

## ORIGINAL RESEARCH



## Sensorimotor Criteria for the Formation of the Autonomic Overstrain of the Athletes' Cardiovascular System

**Authors' Contribution:**

A – Study design;  
B – Data collection;  
C – Statistical analysis;  
D – Data interpretation;  
E – Manuscript preparation;  
F – Literature search;  
G – Funds collection

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**Background and Aim of Study:****Abstract**

Determination of sensorimotor function is an important area of psychophysiological features study of the athletes' body, which are essential for the analysis of cognitive processes, assessment of the central nervous system functional state, sensory sensitivity, development of motor skills, psychophysiological and neurophysiological parameters of brain.

The aim of the study: to define the changes of indexes of the central regulation of sensorimotor function of highly skilled sportsmen at forming of the cardiovascular system overstrain.

**Material and Methods:**

On results research of the cardiovascular system with the use of spiroarteriocardiography before, after load and a next morning in 19 sportsmen of men, which the overstrains of the cardiovascular system was forming, were determine: at 10 – on a sympathetic type, at 9 – on a parasympathetic type. In parallel was determination of index of switching of central settings (SCS) which received from data of research of the sensorimotor system with the use of device the "Computer motion meter".

**Results:**

Right after intensive physical activity the meaningful acceleration of SCSl ( $p < 0.05$ ) and meaningful deceleration of SCSr ( $p < 0.05$ ) is marked at an overstrain on a sympathetic type, and also meaningful deceleration of SCSl ( $p < 0.05$ ) and meaningful acceleration of SCSr ( $p < 0.01$ ) at an overstrain on a parasympathetic type. In the period of recovery deceleration of SCSl and SCSr ( $p < 0.05$ ) at a sympathetic overstrain, and also stability of index of SCSl by comparison to afterload and meaningful dynamics of SCSr ( $p < 0.05$ ) is marked at a parasympathetic overstrain.

**Conclusions:**

At a sympathetic and parasympathetic overstrain the characteristic asymmetric changes of indexes of SCS that can testify to the primary flow of ergotrophic and trophotropic processes in the organism of sportsmen are marked.

**Keywords:**

sensorimotor regulating, overstrain of the cardiovascular system, sportsmen, physical load, sympathetic and parasympathetic overstrains

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## Introduction

Determination of sensorimotor function is an important area of psychophysiological features study of the athletes body (Berdychevskaya, Troiskaia, & Fokin, 2009; Craig, 2005), which are essential for the analysis of cognitive processes (Oppenheimer, Gelb, Girvin, & Hachinski, 1992), assessment of the central nervous system (CNS) functional state, sensory sensitivity (Guzii, Romanchuk, & Mahlovanyy, 2020; Noskin et al., 2005), development of motor skills, psychophysiological and neurophysiological parameters of brain functioning (Boloban, 2006; Kuznetsova, Sychov, & Egorova, 2017).

A large number of scientific publications are devoted to the study of simple and complex sensorimotor reactions of athletes, which are aimed at determining the characteristics of the organization of sensorimotor function taking into account the type of sport, gender, training experience, stages of the training process, etc. (Fokin, Boravova, Galkin, Ponomarev, & Shimko, 2009; Mittly, Németh, Berényi, & Mintál, 2016; Shlyk, 2009). However, there is little research into the central mechanisms of athletes' sensorimotor function due to the complexity of using existing methods in the training process (Sorokina, Selitsky, Ilina, & Zherdeva, 2018). First of all, this relates to the methods of studying the activity of the cerebral cortex. Let us point out that among the latter ones is electroencephalography, the method of evoked potentials, positron emission tomography (Craig, 2005). The method of studying the level of constant potential (LCP) has become widespread (Chikurov, Fedorov, Voinich, & Khudik, 2016; Romanchuk, 2003).

An important component of the study of sensorimotor responses is the understanding of the processes that occur at the central level of movement organization, which is related to the mechanisms of intra- and inter-hemispheric interaction. The latter are analyzed taking into account the activity of both hemispheres and determine the level of functional motor asymmetry (Brahina & Dobrohotova, 1988; Pestryaev & Safina, 2014).

