Pharmacophore

ISSN-2229-5402

Journal home page: http://www.pharmacophorejournal.com

THE EFFECT OF LOW-INTENSITY ELECTROMAGNETIC RADIATION OF EXTREMELY HIGH FREQUENCY ON HEART RATE VARIABILITY

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ARTICLE INFO

Received:
06 March 2024
Received in revised form:
14 June 2024
Accepted:
14 June 2024
Available online:
20 June 2024

Keywords: Heart rate, Electromagnetic radiation, Extremely high frequency, Sympathoadrenal system, Physical activity

ABSTRACT

Due to its high biological efficiency, extremely high-frequency electromagnetic radiation is used in medical practice to treat a wide range of diseases, including the cardiovascular system. The purpose of this work was to study the indicators of heart rate variability during the recovery period after a bicycle ergometric test under the conditions of preventive exposure to low-intensity electromagnetic radiation of extremely high frequency. The study involved 120 young girls in the intermenstrual period. The girls in the experimental group were exposed to 30 minutes of low-intensity electromagnetic radiation of extremely high frequency for 10 days. Then all the subjects took part in bicycle ergometric training. In the experimental group, a decrease in the stress index by 36%, and an increase in the power of the spectrum by 64% was noted, which indicates the activation of the parasympathetic division of the vegetative-vascular nervous system and normalization of vegetative effects on the heart. In the experimental group, compared with the control group, there was a less pronounced change in the considered parameters of cardiac activity.

To Cite This Article: Tanasov EI, Polunina ER, Shapovalov VD, Revin DV, Mikhaelyan DA, Mikhaelyan EA, et al. The Effect of Low-Intensity Electromagnetic Radiation of Extremely High Frequency on Heart Rate Variability. Pharmacophore. 2024;15(4):39-45. https://doi.org/10.51847/Whuu5OqduM

Introduction

Currently, one of the most relevant scientific directions in biology and medicine is the study of modern environmentally friendly and economical technologies using physical factors. A special role in this direction is played by low-intensity electromagnetic radiation (EMR) of the extremely high frequency (EHF) or millimeter range [1-3]. Due to its high biological efficacy, the EMR of EHF is used in medical practice to treat a wide range of diseases, including the cardiovascular system (CVS) [4]. In particular, over the past years, extensive experience has been accumulated in the use of millimeter radiation for the treatment of stable and unstable angina pectoris, coronary heart disease, hypertension, and myocardial infarction [5, 6]. Nevertheless, there is a lack of objective criteria for evaluating the adequacy and effectiveness of the therapy in terms of the functional state of the entire cardiovascular system and the interaction of its departments with each other. It is known that CVS is a highly sensitive indicator of the adaptive reactions of the entire human body to the effects of factors of different nature and intensity [7]. It is possible to judge the degree of tension of the CVS regulatory mechanisms using various methods, but the simplest and most accessible of them is the mathematical analysis of heart rate variability (HRV), which reflects the reaction of the whole organism in response to any influence of external and internal environmental factors [8]. To increase the effectiveness of this diagnosis, various methods are used to determine the homeostatic capabilities of the body. One of the

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most effective methods in this direction is conducting physical tests, in particular bicycle ergometrics with submaximal and maximum loads [9].

The bicycle ergometric test is the ideal and most physiological type of exposure, allowing to evaluation of the compensatory and adaptive reactions of the body. It has several advantages over other stress tests: the adequacy and accurate dosage of the workload of the subject; and the ability to simulate the state of physical stress and stress [10, 11]. In this regard, the study of HRV using the bicycle ergometric method well reflects the degree of tension of the body's regulatory systems due to the activation of the sympathoadrenal system (SAS) that occurs in response to any stressful effect [12-14].

Thus, the purpose of this work was to study the indicators of heart rate variability during the recovery period after bicycle ergometric exercise under the conditions of preventive exposure to low-intensity EMR of EHF.

Materials and Methods

The study involved 120 conditionally healthy female students aged 18-23 years in the intermenstrual period. All the subjects gave their voluntary written consent to participate in the study.

A mathematical analysis of HRV was used as a method to assess the effect of EMR of EHF and physical activity on the body [15]. HRV was studied daily by recording an ECG signal in the first standard lead using a CARDIOVIT MS-2007 device (SCHILLER AG, Switzerland) supporting SEMA software.

