UDC 612.014.44+612.172.2 **A. V. Rybalko**

EFFECT OF DIFFERENT MODES OF OPHTHALMIC PHOTO-STIMULATION ON FUNCTIONAL STATE OF CARDIOVASCULAR SYSTEM

Introduction. *The implementation of visual sensory effects can significantly change the functional state of the cardiovascular system of a man mainly under the compensatory changes of his wave manifestations that may become a relevant way for preventive medicine in terms of cardiovascular disease growth.*

The ***purpose*** *of the research was to determine reactivity of the heart rate's wave structure indexes in different ophthalmic photo-stimulation modes.*

Methods. *The indicators of spectral analysis of heart rate (HR) and struck blood volume (SBV) oscillations were measured on 48 men at different modes of ophthalmic photo-stimulation.*

Results. *Ophthalmic photo-stimulation by light of different wavelengths, light intensity and signal frequency leads to the significant changes of wave structure of heart rate indicators and their synchronization. The indicator changes of cardiovascular system performance at vagotonic individuals are prognostically positive compared to eu- and sympathotonic ones.*

Originality.*The reactivity features of wave structure indicators of heart rate under different ophthalmic photo-stimulation modes were investigated for the first time.*

Conclusions. *Ophthalmic photo-stimulation by the light of different wavelengths, light intensity and signal frequency leads to the simultaneous activation of both parts of the autonomic nervous system. The initial level of vegetative balance affects the regulation features of the heart activity under impulse ophthalmic photo-stimulation.*

Keywords: *ophthalmic photo-stimulation, heart rate variability, spectral analysis.*

Formulation of the problem. Recent researches and publications' analysis. According to generally accepted concepts of physiological dynamics of the functional body state and regulatory processes tension degree one should evaluate by the indexes of the cardiovascular, central and autonomic nervous systems as sensitive adaptation indicators [1, 2]. Heart rate has long been a reliable indicator of variations in the system regulation of vital functions, and therefore the study of heart rate variability has important prognostic and diagnostic value for autonomic nervous system condition and the complete functional body state assessment [3, 4].

The growing number of cardiovascular pathologies, especially during youth, requires finding new methods for correcting the functional state of the human body and selecting options for influencing by different types of sensory stimulation, which action is basing on the mobilization of different adaptive and compensatory reserves available in the cardiovascular system and other body systems. Therefore, the optimization of CVS functioning by non-pharmacological light modulation of rhythmological body functions may be the actual way of improvement [5].

The physiological and therapeutic efficacy of ophthalmic photo-stimulation was verified by numerous researches. The influence of different wavelengths of light and its intensity on central nervous system, psycho-physiological body functions and electrical activity of the cerebral cortex has already been revealed, same as some aspects of impulsive light implementation in the diagnosis and treatment of visual analyzer's pathologies [6, 7, 8, 9]. The light impact on the neuro-humoral regulation of the cardiovascular system being studied recently [10, 11, 12]. However, today in the scientific literature some questions regarding the light of different wavelengths, intensity and signal frequency impact, including specially directed patterns to influence regulatory mechanisms of heart activity, remain unclarified.

The goal of the research was to determine reactivity of the heart rate's wave structure indexes in different ophthalmic photo-stimulation modes.

Materials and methods

The measurements were conducted on 98 people aged 17 to 27 years in compliance with main bioethical provisions of the European Convention on Human Rights and Biomedicine (of 04.04.1997), World Medical Association Declaration of Helsinki on ethical principles of scientific medical researches involving humans (1994-2008) and Ukrainian MOH order number 690 of 23.09.2009.

Ophthalmic stimulation was performed binocularly for 10 minutes with light of different wavelengths and intensity, with 5 minute intervals between sessions, using Lightmaker (c/c Ukraine №16134).

Impulsive ophthalmic stimulation was performed for 10 minutes binocularly with light green color of 400 lux intensity at a signal frequency of 8, 12 and 16 Hz (48 people). Impulse modulation were the stimulation by noise at a 8 to 16 Hz frequency and impacts of wavy light changes of 8 to 16 Hz 6 times per minute (t/m).

Signals were digitized via ADC ADC-1280 (Holit Data Systems, Kyiv, Ukraine), recorded on the hard drive; then critical points of the analyzed signals were determined using the Bioscan.

