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**Original Article**

# Modeling of the morphofunctional state of the biathletes body

SERHIJ PRIYMAK[1], NATALIIA KOLOMIETS[2], VITALIY GOLETC[3]
[1]Department of Biology, Health and Sport, T. H. Shevchenko National University «Chernihiv Colehium», UKRAINE
[2]Department of Criminal Law and Justice, Chernihiv National University of Technology, UKRAINE
[3]Department of Environmental Psychology and Sociology, T. H. Shevchenko National University «Chernihiv Colehium», UKRAINE

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**Abstract**:
*Purpose of study:* to develop models of the morphofunctional state of the body of biathletes to predict the success of the implementation of sports activities.
Materials and methods. The study involved male athletes aged 19-21 years (n = 11) who are members of the National team of Ukraine and the Chernihiv region on biathlon (2 Masters of Sports of Ukraine, World Class, Merited Masters of Sports of Ukraine, 6 Masters of Sports and Candidates in Masters of Sports of Ukraine; 3 first-degree athletes).
*Research methods:* theoretical analysis and generalization of literary and Internet data; pedagogical observation; methods of functional diagnostics; modeling methods; pedagogical experiment; methods of mathematical statistics.
*Results and conclusions.* Athletes are distinguished by the peak of the low-frequency component of the spectrum of the HRV (Low Frequency, Hz) in the basal conditions and the duration of the phase of filling the pulse wave ($D_f$, s). Since the individual components of the spectral analysis of the heart rate variability are characterized by the dominant frequency range, the power and the ratio of the components of the HRV, we have identified the subgroups in accordance with the differentiating trait, which allows to characterize the energy supply of sports activities of biathletes of different qualifications. In particular, in the basal conditions high-level biathlonists are distinguished by a relatively high total power of the spectrum, which is formed mainly due to the power of the high-wavelength component and the recession of the low-wave component, which in turn leads to a significant dominance in the heart rate rhythm of the parasympathetic activity over the sympathetic ($LF \cdot HF^{-1}$, cu). With a decrease in the level of athletes training, there is a shift in the dominance of low- and ultralow-wave components of the HRV. In the restitution phase after the $PWC_{170}$ test, all athletes experience incomplete restoration of the spectral capacities of HRV while preserving the dominance of the sympathetic or parasympathetic level of regulation depending on the qualifications. For various qualifications of athletes-biathlonists there is a certain morphofunctional state of the body systems, which determines the success of the implementation of a professional program. These criteria allow to reduce the expense of an athlete-biathlete training and achieve a high level of achievements in sports activities.
**Key Words**: - heart rate variability, physical working capacity, artificial intelligence, biathlon.

## Introduction

The functions of artificial intelligence are the development and implementation of computer modeling methods for the implementation of multidirectional tasks in various fields of science and technology. The use of sophisticated analysis tools allows to identify peculiarities that cannot be determined by descriptive statistical methods of data interpretation. Methods of artificial intelligence have recently been used to provide management of complex cybernetic systems related to the training of specialists in physical education and sports (Priymak, S. G., Zavorotynskyi, A.V., 2018) . In particular, sophisticated methods of machine learning and the intellectual analysis of data in physical culture and sports analysis take place to substantiate decision-making on multidirectional aspects of sports and pedagogical activities (Wicker P., Breuer C., 2010). Retrospective analysis of the investigated issue points to a diverse approach to the modeling of the morphofunctional state of the body of athletes of various sports. In particular, in some scientific works the following issues are considered: the simulation of cardiac rhythm parameters for assessing the working capacity of runners and cyclists on training sessions (Dimitri de Smet, Marc Francaux, Julien M. Hendrickx and Michel Verleysen, 2016); simulation of physiological processes that affect physical working capacity in the preparation of stayers-athletes and cyclists (Alonso F., Caraça-Valente J. P., González A. L., Montes C., 2002 D'Ascenzi F., Alvino F., Natali B. M., 2013);


Corresponding Author: SERHIJ PRIYMAK[1], E-mail: spriimak1972@gmail.com

development of methods for quantitative assessment of pedagogical impact in the exercise of physical activity (Churchill T. 2014); cycling speed optimization, determined by the regime of energy supply of training and competitive loads (Aftalion A., Bonnans JF, 2014); development of methods for quantitative assessment of pedagogical inmpact in the form of physical activity (Churchill T. 2014); energy supply of gaming activities of students who specialize in volleyball (Nosko, M. O., Danilov, O. O., Maslov, V. M., 2011; Pryimak Serhij, 2017).