The preliminary HRV recording revealed individual typological differences in the subjects, related, in particular, to the values of the stress index (SI), which reflects the activity of the autonomic nervous system. Subjects with average SI values ($50 \leq$ SI ≤ 200 units) are classified as normotonics, with high values (SI$\geq$200 units) as sympathotonics and low values (SI$\leq$50 units) as vagotonics [16, 17]. The experiment involved subjects with only average SI values, the number of which was 60% of the total number of volunteers. This selection allowed us to obtain the most homogeneous group.

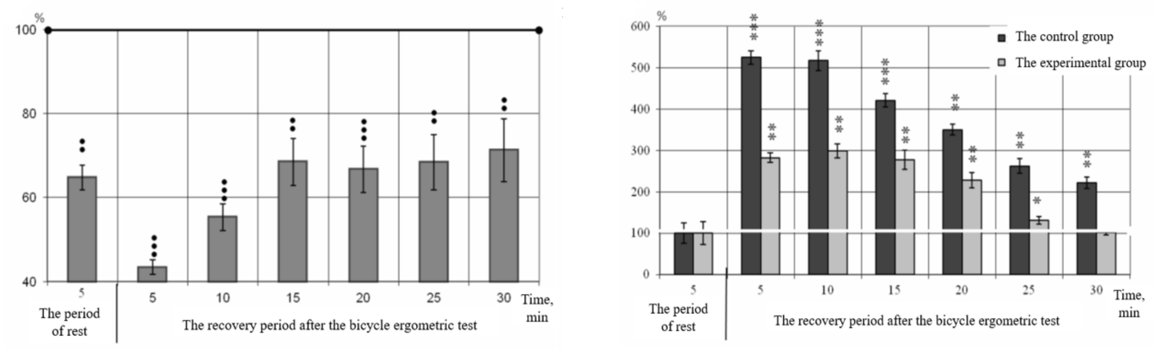
The subjects selected for the experiment were divided into two groups: control (n=31) and experimental (n=42). The subjects of the experimental group were previously exposed to low–intensity EMR of EHF, and the volunteers of the control group were placebo-exposed (without switching on the EHF generator to the network).

Exposure to EMR of EHF was carried out for 10 days, daily, in the morning. Technical characteristics: wavelength 7.1 mm, radiation frequency 42.4 GHz, power flux density – 0.1 MW/cm2. The effect was carried out for 30 minutes on the areas of biologically active points: GI-15 of the right shoulder joint, symmetrical E-34, RP-6, and GI-4. The choice of these points is due to their reflexogenic restorative and stimulating effect on the body [18, 19].

Bicycle ergometric training was performed on the 11th day of the experiment, on an exercise bike Yamaguchi Fitness Bike (Yamaguchi, Russia) according to the method of stepwise continuously increasing loads. The study began with a minimum load of 75 watts, and later, with continuous operation, the load was consistently increased to 100 and 125 watts at each stage, respectively. The duration of the test was 9 minutes – 3 minutes at each stage. During the test, the power rate (pedal speed) of the load performed was 40-50 rpm. The main criterion of the functional state was the heart rate, the increase of which should not exceed the calculated sumbaximal level of 170 beats/min for this age group [20]. HRV was recorded during a 10-day course of EHF therapy, as well as on the 11th day before and after bicycle ergometric training. Spectral methods of HRV analysis (HF - High Frequency, LF - Low Frequency, VLF – Very Low Frequency, TP - Total Power) and the integral exponent of the geometric method – SI [21] were used in the work. Statistical data processing was carried out using the Statistics 6.0 software package. The reliability of the differences in the obtained data was determined using the Mann-Whitney and Wilcoxon criteria.

Results and Discussion

As the results of the study showed, the subjects of the control group, during the 10 days of the experiment, there were no significant changes in the studied parameters. At the same time, significant changes in all the considered indicators were revealed in the experimental group of subjects. So, on the 10th day of observation, the SI values in the subjects of the experimental group decreased by 36% ($p \leq 0.01$) relative to the values of this indicator in the subjects of the control group **(Figure 1a)**. As a result of the spectral analysis of HRV on the 10th day of the experiment, a significant ($p \leq 0.05$) increase in the values of HF by 217%, LF -30%, and TP - 64% was revealed **(Figure 2a)**. The VLF changes were not reliable.



a) b)

Figure 1. Dynamics of the intensity index values during the recovery period after the bicycle ergometric test in subjects on the 11th day of the experiment: a) the experimental group in relation to the values in the control group of subjects, taken as 100%; b) the control and experimental groups in relation to the values of this indicator during the rest period, taken as 100%.