Spectral and cross-spectral analysis was carried out using method of periodograms with Daniel’s smoothing window and periodogram time parameters correction based on the average value of the heart rate in the Caspico program (c/c Ukraine №11262).

In this case, the following components of spectrum were distinguished [3, 4, 13]: 0,15-0,4 Hz (HF) - power in the range of high frequencies, 0,04-0,15 Hz (LF) - power in the range of low frequencies, 0-0,04 Hz (VLF) - power in the range of very low frequencies, 0-0,4 Hz (TP) - total power of the spectrum.

The normalized spectrum power index in the range 0,15-0,4 Hz (HFnorm) and a maximum cross-spectral fluctuations’ power of SBV and t-R-R in the range of 0,04-0,15 Hz were also evaluated.

To detect the wave structure of time series t-R-R, median periodgram construction by the earlier offered method was used [14]. Cross-spectral fluctuations’ power of t-R-R and SBV were measured by the method of cross-periodgrams [15].

The Student’s criterion of paired comparisons (for normal distribution) and Wilcoxon (for abnormal distribution) determined the differences’ probability.

Results and their Discussion

Under the light influence with wavelength of 500 nm and intensity of 400 lux, the spectrum power in the range of VLF- and LF-bands has significantly increased, while changes in case of stimulation by red light were not significant. For both conditions of photo-stimulation, a significant decrease of the spectral power in the high frequency band was been revealed in a time range of fifth-to-tenth minute’s illumination of 100 lux. However, in case of the further increase of the illumination level, no significant changes in a range of respiratory waves were observed.

TP reactivity (Fig. 1) increased authentically and unilaterally in both cases of stimulation at the illumination level of 400 lux, which indicates parasympathetic effects’ strengthening.

The spectrum's total power increasing was mainly a result of a possible increase of this index in the range of low frequencies (between 0.04 and 0.15 Hz), that may have been caused by two reasons in both cases of photo-stimulation: firstly, by sympathetic activity influences increasing, and, secondly, at this level of illumination spontaneous baro-reflex sensitivity increase may occur [16].

HFnorm probable decrease under the influence of red and green light with intensity of 400 lux indicates the strengthening of the sympathetic influences on HR regulation. Such changes of heart rate variability (HRV) described in the works of other researchers [17].

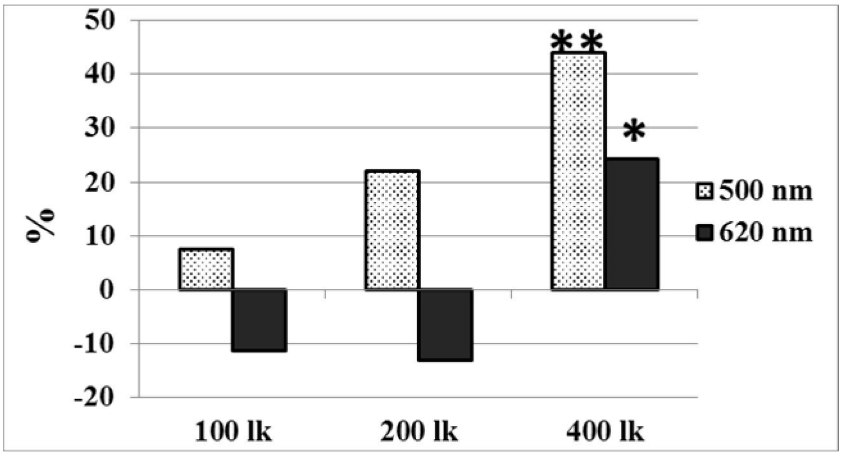

Fig. 1. Reactivity of total power variations in t-R-R interval under the influence of the monochrome light of different illumination level; * - p<0,05, **p<0,01

The analysis of HRV during impulsive photo-stimulation showed a significant increase of spectral power in the range of low and very low frequency in cases of signal frequency of 12 and 16 Hz, indicating activation of the central contour regulation CR (sympathetic vascular center of the medulla oblongata and energy metabolic centers) [4]. According to Haspekova N.B., activation of the suprasegmental cerebral systems disrupts the activity of the sympathetic baro-reflex mechanisms and significantly affects the overall heart rate variability that allows to assess autonomic tone as the tensed vegetative balance involving ergotropic systems [2].

