Науковий вісник Східноєвропейського національного університету імені Лесі Українки
Серія: Біологічні науки, 2018, 4(377)

УДК 612.8

Methodical Approach to the Study of Intersystem Interaction of Human Cardiovascular System and Brain

Liliia Yukhymenko, Mykola Makarchuk

Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
Correspondence: liyukhimenko@ukr.net

Resume. Our study presents theoretical and methodical aspects of the complex experimental electroencephalographic examination of brain and the electrocardiorythmography of heart, which allow obtaining the results of measurements that can be used to assess the psychophysiological state of a person according to the brain-heart system. The investigation emphasizes on the importance of classifying people according to the level of functional mobility of the nervous processes. This research describes peculiarities and a sequence of realization of the experimental study of brain and heart in the resting state and during the performance of mental activity. Multiple approbation of this methodological approach with the participation of different contingents of surveyed persons suggests that such algorithm of a complex research enables to obtain a broad information basis for the evaluation of psychophysiological functions of a person and build predictions of their variability depending on changes of living conditions.

Key words: electroencephalography, cardiorythmography, functional mobility of nervous processes, processing of information, brain and heart interaction.

Методичний підхід до вивчення міжсистемної взаємодії серцево-судинної системи та мозку людини

Лілія Юхименко, Микола Макарчук

Київський національний університет імені Тараса Шевченка, Київ, Україна
Адреса для листування: liyukhimenko@ukr.net

Отримано:12.05.18 ; прийнято до друку: 14.06.18; опубліковано: 25.06.18

Резюме. Подано теоретичні та практичні аспекти комплексного експериментального електроенцефалографічного дослідження головного мозку та електрокардіоритмографічного дослідження серця, що дає змогу отримувати результати вимірювань, які можуть бути використані для оцінювання психофізіологічного стану людини за системою «мозок-серце». Наголошується важливість класифікації людей за рівнем функціональної рухливості нервових процесів. Наведено особливості й послідовність реалізації експериментального дослідження мозку й серця в стані спокою та під час виконання розумової діяльності. Неодноразова апробація цього методичного підходу за участю обстежуваних різного контингенту дає підставу стверджувати, що такий алгоритм комплексних досліджень дає змогу отримувати широкий інформаційний базис для оцінки психофізіологічних функцій людини та будувати прогнози їх варіативності залежно від змін умов життєдіяльності. Застосування цього методичного підходу створює належні умови для проведення детального моніторингу психофізіологічних функцій, оптимізації профвідбору та профорієнтації у багатьох галузях життєдіяльності людини, а також може бути корисним у сфері медицини й реабілітації з метою корекції проявів патології мозку та серця.

Ключові слова: електроенцефалографія, кардіоритмографія, функціональна рухливість нервових процесів, переробка інформації, взаємодія мозку і серця.

Formulation of a Problem and its Value

At the present stage of development of the science and medicine in designs of complex investigation of the human organism the non-invasive tools of registration, monitoring and diagnosing the human functional states continue to be the most priority [1, 2]. Electroencephalography (EEG) and electrocardiorythmography (ECRG) relate precisely to such tools that allow us to investigate brain and heart function without resorting radical surgical methods [3]. The results of researches of heart and brain which we obtained with the help of modern EEG and ECRG devices, evidence of it's reliability because it reflect objectively the qualitative and quantitative characteristics of the functioning of the organism [4, 5].

Analysis of Researches of this Problem

The study proved that EEG is a reliable method for evaluating biocurrents of brain, which is used to judge both the activity of the cerebral cortex, subcortex and many internal organs [6]. ECRG enables to detect rhythm disturbances, monitor the flow of energy changes occurring in the myocardium, monitor the morphological rebuilding of the heart vessels and its walls, and establish changes in impulse conduction that can lead to the cardiovascular pathology [7]. In the first place, central nervous system controls the activity of the heart [8, 9]. Due to the rapid growth of the pace of life, the emergence of new occupations, the deterioration of ecology there is in the world the exponential growth of cardiovascular and neurological morbidity [10, 11]. In our time, scientists consider the diseases of the cardiovascular system as the main cause of cognitive impairment of both vascular and neurodegenerative genesis [12, 13]. They note that the violation of the cognitive functions of the brain is one of the typical concomitant disorders, which accompanies chronic heart failure and manifests by decreasing in memory, attention, the speed of psycho-motor reactions [14, 15]. There is a point of view that the decreasing of cardiac output and stagnant phenomena of the circulatory system due to the insufficient pumping capacity of the heart cause the structural and functional changes in the brain [16, 17, 18] that greatly affects not only the quality of life, but also reduces its duration [19, 20, 21]. This situation causes the importance of a comprehensive study of functions of brain and heart, which can open up a new level of opportunities for timely diagnosis, rational treatment and rehabilitation of people with psychoneurological and cardiological diseases and also contributes increasing of competence of professional orientation and qualitative selection of personnel [22]. Particular importance for the full account of adaptive human capabilities to changing environment, based on the innate properties of the body is to take into account the typological features of higher human nervous activity [23, 24].

Selection of Previously Unsettled Parts of the General Problem

Due to the development of views on the genetic determinism of the main nervous processes, particularly the functional mobility (FMNP), and its role in psycho-physiological functions of a person [25, 26], the methods of the one-hour diagnosing of brain and heart according to the characteristics of the biosignals obtained during the EEG and ECRG of a person, require to follow more precise algorithmic and detailed procedure. We believe that the proposed methodological approach to the complex experimental study of the cardiovascular system of a man and cerebral cortex will allow obtaining objective integral parameters of biosignals, which will make it possible to judge about the peculiarities of psychophysiological states of man, as well as to diagnose and predict their changes.