Note: confidence in relation to background values: * – (p≤0.05), ** – (p≤0.01), *** – (p≤0.001); in relation to control values: • – (p≤0.05), •• – (p≤0.01), ••• – (p≤0.001).

At the same time, there was a significant change in the coefficient of sympathovagal interaction (LF/HF), the values of which by the 10th day of the experiment amounted to 41% (p≤0.01) **(Figure 3a)** relative to the values in the control group of subjects. In addition, the values of this indicator approached one, which indicates the vegetative balance of the body and the greatest autonomy of heart rate regulation (HR) in the subjects of this group.

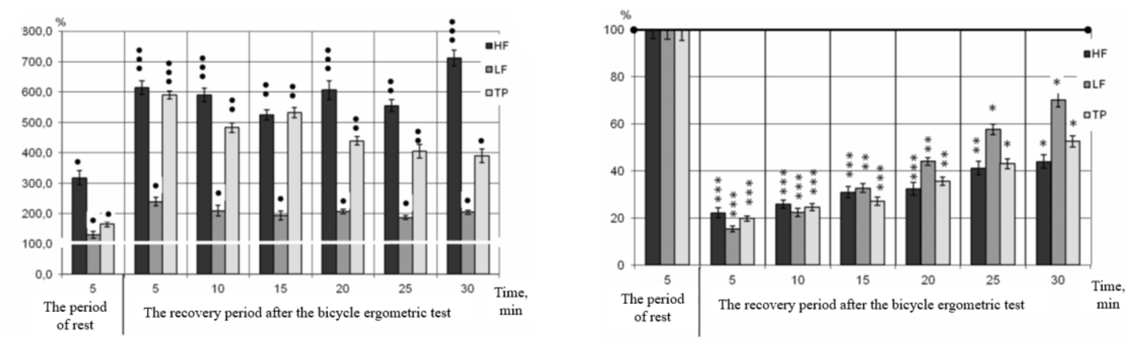
Thus, under the influence of 10-day exposure to EMR of EHF, the subjects of the experimental group showed a decrease in the voltage of the regulatory systems of the body and an increase in the activity of the autonomous HR regulation circuit. At the same time, there was a redistribution of tone between the sympathetic and parasympathetic departments of the autonomic nervous system (ANS), which eventually led to the normalization and stabilization of the regulation processes [22, 23].

Conducting a bicycle ergometric test led to a significant change in the values of all the considered indicators in the subjects of both groups. Thus, in the subjects of the control group, by the 5th minute of the recovery period, the SI values were 524% (p≤0.001) relative to the initial values **(Figure 1b)**.

Over the next 30 minutes, there was a gradual decrease in this indicator, however, by the end of the recovery period, its values exceeded the initial ones by 121% (p≤ 0.01).

It is known that SI reflects the level of tension of the body's regulatory systems [24]. An increase in SI by more than 4 times by the 5th minute of the recovery period after the bicycle ergometric test and the preservation of high values by 30 minutes indicates a high level of tension in the body's regulatory systems and low efficiency of recovery processes. This may be caused by the development of a stress reaction to physical activity in the subjects of this group. The data obtained are confirmed by the analysis of the spectral characteristics of HRV. So, by the 5th minute of the recovery period, the values of HF, LF, and TR indicators were 22.1%, 15.2%, and 19.7% (p≤0.001), respectively, relative to background values **(Figure 2b)**. Over the next 30 minutes, there was a gradual increase in the values of these indicators, and by the end of the recovery period they amounted to 43.9%, 70%, and 52.6% (p ≤0.05), respectively, relative to the initial values, that is, they did not reach the initial level.

Currently, it is considered established that the HF component of the spectrum reflects vagal heart rate control, whereas the LF component characterizes the state of the sympathetic department of the ANS [25] and, in particular, the vascular tone regulation system. In turn, TP reflects the total activity of vegetative influences on HR. Vagal activation is usually accompanied by an increase in TP, while with an increase in the activity of the sympathetic part of the ANS, the values of this indicator decrease [26].