However, these works do not consider the structure and models of the physical state of the biathlonist body due to the biomechanical parameters of movements, the nature of muscle contractions, the power and duration of work, the energy supply regime according to qualification with the use of intellectual data analysis. There is almost no data in the literature on the conditionality of the morphofunctional state of the biathlete body systems, which ensures the success of the professional activity, which determines the relevance of the scientific search. These provisions stipulate the creation of model characteristics of the morphofunctional state of the biathlete body systems in accordance with the qualification.

Hypothesis It is assumed that the models of the morphofunctional state of the biathlete body systems will allow to predict the success of the implementation of sports activities.

Purpose of study: determination of the peculiarities of the morphofunctional state of the biathlete body systems in predicting their success.

**Material & methods**

*Participants:* The following athletes participated in the research (boys n = 17, age 19-21 years) who attend group of biathlon sports-pedagogic perfection. All students are members of the National combined teams of Ukraine and Chernigov region. All are elite athletes.

*Procedure* The research was conducted during December 2010 - March 2013 on the basis of the laboratory of psychophysiology of muscular activity of the National University «Chernihiv Collegium» named after T. G. Shevchenko

*Research methods.* Peculiarities of autonomic regulation of cardiac rhythm were studied on the basis of HRV analysis of 5-7-minute fragments of an electrocardiogram using the Polar RS800 (Polar Electro, Finland) heart rate monitor. Data analysis was carried out using the software Kubios HRV 2.1 (Kuopio, Finland). Artifacts and extrasistals were removed from the electronic recording manually. The following HRV data were analyzed: RRNN, SDNN, RMSSD, pNN 50 (Mikhailov V. M., 2000; Priymak Serhij, 2017). Among the parameters of the spectral (frequency) analysis of heart rate variability (HRV) and cardiointervalography (CIG) were evaluated: the total power of the spectrum (Total Power, TP), power of High Frequency (High Frequency, HF), Low Frequency (Low Frequency, LF) and Very Low Frequency (Very Low Frequency, VLF) components, the contribution of these components to the total spectrum power, as well as the ratio of LF to HF waves calculated according to absolute ($ms^2$) units ($LF \cdot HF^{-1}$, cu). Registration of the studied indicators was carried out in accordance with the recommendations of the joint meeting of the European Society of Cardiologists and the North American Society for Electrostimulation and Electrophysiology on the common standards for analysis of heart rate variability. Peripheral oxygen saturation ($SpO_2$,%) was determined using a photoplethysmographic technique with the use of a pulse oximeter Ohmeda Biox 3700e Puls-Oximeter (Ohmeda, USA) integrated with the computer for long-term monitoring of the pulse wave with the ability to record, analyze and interpret the results (Galkin M., Zmievskoy G., Laryushin A., Novikov V., 2008; Priymak S. G., 2018). The registration of the pulse wave parameters was carried out by means of a photoplethysmographic sensor on the distal phalanx of the 3 finger of the left hand in a state of rest (basal conditions) in the sitting position and after 7 minutes after the $PWC_{170}$ test performed in synchrony with the parameters of the heart rate. During the registration of the above-mentioned indicators, the examinee was limited to the impact of audiovisual stimuli using a light-insulating black mask and sound absorbing headphones that did not create discomfort. The execution of the $PWC_{170}$ test was performed on a bicycle ergometer VE-02 using 2 loads of 5 minutes duration and 3 minutes of rest between the loads in accordance with the standards for its perfomance (Belotserkovskiy Z. B., 2005). Assessment of the level of physical working capacity was carried out on the basis of calculating the absolute ($kGm \cdot min^{-1}$) and relative ($kGm \cdot min^{-1} \cdot kg^{-1}$) values of $PWC_{170}$, in accordance with the body weight of the examinee. In the state of rest, the above-mentioned indicators were determined after the 1st and 2nd loads, in the phases of restitution (3 min after the 1st and 7 min after the 2nd load). Athletes were acquainted with the content of tests and agreed them to be performed. When conducting complex surveys, Ukraine's health care legislation, the Helsinki Declaration of 2013, and the European Community Directive 86/609 on the participation of people in biomedical research were respected.

*Statistical analysis*. One of the methods of machine learning - the decision trees - was used to classify biathletes by qualification. For this purpose Python software (v. 3.6.3 Anaconda custom) with machine learning module Skelit (scikit-learn, v. 0.19.1) using the method of decentrication (Müller A., Guido S., 2017) was used. Using this methodological approach, a decision tree was constructed, indicators that influence the differentiation of athletes by qualification were identified.