No significant differences in the HF-band in conditions of the impulsive photo-stimulation were found. However, HFnorm significantly decreased at all frequencies of impulsive stimulation. At the same time, a more detailed analysis of HRV changes using median spectrograms in conditions of the impulsive photo-stimulation compared to the state of rest showed probable differences in the HF-range at a frequency of 0.26 (8 Hz) and 0.27 (16 Hz) ($p < 0.05$), which may indicate the growing influence of the vagus nerve in these conditions of rhythmic stimulation.

The analysis of HRV indexes reactivity (Fig. 2) showed that with the strengthening of impulsation frequency (8 Hz, 12 Hz, 16 Hz) the number of unidirectional reactions of VLF, LF, TR significantly increased. At the same time, reactivity of such indicators as LF and TP at a frequency of 12 Hz and 16 Hz differed significantly both in the frequency range of 8 Hz and with one another (12 Hz and 16 Hz).

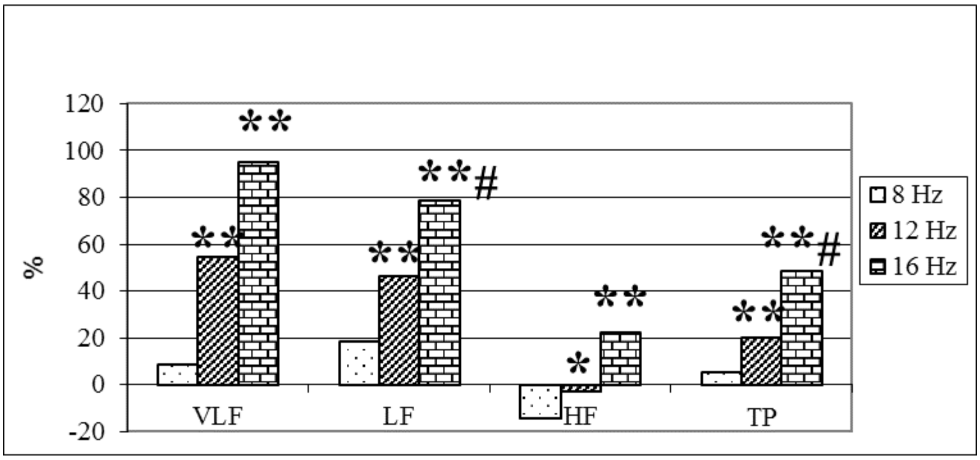

Fig. 2. Reactivity of the heart rate variability indicators in conditions of the impulsive photo-stimulation; * - p <0,05, ** p <0,01 compared to 8 Hz # - p <0.05 compared to 12 Hz

Considering that the functional possibilities level of the cardiovascular system determines the general features of the entire body in adapting processes, it can be assumed that people with different types of circulatory system will have differences in the range of adaptive responses to various experimental effects [18]. Participants of the examination were divided by baseline of HFnorm, which reflects parasympathetic activity of the medulla oblongata cardio-inhibitory center. Significant inter-group differences of the heart rate wave structure indicators were detected at the signal frequency of 12 and 16 Hz (Fig. 3).

