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EFFECT OF BETA-RHYTHM NEUROFEEDBACK ON THE FUNCTIONAL STATE OF MALE ATHLETES DURING TRAINING CAMPS AT MID ALTITUDE

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Introduction. Neurofeedback is a type of biofeedback that targets brain rhythms. The prospects for its application in rehabilitation and sports medicine stem from its non-invasive and non-pharmacological nature of changing the functional state through controlled parameters and body functions. At present, alpha-rhythm neurofeedback training is widely used in sports medicine, whereas the effects of beta-rhythm neurofeedback remain largely unexplored.

Objective. The study aims to investigate the effect of beta-rhythm neurofeedback training on the functional state of body systems in male athletes during intensive training camps conducted in the mid-mountains.

Materials and methods. The study involved 47 highly qualified male athletes divided into a main group of 27 individuals (median age: 21 [18; 24] years) and a control group of 20 individuals (median age: 20 [18.5; 22.5] years). A neurofeedback session targeting beta rhythms consisted of a graphic session (10 min) and a game session (16 min); the course comprised 8–10 sessions. Along with psychophysiological testing, the physiological parameters of the cardiovascular, respiratory, and nervous systems were recorded before the first and after the last sessions. Statistical data processing was performed using Statistica 13.0 software.

Results. A comparison of the parameters of bodily functions in male athletes before and after the neurofeedback training course showed a decrease in physiological strain, as evidenced by heart rate variability, hemodynamics, respiratory parameters, and galvanic skin response. Also, the indicators of mental performance and beta rhythms were noted to increase relative to the control.

Conclusions. The course of neurofeedback training targeting beta rhythms was found to have a positive effect in male athletes, which manifested itself in improved function of the central and autonomic nervous systems, increased cardiac efficiency, and optimization of the respiratory cycle. The obtained results open up prospects for athletes to achieve higher performance by reducing physiological strain and, consequently, fatigue during intensive activities.

Keywords: athletes; neurofeedback; functional capabilities; brain rhythms; nervous system; cardiovascular system

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ВЛИЯНИЕ НЕЙРОБИОУПРАВЛЕНИЯ ПО БЕТА-РИТМУ ГОЛОВНОГО МОЗГА НА ФУНКЦИОНАЛЬНОЕ СОСТОЯНИЕ ОРГАНИЗМА СПОРТСМЕНОВ-МУЖЧИН В ПЕРИОД УЧЕБНО-ТРЕНИРОВОЧНЫХ СБОРОВ В УСЛОВИЯХ СРЕДНЕГОРЬЯ

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Введение. Нейробиоуправление — технология, основанная на принципах биологической обратной связи по ритмам головного мозга. Перспективы его применения в восстановительной и спортивной медицине связывают с неинвазивным и нефармакологическим воздействием, вызывающим изменения функционального состояния по управляемым параметрам и функциям организма. В настоящее время в спортивной медицине широко применяется нейробиоуправление по альфа-ритму головного мозга, в то время как эффекты нейробиоуправления по бета-ритму практически не исследованы.

Цель. Изучение влияния нейробиоуправления по бета-ритму головного мозга на функциональное состояние систем организма спортсменов-мужчин в период интенсивных тренировок на учебно-тренировочных сборах в условиях среднегорья.

Материалы и методы. В исследовании приняли участие 47 спортсменов-мужчин высокой квалификации, разделенных на основную группу (ОГ) — 27 чел., медианный возраст 21 [18; 24] год, контрольную группу (КГ) — 20 чел. медианный возраст 20 [18,5; 22,5] лет. Сеанс нейробиоуправления по бета-ритму головного мозга включал графическую (10 мин) и игровую (16 мин) сессии, курс состоял из 8–10 сеансов. Перед первым и после последнего проводили регистрацию физиологических параметров сердечно-

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сосудистой, дыхательной и нервной систем и психофизиологическое тестирование. Статистическая обработка данных выполнена с помощью компьютерной программы Statistica 13.0.

