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Original Article

Links between system of information processing in brain and heart rate among athletes with different individual-typological characteristic

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Abstract
Purpose: study the systemic interaction of the brain and the heart during the information processing in athletes with different individual and typological properties of the higher parts of the central nervous system.
Material: In 83 athletes while mental working were simultaneously registered: 1) electroencephalogram (EEG), central hemodynamics and heart rate variability (HRV); 2) cerebral hemodynamics and HRV; 3) EEG, HRV and electrical resistance of the skin. Individual and typological features of CNS were determined by functional mobility, strength, and equilibrium of the nervous processes.
Results: It is revealed that brain-heart systemic interaction is organized in the form of a few clusters and has individual and typological features in athletes. The analysis of indicators of neurophysiological and vegetative functions of the surveyed persons indicates that during the processing of information, the interaction of the brain and the cardiovascular system of human was determined by the level of individual and typological properties of the higher parts of the CNS. This is manifested in athletes also during physical load.
Conclusions: Brain-heart systemic interaction is caused by individual-typological properties of central nervous system. It is important for sport orientation, clinical prognosis of cardiovascular and neurological deviations, and optimization of rehabilitation measures.
Key words: systemic interaction of brain and cardiovascular system, athletes, information processing, individual and typological characteristics, central nervous system.

Introduction

It is known that the perception and processing of information is the formation in the central nervous system multiple synaptic relationships that provide the accumulation of a new set of knowledge (Stocco et al., 2017). It is proved that the processing of information depends on the properties of perception, the throughput of the central nervous system, and is estimated by the number of mistakes made (Stewart et al., 2012). The consequence of the processing of information is the corresponding reaction as a universal act of movement. During the sport activity a person is constantly forced to process heterogeneous information.

It allows them to solve current tasks and adapt to new conditions of training and competition activities. The main role in adaptation reorganization during sport activity belongs to the functioning of the brain and heart. The activity of brain and heart during the processing of information is aimed at ensuring the sustainability of the internal environment of the organism as an integral system. Imbalance in the activity of heart and cardiovascular system can cause ischemic destruction of the structures of the brain (Podrigalo et al., 2017; Korobeynikov et al., 2018).

Nowadays we know a number of progressive methodological approaches to the study of the consequences of oxygen starvation of the brain and their correction in sport (Smrcka et al., 2002; Mouzel-Oreg et al., 2015). However, the invasiveness of techniques, the complexity of surgical manipulations can cause complications of various natures: subarachnoid hemorrhage, insufficient occlusion of the middle cerebral artery and other (Tamura et al., 1981). In some cases there are difficulties in extrapolating results to a person from animal studies (Bo et al., 2018). Therefore, among the most promising directions in the study of the relationship between the brain and heart is the development of non-invasive ways of diagnosis, prognosis, correction,

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monitoring and the introduction of preventive measures into sport medicine. Such methods include the instrumental study of the functioning of the brain and the heart during active mental activity.

However, despite the significant achievements in the study of information processing (Tood et al., 2018; Korobeynikov et al., 2017), a number of questions wait for its answers. Why do people perceive, analyze and process information differently in the same conditions? How does it effect on the work of their brain and heart? Why, under these same conditions, some people are more susceptible to cardiovascular and neurological diseases, while others are not?

Probably, the problem needs to be taken into account the set of the personal qualities, genetic properties, typological features, distinguishing one person from others and the use of structural-functional approach (Kozina et al., 2015). The results of the research indicate that the quantitative and qualitative characteristics of information processing depend on individual characteristics, conditions of activity, psychophysiological properties, level of professional training (Makarenko et al., 2011), mental health (Aleshina et al., 2009; Medvidovic et al., 2013). In recent works, it is emphasized that the main value in the processing of information is played by the properties of the basic nervous processes: functional mobility of nervous processes (FMNP), strength (SNP) and equilibrium (ENP) (Yukhimenko et al., 2016, 2018). At the same time, it should be noted that today there is no clear vision about systemic reactions of the organism, in particular, the interaction of the brain and the cardiovascular system during the processing of information during sport activity. Regulatory mechanisms and principles of their interaction during intellectual activities remain insufficiently studied (Herd et al., 2006; Collins et al., 2013). It makes the idea of processing information schematic and to some extent hypothetical. In our opinion, the development of the problem will be useful for application in the field of physiotherapy, rehabilitation, sport orientation and selection and will help to accelerate the recovery of lost functions.