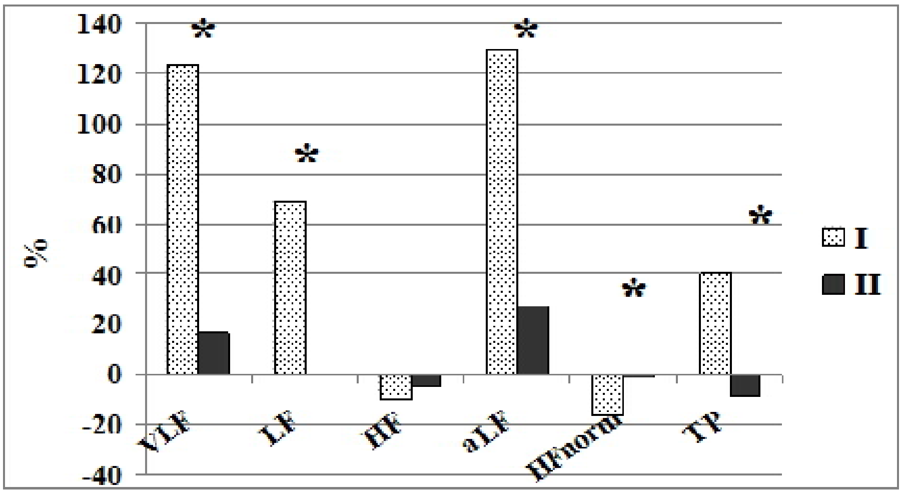

Fig. 3. Medians of the heart rate wave structure reactivity indexes in patients with different baseline of autonomic tone during ophthalmic photo-stimulation with a frequency of 12 Hz, I - vagotonics, II - and in eu- sympathotonic ones * - $p < 0.05$ among groups

In vagotonics during photo-stimulation significantly greater enhance of spontaneous baro-reflex sensitivity was observed than in eu- and sympathotonic ones. In accordance with the principle of physiological relevance, baro-reflex functioning lies in the ability for rapid response of the HR for blood pressure increase and its normalization. [19, 16]. The more changes of the HR will be delayed (or lower will be the amplitude) during shifts in blood pressure, the baro-reflex will be fulfilled less effectively. Therefore, increasing of spontaneous baro-reflex sensitivity in vagotonics during ophthalmic photo-stimulation serves to maintain a stable level of basic hemodynamic indexes, even with greater decreases in blood pressure in a signal frequency of 16 Hz, than in in eu- and sympathotonic ones. Received data regarding heart rate variability reactivity comply with the W. Wielder rule about the output values.

In order to reduce some negative effects of ophthalmic impulsive stimulation (sympathicotony, suprasegmental mechanisms of regulation activation) on the CVS functioning, we analyzed the changes of the HR wave structure at different impulsive patterns of photo-stimulation. In our opinion, expressed effects of specially organized rhythmic impacts can be caused by factors such as low bio-resonant interaction mechanisms of sensory stimuli with endogenous rhythmic processes of the body, which allows to extend the range of the functional body state modification possibilities by creating a new rhythmic patterns of sensory impacts.

A significant increase in the power spectrum of LF- and VLF-range in conditions of the II mode (6 times) compared to the state of Rest and I mode (noise) was discovered. A statistically significant increase in the power range of LF-range, which is also confirmed by a likely decrease of HFnorm in the mode of wave impacts 6 t/m can be explained by the synchronization of the wavy changes in ophthalmic stimulation at a frequency of 0.1 Hz with the Mayer waves that reflect the progress of baro-reflex [19, 16].

Table 1

Indexes of the heart rate's wave structure in conditions
of different ophthalmic photo-stimulation patterns

Indexes	Rest	Noise (8-16 Hz)	6 t/m (8-16 Hz)
VLF, ms^2	1735 [637; 2400]	1514 [1067; 2568]	$2730^{*\#}$ [1689; 3835]
LF, ms^2	1145 [614; 1909]	1204 [739; 1611]	$1647^{*\#\#\#}$ [1261; 2689]
HF, ms^2	1802 [900; 3439]	1623 [859; 2150]	2018 [1035; 4336]
HFnorm, %	58,70 [46,00; 69,58]	59,31 [40,19; 70,50]	51,88* [43,7; 61,73]
TP, ms^2	5196 [2469; 7608]	4318 [3131; 7184]	$5938^{**\#\#}$ [3960; 10917]

Note. ** - p <0.01, *** - p <0.001 compared to a background level, # - p <0,05, ## - p <0,01, ### - p <0,001 between I and II modes of ophthalmic photo-stimulation

A more detailed analysis of the heart rate’s wave structure in the range of 0,04-0,15 Hz using median spectrograms for different conditions revealed probable difference between the state of Rest and noise mode’s impacts at frequencies of 0.08 Hz, 0.11 Hz and Rest, and also light wave changes 6 times per minute at a frequency of 0.11 Hz, becides the higher level of baro-reflex waves’ amplitude at a frequency of 0.1 Hz was observed in the mode of light wave variations (Fig. 4), which confirmed the results of the cross-spectral analysis [15].

