

Relationship between physical fitness, blood microcirculation activity, and nervous system function

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Abstract:

Studying the relationship between physical activity and the functional state and characteristics of central nervous system processes is essential for comprehensively improving the effectiveness of athletic training. **Purpose.** To examine the characteristics of the blood microcirculation system and the level of central nervous system adaptation in students with different fitness levels. **Materials and methods.** The experiment involved 68 students: 42 young men without specialized physical training and 26 athletes practicing sambo wrestling three times a week. Capillary blood flow was assessed using laser Doppler flowmetry with LDF-gram (Laser doppler flowmetry diagram) recording, and standard indicators of microcirculation were analyzed. The data were processed using variation statistical methods with software packages, and the results were presented as mean values with standard errors of the mean. To assess central nervous system adaptation and sensorimotor reaction speed, a simple visual–motor response test was performed using the "choice reaction" method. **Results.** Students actively practicing sambo exhibit greater modulation of capillary blood flow, with moderately enhanced activity of vascular tone regulation mechanisms. In these individuals, the endothelial and myogenic components remain the primary contributors to microvascular tone. Additionally, the athlete group shows increased inflow of oxygenated blood into the capillary bed, accompanied by increased lipid peroxidation processes, which may be related to their higher level of physical fitness. It was determined that young athletes demonstrated a higher level of central nervous system adaptation and faster sensorimotor reaction speeds in visual–motor reaction tests compared to non-athletes. This reflects a greater strength of nervous processes and a more balanced neural function resulting from training loads. **Conclusions.** The level of physical fitness influences the functional activity of blood microcirculation, the rate of metabolic processes in the capillary bed, and the degree of central nervous system adaptation. These findings should be considered when planning training sessions to improve their effectiveness.

Keywords: physical training, functional state, sambo, central nervous system, blood microcirculation

Introduction

Currently, sports and physical education are key factors in stabilizing psycho-emotional balance and normalizing the body's functional state. This underscores the importance of physical activity as a vital component of health-preserving practices, provided it is appropriately dosed (Banach et al., 2023; Graf et al., 2023).

Health improvement can be achieved by maintaining a balance between physical fitness, the body's adaptation to physical exertion, and optimal psycho-emotional conditions (Chen, & Nakagawa, 2023; Pronin, et al. 2023; Xiang et al., 2025). This balance forms the basis for the stable functioning of all bodily systems amidst various environmental influences (Kudryavtsev et al., 2024; Osipov et al., 2024). Properly regulated physical activity acts as a catalyst for activating reserve functions and increasing the body's adaptive capacity (Mincarone

et al., 2024; Brodaty et al., 2025; Romanova et al., 2025), which in turn considerably influences quality of life (Zupkauskienė et al., 2022; Johnson et al., 2025) and longevity of a person (Yu et al., 2021).

One key criterion for assessing functional capacity is the capillary blood flow system, also known as the blood microcirculation system. It is essential in determining the readiness of functional components to operate optimally while maintaining homeostasis (Guerrero et al., 2020). In the microcirculatory bed, essential substances are delivered, and excess metabolic products are removed. This process is crucial during physical activity. Additionally, arteriovenous anastomoses provide alternative pathways for blood flow, which becomes especially important in enhancing tissue perfusion during training. Laser Doppler flowmetry is a method used to study tissue blood perfusion, demonstrating high informational value when applied to skin surface assessments and interpretation (Shiue et al., 2025). This technique allows the evaluation of microvessel blood filling and the dominant systems regulating vascular tone. Additionally, it provides insights into oxidative metabolism, which is crucial for increased oxygen consumption by skeletal muscles (Montero et al., 2015; Hendrickse, & Degens, 2019; Kolokoltsev, et al. 2021). The method operates by measuring the fluorescence rates of blood cells and the reduced form of the coenzyme nicotinamide adenine dinucleotide (NADH). It is non-invasive and can be performed under a wide range of conditions (Mayevsky, 2025).

It is well established that physical activity can induce functional restructuring of the central nervous system. This leads to changes in reaction speed in response to specific signals, which is critically important during physical exercise and sports training (Kitazawa et al., 2021; Nagai et al., 2021; Vorozheikin, et al., 2021). Physiologically, this process occurs through a system of reflex arcs, where signals are initially detected by receptors, then processed in the cerebral cortex, and finally transmitted to the appropriate effector to elicit a response (Roberts et al., 2022).