Результаты. Сравнение параметров функций организма спортсменов-мужчин до и после курса нейробиоуправления показало снижение физиологического напряжения по данным вариабельности сердечного ритма, гемодинамики, показателей дыхания и кожно-гальванической реакции. Одновременно с этим отмечено повышение показателей психической работоспособности и бета-ритма головного мозга по отношению к контролю.

Выводы. Установлено положительное влияние применения курса нейробиоуправления по бета-ритму головного мозга у спортсменов-мужчин, проявляющееся в улучшении работы центральной и вегетативной нервной систем, повышении экономизации сердечной деятельности и оптимизации цикла дыхания. Полученные результаты открывают перспективы достижения спортсменами более высокой работоспособности за счет снижения физиологического напряжения и, как следствие, процессов утомления в условиях напряженной деятельности.

Ключевые слова: спортсмены; нейробиоуправление; функциональные возможности; ритмы головного мозга; нервная система; сердечно-сосудистая система

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Соблюдение принципов этики: исследование одобрено локальным этическим комитетом по экспертизе биомедицинских исследований Северо-Кавказского федерального научно-клинического центра Федерального медико-биологического агентства (протокол № 1 от 14.01.2025). Все участники подписали добровольное информированное согласие на участие в исследовании.

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INTRODUCTION

Neurofeedback is a form of biofeedback that targets electroencephalographic (EEG) parameters and is effectively applied in many fields of medicine [1–3] and sports [4–7]. The prospects for using neurofeedback training to target brain rhythms in rehabilitation and sports medicine stem from its non-invasive and non-pharmacological influence on a person, inducing changes in the functional state through controlled parameters and body functions. A number of researchers have studied the influence of alpha-rhythm neurofeedback on the human body, including athletes [3–5, 7].

Beta-rhythm neurofeedback has been applied quite successfully to psychophysiological conditions such as autism and attention deficit hyperactivity disorder [8, 9]. Given the need for athletes to manage their state and function effectively under conditions of high mental stress, this method could hold significant promise. However, research on the effect of beta-rhythm neurofeedback in sports science and practice is very limited [6]; specifically, a comprehensive approach to studying its influence on the state of body systems is insufficiently described. Therefore, in order to enhance the functional capabilities and recovery of athletes, it is relevant to find empirical and scientific validation for the use of beta-rhythm neurofeedback within the system of biomedical support for high-performance sports.

The study aims to examine the effect of beta-rhythm neurofeedback training on the functional state of body systems in male athletes during intensive training camps conducted in the mid-mountains.

MATERIALS AND METHODS

The study was conducted at the Rehabilitation and Recovery Center for athletes of Russian national teams (Yug Sport, Kislovodsk) at an altitude of 1240 m above sea level. It involved 47 highly qualified male athletes (Candidate Masters of Sports, Masters of Sports, and International Masters of Sports). The athletes were divided into a main group (MG) of 27 individuals (median age: 21 [18; 24] years) and a control group (CG) of 20 individuals (median age: 20 [18.5; 22.5] years). In both observation groups, athletes engaged in various sports (archery, figure skating, badminton, freestyle wrestling, sumo, powerlifting, orienteering (ski disciplines), judo, and freestyle skiing) were represented proportionally. The inclusion criteria were as follows: highly qualified athletes undergoing high training loads. The study excluded athletes who refused to participate in the study or had acute illnesses and injuries.

The MG athletes completed a course of neurofeedback training — biofeedback training targeting beta rhythms — during the training camp period. The CG athletes followed the training plan adopted by the camp, which did not include this neurofeedback course. The study was conducted during the preparatory training period, during which athletes typically had two intensive training sessions daily. All studies began on the 2nd and 3rd day of the training camp, which lasted 14–15 days. The studies were conducted in the first half of the day (before training sessions), while neurofeedback sessions took place in the morning and afternoon in the athletes' free time.

