BIOLOGY, BIOTECHNOLOGY AND ECOLOGY

Lyzogub V.S., Chernenko N.P., Kozhemyako T.V., Dziuban I.O.

Individual reactions of cerebral hemodynamics and heart rate during mental activity with high rate of information presentation

Lyzogub Volodymyr Sergiyovych, Doctor of Biological Sciences, professor, head of department, director Institute
Chernenko Nataliya Pavlovna, assistant professor
Kozhemyako Tatyana Vladimirona, assistant
Dziuban Iuriy Aleksandrovich, assistant
M. Bosyj Scientific Research Institute, department of Anatomy, Physiology and Physical Rehabilitation
B. Khmelnytskyj Cherkasy National University, Cherkasy, Ukraine

Abstract. Analysis of parameters of heart rate variability (HRV), wave structure of heart rate (WSHR) and cerebral hemodynamics (CH) during differentiation and information processing at high rate of its presentation allowed to distinguish three types of individual reactions dependent on functional mobility of nervous processes (FLNP). Normoreactive type of reaction determined in 61% of subjects with high FLNP was characterized by optimal and coordinated reaction of intracranial vessels tonus and systemic sympathicoadrenal mechanisms of heart rate regulation. Another type, hyperreactive, was determined in 63% subjects with low FLNP. This type of vegetative support control of mental activity was characterized by marked activation of systemic sympathicoadrenal and minor activation of regional control mechanisms. The third type of reaction, hyporeactive, was characterized by minor changes of regional and absence of compensatory reactions of systemic control mechanisms and was detected in 6% of subjects with high FLNP and in 10% of subjects with low FLNP.

Keywords: *mental activity, information processing, functional mobility of nervous processes, heart rate variability, cerebral hemodynamics*

Introduction. The question of psychophysiological control of mental capacity in terms of types, volume and intensity of load only began to be studied [6, 9, 15]. Increase of significance of study of peculiarities of influence of increased informational load on organism in global science is evidenced by discovery of several phenomena, including Karoshi syndrome (sudden death on work position [27]) and "burnout disease" ("burnout" [3, 5]), which affect up to 60% of workers exposed to high informational and psychoemotional load. Thus researches demonstrate notable interest in searching reliable indices informative of mental activity control and predicting [1, 20, 25].

Brief summary of relevant publications. Discussion of peculiarities of cardiac function and cerebral hemodynamics (CH) regulation during intensive mental activity has been quite active during the last decate. One reseachers think that mental activity is accompanied by increase of hemodynamic support of encephalon [19, 28]. At the same time reduction in cerebral blood supply has been demonstrated during intense mental activity [22, 23]. It was shown that multidirectional reactions of cerebral hemodynamics take place during mental work [6]. We think that multidirectional cerebral hemodynamics changes to a great extent can be explained by the hypothesis of influence of individually-typoligical characteristics of higher nervous activity (HNA) on such reactions. But the question about connection between individually-typoligical characteristics of higher segments of central nervous system and vegetative reactions during mental activity is quite debatable. Data has been received showing that individually-typoligical characteristics of HNA are not connected with parameters of vegetative reactions in resting state and during short mental work load [4, 16]. Some authors in resting state already observed differences in activation of vegetative control systems of heart activity in people with different individually-typoligical characteristics of HNA [13]. Peculiarities of fatigue development during mental activity are also well described in literature [8, 21]. But individual differences in cerebral hemodynamics and cardiac activity during long-term hard mental activity with high rate of information processing have not been established. Such a study is quite promising for understanding fundamental processes of brain functioning and hemodynamics, and for development of measures for prevention of mental tiredness and diseases of nervous and cardiovascular system.

Research objective - to establish the role of individually-typoligical characteristics of higher nervous activity in peculiarities of heart rate and cerebral hemodynamics regulation during processing of information with high rate of its presentation.