This is especially important when choosing the right strategy when performing technical elements in a particular sport and competing in competitive conditions (Salugin et al., 2023). In addition, the ability to maintain the initial level of concentration directly affects the efficiency of performing motor locomotion (Caggiano et al., 2024).

However, inadequate dosage of training loads can lead to a mismatch in the functioning of the body's physiological systems and the emergence of pre-clinical and premorbid conditions, which has a direct correlation with the final result in physical activity and sports (Bocharin et al., 2022; Kolokoltsev et al., 2022). From the side of blood microcirculation, this may be a violation of metabolic processes in the capillary bed, and from the side of the central nervous system - an asymmetry in the implementation of motor acts after processing the incoming signal and a decrease in the strength and mobility of nervous processes. Taking this into account, periodic monitoring of the physiological systems of the body is necessary to prevent negative conditions and timely adjustment of the training process. This issue has not yet been fully studied, which can reduce the effectiveness of training sessions.

Research aim. To study the characteristics of the blood microcirculation system and the level of central nervous system adaptation in students with different levels of physical fitness.

Materials and methods

The study involved 68 male students from the 1st to 3rd years at the Medical University in Nizhny Novgorod, Russia with an average age of 19.2 ± 1.3 years. The participants were divided into two groups. The first group consisted of 42 students who had no specialized physical training and participated in physical activity only during their elective university physical education classes, which were held once a week for 90 min. The second group consisted of 26 students who practiced sambo wrestling three times a week for 90 min as part of a sports club. Before the study, all participants provided informed voluntary consent in full accordance with the 2008 Helsinki Declaration, which regulates ethical standards in human research. The study involved contributions from researchers representing universities in Russia, Kyrgyzstan, and Kazakhstan.

The subjects were tested under consistent conditions at the beginning of the spring semester of the 2024–2025 academic year, during the middle of the school day, and outside of colloquium and test days. The students were in a state of relative physiological rest. To assess the capillary blood flow system, the laser Doppler flowmetry method was used using the "LASMA-PF" portable laser blood microcirculation device (Moscow, Russia). The LDF-gram (Laser doppler flowmetry diagram) was recorded from the skin of the left-hand index finger while the subjects were seated, with a minimum recording duration of 5 min. The use of the LASMA-PF PAC in scientific research allows a non-invasive investigation of capillary blood flow dynamics and the regulatory functions of the microcirculatory bed. The device uses a specialized sensor that emits laser radiation onto the targeted skin surface; this radiation is then reflected by blood components and received by the device's light detector for data processing. Based on this, changes in capillary blood flow perfusion over time are determined through recording the LDF signal. When using laser Doppler flowmetry, an averaging algorithm calculates the mean Doppler frequency shift across all formed elements (erythrocytes) in the probing area. Consequently, this technique provides a non-invasive functional assessment of the blood microcirculation system (Shiue et al., 2025).

The functional state of the microcirculatory bed system was monitored using the microcirculation index (M, perfusion units), the standard deviation of blood flow oscillation amplitude relative to the arithmetic mean of M (σ), the ratio of tissue blood perfusion along with its variability (variation coefficient, Kv, %), the amplitude of NADH coenzyme fluorescence (ANADn, arbitrary units), and the integral index of oxidative metabolism (IOM, arbitrary units). Based on the mathematical analysis, the amplitudes of oscillations in the skin blood flow components and the primary active and passive regulatory mechanisms were calculated in perfusion units: the endothelial component (Ae), myogenic component (Am), neurogenic component (An), respiratory component (Ad), and cardiac component (Ac). These results were then compared with standard values, which are individually determined for each subject using an algorithm embedded in the device's software by its developers.

To functionally assess the central nervous system and compare sensorimotor reaction levels between groups, a simple visual-motor reaction test was employed. Specifically, the "Choice Reaction" method was used, where participants waited for a light indicator of a specific color to appear and then pressed the corresponding key on a remote control. The stimulus colors were green and red, presented at random intervals to prevent habituation. The interval between stimuli ranged from 0.5 to 2.5 s, with a minimum of 70 impulses delivered. Testing of students was performed outside the training period. During the study, subjects were in a state of relative physiological rest while seated and were not exposed to any external stimuli. Monitoring was performed using the "NS-Psychotest Expert" hardware and software complex (Ivanovo, Russia) with its integrated software. The test measured indicators including average reaction time (M), times of correct and erroneous reactions (Mcor, Merr), standard deviation (SD), total number of errors (NE), and accuracy coefficient (CA). These indicators for each group were compared against normative values presented in Table 1.