It is well known that a modern approach to assessing the interrelation between functional asymmetries and the success of sports activities is linked to an understanding of the dynamic nature of functional interhemispheric interaction. Functional asymmetry is believed to play a regulatory role (Bellenger et al., 2016; Craig, 2005; Guzii, 2019). It provides coordinate presetting of unilateral motor actions. The latter suggests that motor asymmetry is a prerequisite for enhancing the organism's capacity under spatio-temporal conditions of existence (Grabinenko & Zhurba, 2017). Under these conditions, the distribution of functions between the hemispheres of the brain, not being absolute, forms a moving, flexible profile of the hemispheric asymmetry of the brain, the range of adaptive functions of the hemispheric interactions and the dynamics of the main nervous, humoral and immune processes, on which the effectiveness of adaptation to sports activity depends. In this aspect, according to most authors (Crollen, Albouy, Lepore, & Collignon, 2017), the most promising is the study of the dynamics of functional asymmetries in

competitive activities and in the process of individual training of athletes at different stages of preparation, which necessitated our study.

Let us remind that the general structural scheme of the organization of sensorimotor processes is a reflex ring (Nicolas, Vacher, Martinet, & Mourot, 2019; Pankova & Karganov, 2013). Sensory information coming from analyzers initiates regulates and controls movements. Coordination of sensory and motor components of the motor act is the most important condition for the functioning of sensory systems (Herpin et al., 2010; Skyba, Pshenychna, & Ustyenko-Kosorich, 2017; Thayer, Yamamoto, & Brosschot, 2010). Sensorimotor reactions are first of all characterized by such psychophysiological concept as "reaction time" (the term is habitually understood as the time interval between the appearance of a signal and the reaction of a response).

This is a complex formation, which is determined by the sum total of the following elements (Bezrukikh et al., 2000):

- the rate of excitation of the receptor and the transmission of the impulse to the appropriate center of sensitivity;
- the speed of signal processing in the CNS;
- the speed of deciding to respond to a signal;
- the speed of signal transmission before the start of action on the efferent fibers;
- the rate at which the excitation of the muscle develops and the inertia of the body or its individual part is overcome.

The reproduction of all these methods in the practice of rapid diagnostics of the basic properties of the nervous system of the person is either completely excluded or extremely time consuming, so for many years there have been searches for fairly simple, but objective tests to determine the basic properties of the CNS: the strength and functional mobility of the nervous processes, balance of excitation-braking activities (Pankova, 2003).

Among the components of the "reaction time", the parameter characterizing the central level of organization of movements is the speed of processing information in the CNS with the decision to respond to a signal.

That is why our attention was drawn to the method of estimating the sensorimotor function using the "Computer Motion Meter" (CMM-03), which is distinguished by the indicator of switching central settings (SCS), which characterizes the central level of regulation of movements, namely the time of decision about changing the characteristics of motion (Guzii et al., 2020; Korobeynikov & Korobeynikova, 2014).

*The aim of the study.* To determine changes in the indicators of the central regulation of the sensorimotor function of highly skilled athletes in formation of the cardiovascular system overstrain.

## Materials and Methods

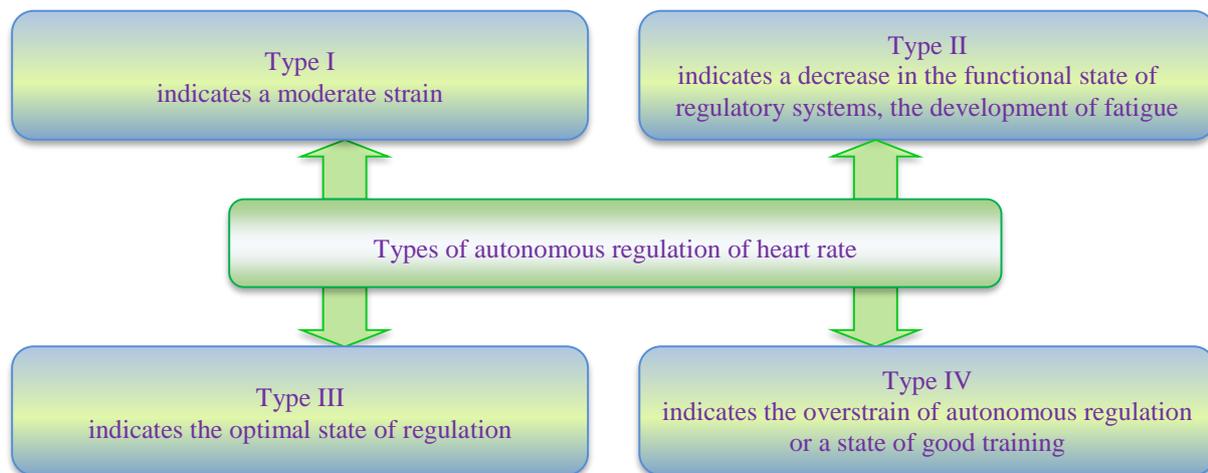
The algorithm of our study involved the study of parameters and indicators that define the changes of the sensorimotor and cardiorespiratory systems under the