Goal: Considering of the methodical aspect of a complex experimental study.

Methods and Sequence of the Research

We recorded the biological currents of the brain according to EEG method with the help of the computer electroencephalograph Neirocom of the KhAI Medica. Also we carried out the fixing of biosignals of cardiovascular activity due to ECRG method by the device Cardiolab + (Kharkiv, Ukraine). We performed the establishment of the individual-typological properties of higher nervous activity (HNA) according to FMNP by the device Diahnost 1M according to the original method [27]. The total time of the experimental study was no more than 20 minutes. We carried out the statistical data processing in accordance with software used devices, as well as Excel 2010 packages, STATISTICA 6.0 for Windows, and using correlation, factor and cluster analysis. We examined all persons in accordance with the provisions of the Helsinki Declaration (1975, later editions 1996–2013). The research procedure was experimentally implemented on the basis of the Institute of Physiology named after M. Bosyi and the Department of Anatomy, Physiology and Physical Rehabilitation of the Cherkasy National University named after Bohdan Khmelnytskyi.

Presentation of the Main Material and Substantiation of the Study Results

We believed that the study of the brain and heart functions should have the several consecutive steps: - registration of passport and anthropometric data of the surveyed persons; - classification of the individuals according to the individual-typological peculiarities of the high nervous activity (according to the level of FMNP); - clarification and observance of conditions for the examination of psychophysiological functions; - parallel registration of EEG and ECRG in two modes: a) record of biosignals in a resting state (background); b) recording the biosignals in conditions of a real activity; - creation of the base of the actual experimental data and their statistical processing; - analysis, scaling, integration of results, forecast, diagnostics, recommendations. We used the following algorithm of the complex experimental study to obtain the objective characteristics of the interaction of brain and heart (fig. 1). In accordance with the algorithm of the study procedure, in the first stage, we carried out the familiarization with the content, the sequence of planned inspections and their duration, entered the necessary data into a personal card (social, anthropometric data, current health status, chronic pathology, traumas in the past) and carried out the instructions on further participation in the experiment. To determine the maximum possible rate of a movement of the hand (for 30 seconds, the interval divided into 6 periods - 5 seconds each), we determined the profile of manual asymmetry. Also the authors of the article established the auditory asymmetry according to the psychoacoustic test of Movement of clock and determined the individual peculiarities of hearing (leading ear). We selected only those individuals for further research who had the asymmetric coefficients not less than 51 %. The research included the study of the current psychological background according to the test Feeling, activity, mood [28]. Also the study took into account the daily activity of the organism of the examined person. We worked according to the classical type of dynamics of a human work capacity, and our research assumed the observation of the highest level of psychophysiological functions in the time interval from 8 till 12–13 o'clock [29].

We carried out the research in a special sound and light-proof chamber, where we maintained the proper pressure, humidity and comfortable temperature. The examined person was in a comfortable armchair in a semi-lying position. Before conducting the research, he got 2–3 minutes to get accustomed to the electrode located on the head and the body, adjusting to the procedure