Materials and methods. In total 158 students of Computer Technologies department have been tested (age: 18-21 years). Individually-typological characteristics of main nervous processes (functional lability [FLNP]), heart rate variability (HRV), wave structure of heart rate (WSHR), rheoencephalography parameters (REG) and mental capacity were determined.

Mental capacity was diagnosed during work on a computer during 30 minutes with high rate of information presentation, which was individual for each subject. Volume of information processed during 30 minutes and quantity of mistakes at the beginning, in the middle and at the end of work were determined.

FLNP was measured using M.V. Makarenko methodics [11] on a computer complex "Diagnost-1" in forced pace mode (constantly increasing load). The highest speed of differentiation of positive and inhibitory stimuli which were presented randomly one after another was determined. Quantitative parameter of FLNP used was the maximum speed of stimuli presentation at which subject was making not more than 5-5.5% mistakes.

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Immediately before the main test and during 30 minutes of processing of information with high rate of stimule presentation HRV, WSHR and REG were determined.

Parameters of HRV and WSHR were measured using software "Caspico" [9]. Main characteristics of HRV and WSHR were established. During HRV analysis mean cardiointerval (R-R), standard deviations of NN intervals (SDNN), mode (Mo), mode amplitude (aMo), regulatory systems tension index (IN) and heart rate (HR). Power of WSHR in high-frequency (0.15-0.4 Hz; HF), low-frequency (0.04-0.15 Hz; LF) and very low-frequency (<0.04 Hz; VLF) ranges, total spectrum power (TP), indices of vagosympathetic tension (LF/HF), vegetative nervous system reactivity (ratios of LF/HF and IN during tast fulfillment to baseline values) were calculated. The latter characterised the reaction of systemic mechanisms of regulation [2].

REG was measured using fronto-mastoidal (FM) electode layout. REG parameters were determined using computer diagnostic complex ReoCom XAI, which allows registering of electrocardiogram (ECG) and reogram (RG), and blood pressure was measured. The following indices were determined: reographyc systolic index (RSI, Ohm), large arteries tonus (Tl, cu), medium and small arteries tonus (Tms, cu), bisferious index (BI, %), cerebral vessels reactivity index (CVRI), which was calculated as ratio of BI during task fulfillment to baseline value [26]. The latter characterised the reaction of intracranial resistance vessels and regional vasomotor control mechanism [14].

Statistic analysis was done in software Excel-2003 and Statistica for Windows. Parametric and nonparametric methodics of analysis were used.

Results and discussion

By FLNP values all subjects were divided into 3 groups: with low, medium and high FLNP. During mental activity with individually high rate of stimuli presentation subjects with low FLNP processed from 2400 to 2700 stimuli and made on average 134.1±12.09 mistakes (5.59%). At the same time their agemates with high level of FLNP demonstrated much higher volume of information processed, from 3600 to 4500 stimuli, and mean number of mistakes was 307.6±13.00 (9.32%; $p<0.05$). Subjects with medium FLNP showed intermediate values.

So mental capacity in differentiating positive and inhibitory signals presented at maximum speed was dependent on typological characteristics of HNA. Subjects with high FLNP demonstrated higher values of volume of information processed and mistakes in comparison to subjects with low FLNP ($p<0.05$).

Our results show that activation of cardiac activity control mechanisms and cerebral hemodynamic reactions during information processing with high speed of stimuli differentiation depends on FLNP. Analysis of parameters of REG, HRV and WSHR allowed to measure the tension level and to distinguish main variants of vegetative control mechanisms participation in maintenance of mental activity.