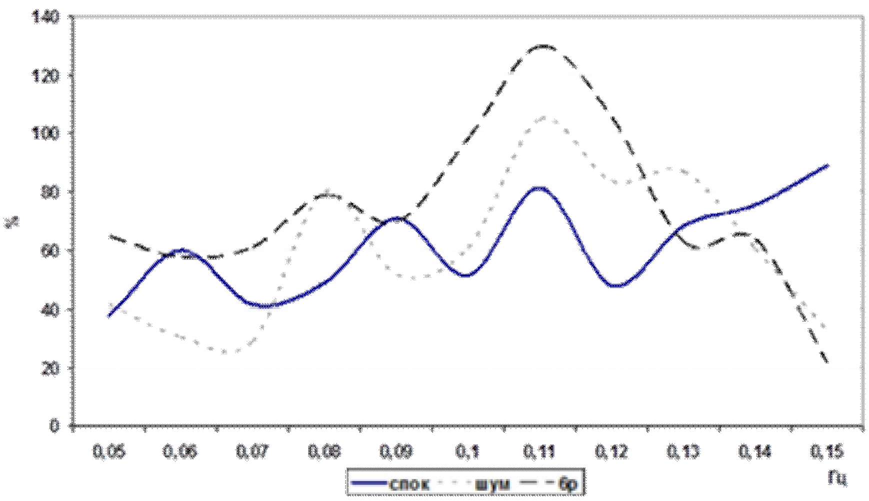

Fig. 4. Normalized t-R-R fluctuations of median spectrogram at various patterns during the ophthalmic photo-stimulation.

Conclusions

1. Ophthalmic stimulation with the monochrome light of 500 nm wavelength and illumination intensity of 400 lux results in significant improvements of the hemodynamic indexes’ wave structure and their synchronization.
2. During ophthalmic photo-stimulation at a frequency of 12 Hz and 16 Hz a the heart rate waves’ power increase of very low and low frequencies occured, which indicates the activation of the heart rate sympathetic modulation, strengthening of central and humoral-metabolic effects activity and regulatory mechanisms of the cardiovascular system tension.

3. It was revealed that the original level of vegetative balance influences the features of the heart activity regulation in conditions of impulsive ophthalmic photo-stimulation. The cardiovascular system's activity indicators' fluctuations are predictably positive in vagotonics compared to eu- and sympathotonic ones.
4. The increase in heart rate waves' amplitude in the range of 0,04-0,15 Hz during the ophthalmic stimulation by wave impacts of 6 t/m is caused by the increased baro-reflex spontaneous sensitivity due to resonance mechanism.