**Results**

To achieve the goal, a group of athletes was divided into 2 sets of data - training and test, which allowed to develop a model morphofunctional body state, which details individual indicators by informativity in accordance with the qualification and dominance of the regime of activities energy supply. In particular, on the training set the correctness of the classification was 100.0%, on the test set - 83.3%, which in our opinion is optimal and allows us to explain the hierarchy and the range of oscillation of signs (Fig. 1). Increasing or decreasing the depth of the decisions tree leads to a deterioration of the generalizing properties of the tree, in particular, the correct classification of the group of athletes in the test data set (Fig. 1).

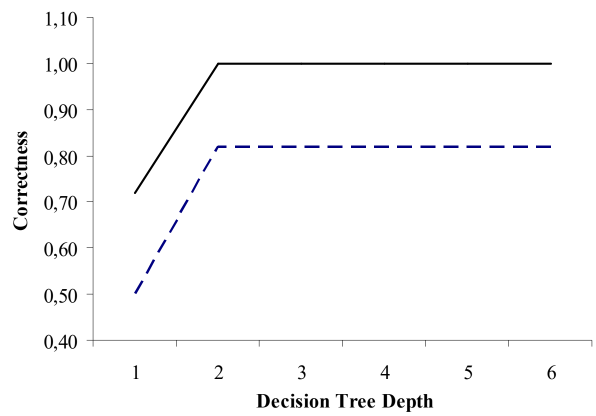


Fig. 1. Correctness of the model on the training and test sets of the morphofunctional state of the biathlete body systems

Note:

correctness on the training set;

correctness on the test set.

As a result of the analysis, the two most influential features were identified which highly differentiate biathletes with a high degree of qualification - highly skilled, medium skilled, low skilled, and energy supply dominance in the implementation of activities. A sub-group of highly skilled biathletes was formed from athletes holding sports titles Merited Master of Sports of Ukraine, Master of Sports of Ukraine World Class, Master of Sports of Ukraine; subgroup of medium skilled - sports degrees of the Candidate for the Master of Sports of Ukraine and the first sports degree; Sub-group of low-skilled - the second and third sports degrees.

In particular, biathletes are distinguished by the peak of the low-frequency component of the spectrum of the HSV (Low Frequency, Hz) in basal conditions and the duration of the phase of filling the pulse wave ($D_f$, s) (Fig. 2).

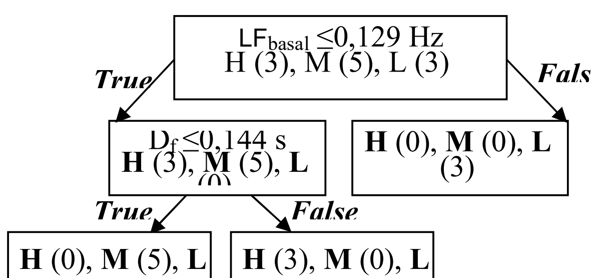


*Fig. 2. Decisions tree of differentiation of biathletes according to qualification*

*Note :* **H** *- highly skilled;* **M** *- medium skiled;* **L** *- low skilled;* $LF_{basal}$ *- The power of the low-frequency component HRV (Low Frequency, Hz) in the basal conditions;* $D_f$ *- Duration of the phase of filling the pulse wave (s).*

The most informative trait that determines the morphofunctional state of the biathletes body systems is the index of peak low frequency oscillation of the spectrum of HRV (Low Frequency, Hz) in the basal conditions, which allows to separate 2 groups of athletes with a range of oscillations of this feature within the range 0.043-0.112 Hz (9 persons) and 0.137-0.146 Hz (3 persons) (Fig. 2).

The first group, which is characterized by relatively low values of the peak low-frequency component of the spectrum of HRV, includes a subgroup of biathletes of high and average qualification (9 out of 9). The second subgroup, with relatively high values of this trait (0,137-0,146 Hz), includes low-skilled athletes (3 out of 3).

Since the individual components of the spectral analysis of the heart rate variability are characterized by the dominant frequency range, the power and the ratio of the components of the HRV, we have identified the subgroups in accordance with the differentiating trait, which allows to characterize the energy supply of sports activities of biathletes of different qualifications (Table 1).