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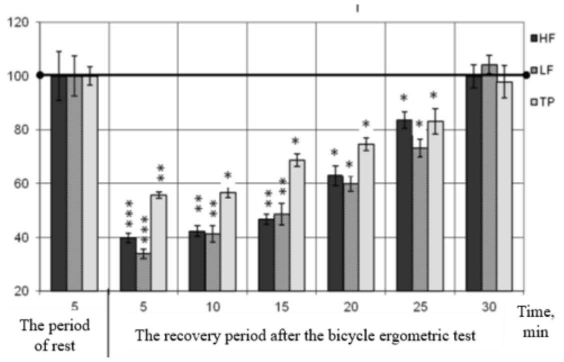


c)

Figure 2. Dynamics of spectral analysis values during the recovery period in the subjects: a) the experimental group in relation to the values of these indicators in the control group of subjects, taken as 100%; b) the control group in relation to the values of these indicators during rest, taken as 100%; c) the experimental group in relation to the values of these indicators during rest, taken as 100%.

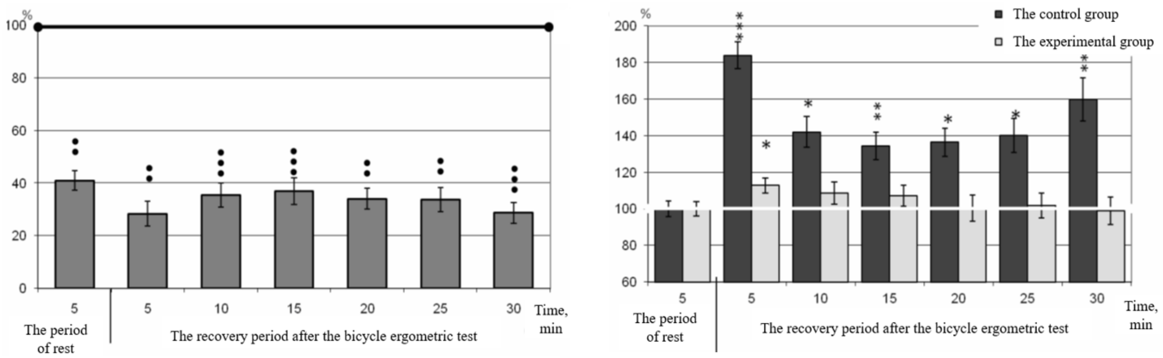
Note: confidence in relation to background values: * – (p≤0.05), ** – (p≤0.01), *** – (p≤0.001); in relation to control values: • – (p≤0.05), •• – (p≤0.01), ••• – (p≤0.001).

Thus, a significant decrease in spectral analysis in the subjects of the control group during the recovery period after the bicycle ergometric test indicates the predominance of the activity of the sympathetic regulation circuit over the parasympathetic, as well as an increase in the activity of the central heart rate regulation circuit in the subjects of the control group.

Conducting a bicycle ergometric test on volunteers of the control group also led to a significant change in the coefficient of sympathovagus interaction. So, by the 5th minute.

During the recovery period, the values of LF\HF increased by 84% relative to the background values (p≤0.001) **(Figure 3b)** and amounted to 4.4. During the next 30 minutes, there was a slight decrease in this indicator, but by the end of the recovery period, its values remained 60% higher than the initial level of this indicator.

It is known that this indicator reflects the relative activity of the sympathoadrenal system of the body [27, 28]. Consequently, a significant increase in the LF/HF value by 5 minutes, as well as the absence of its complete recovery by 30 minutes after the bicycle ergometric test, indicates a significant increase in SAS activity after physical exertion.



a) b)

Figure 3. Dynamics of the values of the sympathovagus balance coefficient during the recovery period after the bicycle ergometric test in the subjects: a) the experimental group in relation to the values in the control group of subjects, taken as 100%; b) the control and experimental groups in relation to the values of this indicator during rest, taken as 100%.

Note: confidence in relation to background values: * – (p≤0.05), ** – (p≤0.01), *** – (p≤0.001); in relation to control values: • – (p≤0.05), •• – (p≤0.01), ••• – (p≤0.001).

Thus, a significant increase in the activity of the central circuit of heart rate regulation, a decrease in the activity of vagal influences, and excessive activation of SAS (one of the main stress-implementing systems of the body) against the background of low efficiency of recovery mechanisms is a typical reaction of the body to stress.

Conducting a bicycle ergometric test in an experimental group of subjects led to less pronounced changes in the values of all the considered indicators.