Література

1. Валькова Н. Ю. Количественная оценка вегетативной регуляции: методология, системное исследование влияния внешних и внутренних факторов: дис. … докт. биол. наук: 03.00.13 / Валькова Надежда Юрьевна. – Архангельск: НЮ, 2007.
2. Хаспекова Н. Б. Диагностическая информативность мониторирования вариабельности ритма сердца / Н. Б. Хаспекова // Вестник аритмологии. – 2003. – Т. 32. – С. 15.
3. Бабунц И. В. Азбука анализа вариабельности сердечного ритма / И. В. Бабунц, Э. М. Мириджанян, Ю. А. Машаех // Ставрополь: Принт-мастер, 2002. – 112 с.
4. Михайлов В. М. Вариабельность ритма сердца: опыт практического применения метода / В. М. Михайлов. – Иваново: Ивановская государственная медицинская академия, 2003. – 290 с.
5. Быков А. Т. Восстановительная медицина и экология человека: руководство / А. Т. Быков, Т. Н. Маляренко // М.: ГЭОТАР-Медиа. – 2009. – 688 с.
6. Гойденко В. С. Стимуляция светом. Краткий обзор литературы, патентов и авторских свидетельств на изобретения / В. С. Гойденко, Е. Е. Мейзеров., Г. А. Адашинская // М.: Медицина, 1998. – С. 7-22.
7. Готовский Ю. В. Цветовая светотерапия / Ю. В. Готовский, Л. Б. Косарева, Ю. Ф. Перов // – М.: Имедис, 2009. – 464 с.
8. Долина И. В. Интенсивная светотерапия / И. В. Долина // Военная медицина. – 2010. – №. 2. – С. 118-122.
9. Луговая А. М. Цветоимпульсная терапия / А. М. Луговая, В. В. Малахов, В. В. Чернышев // Результаты и перспективы. – 2005. – Т. 7. – С. 27-31.
10. Королёва М. А. Вариабельность сердечного ритма при воздействии интенсивного света в зависимости от индивидуальных особенностей организма человека / М. А. Королёва, И. М. Воронин, С. В. Шутова // Вестник Тамбовского университета. – 2008. – Т. 13. – С. 184-187.
11. Choi C. J. Reactivity of heart rate variability after exposure to colored lights in healthy adults with symptoms of anxiety and depression / C. J. Choi, K. S. Kim, C. M Kim // International Journal of Psychophysiology. – 2011. – Т.79, № 2. – P. 83-88.
12. Sakakibara S., Honma H., Kohsaka M. Autonomic nervous function after evening bright light therapy: spectral analysis of heart rate variability / S. Sakakibara, H. Honma, M. Kohsaka // Psychiatry Clin Neurosci. – 2001. – V. 54, № 3. – P. 363 - 364.
13. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart Rate Variability / Standards of Measurements, Physiological Interpretation, and Clinical Use // Circulation. - 1996. - V. 93. - P. 1043-1065.
14. Коваленко С. О. Аналіз варіабельності серцевого ритму за допомогою методу медіанної спектрограми / С. О. Коваленко // Фізіологічний журнал. – 2005 – Т.51, № 3. – С. 92-95.
15. Коваленко С. О. Крос-спектральний аналіз коливань ударного об'єму крові та тривалості інтервалу R-R у чоловіків в спокої та при різних навантаженнях // Фізіологічний журнал. – 2008. – Т. 54, № 1. – С. 79-84.
16. Cevese A. Baroreflex and oscillation of heart period at 0.1 Hz studied by α-blockade and cross-spectral analysis in healthy humans / A. Cevese, G. Gulli, E. Polati // The Journal of physiology. – 2001. – Т. 531, № 1. – С. 235-244.
17. Петров К. Б. Дифференцированное применение офтальмостимуляции для профилактики дезадаптивных расстройств у спортсменов / К. Б. Петров, С. Н. Коренева // Вопросы курортологии, физиотерапии и ЛФК. – 2010. – Т. 3. – С. 39-43.
18. Billman G. E. The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance / G. E. Billman // Frontiers in physiology. – 2013. – Т. 4. – С.26.
19. Merritt M.M., Sollers J.J., Evans M.K., Zonderman A.B., Thaver J.F. Relationships among spectral measures of baroreflex sensitivity and indices of cardiac vagal control // Biomed Sci Instrum. – 2003. – V.39. – P. 193-198.

References

1. Valkova, N. Yu. (2007). Kolychestvennaia otsenka vehetatyvnoi rehuliatsyy: metodolohyia, systemnoe yssledovanye vlyianyia vneshnykh y vnutrennykh faktorov. Sc d dis. Arkhanhelsk, 343 (in Rus.).