influence of intense physical activity, as well as during the recovery period. The computer motion meter (CMM) was used to investigate the sensorimotor system (Noskin et al., 2005; Pivovarov, 2006). The study of the cardiorespiratory system was performed using the “Spiroarteriocardiogram” (SACR) (Guzii & Romanchuk, 2018; Noskin et al., 2005) before examination of the sensorimotor system. The tests were performed before exercise ( $S_1$ ), immediately after exercise ( $S_2$ ), and the next after exercise ( $S_3$ ) morning (stages of the study).

According to this algorithm, 202 highly skilled male athletes aged  $22.6 \pm 2.8$  years were studied using CMM and SACR. Experience in sports was  $10.3 \pm 3.1$  years. In our study, highly skilled athletes of acyclic sports (karate, taekwondo, kickboxing, boxing, water polo,

football) participated under the impact of various intense physical activities, which were performed in the preparatory, pre-competitive and competitive periods of the annual training cycle. According to the results of the SACR, 19 athletes were identified with observed changes according to HRV measurements, which indicated the development of cardiovascular system overstrain (Guzii, 2019).

The determination of overstrain was based on the evaluation of changes in autonomic regulation of cardiac rhythm, which was suggested by Shlyck (2009) and considered the stress index as well as ANS activity in the very low frequency diapason (VLF). In general, there are 4 types of autonomous regulation of heart rate (Figure 1).



**Figure 1.** Types of autonomous regulation of heart rate.

Determining the type of autonomic regulation of cardiac rhythm at each stage of the study ( $S_1$ ,  $S_2$  and  $S_3$ ) allowed us to establish characteristic changes of types under the influence of intense physical load (Guzii, 2019). At the same time, variants that characterized the activity of the sympathetic and parasympathetic branches of regulation were fixed in the dynamics of observations. We have assigned the following options:

- option 1: with the initial optimal state of the regulatory systems, or the overstrain of autonomous regulation (III and IV type); after intensive training load – reduction of the functional state of the regulatory systems (type II); on the next after training morning – a decrease in the functional state of regulatory systems (type II). Such variant was registered in 10 cases and characterized the development of overstrain of the cardiovascular system by sympathetic type;