Table 1. Reference values of sensorimotor reaction parameters for the students studied (a.u. - arbitrary units)

No.	Indicator	Standard
1	M, ms	332 – 434
2	Mcor, ms	332 – 434
3	Merr, ms	332 – 434
4	SD, ms	69 – 113
5	NE, units	–
6	CA, a.u.	0.04 – 0.18

The data were analyzed using variation statistics with Statistica 10.1 for Windows and Microsoft Excel 2016 software packages (Privolzhsky Research Medical University, Nizhny Novgorod, Russia). Values are presented as the arithmetic mean (M) and standard error (m). Data distribution normality was assessed using the Shapiro–Wilk test. Because the data did not follow a normal distribution, the nonparametric Mann–Whitney test was applied. Differences were considered statistically significant at $p < 0.05$.

Results

According to our data, the state of microcirculation based on the LDF-gram indicates a relative predominance of active mechanisms of blood flow regulation among the subjects (Table 2).

Table 2. Laser Doppler flowmetry indicators in students with different levels of physical fitness (n = 68), $M \pm m$

Indicator	Non-athletes (n = 42)	Athletes (n = 26)
Microcirculation (M), perfusion units	19.9 ± 10.2	20.0 ± 8.3
Mean square deviation of blood flow oscillation amplitude (σ), perfusion units	2.5 ± 2.5	3.1 ± 1.3*
Variation coefficient (Kv), %	13.2 ± 6.1	16.8 ± 6.5*
Endothelial component (Ae), perfusion units	0.9 ± 0.7	1.0 ± 0.4*
Myogenic component (Am), perfusion units	0.9 ± 0.7	1.1 ± 0.6*
Neurogenic component (An), perfusion units	0.9 ± 0.6	0.8 ± 0.3
Respiratory component (Re), perfusion units	0.5 ± 0.4	0.4 ± 0.1
Cardiac component (Cardiac), perfusion units	0.6 ± 0.3	0.6 ± 0.3
Anadn, arbitrary units	0.7 ± 0.2	0.7 ± 0.3
Oxidative metabolism index (OMI), arbitrary units	6.9 ± 3.4	8.3 ± 5.8*

*Note. * Indicated statistically significant differences in microcirculation indicators between students with different levels of physical fitness, $p < 0.05$.*

Thus, the blood microcirculation index is nearly identical in both groups of student subjects. The relatively high value of this index suggests a slight decrease in arteriole tone and an increase in their blood volume. Student athletes exhibit greater modulation of capillary blood flow, reflected by a higher standard

deviation of blood flow oscillation amplitude (3.1 ± 1.3 perfusion units in sambo wrestlers versus 2.5 ± 2.5 perfusion units in regular students, $p < 0.05$). This difference may result from reduced tonic sympathetic activity in athletes and a moderate enhancement of active mechanisms regulating vascular tone.

The analysis of spectral blood flow oscillations identified the dominant factors among the active mechanisms regulating vascular tone, with a stronger expression observed in sambo athletes. Statistically significant differences in tone-regulating factors were found between the student groups. Specifically, differences were noted in the endothelial component, which activates vasodilation mechanisms, and the myogenic component, which modulates vessel tone through the smooth muscle of the vascular wall ($p < 0.05$).

The contribution of the respiratory and cardiac regulatory components is less pronounced, with no statistically significant differences observed. Additionally, increased activation of the endothelium-dependent regulatory component in student athletes is supported by a variation coefficient that is 27.3% higher compared to students participating in elective physical education classes ($p < 0.05$). Thus, considering the spectral components in this study, there is sufficient stability in the blood microcirculation system, characterized by activation of endothelial and myogenic regulatory components, indicating a relative increase in blood outflow from the microcirculatory bed. A decrease in arterial blood inflow accompanied by an increase in vascular tone was observed. We suggest that this characteristic may result from the effects of regular physical activity in the subjects. Despite these features of the microcirculation system identified through LDF-gram analysis, all indicators remain within normal ranges. The tissue blood flow level in both groups corresponds to the mesoemic type.

No statistically significant differences were found in the assessment of the coenzyme NADH between the student groups; however, the oxidative metabolism index (OMI) was 20.3% higher in the athlete group ($p < 0.05$). This suggests an increased influx of oxygenated blood into the capillary bed and its utilization in tissues experiencing high lipid peroxidation. This finding may also be related to the higher fitness level of students engaged in sambo wrestling. In the next phase of the study, the functional state of the central nervous system was evaluated using a simple visual-motor reaction test ("choice reaction"), as shown in Figure 1.

