electric impulses of a certain current on a biologically active point of MC-7 located on the inside of the wrist of the left hand, through which the micro-current pulse is sent to all organs, causing a response. In humans, each organ works in a strictly defined, inherent rhythm. Responses of these rhythms are gathered through a feedback return device and then compared in the programme with the reference rhythms proper to a healthy person of the appropriate sex and age. The result of processing the organism's testing is four indicators that estimate the CHL, functional states of organs and systems, energy resources of organs and systems that determine their adaptive responses to various loads, and psycho-emotional state by a five-point system. The point system and the health level corresponding to it as well as the analysis of state are shown in Table 2. The range of scores for the functional state of organs/systems and activation levels as well as the corresponding interpretations are presented in Table 3. Estimates of the level of energy resources of organs and systems, loadings and risks of disease development, and comments on them are provided in Table 4.

Table 2. Interpretation of scoring of the common health level by means of the HSC ROFES

Point system of common health level	Interpretation of condition assessment (state analysis)
5 (high)	High energy resource, ensuring the functioning of self-regulation mechanisms of the organism
4 (middle, nearly high)	Borderline assessment, closer to the high energy resource, ensuring the functioning of self-regulation mechanisms of the organism
3 (middle)	The middle energy resource. Self-regulation mechanisms are supported.
2 (middle, nearly low)	Marginal raring, nearly low energy resource
1 (low)	Exhaustion of energy resources. Failure of adaptation to factors of environmental influence can be observed.

Table 3. Interpretation of scoring of functional condition of organs/systems and their activation levels by means of the HSC ROFES

Point system of common health level	Interpretation of condition assessment (state analysis)
5 (perfect)	No tension
4 (good)	Weak tension
3 (satisfactory)	Middle tension
2 (inadequate)	Strong tension or depressed
1 (ultimate)	Tension limit

Table 4. Interpretation of scoring of energy resource level of organs and systems by means of the HSC ROFES

Point system of common health level	Interpretation of condition assessment (state analysis)
5	Energy resource of an organ is high, optimal loadings. The risk of disease development is minimal or a compensated process.
4	Energy resource of an organ is good, insignificant loadings. Low risk of disease development or a compensated process.
3	Energy resource of the organ is decreased, which is loading consequence. There is a middle risk of disease manifestation.
2	Loss of energy resource of the organ that is a heavy loading consequence. Risk of disease development with prolonged exposure in this condition is increased.
1	The large loss of energy resource of the organ is observed as an excessive load consequence. Risk of disease development with prolonged exposure in this condition is high.

Statistical analysis

Statistical analysis was performed using the Statistica 6.0 programme (Stat Soft, Inc., USA). Due to the small sample size, an assumption and testing of the hypothesis that the distribution of samples was not normal were not made, and non-parametric analytical methods were used: the Spearman correlation coefficient (r), the comparison of two independent groups by Mann–Whitney (U), Kolmogorov–Smirnov, Wald–Wolfowitz, comparison of several independent groups using the Kruskal–Wallis H-test, and a median test with a minimum level of statistical significance of $p < 0.05$. To compare the results of the screening of athletes before and after competition, the Wilcoxon W-test for dependent samples was used. However, of special interest was the comparison of the results using two or more independent samples, indicated with widely used parametric methods, which allowed to compare two or more independent samples: t-test, Newman–Keuls, and Duncan. The descriptive statistics are presented by the main characteristics: m - mean value, Me - median, σ - standard deviation. A wide range of applied methods makes it possible not only to establish group differences according to generally accepted characteristics (mean, median), but also to estimate the direction of changes in characteristics in groups and the difference in distribution functions [10, 11].

Results

Analysing the results of the assessment of organs and organ systems in all athletes by means of the HSC ROFES (Table 5), it should be noted that indices of the functional and resource status of organs and systems corresponded to high values (4 and 5 points). These indicated a high energy resource of CHL and individual organs and systems, the absence of tension in their functional state, as well as the compensation of loads. In this case, the point score of the resource state of most organs and systems was significantly one point lower in comparison with their functional state. The resource condition of the thyroid gland and cardiovascular system (score: 3 points) became an exception.