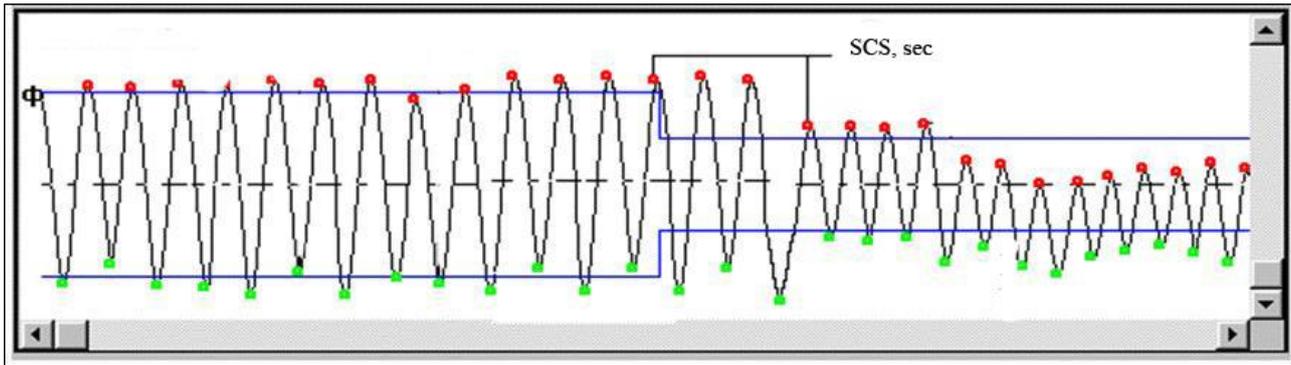
- option 2: with initial overstrain of autonomous regulation (type IV); after intensive training load – optimal state of regulatory systems, or overstrain of autonomous regulation (III and IV types); the next morning after training – overstrain of autonomous regulation (type IV). This variant was registered in 9 cases and characterized the development of the cardiovascular system overstrain by parasympathetic type.

According to the results of the selection, we formed 2 observation groups: OG1 consisted of 10 athletes, who

were noted into overstrain of the sympathetic type, and OG2 consisting of 9 athletes, who were noted into overstrain of parasympathetic type. The comparison group (CG) consisted of totally 202 highly skilled athletes.

With the help of CMM, the results of performing three simple motor tests (Crollen et al., 2017; Pankova, 2003) performed by the right and left hands determined 25 digital motion parameters. In this study we will look the change of the parameter of the switching of central settings (SCS, sec.), which reveals the activity of the prefrontal cerebral cortex and, given the asymmetry, can be informative about of the course energy processes in the body of athletes (Romanchuk, 2007). In Figure 2 shown principle of measured this parameter.

This test consists in performing repeated turns of the lever in the horizontal plane left and right in the range indicated by light markers. The task is determined by the instruction: “Will necessary turning the lever as fast as possible from the one light marker to another. You will need to change the direction of movement exactly on the light marker.” This instruction defines the main feature of the motor task – the conflict between the requirements of accuracy and speed. Accordingly, with the help of this test, an individual balance is determined for each subject between the maximum possible speed and accuracy of movement, which is achieved during the implementation of the task.



**Figure 2.** The principle of determining the SCS (sec) in a motion test with use the device “CMM”.

SCS is measured as follows. After making turns of the lever with a stable amplitude for 10–15 sec (the period of “working on” into a certain moving mode), one of the LEDs is suddenly turned off for the subject and another pair of markers is turned on. The distance between them and the position on the perimeter differ from those for the previous pair. In accordance with the changed position of the signals defining the range of lever turns, the subject must urgently change the mode of movement – its amplitude and spatial orientation. In the test program, the movement mode changes twice for each hand. Non-parametric methods of analysis using Wilcoxon and Mann-Whitney criteria were used to identify differences between groups and indicators in the dynamics of observation.

## Results

In Table 1 presents the characteristic differences of routine indicators of body structure and cardiovascular activity in the groups being analyzed. The differences from the CG in OG<sub>2</sub>, which relate to: significantly

smaller values of body mass (BM) ( $p < 0.05$ ), body mass index (BMI) ( $p < 0.05$ ), chest circumferences (CC) ( $p < 0.05$ ), contours abdomen ( $p < 0.05$ ), contours hips ( $p < 0.05$ ), significantly greater values of thorax mobility ( $p < 0.05$ ), force index (FI) ( $p < 0.05$ ). Significant were the differences in systolic blood pressure (ATS) ( $p < 0.05$ ), vegetative index ( $p < 0.05$ ), Robinson index ( $p < 0.05$ ), Baevsky AP ( $p < 0.05$ ), which are significantly smaller and indicate a better functional state of the body and a pronounced predominance of parasympathetic effects. This fact is confirmed by significantly higher values of the physical state level (PSL) according to Pirogova ( $p < 0.05$ ).