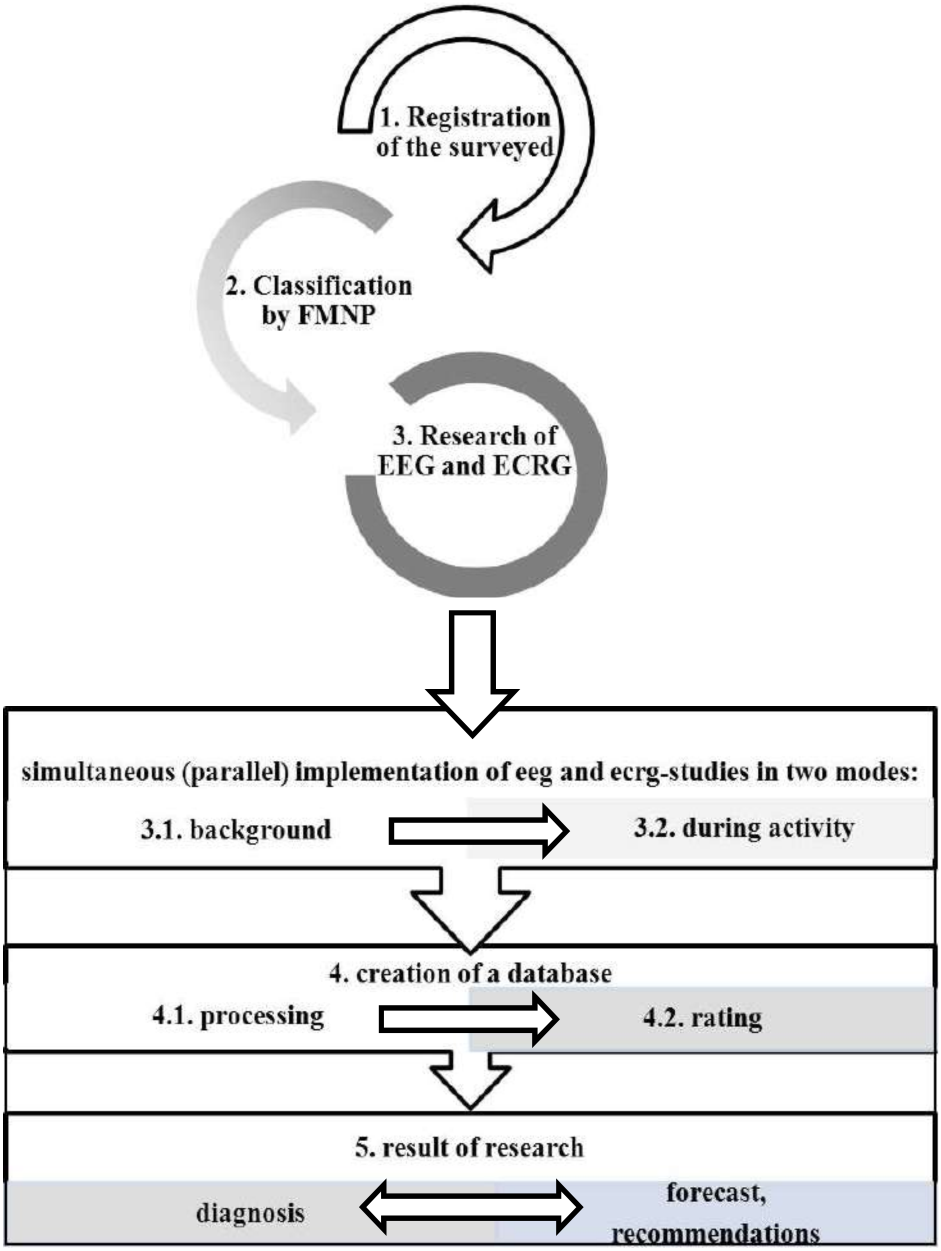

Fig. 1. *Scheme of the Algorithm Realization of the Complex Procedure of the Brain and Heart Experimental Study*

of research, which contributed to the reduction of artifacts occurring during EEG and ECRG records.

At the second stage of the study procedure, we determined the individual-typological features according to the characteristics of FMNP: - for the understanding of the characteristics of the latent period of perception of the stimulus by the receptors of the corresponding analyzer and carried out the determination of the simple sensory-motor reactivity on stimuli of different modality (geometrical figures, sound tones); - to find out the associative processes, reactions of choice and differentiation of stimuli after 3-time training and the ability to quickly switch between excitation and inhibition [23]; - the study included the applying of the imposed rhythm mode, which allowed the detecting of the highest speed of the error-free response of selection and differentiation of the stimulus for a limited amount of time; the research included also the using of the feedback mode as a criterion for the processes of autoregulation during the processing of complex information. We believe that in order to the modeling of the active work of brain and heart, a test of 5-minute processing and differentiation of sensory stimuli of auditory modality by the Diahnost 1M device should be used particularly in the feedback mode, which allows surveyed persons to adjust the pace of work to individual psychophysiological possibilities, which helps them to avoid fatigue [27]. The quantitative and qualitative parameters which were obtained in different test modes allowed us to receive an integral index of the level of FMNP.

We established the level of the investigated individual-typological property after determining of the absolute values of the FMNP. The maximum rate of presentation and processing of signals was considered as the indicator of the level of FMNP in which the surveyed person did not exceed 5,0–5,5 % of errors at the highest speed. Detection of the individual-typological features of HNA according to FMNP allows taking into account the quantitative and qualitative characteristics of information processing and psychophysiological features of a man [25], manifested in both brain and heart functions [30, 31]. The third phase of the research was to implement the simultaneous fixation of the brain and heart biosignals initially in a resting state (background), and then during the performance of activities for the assessment of stationary and transient processes of the brain-heart system. We placed electrodes in accordance with the generally accepted scheme of 10–20 for unification of the research and possibility of comparing the obtained indicators [5, 32]. We began the recording of the heart biological currents from the first minute of the loading test and fixed them till the end of the 5 minute processing of information with subsequent spectral analysis of the heart rate variability [32, 33]. In our studies, the background record was designed for measurement of EEG and ECRG in the resting state of the examined individual. The recording of transient processes was represented by bioelectric oscillations in the form of a wave or a complex of waves which