We put forward the hypothesis that the systemic interaction of the brain and the cardiovascular system has a complex organization, which contains various components and the relationship between these components is determined by the level of individual and typological properties of the higher parts of the central nervous system. We emphasize that studies of brain activity and functioning of the cardiovascular system of a athletes during processing of information that would take into account the degree of functional mobility, strength and equilibrium of nervous processes at the system level were not carried out

The purpose of the research: to study the systemic interaction of the brain and the heart during the information processing in athletes with different individual and typological properties of the higher parts of the central nervous system.

Materials and methods

Participants

The study was attended by 83 track and field athletes, age 18-22, students of Bohdan Khmelnytsjyi National University of Cherkasy. The survey was conducted in compliance with the rules of bioethics and the positions of the Helsinki Declaration (1975, 1996-2013) and with the permission of the Bioethics Commission of the University after the voluntary consent of every surveyed person.

Procedures and experimental design

The establishment of individual and typological features of the higher parts of the CNS was performed according to the FMNP, SNP and BNP of the neural processes on the computer device ("Diagnostic-1M", Ukraine) according to the original method (Makarenko et al., 2007).

Investigation of the induced cortical activity was performed with cognitive hearing potentials P300 by the computer encephalograph "NeuroCom" (product "Medica", Ukraine) with binaural stimulation of 50 ms duration with a sequence period of 1-2 s, with an intensity of 75-85 dB with the placement of electrodes according in zones C3, C4. The frequency of the tone of a significant stimulus was 2000 Hz, and not significant - 1000 Hz. The latency and amplitude of the components P1, N1, P2, N2, P3, N3 and intermediate latencies P1-N1, N1-P2, P2-N2, N2-P3, P3-N3 were evaluated. The latencies of P300 in the surveyed persons were in the normal limits of P300 time values taken at the clinic for the persons of 20 years old (the average is 320 ms, the upper limit is 360 ms).

Subsequently, the surveyed persons participated in complex researches conducted in three stages.

At the first stage, the EEG, central hemodynamic (CH) and HRV were recorded simultaneously at the same time. At the second stage, cerebral hemodynamic (CbH) and HRV were recorded simultaneously. In the third stage, EEG, HRV and electrical resistance of the skin (ERS) were recorded simultaneously.

At the beginning of every stage of the research, firstly the test indexes, were recorded in a resting state, and then during the processing of information. For the processing of information, a 5-minute test on the differentiation of auditory information, which was given binaurally through the headphones, was used.

Analytical methods

Registration of EEG was carried out in 19 leads by the computer encephalograph "NeuroCom" of KhAI Medica (Ukraine) with the placement of electrodes according to the international system of 10-20. As a reference, a combined ear electrode is used. The power of α (alpha, 8-13 Hz, 30-70 μV), β (beta, 14-35 Hz, 5-30 μV) and θ (theta, 4-7 Hz, 25-35 μV) rhythms was analyzed in all leads with the calculation of the coefficient of the brain activation (CA) in the frontal, temporal, parietal, central and occipital parts of the cerebral cortex.

The registration and analysis of cardiac rhythm (CR) was carried out by the device "Cardiolab +" (Ukraine) with the definition of SDNN, and spectral characteristics of HR (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), the general oscillation power of 0-0.4 Hz (TP), and the assessment of the weight-sympathetic balance (LF/HF) (Korobeynikov et al., 2018).

The registration of CH were performed on the Reocom KHAI Medica (Ukraine) device with the definition of the minute volume of blood (MVB), the cardiac index (CI), and the total peripheral vascular resistance (TPVR) The registration of CbH were performed in the front-mastoid leades at the Reocom KHA Medica (Ukraine) device with the definition of: minute volume of blood (MVB), total peripheral vascular resistance (TPVR), blood pressure (BP), cardiac index (CI), tone of vessels of different caliber, dicrotic index (DI), amplitude-frequency index (AFI) (Brisswalter et al., 2002).