At the same time in OG<sub>1</sub> compared with CG differences show significantly greater values of body mass, ( $p < 0.05$ ), body area, ( $p < 0.05$ ), chest excursions, ( $p < 0.05$ ), hips ( $p < 0.05$ ), abdomen ( $p < 0.05$ ) and fat content ( $p < 0.05$ ). There are lower SBP values ( $p < 0.05$ ) against higher DBP values ( $p < 0.05$ ). However, all other routine indicators and indices of the cardiovascular system from the CG are not significantly different.

**Table 1.** Morphofunctional differences athletes at baseline at overstrain by sympathetic (OG<sub>1</sub>) and parasympathetic (OG<sub>2</sub>) in comparison with comparison group (CG).

Parameter	CG n=202	OG <sub>1</sub> n=10	OG <sub>2</sub> n=9
BM, kg	72.0 (62.0; 82.0)	80.0 (61.0; 94.0) <sup>a</sup>	66.5 (61.0; 81.0) <sup>b</sup>
Length, cm	179.0 (170.0; 185.0)	181.5 (170.0; 189.0)	179.0 (175.0; 185.0)
BMI, kg/m <sup>2</sup>	22.5 (20.9; 25.2)	23.6 (21.4; 27.3)	20.5 (19.9; 24.2) <sup>ab</sup>
Body area, m <sup>2</sup>	1.92 (1.74; 2.04)	2.02 (1.70; 2.18) <sup>a</sup>	1.85 (1.74; 2.03) <sup>b</sup>
Chest circumferences, cm	96.0 (91.0; 101.0)	98.5 (89.0; 113.0)	91.0 (90.0; 96.0) <sup>ab</sup>
Thorax mobility, cm	7.0 (5.0; 8.0)	8.5 (7.0; 10.0) <sup>aa</sup>	8.0 (7.5; 9.0) <sup>a</sup>
Contours abdomen, cm	78.0 (74.0; 86.5)	82.5 (74.0; 92.0)	75.0 (73.0; 82.0) <sup>ab</sup>
Contours hip, cm	52.0 (48.0; 56.5)	56.0 (50.0; 60.0) <sup>a</sup>	48.0 (45.0; 57.0) <sup>ab</sup>
FI, %	64.4 (59.5; 68.9)	64.5 (51.1; 77.3)	66.3 (55.6; 68.9) <sup>a</sup>
VLC, ml	4800 (4400; 5600)	4850 (4400; 6600)	4850 (4500; 4900)
VI, ml/kg	67.9 (61.9; 73.1)	65.2 (62.9; 70.2)	69.3 (59.3; 73.8)
BFP, %	11.8 (8.7; 18.1)	18.4 (8.1; 19.0) <sup>a</sup>	13.3 (6.5; 20.3)
SBP, mmHg	120 (110; 130)	115 (110; 120) <sup>a</sup>	115 (100; 120) <sup>a</sup>
DBP, mmHg	70 (64; 80)	80 (70; 80) <sup>a</sup>	70 (70; 80)
Vegetative index	-0.19 (-0.35; -0.05)	-0.27 (-0.59; -0.05)	-0.34 (-0.45; -0.28) <sup>ab</sup>
Robinson's index	71.8 (64.6; 81.8)	73.6 (65.1; 75.7)	60.3 (51.7; 75.8) <sup>ab</sup>
Baevsky's AP	2.02 (1.87; 2.25)	1.98 (1.84; 2.12)	1.79 (1.52; 1.99) <sup>abb</sup>
Pirogova's LPS	0.746 (0.672; 0.822)	0.736 (0.692; 0.762)	0.823 (0.753; 0.901) <sup>ab</sup>

Note. <sup>a</sup> –  $p < 0.05$ , <sup>aa</sup> –  $p < 0.01$ , between OG<sub>1</sub> and OG<sub>2</sub> in comparison with CG; <sup>b</sup> –  $p < 0.05$ , <sup>bb</sup> –  $p < 0.01$ , between OG<sub>2</sub> and OG<sub>1</sub>.