Beta-rhythm neurofeedback was implemented using a multi-channel BI-012-2 device with “Boslab” software (COMSIB, Novosibirsk). This setup enables simultaneous monitoring and recording of an electroencephalogram (EEG, CZ-FZ bipolar electrode montage; reference electrode placed on the earlobe as per the international 10–20% electrode placement system), a forehead muscle electromyogram (EMG, active electrode placement: frontal belly of the occipitofrontalis muscle, with a 3–4 cm distance between electrode centers and with the reference electrode placed between the active ones), electrocardiogram (ECG, active electrode placement: supraclavicular fossae, with the reference electrode placed on the trapezius muscle), a photoplethysmogram (PPG, sensor placement on the distal phalanx of the 2nd finger of the dominant hand), and respiration (sensor placement: xiphoid process). The methodology is aimed at increasing activity in the beta range.

A beta-rhythm neurofeedback session included a graphic session (10 min, auditory feedback) and a game session (16 min, visual feedback); the course consisted of 8–10 sessions. Beta training effectiveness was calculated by the software based on the dynamics of the average amplitudes of beta and theta rhythms during monitoring before and after each training session. Training was considered effective upon achieving a beta-rhythm increase and a theta-rhythm decrease. Before the first and after the last neurofeedback session, physiological signals were recorded, and psychophysiological testing was performed (using the “Sports Psychophysiologicalist” hardware and software system (NMC Analyst, Omsk)). This assessed the properties of the nervous system based on the individual unit of time (IUT), mental performance using the Schulte test, and personal and situational anxiety using the Spielberger–Khanin questionnaire [12].

Statistical data processing was performed using Statistica 13.0 software. Standard descriptive statistics were calculated: median (*Me*); upper [Q1] and lower [Q3] quartiles. These indicators were compared using non-parametric tests: the Wilcoxon test (to analyze the dynamics of data in two dependent groups) and the Mann–Whitney *U*-test (to assess differences between two independent groups).

RESULTS

The conducted study revealed no statistically significant differences in the parameters of psychophysiological status, heart rate variability (HRV), and brain rhythms in the MG and CG athletes prior to the course of beta-rhythm neurofeedback. The baseline parameters of the nervous and cardiovascular systems were within physiological norms.

A comparison of data on the psychophysiological status of MG athletes before and after the biofeedback training course yielded low levels of situational anxiety (prior to training: 28 [25; 32] points; after training:

28 [23; 31] points) and personal anxiety (prior to training: 29 [26; 31] points; after training: 29 [25; 32] points), indicating no statistically significant changes. The CG athletes also exhibited no statistically significant changes in the levels of situational (prior to training: 33 [28; 37.5] points; after training: 30 [24; 36] points) and personal anxiety (prior to training: 31 [28; 33.5] points; after training: 29.5 [24.5; 37.5] points). The IUT was 0.92 [0.88; 0.96] a.u. in the MG and 0.92 [0.88; 0.97] conventional units in the CG, corresponding to the sanguine, balanced type of higher nervous activity. This is consistent with previously obtained and published data on the predominance of the sanguine temperament among highly qualified athletes [13].

An assessment of mental performance parameters, conducted in the MG before and after the biofeedback training course using the Schulte test, revealed a statistically significant ($p < 0.0001$) improvement in the cognitive performance efficiency (prior to training: 36.91 (30.02; 44.78) s; after training: 32.28 [27.17; 37.53] s (Fig. 1A)), cognitive activation (prior to training: 1.002 [0.903; 1.102] a.u.; after training: 0.904 [0.852; 0.936] a.u., $p < 0.004$ (Fig. 1B)), and mental stability (prior to training: 1.02 [0.925; 1.118] a.u.; after training: 0.95 [0.887; 1.035] a.u., $p < 0.05$). In the CG, no statistically significant changes were observed in the cognitive performance efficiency (Fig. 1A), cognitive activation (Fig. 1B), and stability.

In addition, cognitive activation was statistically significantly lower (better) in the MG (0.904 [0.852; 0.936] a.u.) after the training course as compared to the CG (1.01 [0.853; 1.115] a.u.), whereas before the training no statistically significant differences were observed (Fig. 1B).