Table 1. The correspondence of the power of the low-frequency component of the HRV in the basal conditions (Low Frequency $_{basal}$ , Hz) to the individual parameters of the heart rate variability of the biathletes depending on the qualification

| State of determination | Indicators | Low Frequency $_{basal}$ | | | Δ,% | | |
|---|---|---|---|---|---|---|---|
| | | ≤0.129 Hz | | > 0.129 Hz | | | |
| | | Highly skilled | Medium-skilled | Low-skilled | Hs-Ms | Hs-Ls | Ms-Ls |
| | | 0.051-0.063 | 0.043-0.121 | 0.137-0.146 | | | |
| | | 0,0570 ± 0,006 | 0.0840 ± 0.028 | 0,1367 ± 0,031 | 47.37 | 139.82 | 62.74 |
| Basal conditions | $VLF_{basal}$, ms$^2$ | 8459.15 ± 519.15 | 3344.90 ± 799.79 | 6214.69 ± 926.38 | -46.18 | -26.53 | -60.46 |
| | $LF_{basal}$, ms$^2$ | 4270.47 ± 373.79 | 3839.17 ± 565.42 | 2257.79 ± 337.8 9 | 70.04 | -47.13 | -10.10 |
| | $HF_{basal}$, ms$^2$ | 9546.20 ± 471.58 | 3858.62 ± 981,60 | 3555.13 ± 451.73 | 8.54 | -62.76 | -59.58 |
| | Total $Power_{basal}$, ms$^2$ | 22275.83 ± 1249,01 | 11042.68 ± 484.97 | 12027,61 ± 316,00 | -8.19 | -46.01 | -50.43 |
| | $VLF_{basal}$, % | 36.92 ± 2.23 | 33.70 ± 3.53 | 43.09 ± 2.31 | -21.79 | 16.71 | -8.72 |
| | $LF_{basal}$, % | 18.21 ± 4.51 | 36.94 ± 3.37 | 21.07 ± 3.44 | 75.32 | 15.71 | 102.86 |
| | $HF_{basal}$, % | 44.87 ± 3.01 | 27.06 ± 4.82 | 38.82 ± 3.96 | -30.29 | -13.48 | -39.69 |
| | $LF_{basal} \cdot HF_{basal}^{-1}$, cu | 0.41 ± 0.01 | 1.56 ± 0.08 | 1.61 ± 0.06 | 155.74 | 48.78 | 280.49 |
| Restitution | $VLF_{restitution}$, ms$^2$ | 728.75 ± 64.99 | 286.64 ± 72.03 | 581.63 ± 42.70 | -50.72 | -20.19 | -60.67 |
| | $LF_{restitution}$, ms$^2$ | 1416.87 ± 111.06 | 1318.33 ± 411.02 | 960.17 ± 86.18 | 37.30 | -32.23 | -6.95 |
| | $HF_{restitution}$, ms$^2$ | 4280.09 ± 824.27 | 1650.64 ± 197,05 | 549.20 ± 63.76 | 200.55 | -87.17 | -61.43 |
| | Total $Power_{restitution}$ ms$^2$ | 6425.72 ± 349.40 | 3255.61 ± 359.57 | 2091.01 ± 356.30 | 55.70 | -67.46 | -49.33 |
| | $VLF_{restitution}$, % | 16.36 ± 1.79 | 18.67 ± 1.81 | 24.35 ± 1.38 | -23.33 | 48.84 | 14.12 |
| | $LF_{restitution}$, % | 22.47 ± 1.63 | 41.01 ± 2.58 | 33.72 ± 4.67 | 21.62 | 50.07 | 82.51 |
| | $HF_{restitution}$, % | 61.17 ± 8.98 | 40.32 ± 2.73 | 41.92 ± 2.06 | -3.82 | -31.47 | -34.09 |
| | $LF_{restitution} \cdot HF_{restitution}^{-1}$, cu. | 0.38 ± 0.08 | 1.42 ± 0.09 | 1.50 ± 0.08 | -5.33 | 294.74 | 273.68 |
| $BH_{in}$ , s | | 114.75 ± 2.25 | 139.56 ± 6.52 | 130.00 ± 5.33 | 7.35 | 13.29 | 21.62 |
| $BH_{ex}$ , s | | 67.75 ± 7.63 | 91.67 ± 12.96 | 98.00 ± 16.00 | -6.46 | 44.65 | 35.31 |
| $PWC_{170} \cdot kg^{-1}$, $kGm \cdot min^{-1} \cdot kg^{-1}$ | | 25.79 ± 1.31 | 21.48 ± 1.57 | 20.86 ± 1.19 | 2.97 | -19.12 | -16.71 |