Table 2 presents the absolute values of the measurement of SCS when performing the test with the right and left hands at all stages of observation of athletes. The most significant acceleration in the initial state (S<sub>1</sub>) of the SCS when performing the test with the left (SCSI) and right (SCSr) hands was in OG<sub>1</sub> compared with CG and OG<sub>2</sub> (P-value<0.05). At the same time, when performing the

test with the right hand in the initial state in OG<sub>2</sub>, the greatest slowdown of SCS (P-value<0.05) was observed among the studied groups. That is, a reduction in the time of SCSI and SCSr prior to exercise may predict an excessively sympathetic response to the cardiovascular system.

**Table 2.** Differences in switching rates of switching of central settings in highly skilled athletes under the influence of intense training load and in the period of early recovery thereafter.

Parameter	Control point	CG n=202	OG <sub>1</sub> n=10	OG <sub>2</sub> n=9
SCSI	S <sub>1</sub>	1.62 (1.15; 2.42)	1.26 (0.96; 1.38) <sup>a</sup>	1.90 (1.49; 2.20) <sup>b</sup>
	S <sub>2</sub>	1.49 (1.07; 2.29)	0.96 (0.91; 1.82) <sup>ac</sup>	2.20 (1.38; 3.22) <sup>bca</sup>
	S <sub>3</sub>	1.67 (1.24; 2.35)	1.65 (1.24; 2.09) <sup>cd</sup>	2.45 (1.68; 3.11) <sup>abc</sup>
SCSr	S <sub>1</sub>	1.62 (1.07; 3.08)	1.15 (0.85; 1.51) <sup>a</sup>	1.82 (1.71; 2.12) <sup>abb</sup>
	S <sub>2</sub>	1.57 (1.13; 3.36)	1.51 (1.24; 1.65) <sup>c</sup>	1.38 (1.26; 1.46) <sup>abcc</sup>
	S <sub>3</sub>	2.04 (1.21; 3.77) <sup>dc</sup>	1.95 (1.13; 2.28) <sup>cd</sup>	1.73 (1.13; 1.76) <sup>abcd</sup>

Note. <sup>a</sup> – p<0.05, between OG<sub>1</sub> and OG<sub>2</sub> in comparison with CG; <sup>b</sup> – p<0.05, <sup>bb</sup> – p<0.01, between OG<sub>1</sub> and OG<sub>2</sub>; <sup>c</sup> – p<0.05, <sup>cc</sup> – p<0.01, between S<sub>2</sub> and S<sub>3</sub> in comparison with S<sub>1</sub>; <sup>d</sup> – p<0.05, between S<sub>2</sub> and S<sub>3</sub>.

At S<sub>2</sub>, sufficiently characteristic changes are observed, which indicate the absence of changes in the SCSI and SCSr indicators in CG, a significant acceleration of SCSI (P-value<0.05) and a significant slowdown of SCSr (P-value<0.05) in OG<sub>1</sub>, as well as a significant slowdown of SCSI (P-value<0.05) and a significant acceleration of SCSr (P-value<0.01) in OG<sub>2</sub>. That is, after physical load a significant acceleration of the accelerated SCSI in the initial state, which is accompanied by a significant slowing of the accelerated SCSr in the initial state, can predict an excessively sympathetic response of the cardiovascular system. On the other hand, significant slowdown (within the regulatory limits) of the SCSI against the background of significant acceleration (within the regulatory limits) of the SCSr can predict excessive parasympathetic response of the cardiovascular system.

At S<sub>2</sub>, changes in SCS indices in CG indicate a significant slowdown of SCSr (P-value<0.05) compared to S<sub>1</sub> and S<sub>2</sub> with the invariance of SCSI; in OG<sub>1</sub>, SCSI and SCSr indicators indicate a significant increase compared to S<sub>1</sub> and S<sub>2</sub> (P-value<0.05); in OG<sub>2</sub>, SCSI is significantly different from S<sub>1</sub> (P-value<0.05) but not S<sub>2</sub>, and SCSr is significantly less than S<sub>1</sub> (P-value <0.05) and significantly greater than S<sub>2</sub> (P-value<0.05). That is, characteristic of OG<sub>1</sub> the next morning after training is the slowdown of the central level of regulation of sensorimotor function in comparison with the baseline level when performing tests with the right and left hands. The OG<sub>2</sub> is characterized by a slowdown of the central level of regulation of the sensorimotor function compared to the baseline level when performing the test with the left hand and speeding up when performing the test with the right hand.