An analysis of time-domain HRV parameters in the MG athletes before and after the beta-rhythm neurofeedback training course (Table 1) revealed a statistically significant decrease in heart rate (HR) ($p < 0.04$), as well as in the number of successive RR intervals differing by over 20 ms ($pNN20$) ($p < 0.05$) and by over 10 ms ($pNN10$) ($p < 0.05$). The CG athletes exhibited a statistically significant decrease in the HR and stress index (SI) ($p < 0.02$). Also, after the training course, the MG athletes showed an upward trend in the average duration of RR intervals, the standard deviation of RR intervals (SDNN), the mode (Mo), and the autonomic index (AI), as well as a downward trend in the stress index (SI), as compared to baseline data.

The frequency-domain analysis of HRV in athletes who completed the training course (MG) indicates a statistically significant increase in the power of very low frequency (VLF) waves (before: 490.25 [207.26; 1115.16] ms^2 ; after: 890.23 [309.16; 1957.22] ms^2 , $p < 0.04$) (Fig. 2A) and an increase in the VLF power as a percentage of the total spectral power (%VLF) (before: 31.74 [15.12; 42.18]%; after: 40.23 [28.85; 53.63]%, $p < 0.01$) (Fig. 2B). In the CG, no statistically significant changes in these parameters were found. By the end of

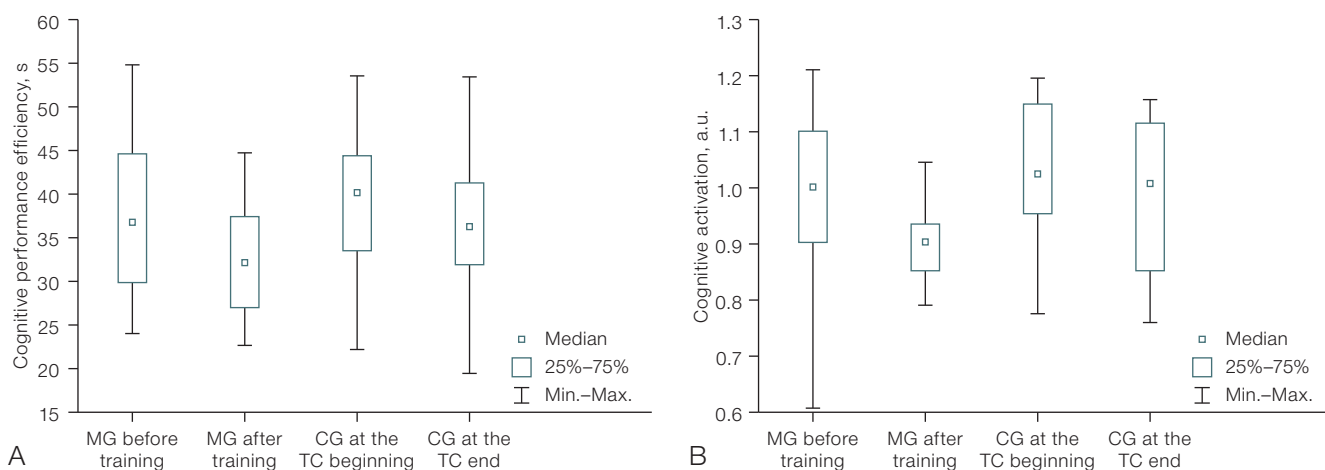


Figure prepared by the authors based on their own data

Fig. 1. Cognitive performance efficiency (A) and cognitive activation (B) of male athletes in the main and control groups before and after the course of beta-rhythm neurofeedback training: MG — main group; CG — control group; TC — training camp

Table 1. Time-domain parameters of heart rate variability in the main and control groups before and after the course of beta-rhythm neurofeedback training (monitoring phase)