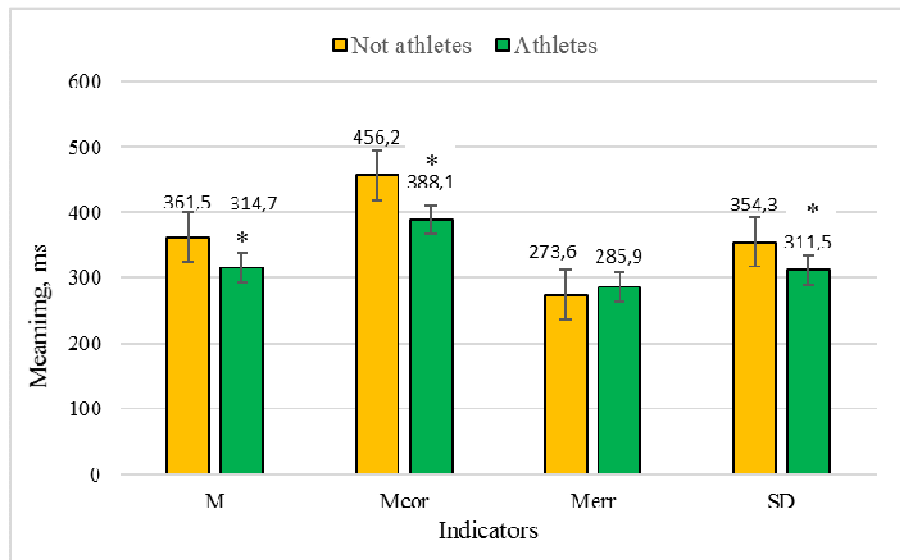


Fig. 1. Average reaction times (ms), number of correct and incorrect reactions, and standard deviation in the visual-motor reaction test among young men with different levels of physical fitness

*Note. * Indicates statistically significant differences in the indicators between the subject groups, $p < 0.05$.*

The average reaction time of young men participating in motor activities during elective physical education classes falls within the normal range. In contrast, students involved in sports show reaction times below the lower limit of this range, indicating superior reaction speed relative to their training level. At the same time, the average time of correct reactions among athletes remains within the normal range, whereas in the other group, it exceeds the acceptable normal limits. An opposite trend was observed for the average time of incorrect reactions—in both groups, this parameter was below the normal range ($p < 0.05$ for all indicators). Considering this, we can infer a relative predominance of inert processes in the non-athlete group. The average number of errors was 5.8 ± 1.7 for non-athlete students and 3.9 ± 1.2 for young sambo wrestlers ($p < 0.05$), as shown in Figure 2.

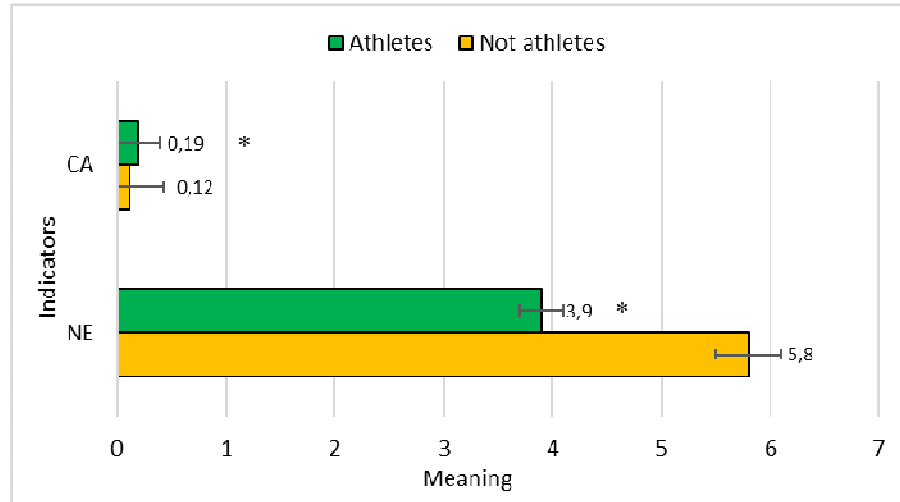


Fig. 2. Total number of errors (units) and accuracy coefficient (arbitrary units) in the visual–motor reaction test among students with different levels of physical fitness

*Note. * Indicates statistically significant differences in the indicators between subject groups, $p < 0.05$.*

The presented data indicate that attention stability during testing is maintained among individuals classified as athletes. This trend is further supported by the accuracy coefficient, which was 0.12 ± 0.04 in the non-athlete group and 0.19 ± 0.05 ($p < 0.05$) in the group of students with higher physical fitness. This confirms greater attention stability in athletes during testing. Accordingly, students engaged in more intense physical activity demonstrated a higher level of central nervous system adaptation, reflecting a more stable balance of nervous processes and greater overall resilience.