Changes in ERS were fixed using the computer polygraph "Axciton" (USA). Assessment of success of the student's studying was conducted according to the final grades per semesters.

Statistical methods

The results were processed by non-parametric statistics with the definition of Mann-Whitney criteria and the conduct of the rank correlation analysis according to the Spirmen (Rs) coefficient (Glantz, 2002) using the packets of programs Excel-2010 and "STATISTICA 6.0 for Windows".

Results

Analysis has established a high variation of neurodynamic characteristics, indicating the existence of the individual-typological features of the higher parts of the CNS in the surveyed persons. Therefore, athletes were divided into two groups according to the speed of information processing: I group - with a high level of FMNP (44 persons), the II group - low (39 people). The manifestation of FMNP in the indicators of work of the brain and heart will be presented because we have found that athletes with high FMNP also had high levels of SNP and ENP.

Comparison of neurophysiological and vegetative indices of the surveyed persons, observed in resting conditions, did not reveal the existence of probable differences between them ($P \geq 0.05$). In contrast, comparing the indicators of the brain and the heart work during the processing of information indicated the existence of differences between the surveyed groups I and II (Table 1).

Tab. 1. Indicators of neurophysiological and vegetative functions during processing of information in the surveyed athletes with different levels of functional mobility of nervous processes (median, limits of 75 and 25 percentile)

Name	Group I (n=44 persons)	Group II (n=39 persons)
Amplitude of the rhythms of the electroencephalogram		
α-rhythm, μV^2	14.4* [17.3; 5.7]	7.4 [10.3; 4.1]
β- rhythm, μV^2	28.5* [37.5; 16.3]	16.5 [20.6; 7.9]
θ- rhythm, μV^2	4.3* [6.1; 2.1]	8.4 [10.8; 3.7]
Characteristics of the blood circulation of the brain		
Amplitude-frequency index, 1/s	0.4* [0.8; 0.2]	0,2 [0.3; 0.1]
Dicrotic index, %	57.1 [72.2; 47.6]	62.3 [80.1; 36.3]
Tonus of large vessels, conventional units	0.8* [1.9; 0.3]	1.2 [3.4; 0.6]
Characteristics of the variability of the heart rate		
TP, ms^2	3744.4* [3972.6; 3230.7]	1950.8 [2241.3; 1521.5]
VLF, ms^2	2036.43* [2187.1; 1667.2]	971.2 [1192.4; 723.1]
LF, ms^2	818.99 [1073.5; 681.8]	589.9 [655.8; 367.9]
HF, ms^2	889.15* [1229.8; 673.2]	389. 4[418.1; 212.8]
Characteristics of central hemodynamics		
MBV, l/min	5.2* [7.91; 1.32]	4.0 [5.2; 1.4]
HI, $l/minm^2$	2.6* [5.3; 1.0]	1.3 [2.1; 0.7]
TPVR, $dyn \cdot s \cdot c^{-5}/ m^2$	1882.1* [2452.1; 1362.6]	2289.2 [3594.8; 1881.1]

* - probability of difference $P \leq 0.05$ of the indexes in the examined athletes of the group I and group II.

The processing of information revealed features in the regulation of the CR, which was expressed in the degree of activation of vegetative regulation, and such differences were caused by FMNP. In the examined group I, higher values of TP, as well as HF, VLF ($P \leq 0.05$) and LF modulation were recorded, than in the persons of the group II. According to the theory of the genesis of the skin-galvanic reaction, the secretory activity of the sweat glands is closely related to the activity of the CNS, the sympathetic department of the autonomic nervous system and the emotional state (Mistell et al., 2011). Differences in fluctuations of ERS of examined persons with different levels of FMNP were revealed. The individual dynamics of the ERS in athletes with high FMNP demonstrated a higher degree of excitation and reactivity of the nervous system. The curve of the change in ESR of surveyed person with low FMNP in the background of the low speed of information processing and the greater total number of mistakes made evidence of an increase in inhibitory processes, the transition to protective braking, slowing down of movements and the risk of regulatory imbalances.