Parameters	MG (n = 27)		CG (n = 20)	
	Before training	After training	At the TC beginning	At the TC end
RR, ms	764.26 [663.91; 825.18]	792.21 [747.25; 881.17]	724.03 [662.14; 862.36]	823.32 [763.6; 887.09]
SDNN, ms	44.78 [28.46; 65.64]	50.43 [44.43; 73.8]	49.87 [33.18; 67.69]	57.67 [48.53; 83.17]
Mode, ms	775 [675; 825]	825 [725; 875]	725 [675; 875]	800 [750; 875]
HR, bpm	83.01 [73.15; 91.07]	75.59 [68.38; 80.58]*	83.23 [70.15; 90.83]	73.3 [68.01; 78.8]♦
SI, a.u.	61.94 [26.58; 120.14]	51.42 [29.12; 96.07]	55.27 [34.19; 128.22]	44.71 [23.18; 76.09]♦
AI, %	6.42 [4.73; 10.43]	7.63 [5.38; 9.07]	6.84 [4.94; 10.5]	7.79 [6.21; 9.96]
LF/HF, a.u.	2.08 [0.78; 2.85]	1.76 [1.14; 2.98]	1.7 [0.59; 3.28]	1.79 [0.69; 3.39]
pNN50, %	10.47 [0.8; 36.84]	10.48 [3.31; 30.41]	13.56 [2.12; 42.44]	15.29 [4.75; 35.86]
pNN20, %	45.07 [11.07; 62.21]	47.04 [35.88; 64.23]*	39.91 [24.34; 76.34]	54.37 [36.22; 69.52]
pNN10, %	70.32 [42.19; 82.07]	71.37 [67.13; 82.51]*	68.43 [54.95; 88.25]	76.19 [66.2; 84.07]

Table compiled by the authors based on their own data

Note: Data are presented as median and interquartile range *Me* [Q1; Q3]; RR — mean RR interval length; SDNN — standard deviation of RR intervals; MG — main group; CG — control group; Mode (Mo) — the most frequently occurring value of RR interval duration; HR — heart rate; SI — stress index of regulatory systems; AI — autonomic index; LF/HF — ratio of low-frequency to high-frequency power in the heart rate variability spectrum; pNN50 — number of successive RR intervals differing by > 50 ms; pNN20 — number of successive RR intervals differing by > 20 ms; pNN10 — number of successive RR intervals differing by > 10 ms, TC — training camp; * — $p < 0.05$, ♦ — $p < 0.02$ — according to the Wilcoxon test; a.u. — arbitrary units; bpm — beats per minute.

the training camp, the amplitude of the mode (AMo) — the proportion of RR intervals falling within the modal range relative to all intervals — decreased both in the MG (before: 44.37 [30.26; 57.59]%; after: 40.03 [28.35; 48.6]%) and CG (before: 45.17 [30.67; 57.63]%; after: 35.69 [29.61; 44.86]%).

Brain rhythm parameters, specifically the beta rhythm, in the MG before and after the neurofeedback course and in the CG (Table 2) revealed statistically significantly higher beta rhythm amplitudes ($p < 0.05$) and lower values of the theta rhythm index ($p < 0.05$) in the MG athletes at the end of the training camp as