During 30-min task fulfillment only subjects with low FLNP showed increase in aMo and IN and decrease in SDNN in comparison to baseline values ($p<0.05$). Subjects with low FLNP during mental activity with individually high rate of information presentation showed increased activation of sympathetic and decrement in activation of parasympathetic segments of VNS and increase in centralisation of HR control. Subjects with low FLNP had higher aMo and IN, and lower SDNN values in comparison to subjects with high FLNP ($p<0.05$). For example, in the middle of 30-min period of mental activity aMo was 55.7% (49.9; 60.4%) and 43.1% (39.9; 51.0%) in subjects with low and high FLNP, accordingly ($p<0.05$). Regulatory systems tension index (IN) in these conditions was 233.4 (202.9; 314.3) and 94.8 (74.5; 152.3) conditional units (cu) in subjects with low and high FLNP, accordingly ($p<0.05$), which indicates higher activation of central, suprasegmentary levels of control in subjects with low FLNP [2, 12].

Thus subjects with low and high FLNP during information processing demonstrated different level of vegetative control mechanisms involvment. Changes of HRV and WSHR parameters during information processing at high speed of its presentation in subjects with different FLNP are shown on radar chart (Fig. 1).

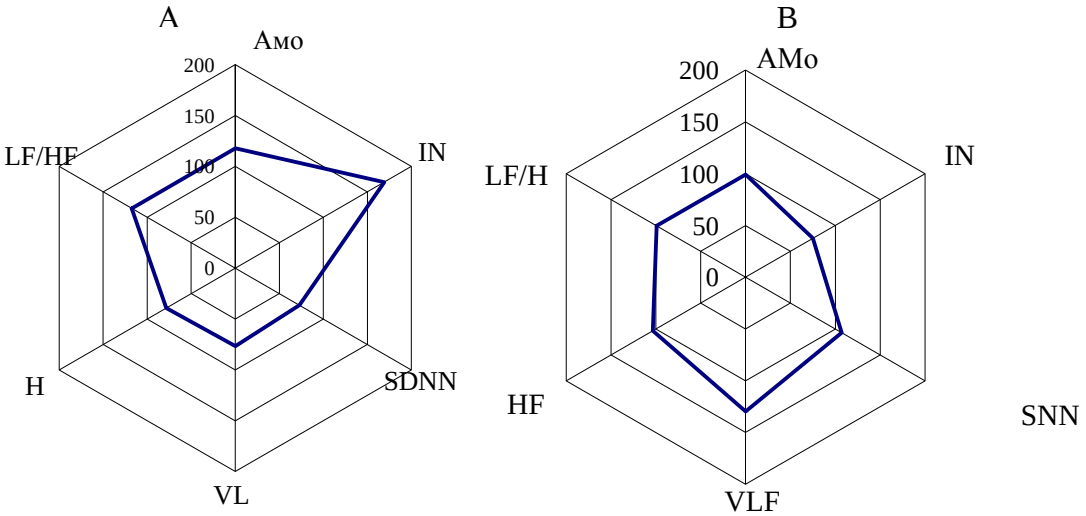

Fig. 1. Changes of HRV and WSHR parameters during information processing in comparison with baseline; A - subjects with low FLNP, B - subjects with high FLNP.

It can be seen that parameters of HRV and WSHR in these groups have the following peculiarities. Firstly, comparison of values in groups with low and high FLNP show that changes of some parameters (aMo, IN, SDNN, VLF) are opposite and do not coincide. Secondly, parameters HF, LF/HF change in the same direction but in varying degrees. It can be stated that mechanisms of vegetative support of heart activity during information processing differ in subjects with different FLNP.

WSHR in subjects with high FLNP during information processing was characterised with much higher HF, VLF and TP and with lowe LF-norm ($p<0.05$). For example, in the middle of 30-min period of mental activity HF was 126.4 (70.3; 281.9) ms² and 237.3 (158.5; 331.5) ms² in subjects with low and high FLNP, accordingly ($p<0.05$). VLF was 373.02 (262.1; 457.6) ms² and 562.1 (420.7; 1003.8) ms² in subjects with low and high FLNP, accordingly ($p<0.05$). TP in these conditions was 834.9 (755.5; 982.8) ms² and 1567.3 (1092.2; 2048.3) ms² in subjects with low and high FLNP, accordingly ($p<0.05$). LF power in normalised units (LF-norm) was equal to 35.6 (21.1; 65.02) ms² and 21.4 (18.9; 57.7) ms² in subjects with low and high FLNP, accordingly ($p<0.05$). Subjects with medium FLNP showed intermediate spectral power values. Such results may indicate that subjects with high FLNP have higher level of activation of central and peripheral mechanisms of HR control. Results of subjects with high FLNP are indicative of domination of suprasegmental influences and show higher activation of central and metabolic levels of HR control [2, 15]. That is why higher TP values along with high VLF during mental activity in subjects with high FLNP should be considered as one of specific mechanisms of cerebral hemodynamics (CH) and HR control [7].