*Note:* $BH_{in}$ - *the duration of breath hold on the inhale, s;* $BH_{ex}$ – *the duration of breath hold on the exhale, s.*

In particular, in the basal conditions high-level biathlonists are distinguished by relatively high total power of the spectrum (22275,83 ± 1249,01 ms$^2$), which is formed mainly due to the power of the high-wavelength component (9546,20 ± 471,58 ms$^2$) and the recession of the low-wavelength component (4270.47 ± 373.79 ms$^2$), which in turn leads to a significant dominance in the regulation of the heart rhythm of activity of parasympathetic effects over sympathetic (LF basal · HF basal $^{-1}$ = 0.41 ± 0.01 cu) (Table 1). Herewith, the ratio of VLF : LF : HF was 36.92 : 18.21 : 44.87%, respectively (Table 1).

The domination of the HF component in the structure of the HRV is consistent with the theory of adaptive and trophic protective action of the wandering nerves and reflects the individual resistance of the healthy body to physical activity and other stress factors (Galkin, M., Zmievskoy, G., Laryushin, A., Novikov, V ., 2008; Gavrilova, EA, 2015) . With a decrease in the level of athletes training, there is a shift in the dominance of low- and very low-wave components of the HRV. In particular, if for medium skilled athletes under the basal conditions we observed the domination of the low-wavelength component of the spectrum (36.94 ± 3.37%), then for low-skilled – very low-wavelength (43.09 ± 2.31%) with correspondingly lower total spectral power (11042.68 ± 484.97 $ms^2$ and 12027.61 ± 316.00 $ms^2$ ). At the same time, low-skilled athletes have a sharp shift in the balance of regulation toward sympathetic due to the domination of the low-frequency component of the rhythm ($LF \cdot HF^{-1}$ cu), within the range of 1.56-1.61 cu (Table 1).

In the restitution phase after the PWC170 test , all athletes have incomplete recovery of the spectral capacities of HRV (VLF, LF, HF, TP, $ms^2$ ) within the range of 239.19-475.21% while preserving the dominance of the sympathetic or parasympathetic level of regulation depending on the qualifications. In particular, the high-wavelength component of the spectrum (61.17 ± 8.98%) remains for highly skilled at the expense of the reduced very low-wave (16.36 ± 1.79%). For the medium and low-skilled, there is a shift in the ratio of power to the low- and high-wavelength components due to the recession of the very low-wave with the preservation of the relative ratio (VLF : LF : HF, %) for the medium-skilled biathletes (Table 1). In addition, in the period of restitution, the dominance of sympathetic or parasympathetic regulation of biathletes of different qualifications is preserved, as indicated by the ratio of low to high frequency components of the rhythm ($LF_{restitution} \cdot HF_{restitution}^{-1}$ cu) in particular, for the highly skilled parasympathetic remains dominating (0,38 ± 0,08 cu), for the medium and low skilled - sympathetic (1,42 ± 0,09 cu and 1,50 ± 0, 08 cu respectively).

At the same time, highly skilled biathlonists have a significantly higher absolute and relative level of physical working capacity (1732.71 ± 129.98 $kGm \cdot min^{-1}$ ; 25.79 ± 1.31 $kGm \cdot min^{-1} \cdot kg^{-1}$ ) in comparison with the medium (1472.90 ± 199.11 $Kg \cdot min^{-1}$ ; 21.48 ± 1.57 $Kg \cdot min^{-1} \cdot kg^{-1}$ ) and low skilled (1303.16 ± 143.27 $Kg \cdot min^{-1}$ ; 20.86 ± 1.19 $Kg \cdot min^{-1} \cdot kg^{-1}$ ) (Table 1). In our opinion, highly skilled biathlonists have moderate vagotonia along with the economization of the functioning of the respiratory and cardiovascular systems in the basal conditions, the high level of physical working capacity in aerobic mode, faster and qualitative restitution of the indicators of HRV after performing the metered physical load.

For less skilled athletes, the dominance of sympathetic regulation, the tendency to anaerobic energy supply of the implementation of a sample with a relative cost-effectiveness of the activity are typical. Scientists point to a similar tendency, who, studying the effect of exercise on the body of athletes of different skill levels, suggest that the dominance of the low-wavelength component of the HRV is typical for speed-power sports, in which there is a need to mobilize glycolytic capabilities of the body (Simões, R. P., Castello-Simões, V., Mendes, R. G., Archiza, B., Santos, D. A., Machado, H. G., Bonjorno, Jr. J. C., Oliveira, C. R., Reis, M. S., Catai, A. M., Arena, R., Borghi-Silva, A., 2013; Gavrilova, E. A., 2015).