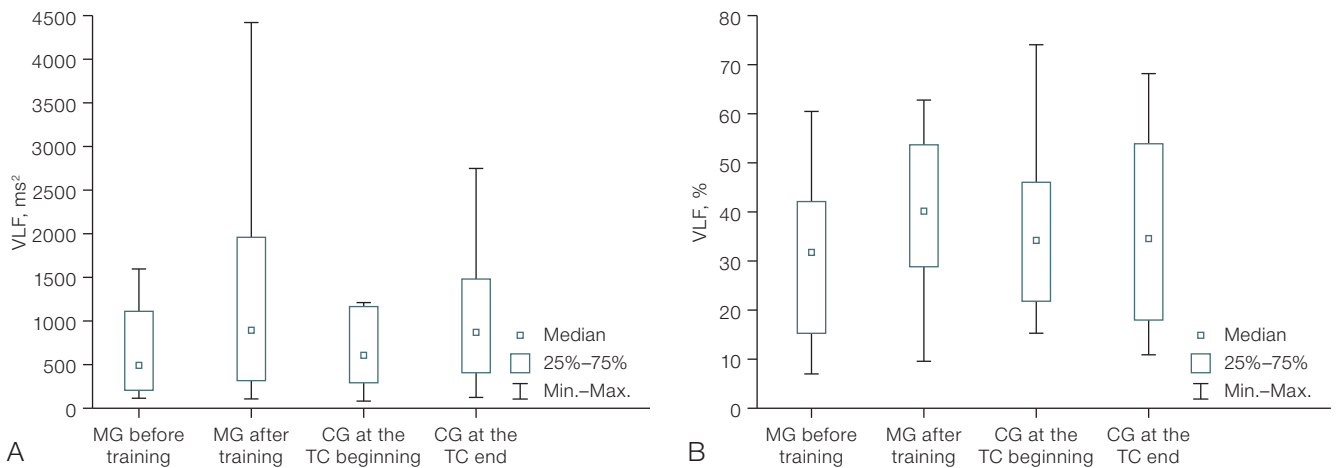


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Fig. 2. Indicators of the power of very slow (very low frequency, VLF) waves (A) and the percentage of very slow waves (B) in the main and control groups before and after the course of beta-rhythm neurofeedback training: MG — main group; CG — control group; TC — training camp

Table 2. Brain rhythm parameters in the main group (before and after the neurofeedback course) and the control group based on the beta activity (monitoring phase), *Me* [Q1; Q3]

Parameters	Main group [n = 27]		Control group [n = 20]	
	Before	After	TC beginning	TC ending
Alpha rhythm amplitude, μV	2.16 [2; 2.83]	2.22 [1.74; 2.86]	1.89 [1.58; 2.5]	1.91 [1.57; 2.15]
Beta rhythm amplitude, μV	1.52 [1.32; 1.8]	1.64 [1.25; 1.8]*	1.49 [1.18; 1.6]	1.33 [1.2; 1.63]*
Theta rhythm amplitude, μV	2.56 [2.24; 3]	2.57 [2.18; 3.03]	2.38 [2.03; 3.11]	2.51 [2; 2.72]
Theta/Beta ratio, a.u.	1.73 [1.5; 2.08]	1.75 [1.53; 2.2]	1.89 [1.63; 2.27]	1.89 [1.7; 2.11]
Alpha rhythm index, %	35.49 [30.69; 38.9]	34.67 [29.95; 37.08]	31.17 [29.29; 36.96]	32.27 [30.38; 34.24]
Beta rhythm index, %	24.37 [22.14; 26.85]	23.95 [21.8; 27.18]	23.87 [22.14; 26.8]	24.39 [21.91; 26.29]
Theta rhythm index, %	38.98 [36.19; 44.91]	40.88 [36.5; 45.6]*	43.32 [38.93; 47.85]	43.52 [41.13; 48.07]*

Table compiled by the authors based on their own data

Note: Data are presented as median (*Me*) and interquartile range [Q1; Q3]; index — the proportion of rhythm power relative to the power of other rhythms; TC — training camp; * — $p < 0.05$ — significant differences between the main group after the neurofeedback course and the control group at the end of the training camp according to the Mann–Whitney *U*-test.

compared to the CG. After the training, the MG athletes exhibited an upward trend in the amplitude of alpha and beta brain rhythms, while in the CG, the amplitude of the beta brain rhythm decreased. The brain rhythm analysis performed during the first and last (mostly the eighth) biofeedback training sessions showed no statistically significant changes in EEG rhythm parameters.

An analysis of respiratory parameters in the MG and CG before and after the beta-rhythm neurofeedback course indicates only one statistically significant change in the MG: the ratio of inhalation to exhalation duration (before: 0.716 [0.674; 0.777] a.u.; after: 0.753 [0.692; 0.831] a.u., $p < 0.05$). Conversely, the CG athletes exhibit no statistically significant changes. Also, the MG showed an upward trend in the duration of the respiratory cycle (before: 3.52 [3; 4.18] s; after: 3.65 [3.18;

4.1] s) and exhalation (before: 2.06 [1.71; 2.63] s; after: 2.12 [1.85; 2.61] s).