So features of main nervous processes not only present neurodynamic base of highest possible rate of faultless response but form peculiarities of control of vegetative mechanisms that create corresponding background for mental activity.

During information processing with high rate of differentiation of positive and inhibitory stimuli statistically significant ($p<0.05$) changes of RSI relative to baseline values were detected only in the left cerebral hemisphere in subjects with high FLNP. Baseline RSI in this group was 0.43 (0.399; 0.59) Ohm and during load rose by 18.5% ($p<0.05$). Comparison of CH in groups demonstrated much higher blood filling of both right and left hemispheres during mental work in subjects with high FLNP compared to low FLNP.

At the same time redistribution of blood in favour of the left cerebral hemisphere was seen. Subjects with high FLNP showed significantly higher (by 25%) RSI in the left hemisphere in comparison to subjects with low FLNP ($p<0.05$).

During high speed of information presentation CVRI and IPAHC depended on individually-typoligical characteristics of HNA (Fig. 2).

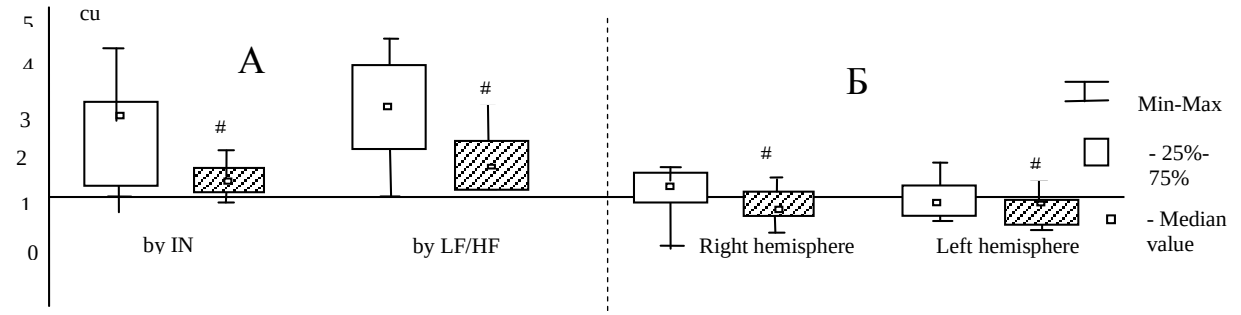

Fig. 2 Cerebral vessels reactivity index (CVRI) - B (in the right and left cerebral hemispheres) and vegetative nervous system reactivity - A (by IN and LF/HF) during individually high speed of information processing in subjects with low (☐) and high FLNP (▨): $p<0.05$ - statistically significant differences between groups with low and high FLNP.

Comparison of CVRI and IPAHC values in subjects with different FLNP showed that during high speed of information processing 61% subjects with high FLNP demonstrated coordinated normoreactive changes of both indices of CH and HR. 63% subjects with low FLNP had hyperreaction of LF/HF and minor changes in CVRI. Hyporeactive reaction type was characeterized by marginal changes of regional and absence of compensatory systemic control mechanisms. Such reaction type was detected in 6% of subjects with high FLNP in comparison to 10% of subjects with low FLNP. Probably, subjects with low FLNP have lower threshold level of vegetative reactivity of limbic-reticular complex, and thus we sooner see discoordination of cortico-subcortical interwork that plays substantial role in development of adverse reactions of incracranial vessels. Normoreactive reaction to mental work typical for subjects with high FLNP is achieved by activity of two interconnected control mechanisms - a systemic (nonspecific) sympathoadrenal and a regional (specific) vasomotor. The first one provides mobilisation of energy reserves required and the second one controls their effective use [12, 20, 26].