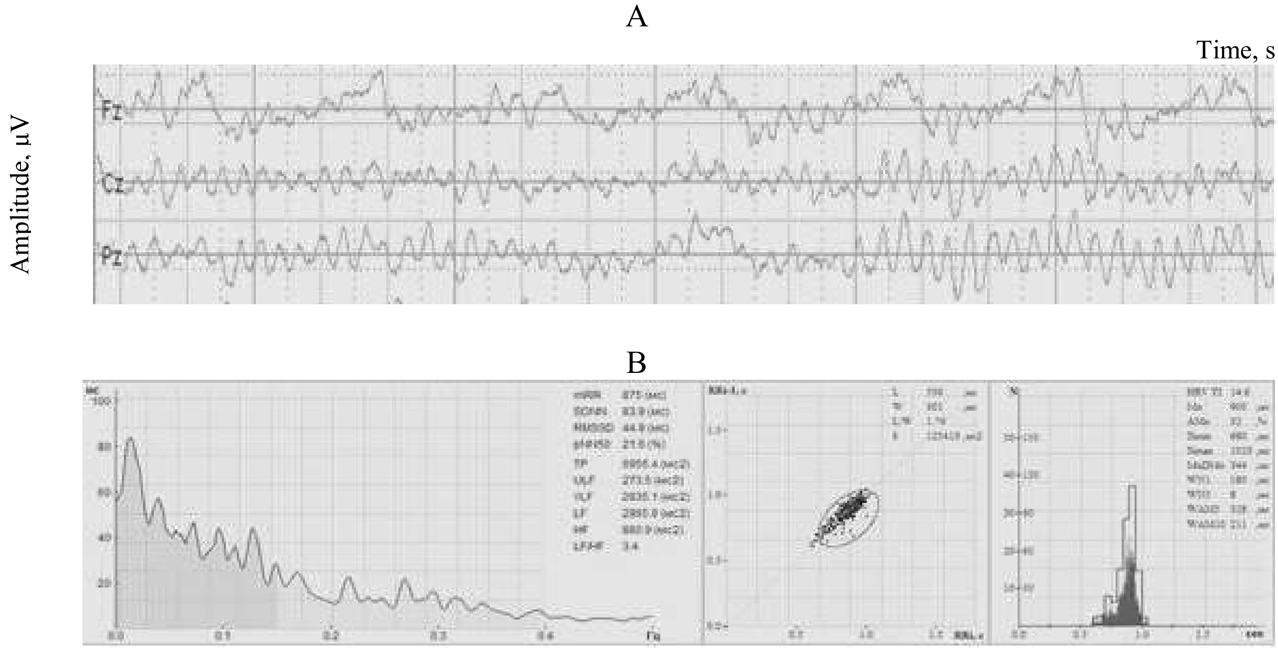

Fig. 2. *Example of EEG (A) and ECRG (B) Background Recording of Operator With High Level of FMNP*

were generating in a response to stimuli during an active work. This article presents the results of the examination of operators of the mobile communication in order to visualize the practical implementation of the research algorithm. We presented the fragments of the complex registration of EEG (in the leads of Fz, Cz, Pz) and ECRG in the background and during the activity (computer processing of information) of two operators with different level of FMNP. Firstly according to the study scheme we carried out the fixing and analyzing of the one-hour background recording of EEG and ECRG of an operator with a high level of FMNP (fig. 2).

Then we were reordering and analyzing the complete recording of EEG and ECRG of the same operator during the performance of the work (fig. 3).

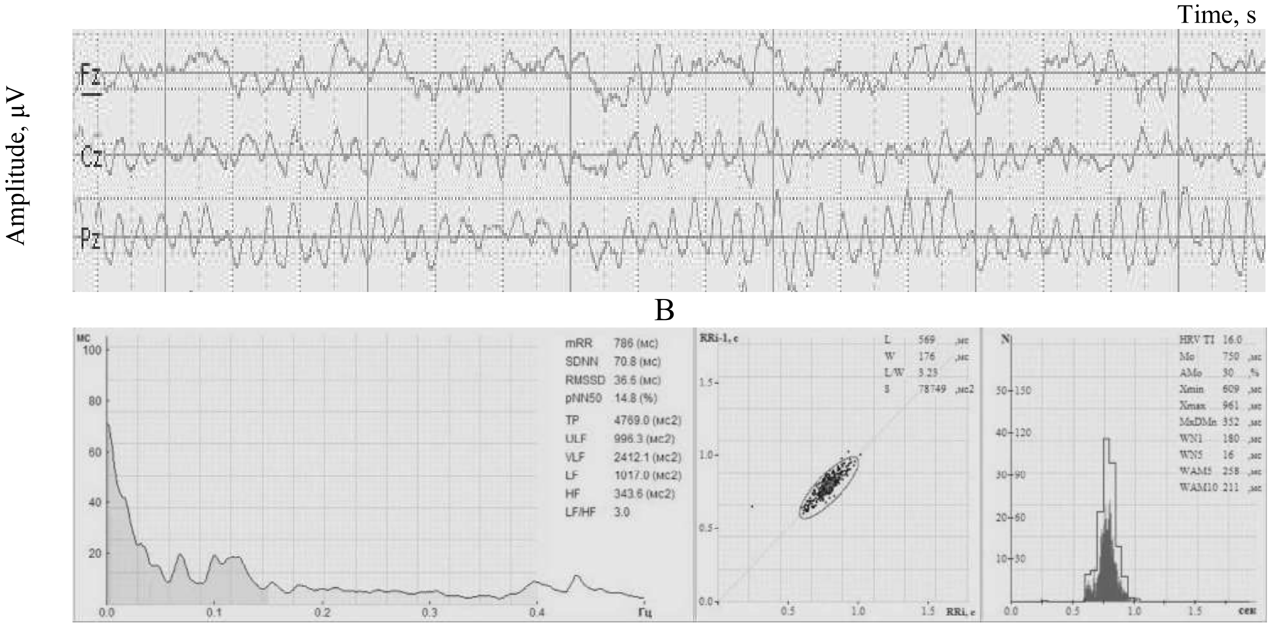

Fig. 3. *Example of EEG (A) and ECRG (B) Recording of Operator With High Level of FMNP During the Performance of Work*

Similarly, we performed the registration and analysis of the biocurrents of the brain and heart of an operator, which had, for example, low FMNP under background conditions (fig. 4) and during the information processing (fig. 5).

Subsequently, we carried out the statistical analysis of the actual data of a complex study of the brain and heart of the surveyed persons with different gradations of the investigated typological properties in the resting state and during the processing of information.

Earlier we carried out the survey of operators and used the same methodological approach which showed that the results of the comparison of EEG and ECRG records indicated that there were no significant differences between the indices of individuals with different levels of FMNP obtained in the resting state ($P \geq 0{,}05$). In contrast, the comparative analysis of the brain and heart parameters, which we were recording during the processing of information in individuals with different gradations of the investigated typological properties of HNA, detected differences in the spectral power of the heart rate, activation of the frontal and parietal portions of the cerebral cortex and the power of α-, β- , θ-ranges of waves of the frontal, temporal and occipital regions of the cerebral cortex ($P \leq 0.05$-0.01). The authors of the article found out that the operators with a