Thus, the SI values by the 5th minute of the recovery period were 282% (p≤0.01) **(Figure 1b)** relative to the initial values, which is 57% (p≤0.001) less than in the subjects of the control group.

By the 30th minute of the recovery period, there was a complete restoration of the values of this indicator, as evidenced by the lack of reliability in relation to the initial values. Thus, the changes obtained indicate that as a result of preventive 10-fold EHF

exposure, there was a less pronounced increase in the voltage level of the regulatory systems of the body in the subjects after the bicycle ergometric test.
Less pronounced changes were also revealed during the analysis of the spectral characteristics of HRV. Thus, the values of HF, LF, and TP by the 5th minute of the recovery period were 39.6% ($p \le 0.001$), 33.8% ($p \le 0.001$), and 55.9% ($p \le 0.01$), respectively **(Figure 2c)**, relative to the initial values, while exceeding the values of these indicators in the control group by 514%, 74% and 490% ($p \le 0.05$), respectively **(Figure 2a)**. During the next 30 minutes of the recovery period, the values of these indicators were completely restored in relation to the values of these indicators to the bicycle ergometric test ($p \le 0.05$). Consequently, preventive course EHF exposure led to a less pronounced centralization of heart rate control in response to submaximal physical activity.
Repeated EHF exposure also led to the fact that the values of the LF/HF coefficient also underwent smaller changes under the influence of physical activity. Thus, by the 5th minute of the recovery period, the values of this indicator increased by 12% **(Figure 3b)** and amounted to 1.3. At the same time, the absence of significant differences with background values was observed by the 10th minute of the recovery period. These changes indicate a slight increase in SAS activity and a rapid restoration of the vegetative balance of the body in this group of subjects [29].
Thus, initially, the low level of tension of the regulatory systems of the body and the high activity of the autonomous circuit of regulation of the heart rate of the experimental group of subjects at rest achieved thanks to the preventive EHF effect, led to the fact that as a result of the bicycle ergometric test, there was no significant decrease in the activity of vegetative effects on the heart rate and excessive tension of the regulatory systems of the body in the experimental subjects groups. At the same time, a slight change in the balance between the individual components of the autonomic nervous system after a bicycle ergometric test and its rapid recovery to its original level indicates the absence of hyperactivity in the SAS organism [30].
At the same time, the conducted study complements the above data and indicates the stress-limiting effect of EMR of EHF on the behavior of submaximal physical activity in the experimental group of subjects.

Conclusion

Conducting a 10-fold EHF exposure led to a decrease in the intensity of regulatory systems (a decrease in SI by 36%; $p \le 0.01$), as well as an increase in the current power of the spectrum (by 64%; $p \le 0.01$), and the fact that the increase in the power of HF components (by 217%; $p \le 0.05$). This occurred to a much greater extent than the power of the LF component (by 30%; $p < 0.05$), indicating greater activation of the parasympathetic division of the ANS and normalization of vegetative effects on the heart.
Conducting a bicycle ergometric test in the control group of subjects led to a change in all the considered indicators (a decrease in HF by 78%, LF by 85%, TP by 81% ($p \le 0.01$) and an increase in LF/HF by 84% and IN by 424% ($p \le 0.001$)) by the 5th minute of the recovery period after a bicycle ergometric test, as well as the lack of their full recovery by 30 minutes, indicate the development of a stress reaction in response to submaximal physical activity.
After the bicycle ergometric test, the subjects who underwent 10-fold EHF exposure had a less pronounced change in all the parameters under consideration (decrease in HF by 61%, $p \le 0.001$; LF by 67%, $p \le 0.001$; TP by 45%, $p \le 0.01$; and an increase in LF/HF by 12%, $p \le 0.05$; and IN at 182%; $p \le 0.01$) at the 5th minute of the recovery period, the subjects of the experimental group also experienced less pronounced than in the control group, which indicates the absence of a stress reaction in the subjects of the experimental group, and their complete recovery by 30 minutes indicates a rapid restoration of vegetative balance.

Acknowledgments: None

Conflict of interest: None

Financial support: None

Ethics statement: The examinations were conducted following the standards of good clinical practice and the principles of the Helsinki Declaration of the World Medical Association (WMA Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects, 2013). The preliminary survey made it possible to exclude persons with somatic and acute infectious diseases from participating in the survey during the last month. All persons participating in the experiment gave their voluntary written consent to the experiment.

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