The proof of this assumption is the resistance to hypoxia, determined by the results of breath hold on inhalation and exhalation (Table 1). Since breath hold in the exhalation directly reflects the resistance of the body to hypoxia, it may indicate increased relative capacities of mid- and low-skilled biathlonists to perform cyclic loads that are performed with the mobilization of glycolytic energy substrates. This tendency leads to a shift in the balance of HRV regulation towards sympathetic with the domination of low and very-low wavelength components, both in the basal conditions and in the restitution phase, which determines the understated results of cyclic aerobic direction loading, in particular $PWC_{170}$ .

**Dicussion**

The training of athletes is a multidisciplinary specially organized process. The training process includes development and improvement of special physical and mental qualities; mastering certain motor skills specific for this type of sports activity. All this must be taken into account when planning and conducting training in groups of higher sports skills (Priymak, S. G., Terentieva, N. O., 2017). For a certain type of sports activity, in particular biathlon, there is a specific morphofunctional state of the body systems, which determines the success of the implementation of a professional program. The morphofunctional state of the body systems characterizes the correspondence of the peculiarities of the structure and functional capabilities when performing the metered physical loads. These criteria allow to reduce the expenditure part of the training of athletes of higher sporting skills to achieve a high level of success in professional activities. Such an assertion is of great relevance in the applied type of skiing - biathlon. It combines a high level of mastering physical abilities and skills with a static dynamic function. This function is realized when firing at fire lines, athletic orientation and athletic selection. Peculiarities of the morphofunctional state is one of the main indicators that have a significant impact on the success in the competitive activities. Therefore, in the vast majority athletes who achieve victories have a high level of morphofunctional capabilities of the body in a particular sport.

At the same time, morphofunctional support for the implementation of metered physical loads of athletes can determine their sports ability and their perspectives at the initial stages of long-term training (Priymak, S. G., Terentieva, N. O., 2017). So athletes in speed-power sports (martial arts, gaming sports) have central one dominating, and athletes in cyclical - an autonomous circuit of regulation of the cardiac rhythm. The variability of the rhythm is more pronounced in dynamic exercises compared to static exercises (Gavrilova, E. A., 2015). Athletes with the predominance of aerobic stresses have the highest rates of heart rate variability. They have highest values of SDNN, RMSSD, pNN50, and HF, and low values of the $LF \cdot HF^{-1}$ coefficient as

compared to the general population of athletes (Sztajzel, J., Jung, M., Sievert, K., 2008). The lowest sympathetic activity among athletes have triathlonists (Bersenev, E. Y., 2008).
Studying the individual portrait of the athletes HRV, taking into account the orientation of the training process in the dynamics during the preparation for the competition, can give the coach valuable information and help to predict the results of the athletes performance. According to D. J. Plews with co-authors, even the dynamics of rhythm cardiogram within one week provides fairly reliable information about the course of adaptation of the body to the training process (Plews, D. J., Laursen, P. B., Stanley, J., Kilding, A. E., Buchheit, M., 2013).

**Conclusions**

For highly skilled biathlonists, the relatively high total power of the spectrum in the basal conditions (Total Power, $ms^2$), which is formed at the expense of the power of the high-frequency component (High Frequency, ms 2 ) and the recession of the low-frequency component (Low Frequency, ms 2 ) which in turn leads to a significant dominance in the regulation of the heart rate of activity of parasympathetic effects over the sympathetic ($LF_{basal} \cdot HF_{basal}^{-1}$). With a decrease in athletes qualification, there is a shift in the dominance of low- and very low-wave components of the HRV. In the restitution phase after the $PWC_{170}$ test all biathlonists have a lack of restoration of spectral capacities of HRV (VLF, LF, HF, TP, $ms^2$) within the range of 239,19-475,21% while preserving the domination of the sympathetic or parasympathetic level of regulation depending on qualifications. Highly skilled athletes have moderate vagotonia along with the economization of the functioning of the respiratory and cardiovascular systems in the basal conditions, the high level of physical working capacity in aerobic mode, faster and qualitative restitution of the indicators of HRV after performing the metered physical load. For less skilled athletes, the dominance of sympathetic regulation, the tendency to anaerobic energy supply of the implementation of a sample with a relative cost-effectiveness of the activity are typical.

Developed model of the morphofunctional state of the biathletes body systems allows make forecast of the success of sports activities.

**Conflicts of interest** - The authors state that there are no conflicts of interest.

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