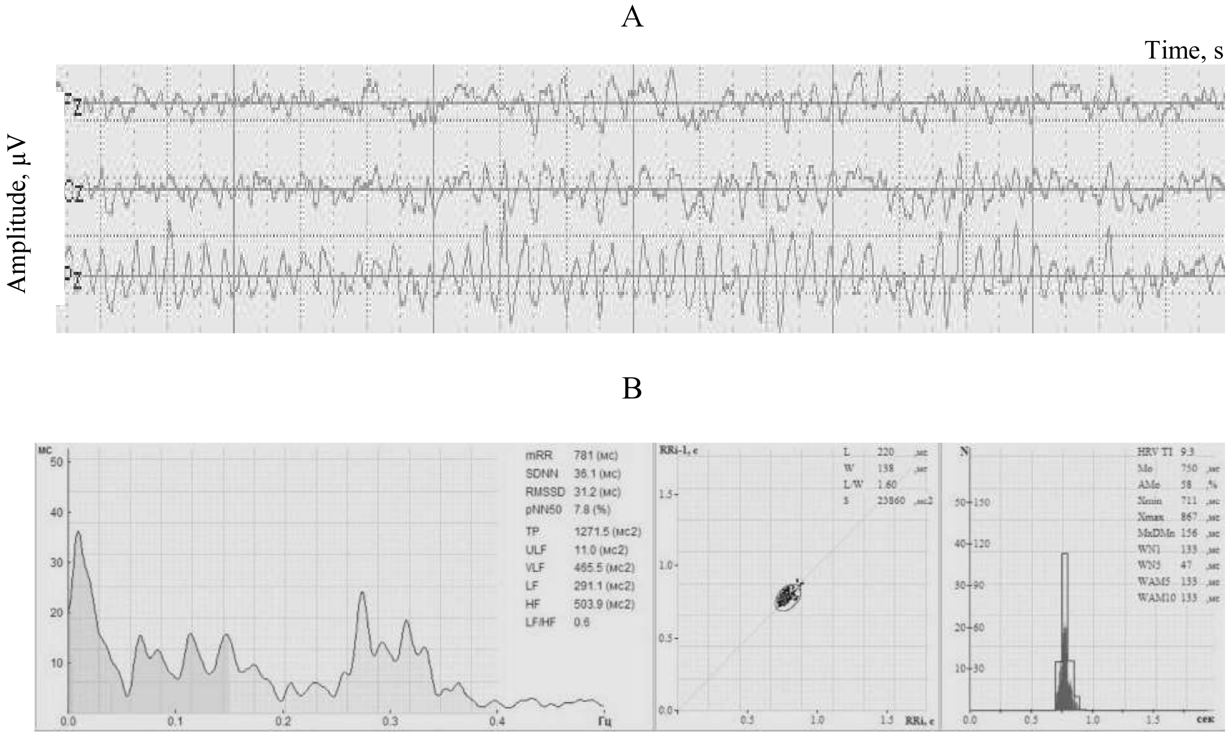

Fig. 4. *Example of EEG (A) and ECRG (B) Background Recording of Operator with Low Level of FMNP*

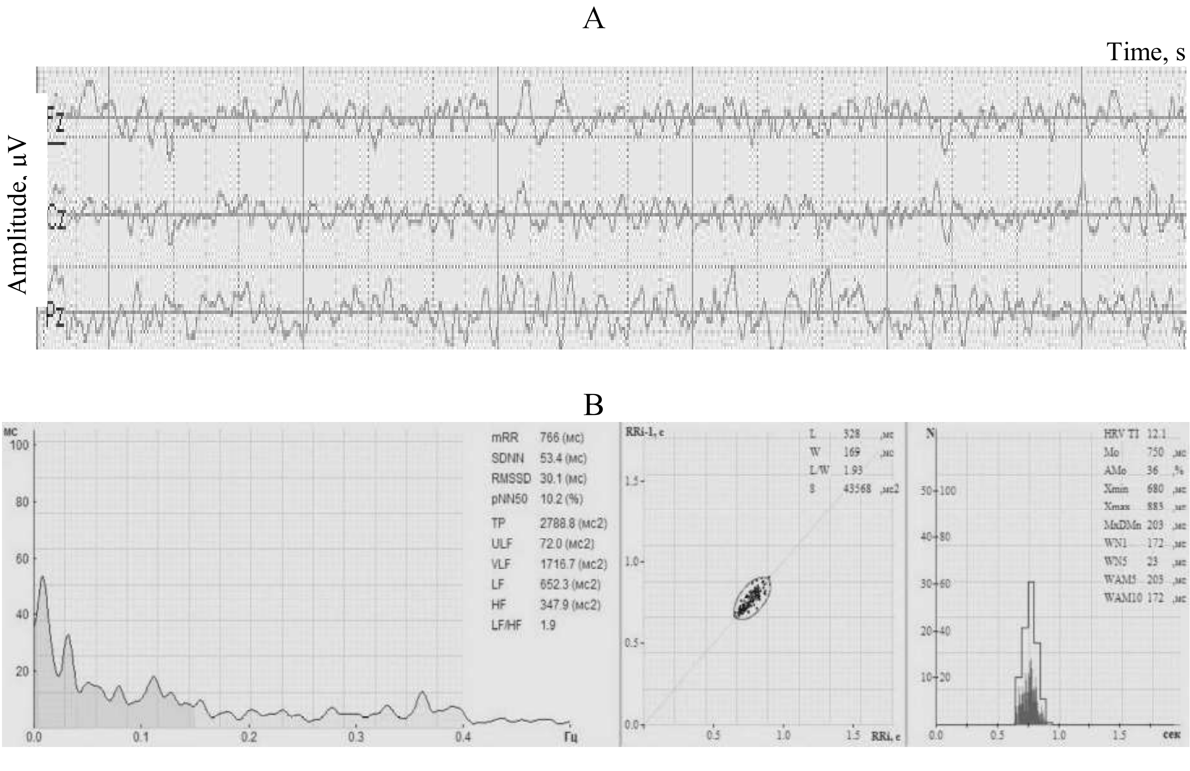

Fig. 5. *Example of EEG (A) and ECRG (B) Recording of an Operator with a Low Level of FMNP During the Performance of Work*

high level of FMNP achieved more quantity of the processing of stimuli (which indicated on the higher effectiveness of the performed activity) by increasing the tension of neurodynamic, neurophysiological and autonomic mechanisms of the cardiac regulation [34, 35, 36, 37]. We received the similar data, which were recorded by the same study procedure of the examination of students that confirmed the results that we were getting during the research of the mobile communication operators. Thus elucidation of the neurovisceral features of the processing of the sensory information of students with different levels of FMNP allowed us to identify the individual-typological peculiarities of interactions in the brain-heart system, which pointed on the existence of different strategies for their autoregulation [34, 38, 39].