The indicators of general psychophysiological strain in the MG after the neurofeedback course and in the CG revealed no statistically significant changes. However, the MG athletes exhibited a non-significant downward trend in the amplitude of total bioelectrical activity in the forehead muscles (before: 7.39 [5.45; 8.48] μV ; after: 6.23 [5.52; 7.84] μV), skin conductance level (before: 4.16 [2.21; 6.34] μS ; after: 2.73 [2.06; 6.54] μS), and skin conductance amplitude (before: 0.259 [0.13; 0.369] μS ; after: 0.199 [0.111; 0.346] μS). This indicates a reduction in general psychophysiological strain.

Both before and after the beta-rhythm neurofeedback course, the central hemodynamic parameters in the MG were within the physiological norm; however,

their analysis based on photoplethysmography data showed a statistically significant increase in the systolic wave amplitude on the photoplethysmogram after the course (before: 889.64 [601.31; 1359.57] mV; after: 1012.98 [759.76; 1413.33] mV, $p < 0.04$). Also, the MG athletes exhibited a downward trend in the indicator of the adequacy of regulation processes (IARP) (before: 60.92 [38.06; 78.3] a.u.; after: 47.37 [33.98; 67.59] a.u.). No changes in these parameters were found in the CG.

DISCUSSION

In many sports, training effectiveness significantly depends on the athlete's ability to concentrate under conditions of high emotional stress. A large number of works are available on the implementation of alpha-stimulating neurofeedback into the training process [4, 5, 7, 12–16]. Published research indicates that alpha-rhythm neurotraining contributes to a more stable psycho-emotional state under competitive conditions by reducing pre-start tension [17]. The influence of alpha-range neurofeedback on HRV parameters, hemodynamics, and maximal oxygen consumption during exercise testing is reported in athletes [5]. The positive effect of neurotraining on the emotional state and psychophysiological functions of e-sports athletes is noted [18]. Portuguese scientists show that a repeated course of alpha-rhythm neurofeedback can improve cognitive abilities in athletes [7]. However, these studies examine the application of neurofeedback targeting only alpha rhythms.

The present study examines the effect of neurofeedback training targeting beta rhythms, which are associated with higher cognitive processes and concentration; excessive beta rhythm activity signals physiological strain and anxiety. Since sports activities involve high physical and psycho-emotional stress, the sessions were aimed at reducing the strain on the body's physiological systems (increased efficiency; achievement of

optimal functioning) while simultaneously increasing the beta rhythm amplitude, thus ensuring high brain activity. The course of beta-rhythm neurofeedback was shown to decrease centralization and increase parasympathetic influences, with a predominance of mostly autonomic heart rate regulation. All this confirms achieving the planned state, i.e., increased efficiency of the cardiovascular system in athletes. Other physiological parameters indicated a strain decrease as well: forehead muscle EMG, GSR, and respiration. The athletes also showed an increased level of mental performance, cognitive activation, and stability, which indicates improved concentration and other cognitive functions.

Data on brain rhythms in male athletes recorded during the first and last biofeedback training sessions revealed no changes. Apparently, the functional state of body systems in male athletes is more sensitive to biofeedback training than the amplitude characteristics of EEG rhythms, which are more stable when solving tasks aimed at concentration.

The obtained results open up prospects for athletes to achieve higher performance by reducing physiological strain and, consequently, fatigue during intensive training and competitive activities.

CONCLUSION

The conducted study established a positive effect of completing a beta-rhythm neurofeedback training course in male athletes. This effect manifested as improved function of the central nervous system (cognitive performance efficiency, cognitive activation, mental stability, and amplitude of alpha and beta brain rhythms) and the autonomic nervous system (decreased centralization, enhanced parasympathetic influences, and predominance of autonomic heart rate regulation). Positive shifts were also noted in autonomic systems: more efficient cardiac activity (decreased heart rate), lengthened respiratory cycle, and prolonged exhalation.

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