Thus CH and HR regulation during mental activity with high rate of information processing is connected with individually-typological characteristics of HNA and depends not only on complexity of the task but also on basic characteristics on main nervous processes.

During mental work with high rate of information processing subjects with different FLNP demonstrate vegetative reactions in mechanisms of HR and CH control that

differ in magntude and direction. Subjects with low FLNP during information processing with high rate are characterized by lower brain working capacity and higher activation of mechanisms of vegetative control of HR (mainly due to sympathetic segment of VNS), and also by lower CH values.

Integral analysis of variational and spectral cardiointervalography and rheoencephalography parameters, along with characteristics of main nervous processes represents an important component in systemic approach to determination of role of individually-typoligical characteristics of higher nervous activity in vegetative support of mental activity. Presented work substantiates rationale of using individually-typoligical characteristics of higher segments of central nervous system for objective evaluation of mental activity results and vegetative mechanisms of control of heart rate and cerebral hemodynamic reactions.

Conclusions

1. So long-term mental activity in differentiating positive and inhibitory signals presented at maximum speed is dependent on individually-typological characteristics of HNA. Subjects with high FLNP processed more information and were making less mistakes in comparison to subjects with low FLNP.

2. 61% of subjects with high FLNP in comparison to subjects with low FLNP showed coordinated normoreactive decrease in intracranial vessels tonus on the background of minor exertion of systemic mechanisms of heart rate regulation.

3. Hyperreactive type of vegetative support control of mental activity was characterized by marked activation of systemic sympathicoadrenal and minor activation of regional control mechanisms. Such type of individual reactions of vegetative support of mental activity was found in 63% of subjects with low FLNP.

4. Detected relationships between FLNP and mechanisms of vegetative control of heart function and cerebral hemodynamics serve as evidence of their coordinated action in forming individual reactions of adaptation to specific mental activity. Typologic characteristics of main nervous processes form the psychophysiologic basis of mental activity during information processing and determinate different contribution of vegetative mechanisms of regulation of heart rate and cerebral hemodynamics.

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Лизогуб В.С., Черненко Н.П., Кожемяко Т.В., Дзюбан Ю.А. Индивидуальные реакции гемодинамики головного мозга и сердечного ритма во время умственной деятельности с высокой скорости предъявления информации

Аннотация. Анализ показателей вариабельности (ВСС) и волновой структуры сердечного ритма (ХССР) и гемодинамики головного мозга (ГГМ) при дифференцировании и переработке информации на высокой скорости ее предъявления позволил выделить три типа индивидуальных реакций, которые находились в зависимости от функциональной подвижности основных нервных процессов (ФРНП). Нормореактивний тип реакции обнаружен у 61% обследуемых с высокой ФРНП, характеризовавшийся оптимальной и согласованной реакцией тонуса интракраниальных сосудов и системных, симпатоадреналовых механизмов регуляции сердечного ритма. Второй тип – гиперреактивных, обнаружили в 63% лиц с низкой ФРНП. Он сопровождался выраженной активацией системных, симпатоадреналовой и незначительной - регионарных механизмов регуляции. Третий тип реакций - гипореактивный отличался незначительными изменениями регионарных и отсутствием компенсаторных реакций системных механизмов регуляции был зарегистрирован в 6% с высокой и 10% лиц с низкой ФРНП.

Ключевые слова: *умственная деятельность, переработка информации, функциональная подвижность нервных процессов, вариабельность сердечного ритма, церебральная гемодинамика головного мозга*