It is known that parameters of the biosignals of EEG and ECRG which are fixed with the help of an electroencephalograph and an electrocardiogram have the relevant features which reflect a certain physiological meaning [40]. It should be assumed that the actual material, collected during this procedure of the integrated study of human brain and heart, can be the basis for assessing the psycho-physiological functions of people of different functional states (resting state and real activity) and also has the differences of the level of the individual-typological properties of HNA. The results of our studies showed that the signals of biocurrents of brain, in so-called α-, β- and θ-ranges of frequencies in all leads that had the generally recognized characteristics of frequency and power of the rhythm spectra (α-rhythm of 8–13 Hz, 30–70 μV; β-rhythm 14–35 Hz, 5–30 μV; θ-rhythm 4–7 Hz, 25–35 μV), zonal activity (for every rhythm), amplitude and frequency of asymmetry carry an important information and were required for inclusion [5, 8]. Their fixation and analysis makes it possible to judge about the involvement of the cortical and subcortical structures in the creating of an emotional background and the support of attention due to θ-rhythm indices [41], activating memory mechanisms according to the changes of α-rhythm [42], as well as to take into account the effects of nonspecific systems of the central nervous system according to the activity of the cerebral cortex at β-rhythm fluctuations [43], which lasted directly during the processing of information.

Analysis of biocurrent of the heart due to SDNN and spectral characteristics of the cardiac rhythm (very low frequencies of 0–0,04 Hz (VLF), low frequencies of 0,04–0,15 Hz (LF), high frequencies of 0,15–0,4 Hz (HF), general oscillation power of 0–0,4 Hz (TP), as well as weight-sympathetic balance (LF / HF) [32, 33, 44], allowed us to identify different strategies of adaptive reorganization and differences in the tension of regulatory mechanisms of individuals with different levels of FMNP in conditions of a real activity.

Conclusions and Perspectives of the Further Research

Consequently, the proposed experimental study procedure with the use of the typological approach to the brain-heart system was repeatedly approbated and proved the possibility of the obtaining an objective information about the psychophysiological state of man and the individual characteristics of the interaction of brain and cardiovascular system in real conditions of activity. Due to the subsequent statistical processing of the brain and heart biorhythms with using factor and cluster analysis it becomes possible to realize with certain authenticity the diagnostic and prognosis of the psychophysiological functions of the organism.

The development of the differential scales for assessing the work of the brain-heart system according to the basis of the individual neurodynamic and neurovegetative characteristics, which should be used as a criterion for the diagnostic or prognosis of the psychophysiological functions of a person, is one of the prospects of our further research. In our opinion, the information, obtained as a result of experimental research, will serve as the basis for an expert assessment that will have a genetically determined basis according to the individual-typological peculiarities of a person and will allow the detailed monitoring of the psychophysiological functions, optimize the professional selection in many areas of the human life and will be useful in the field of medicine and rehabilitation in order to correct the manifestations of the brain and heart pathology.

So we have considered the methodical approach of the complex experimental study of the brain's and heart's interaction for the determining objective quantitative and qualitative characteristics of the biosignals, as well as the necessity of classification of people, according to the level of their individual-typological features (functional mobility of nervous processes). Also we have analyzed the peculiarities of realization of experimental research during background conditions and real activity and have proposed the complex procedure of implementation the integrated experimental research according to the basis of the typological approach which has allowed the creating of a powerful information basis for the evaluation of the psychophysiological functions of a person.

Literature

1. Панченко, О. А.; Минцер, О. П. *Применение информационных технологий в современной реабилитологии.* КВИЦ: Киев, 2013; с 25–72.

2. Олар, О. І.; Микитюк, О. Ю.; Федів, В. І. Інноваційні технології в медицині: стан і перспективи. *Буковинський медичний бюллетень,* 2013; 17, 2(66), с 155–160.

3. Nelson, M. R.; Stepanek, J.; Cevette, M.; Covalciuc, M.; Hurst, R. T.; Tajik, A. J. Noninvasive Measurement of Central Vascular Pressures With Arterial Tonometry: Clinical Revival of the Pulse Pressure Waveform? *Mayo Clinic Proceedings* 2010; 85(5), 460–472.

4. Макарчук, М. Ю.; Куценко, Т. В.; Кравченко, В. І.; Данилов, С. А. *Психофізіологія: навчальний посібник.* ООО Інтерсервіс: Київ, 2011; с 31-51.

5. Чернинський, А. О.; Крижановський, С. А.; Зима, І. Г. *Електрофізіологія людського мозку*: методичні рекомендації до практикуму. Видавець В. С. Мартинюк: Київ, 2011; с 5–35.

6. Гнездицкий, В. В. *Обратная задача ЭЭГ и клиническая электроэнцефалография (картирование и локализация источников электрической активности мозга).* МЕДпресс; информ: Москва, 2004; с 34–47.