In the development of overstrain of cardiovascular system at a sympathetic type, the slowdown of the SCS with both the right and left hand is noted, as compared to the initial state and the state after physical activity. In this case, the SCS values do not differ in the OG. At the same time, at overstrain by parasympathetic type, the

slowdown is observed when performing the test with the left hand, in comparison with the initial state, and it does not differ from the state after exercises and is significantly slower than in the OG (P-value<0.05) and at sympathetic overstrain (P-value<0.05). On the other hand, when performing the test with the right hand, the SCSr has intermediate values between S<sub>1</sub> and S<sub>2</sub>, which indicates the reverse tendency of the central processes of sensorimotor regulation the next morning after training, which, at the same time, are significantly faster than in the OG (P-value<0.05) and at sympathetic overstrain (P-value<0.05).

That is, characteristic asymmetric changes at the central level of regulation of sensorimotor function are noted at sympathetic and parasympathetic overstrains of the cardiovascular system of athletes.

### Discussion

According to the results of the analysis of the data in the initial state, before physical activity, rather informative differences between the studied groups were revealed, which indicated a greater speed of the processes of switching movements in the cortical motor areas of both hemispheres in individuals who subsequently formed an overreaction of the sympathetic division of the ANS, which led to overstrain of the cardiovascular system.

An asymmetric functional response to intense physical activity, characterized by significant acceleration of central processes in the right hemisphere and significant slowdown in the left, is different for sympathetic overstrain. This information complements the data obtained by Fokin et al. (2009) in the study of the level of constant potential of the brain, which indicate the greater importance of the right hemisphere in determining the effects of stress. It should also be mentioned that, according to many scientists (Berdychevskaia et al., 2009; Noskin et al, 2005), the change of the dominant hemisphere occurs when the athlete's performance is reduced. However, in this case it is not possible to talk about it.

Importantly, the asymmetric functional response to physical activity, but of the opposite orientation, is also characteristic of parasympathetic overtraining. It is characterized by slowing of the central processes in the premotor zone of the right hemisphere and acceleration in the left hemisphere. That is, given the data obtained by Pestryayev and Safina (2014), who showed that in most cases the left hemisphere has closer functional connections with trophotropic systems of regulation and the right one with ergotropic systems, it can be stated that the results obtained by the study of the sensorimotor function fully reflect the processes occurring in the autonomous regulation of the cardiovascular system. In this case, such changes in the central mechanisms of regulation precede the development of overstrain of the ANS in the regulation of the heart (Moskvyn & Moskvyna, 2015; Romanchuk, 2007).

Characteristic of all athletes during the recovery period is a certain slowdown of the central processes of the left hemisphere, although the processes in the right hemisphere remain unchanged compared to the original state and the state after physical activity.

Changes in the central mechanisms in athletes with the formation of cardiac-vascular system overstrain in the sympathetic type, in which the excitation processes were significantly slowed down in the right and left hemispheres of the brain, both in comparison with the initial state and with the state after loading, were informative. In this case, the functional asymmetry that arose after intense physical activity disappeared. This variant of changes testifies to the deterioration of both energy and plastic processes in the body of athletes.

Athletes with the formation of parasympathetic overstrain during the recovery period show the most pronounced slowing of the central processes in the right hemisphere, which, given the previously mentioned data, can indicate significant energy savings. At the same time, significant activation of the left hemisphere after intense physical activity remains sufficiently active the following morning after intensive training in comparison with the initial state, which can testify to the intensive course of trophotropic processes in the body of athletes (Chermit, Shakhanova, & Zabolotniy, 2014; Romanchuk, 2003).

### Conclusions

In the case of sympathetic and parasympathetic overstrains of the cardiovascular system of athletes under the influence of intense physical activity and in the period of recovery, characteristic asymmetric changes at the central level of regulation of sensorimotor function are noted which can attest to the predominant course of ergotropic and trophotropic processes in organism of athletes. The studies have underlined the importance of testing the sensorimotor function in the training.

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### Ethical approval

Permission for this study was obtained from the ethics committee of both institutions and informed consent was obtained from athletes.

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