Table 5. Descriptive statistics of indices estimated by means of the HSC ROFES in the group of all athletes (n = 13, number of measurements: 39)

Parameter by ROFES	Mean value (m) ± standard deviation (σ)	Median (Me)	Mean value (m) ± standard deviation (σ)	Median (Me)
	Functional state		Resource state	
Common health level (CHL)	4.74±0.64	5.00	4.62±0.63	5.00
Immune system	**4.44±0.50**‡	**4.00**†	3.72±0.69	4.00
Cardiovascular system	**4.56±0.55**‡	**5.00**†	3.31±0.75	3.00
Cervical spine	**4.49±0.51**‡	**4.00**†	4.82±0.45	5.00
Thoracic spine	**4.64±0.49**‡	5.00	4.23±0.99	5.00
Lumbosacral spine	4.54±0.51	5.00	4.72±0.60	5.00
Bronchus	4.54±0.51	5.00	4.46±0.55	4.00
Lungs	**4.59±0.50**‡	**5.00**†	4.21±0.52	4.00
Liver	4.72±0.46	5.00	4.53±0.66	5.00
Stomach	4.44±0.60	4.00	4.44±0.60	4.00
Large intestine	**4.67±0.48**‡	**5.00**†	3.49±0.60	4.00
Pancreas	**4.49±0.51**‡	**4.00**†	3.54±0.55	4.00
Thyroid gland	**4.46±0.60**‡	**5.00**†	3.5±0.72	3.00
Adrenal gland	**4.21±0.66**‡	**4.00**†	4.59±0.59	5.00
Kidney	**4.44±0.50**‡	**4.00**†	4.77±0.54	5.00
Urinary	**4.21±0.66**‡	**4.00**†	3.65±0.67	4.00
Uterus (girls)	**4.70±0.47**‡	**5.00**†	3.90±0.55	4.00
Uterine tubes (girls)	**4.85±0.37**‡	**5.00**†	3.75±0.75	4.00
Prostate (man)	5.00*	5.00	2.95±0.56	3.00
Tension of compensatory forces of organism (stressful state) – situational	2.95±0.76	3.00		
Fatigue sign/internal emotional stress	4.49±0.22	5.00		
Signs of neurosis, irritation	4.05±0.64	4.00		

*In all male athletes the index of the functional state of the prostate is 5; † the differences between the indices of functional and resource states (non-parametric comparison method) are statistically significant (Mann–Whitney, $p < 0.005$); ‡ differences in the functional and resource states (parametric comparison method) are statistically significant (t-test, $p < 0.01$, for 'thoracic spine' $p < 0.05$).

When comparing CHL and the functional state of organs and systems of girls and boys (Table 6), statistically significant differences in the parameters 'common health level' and 'bladder' were revealed. At the same time, in girls, the indices of the CHL (mean/median) were higher than those of young men, and assessment of the functional state of the bladder was lower (m/Me): 4.95/5 (girls) and 4.53/5 (boys), 3.95/4 (girls) and 4.47/5 (boys), respectively.

Table 6. Statistically significant differences between groups (by different grouping characteristics) by the studied indices of the common health level and functional state of organs and organ systems

Statistical analysis techniques	*Grouping characteristic «gender»*	*Grouping characteristic «result»*
Non-parametric (Mann–Whitney [U], Kruskal–Wallis [H])	CHL, urinary	Cardiovascular system, liver
Parametric (T-test et al.)	CHL, urinary	Cardiovascular system, lungs, liver
Wald–Wolfowitz	Lumbosacral spine, adrenal glands	Age, cardiovascular system, cervical spine, lumbosacral spine

Note. The results of multiple intergroup comparisons of more than two groups by different methods are presented in pairs ($p < 0.05$).

When comparing the groups by the grouping characteristic 'result' (due to improved/non-improved results of competitive activity), a statistically significant decrease in the functional state of the cardiovascular system, liver (nonparametric and parametric methods), and lungs (parametric comparison methods) was detected (Table 6). In the group of athletes who did not improve the result at the competitions, the lung condition was rated on 5 points ($m = 4.83$), and in the group with improved result, this score was 4 points ($m = 4.48$). These differences are probably connected to both activation of adaptation mechanisms and physiological features of sportsmen, since all indices conformed to normal ones.

The indicator 'liver' was differentiating in groups of athletes, combined by both gender and improving the result (Table 7). First of all, we note that the values of indices of the liver's resource status are lower than those of the functional state in all groups, regardless of the grouping feature. For example, in a group of athletes without improving the result in competitions, the functional state of the liver was estimated at 5 points (m/Me), and the resource on average 4.5 (m/Me), unlike the improved athletes with scores of 4.6/5.0 and 4.1/4.0, respectively. In general, in the group of girls, the point score of the resource state of the indicators 'lumbosacral spine' (4.8/5.0) and 'kidneys' (4.8/5.0) was higher than that in the group of young men (3.6/4.0 and 4.3/4.0, respectively). In the group of athletes who improved the result in competitions, values of indicators 'lumbosacral spine' and 'liver' were estimated by a smaller score compared with not improved: 4.0/4.0 and 4.1/4.0 versus 4.7/5.0 and 4.5/4.5, respectively.