7. Greene, S. J.; Vaduganathan, M.; Wilcox, J. E.; Harinstein, M. E.; Maggioni, A. P.; Subacius, H.; Zannad, F.; Konstam, M. A.; Chioncel, O.; Yancy, C. W.; Swedberg, K.; Butler, J.; Bonow, R. O.; Gheorghiade, M. The prognostic significance of heart rate in patients hospitalized for heart failure with reduced ejection fraction in sinus rhythm. *European Journal of Heart Failure* 2013; 6, 48–806.

8. Seeley, R. R.; Stephens, T. D.; Tate, P. *Anatomy and physiology* (6th ed). McGraw-Hill (TSDAS Digital Library: QP34.5 See): Boston, 2003.

9. Солодков, А. С.; Сологуб, Е. Б. *Физиология человека. Общая. Виды спорта.* Спорт: Москва: Спорт, 2018; с 123-135.

10. Filippatos, G.; Khan, S. S.; Ambrosy, A. P.; Cleland, J. G.; Collins, S. P.; Lam, C. S.; Angermann, C. E.; Ertl, G.; Dahlstrom, U.; Hu, D.; Dickstein, K.; Perrone, S. V.; Ghadanfar, M.; Bermann, G.; Noe, A.; Schweizer, A.; Maier, T.; Gheorghiade, M. REgistry to assess medical Practice with l Ongitudinal obseRvation for Treatment of Heart Failure (REPORT-HF): rationale for and design of a global registry. *European Journal of Heart Failure* 2015; 17, 527–533.

11. Рачин, А. П.; Выговская, С. Н.; Нувахова, М. Б.; Дорогинина, А. Ю. Хроническая церебральная ишемия: от правильного диагноза до адекватной терапии. *Российский медицинский журнал* 2015; 12, с 694-698.

12. Maggioni, A. P.; Dahlstrom, U.; Filippatos, G.; Chioncel, O.; Crespo Leiro, M.; Drozdz, J.; Fruhwald, F.; Gullestad, L.; Logeart, D.; Fabbri, G.; Urso, R.; Metra, M.; Parissis, J.; Persson, H.; Ponikowski, P.; Rauchhaus, M.; Voors, A. A.; Wendelboe Nielsen, O.; Zannad, F.; Tavazzi, L. Heart Failure Association of the European Society of Cardiology (HFA). EURO observational Research Programme: regional differences and 1-year follow-up results of the Heart Failure Pilot Survey (ESC-HF Pilot). *European Journal of Heart Failure* 2013; 15, 808-817.

13. Богданов, А. Р.; Богданов, П. П.; Мазо, В. К.; Феофанова, Т. Б. Когнитивные нарушения при дисциркуляторной энцефалопатии и ожирении, *Международный научно-исследовательский журнал* 2015; 15(2), с 46–51.

14. Vogels, R L.; Scheltens, P.; Schroeder-Tanka, J. M.; Weinstein, H. C. Cognitive impairment in heart failure: a systematic review of the literature. *European Journal of Heart Failure* 2007; 9, 440–449.

15. Mohebbi, M.; Nguyen, V.; McNeil, J. J.; Woods, R. L.; Nelson, M. R.; Shah, R. C.; Storey, E.; Murray, A. M.; Reid, C. M.; Kirpach, B.; Wolfe, R.; Lockery, J. E.; Berk, M. Psychometric properties of a short form of the Center for Epidemiologic Studies Depression (CES-D-10) scale for screening depressive symptoms in healthy community dwelling older adults. *General Hospital Psychiatry* 2018; 51, 118‒125.

16. Tavazzi, L.; Senni, M.; Metra, M.; Gorini, M.; Cacciatore, G.; Chinaglia, A.; Di Lenarda, A.; Mortara, A.; Oliva, F.; Maggioni, A. P. Outcome Investigators. Multicenter prospective observational study on acute and chronic heart failure: the one-year follow-up results of IN-HF outcome registry. *Circulation Heart Failure* 2013; 6, 473‒481.

17. Ambrosy, A. P.; Fonarow, G. C.; Butler, J.; Chioncel, O.; Greene, S. J.; Vaduganathan, M.; Nodari, S.; Lam, C. S.; Sato, N.; Shah, A. N.; Gheorghiade, M. The global health and economic burden of hospitalizations for heart failure: lessons learned from hospitalized heart failure registries. *Journal* of the *American College* of *Cardiology* 2013; 63, 1123‒1133.

18. Воронков, Л. Г.; Солонович, А. С. Когнітивна дисфункція при хронічній серцевій недостатності: механізми, наслідки, можливості корекції. *Серцева недостатність та супутні захворювання* 2017; 2, с 39‒46.

19. Gaviria, M.; Pliskin, N.; Kney, A. Cognitive impairment in patients with advanced heart failure and its implication on decision-making capacity. *Congest Heart Fail* 2011; 17, 175-179.

20. Hajduk, A. M. Cognitive impairment and self-care in heart failure. *Clinical Epidemiology* 2013; 5, 405‒415.

21. Cook, T. D.; Greene, S. J.; Kalogeropoulos, A. P.; Fonarow, G. C.; Zea, R.; Swedberg, K.; Zannad, F.; Maggioni, A. P.; Konstam, M. A.; Gheorghiade, M.; Butler, J. Temporal Changes in Postdischarge Mortality Risk After Hospitalization for Heart Failure (from the EVEREST Trial), *American Journal of Cardiology* 2016; 117, 4, 611‒616.

22. Thayer, J. F.; Ahs, F.; Fredrickson, M.; Sollers III, J. J.; Wager, T. D. A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience* & *Biobehavioral* 2012; 36(2), 747‒756.