2. Khaspekova, N. B. (2003). Dyahnostycheskaia ynformatyvnost monytoryrovanyia varyabelnosty rytma serdtsa. *Vestnyk arytmolohyy (Gazette arrhythmology*), 32, 15 (in Rus.).
3. Babunts, Y. V. Myrydzhanian, E. M., Mashaekh, Yu. A. (2002). *Azbuka analyza varyabelnosty serdechnoho rytma*. Stavropol: Prynt-master 112 (in Rus.).
4. Mykhailov, V. M. (2003). *Varyabelnost rytma serdtsa: opyit praktycheskoho prymenenyia metoda.* Yvanovo: Yvanovskaia hosudarstvennaia medytsynskaia akademyia 290 (in Rus.).
5. Byikov, A. T. Maliarenko, T. N. (2009). *Vosstanovytelnaia medytsyna y ekolohyia cheloveka: rukovodstvo*. Moskva: HEOTAR - Medya 688 (in Rus.).
6. Hoidenko, V. S. Meizerov, E. E., Adashynskaia, H. A. (1998). *Stymuliatsyia svetom. Kratkyi obzor literaturyi, patentov y avtorskykh svydetelstv na yzobretenyia.* Moskva: Medytsyna 7-22 (in Rus.).
7. Hotovskyi, Yu. V., Kosareva, L. B., Perov, Yu. F. (2009). *Tsvetovaia svetoterapyia.* Moskva: Ymedys 464 (in Rus.).
8. Dolyna, Y. V. (2010). Yntensyvnaia svetoterapyia. *Voennaia medytsyna (Military medicine),* 2, 118-122 (in Rus.).
9. Luhovaia, A. M., Malakhov, V. V., Chernyishev V. V. (2005). Tsvetoympulsnaia terapyia. *Rezultatyi i perspektivy* (*Results and Prospects),* 7, 27-31 (in Rus.).
10. Korolyova, M. A., Voronyn, Y. M., Shutova, S. V. (2008). Varyabelnost serdechnoho rytma pry vozdeistvyy yntensyvnoho sveta v zavysymosty ot yndyvydualnыkh osobennostei orhanyzma cheloveka. *Vestnyk Tambovskoho unyversyteta* (*Vestnik Tambov University*), 13, 184-187 (in Rus.).
11. Choi, C. J., Kim, K. S., Kim C M. (2011). Reactivity of heart rate variability after exposure to colored lights in healthy adults with symptoms of anxiety and depression. *International Journal of Psychophysiology,* 79, 2, 83-88.
12. Sakakibara, S., Honma, H., Kohsaka, M. (2001). Autonomic nervous function after evening bright light therapy: spectral analysis of heart rate variability. *Psychiatry Clin Neurosci*, 54, 3, 363 - 364.
13. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart Rate Variability / Standards of Measurements, Physiological Interpretation, and Clinical Use. (1996). *Circulation*, 93,1043-1065.
14. Kovalenko, S. O. (2005). Analiz variabelnosti sertsevoho rytmu za dopomohoiu metodu mediannoi spektrohramy. *Fiziolohichnyi zhurnal* (*Physiological journal),* 51, 3, 92-95 (In Ukr.).
15. Kovalenko, S. O. (2008). Kros-spektralnyi analiz kolyvan udarnoho obiemu krovi ta tryvalosti intervalu R-R u cholovikiv v spokoi ta pry riznykh navantazhenniakh. *Fiziolohichnyi zhurnal* (*Physiological journal),* 54, 1, 79-84. (In Ukr.).
16. Cevese, A., Gulli, G., Polati, E. (2001). Baroreflex and oscillation of heart period at 0.1 Hz studied by α-blockade and cross-spectral analysis in healthy humans. *The Journal of physiology*. 531, 1, 235-244.
17. Petrov, K. B., Koreneva, S. N. (2010). Dyfferentsyrovannoe prymenenye oftalmostymuliatsyy dlia profylaktyky dezadaptyvnykh rasstroistv u sportsmenov. *Voprosy kurortolohyy, fyzyoterapyy y LFK. (Questions balneology, physiotherapy and exercise therapy),* 3, 39-43 (in Rus.).
18. Billman, G. E. (2013). The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. *Frontiers in physiology*, 4, C.26.
19. Merritt, M.M., Sollers, J.J., Evans, M.K., Zonderman, A.B., Thaver, J.F. (2003). Relationships among spectral measures of baroreflex sensitivity and indices of cardiac vagal control. *Biomed Sci Instrum*, 39, 193-198.

Анотація. Рибалко А.В. Зміни хвильової структури серцевого ритму при різних режимах офтальмофотостимуляції. *Проведені вимірювання показників спектрального аналізу коливань ЧСС та УОК на 48 чоловіках при різних режимах офтальмофотостимуляції. Офтальмофотостимуляція світлом різної довжини хвилі, інтенсивності освітлення та частоти подачі сигналу призводить до значущих зрушень хвильової структури показників серцевого ритму та їх синхронізації. Зміни показників діяльності серцево-судинної системи у ваготоніків є прогностично позитивними у порівнянні з еу- та симпатотоніками.*

Ключові слова: *офтальмофотостимуляція, варіабельність серцевого ритму, спектральний аналіз.*

Черкаський національний університет імені Богдана Хмельницького

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