Discussion

During educational activities in a higher educational institution, there is an impact of significant academic loads, which are associated with the intensification of educational activities, the use of modern teaching features, and the violation of the basics of a healthy lifestyle (Kolokoltsev et al., 2022). This leads to stress on the regulatory systems of the body and the development of specific compensatory reactions (Bocharin et al., 2022; Tang et al., 2022). In this regard, the requirements for the physiological systems of the students' body increase, which necessitates the use of modern diagnostic tools under conditions of rest and exposure to physical activity (Romanova et al., 2025). Under current conditions, an effective study of adaptive mechanisms and the identification of negative trends in declining health is an important issue in the field of medical and biological support and student support in an educational organization of higher education (Wang et al., 2025).

The results of our study indicate that both groups of subjects have a relative predominance of active mechanisms of blood flow regulation. A sufficiently high value of the microcirculation indicator indicates a slight increase in the blood volume in the arterioles with a deeper modulation of capillary blood flow among student-athletes. In the group of athletes and students not involved in sports, the predominant components of vascular tone regulation are the endothelial and myogenic components, which is consistent with the results of the study of other authors (Montero et al., 2015; Hendrickse, & Degens, 2019). These changes are more pronounced in the group of athletes, which is additionally confirmed by the dynamics of the variation coefficient. It is assumed that regular physical activity can have such effects observed when recording LDF grams among the studied students, and the level of tissue blood flow in them corresponds to the mesoemic type. With this type, tissue blood flow is represented by the average value of LDF-metry indicators and the balance of the mechanisms of vasomotor, metabolic and neurogenic regulation of microcirculation (Shiue et al., 2025). At the same time, a higher level of fitness of the body of sambo wrestlers contributes to the intensification of oxidative metabolism processes in the capillary bed, which is reflected in the dynamics of this indicator. In athletes, the oxidative metabolism indicator was 20.3% higher compared to the result of the examination of students who were classified as non-athletes, $p < 0.05$. An increase in oxidative metabolism indicates an increase in the reserve capacity of the athletes' body, as reported by the research materials of a number of authors (Mincarone et al., 2024; Brodaty et al., 2025; Romanova et al., 2025) with whose conclusions we agree.

In our study of the level of adaptation of the central nervous system using visual-motor reaction testing, a higher level of stabilization and strength of nervous processes was observed in the group of students classified as athletes. Students in this group demonstrated a lower value of the average time of all reactions, more correct reactions and standard deviation. In addition, they recorded fewer errors and a higher value of the accuracy

coefficient. Similar results were achieved among individuals performing physical activity according to other authors (Kitazawa et al., 2021; Nagai et al., 2021). The results of our research confirm the authors' conclusion about the positive effect of physical activity on the restructuring of the central nervous system. This is of great importance when practicing motor activity and sports training. Coaches and sports specialists need to use the data obtained in building the educational and training process for athletes who practice martial arts. This will increase the effectiveness of training sessions and prevent the development of overtraining and overfatigue in individuals who practice sambo wrestling.

Conclusion

It has been established that students who are actively involved in sambo wrestling have a higher modulation of capillary blood flow with moderate intensification of active mechanisms of vascular tone regulation. In them, endothelial and myogenic components make a significant contribution to the formation of the tone of the microcirculatory bed.

In the group of athletes, an intensification of the influx of oxygenated blood into the capillary bed is noted, which is accompanied by an increase in the processes of lipid peroxidation, which may be associated with a higher level of metabolic processes that are due to physical fitness.

A high level of adaptation of the central nervous system and the speed of sensorimotor reactions according to the testing of the visual-motor reaction is registered among student-athletes involved in sambo. This indicates a more significant level of strength of nervous processes and their qualitative balance under the influence of pronounced training loads. The revealed feature of the relationship between the level of physical fitness of students and the functional activity of blood microcirculation, the rate of metabolic processes in the capillary bed and the level of adaptation of the central nervous system must be taken into account when constructing educational and training sessions in sambo wrestling to increase their effectiveness.

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