Table 7. Statistically significant differences between groups (by different grouping characteristics) in terms of energy resources of organs and organ systems, detected by some statistical techniques

Statistical analysis techniques	*Grouping characteristic «gender»*	*Grouping characteristic «result»*
Non-parametric (Mann–Whitney [U], Kruskal–Wallis [H])	Lumbosacral spine, kidney	Lumbosacral spine, liver
Parametric (T-test et al.)	Lumbosacral spine, kidney, liver	Liver
Wald–Wolfowitz	Lumbosacral spine	Age, lumbosacral spine, bronchial tubes, large intestine

Note. The results of multiple intergroup comparisons of more than two groups by different methods are presented in pairs ($p < 0.05$).

Discussion

The revealed statistically significant differences in functional and resource parameters (Table 5) may indicate a tension of the adaptive capacity of organs (before obvious function changes, the compensated process) that are especially involved in energy metabolism and hormonal regulation. The results obtained become worthy of attention of sport medicine experts at the stage of revision of routine biochemical and hormonal blood parameters when monitoring the functional state of athletes at different stages of the training cycle, and for making a clinical decision [6, 9, 15]. The obtained data confirm the possibility of using ROFES technology for pre-nosological screening and monitoring the functional state and adaptive resources of the athlete's organism as a non-invasive analogue of estimation of biochemical and hormonal blood indices in 'field conditions'. The revealed statistically significant differences in the parameters 'common health level' and 'bladder' in girls and boys (Table 6) may indicate sexual differences (physiological) and the influence of cooling as a risk factor for high and high-skilled athletes in this sport [3]. This requires further study and comparative analysis with laboratory indicators of blood and urine.

The result of group comparisons by the Wald–Wolfowitz criterion, which allowed us to divide groups on parameters of the functional and resource state by the estimation of the lumbosacral spine, is noteworthy (Tables 6 and 7). This indicator should be paid close attention, since this statistical test reveals significant differences not only in the average of two samples, but also in the form of distribution. It is probably advisable to evaluate (monitor) the state of the said spine department in swimmers in view of the influence of another specific factor of this sport: gravity. Moreover, the given indicator became differentiating at the division of groups on gender by an estimation of a resource status of organism and organ systems. This fact can be evidence of the tension of this spine segment without manifestations at the functional level and also highlight the significance of the Wald–Wolfowitz test in the analysis of such data (Table 7).

The identity of parameters differentiating groups, revealed at the same time by different statistical methods, especially on small samples, may confirm the stability of these parameters' changes within the group. The difference of the parameters differentiating groups at the assessment of the functional and resource status of the organism may indicate the sensitivity of the measurement methodology underlying the HSC ROFES.

When comparing rofograms of the athletes received before and after the competition with the Wilcoxon W-criterion, no statistically significant differences were revealed with the tendency of decreasing the resource status of organs and systems after the competition. The absence of differences is probably associated with the small number of observations (11 people). In general, the tendency to reduce the resource and functional state of organ systems in athletes who have improved the result in competitive practice can be considered from several positions: physiological adaptation (intensification of metabolic and regulatory processes), psychological state (greater involvement and focus on results), and individual features (predisposition to this sport, etc.). Interestingly, the above-mentioned differences between groups are established on the condition of precisely those organs and systems that make a great contribution to adaptation to the loads: the cardiovascular system, lungs, and liver, which can be defined as organs and systems non-specific to this kind of sport, and the lumbosacral spine and bladder, which can be considered organs specific to swimming.

Conclusion

All indicators determined by the HSC ROFES in athletes were estimated as 'good' and satisfied the physiological norm. This indicates a compensated process of adaptation to heavy loads. The HSC ROFES showed high sensitivity to minimal changes in both the functional and resource states of organs and systems, without pronounced stress, when the organism condition is rated as 'norm'. Indices of resource status can become the criteria for monitoring and even prognosis of changes in conditions of organ systems at the pre-nosological level. These indices can, as a whole, become criteria to evaluate fatigue and recovery of the athlete, which is especially important for detecting overtraining syndrome. In our opinion, the indicators of the resource state are the main factors of trainers' administrative decision and can become the criteria for personalised, preventive pedagogical control.

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