23. Макаренко, М. В. Метод проведення обстежень та оцінки окремих нейродинамічних властивостей вищої нервової діяльності людини. *Фізіологічний журнал* 1999; 45(4), с 125-131.

24. Моренко, А. Г. *Особливості мозкових процесів під час виконання мануальних рухів у відповідь на сенсорні сигнали осіб з високою та низькою альфа-частотою.* Східноєвропейський національний. ун-т ім. Л. Українки: Луцьк 2014; с 7‒8, с 151‒182.

25. Makarenko, M. V. *Sensomotor reactivity and the success of flight training. Military medicine of Ukraine* 2016; 16, 52–57.

26. Поручинська, Т. Ф.; Шевчук, Т. Я.; Романюк, А. П.; Дмитроца, О. Р. Особливості тета-активності ЕЕГ мозку осіб з різною силою нервових процесів при вербальній та невербальній активності. *Біологічні системи* 2016; 8(1), с 138-142.

27. Макаренко, М. В.; Лизогуб, В. С.; Галка, М. С.; Юхименко, Л. І.; Хоменко, С. М. *Метод оцінки психофізіологічного стану слухового аналізатора.* Патент на винахід 96496 IPC A 61B5 / 16, UA pub. 10.11.2011. Бюл 21.

28. Миронова, Е. Е. *Сборник психологических тестов.* Женский институт ENVILA: Минск 2005; с 15‒82.

29. Голінько, В. І.; Клочков, В. Г.; Чеберячко, С. І. *Аналіз умов праці операторів*. НГУ: Донецк 2010; с 24-78.

30. Макаренко, М. В.; Лизогуб, В. С.; Юхименко, Л. И. Реакции автономной нервной системы студентов с различными свойствами высшей нервной деятельности в ситуации экзаменационного стресса. *Физиология человека* 2006; 32(3), с 136‒138.

31. Макаренко, М. В.; Лизогуб, В. С.; Юхименко, Л. І.; Хоменко, С. М. Серцевий ритм у людей з різними рівнями обробки слухової інформації. *Фізіологічний журнал* 2011; 57(3), с 33‒39.

32. Anonymous. *Heart rate variability: standards of measurement, physiological interpretation and clinical use.* Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996; 1, 93(5), 1043‒65.

33. Баевский Р. М. Вариабельность сердечного ритма: теоретические аспекты и возможности клинического применения. *Ультразвуковая и функциональная диагностика* 2001; 3, с 106‒127.

34. Макаренко, Н. В.; Лизогуб, В. С.; Юхименко, Л. И.; Хоменко, С. Н. Технология анализа индивидуально-типологических особенностей высшей нервной деятельности на базе комплекса «Диагност-2». Материалы XVI Международной Конференции по нейрокибернетике Ростов-на-Дону, Россия, сентябрь 24-28, 2012; Кирой В. Н., Шапошников Г. Д., Петровский В. В., Бутенко В. С., Подладчикова Л. Н., Самарин А. И., Сухов А. Г., Федоренко Г. М., Узденский А. Б., Хренкова В. В., Фокин В. Ф. Ред.; НИИ СФУ, 2012; с 196‒199.

35. Макаренко, Н. В.; Лизогуб, В. С.; Юхименко, Л. И.; Хоменко, С. Н. Регуляция работы сердца во время слухомоторной деятельности операторов мобильной связи с разным уровнем функциональной подвижности нервных процессов. *Актуальные проблемы транспортной медицины* 2013; 2(32), с 78-84.

36. Лизогуб, В. С.; Макаренко, Н. В.; Юхименко, Л. И.; Хоменко, С. Н.; Кожемяко, Т. В. Роль свойств основных нервных процессов и психофи-зиологических функций в обеспечении деятель-ности операторов мобильной связи. *Science and Education a New Dimencion: Natural and Technical Sciences* 2013; I, 2(15), с 7-13.

37. Юхименко, Л. І.; Макарчук, М. Ю.; Хоменко, С. М. З'ясування нейродинамічних та нейровегетативних критеріїв успішності праці операторів мобільного зв'язку. Тези Доповідей VI Всеукраїнської Науково-практичної Конференції, Черкаси, Україна, Вересень 20-22, 2017; ЧНУ: Черкаси, 2017; с 87.

38. Yukhymenko, L.; Khomenko, S. Structural organization of psychophysiological functions of human in conditions of real activity. *Scientific journal Fundamentalis scientiam* 2017; 10(10), 10-15.

39. Yukhymenko, L. Individual features of heart rhythm and electrical resistance of the skin in conditions of sensory-motor reaction in people with different level of functional mobility of nervous processes. *Colloquium-journal* 2018; 2(13), 4-7.

40. Shyh-Yueh, Cheng. *Mental Fatigue Measurement Using EEG*, Hong-Te Hsu Risk Management Trends, Ed. By Giancarlo Nota 2011; 56-64.

41. Павленко, В. Б. Нейробиологические факторы психической индивидуальности и их электрофизиологические корреляты. В кн.: Системные реакции в биопотенциалах головного мозга человека и животных (коллективная монография) 2001; Симферополь с 276-336. http://pfl.crimea.edu/art_9.pdf.

42. Klimesch, W.; Sauseng, P.; Hanslmayr, S. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Research Rewiews 2007; 53, 63-88. 43. Тебенова, К. С. Изучение биоэлектрической активности мозга операторов телефонной станции. *Современные проблемы науки и образования* 2009; 4, с 138-141.

44. Wrisswalter, J.; Collardeau, M.; Arcelin, R. Effects of the exercise on cognitive performance. *J Sports Medicine* 2002; 32, 555-566.