In all of the surveyed athletes the increasing of the CR, TPVR and decreasing of SBV, MBV and HI were recorded during the processing of information. In the examined people of the group II in relation to the surveyed persons of the group I the lower MBV, HI, CR and the higher TPVR were recorded. Representatives of the group I demonstrated a slightly narrowed range of back-up hemodynamic capabilities, a small amount of cholinergic, intracardiac, and system extracardial regulation mechanisms.

The analysis of brain-induced activity indicated that the latency of the wave P3 in both hemispheres ($P \leq 0.001$) and P2 in the right hemisphere of the examined group I compared with the group II was lower (Fig. 1). The higher power of the amplitudes of intermediate intervals N2–P3 in the right hemisphere ($P \leq 0.001$) and P3-N3 in both hemispheres, with the prevalence of the right hemisphere ($P \leq 0.05$, $P \leq 0.001$) in the examined persons was detected in the group I in relation to group II. Correlation analysis between FMNP and latencies of P300 revealed the existence of a link indicating the relationship between the velocity time characteristics of the investigated typological property and the latency of the component P2 ($P \leq 0.05$).

Comparison of the amount of processed information, depending on the properties of the main nervous processes, showed that the number of processed information was higher (648.4±7.3 signals) among students in group I than in the group II (521.2±6.8 signals), ($P \leq 0.05$). The analysis of the academic success of the surveyed persons confirmed that the students of the group I, in contrast to the people of the group II, had better achievement in most of the educational disciplines.

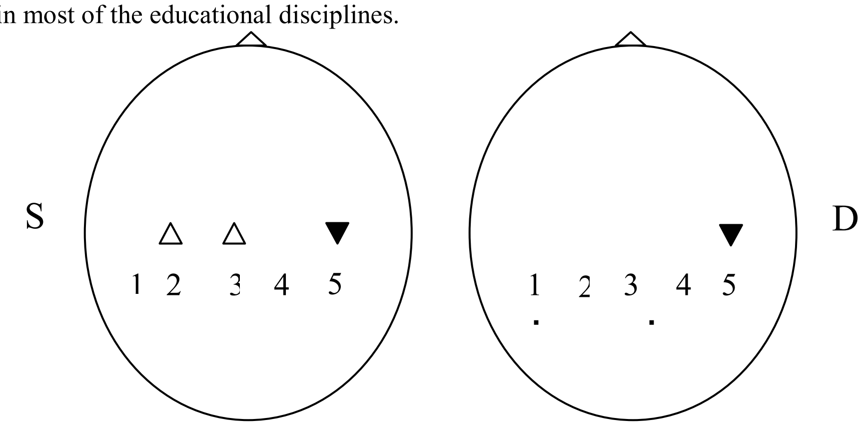

Fig. 1. Differences in components of latent periods of induced potentials in the study of cognitive P300 in the left (S) and right (D) hemispheres of the examined group I in comparison with the persons of the II group; lower (higher) latent period of P300 of the examined group I, white triangles - the reliability of the differences at the level $P \leq 0.05$, black triangles - at the level of $P \leq 0.001$; 1 - component P1, 2 - component N1, 3 - component P2, 4 - component N2, 5 - component P3 of the latent period

Correlation analysis has established the existence of a link between the indicators of FMNP and neurophysiological and vegetative indicators. The closest connection between the FMNP and the success of the learning outcomes ($R=0.56$; $P \leq 0.01$) were established SDNN, HF and LF ratios correlated with FMNP at the level of $Rs=0.54$, $Rs=0.5$ and $Rs=0.45$ ($P \leq 0.05$). The correlation between FMNP and cortex activity in the frontal, wax and posterior regions of the brain was established at the level of $Rs=0.33$ for α, $Rs=0.32$ for β and $Rs = -0.23$ for θ-rhythms of EEG ($P \leq 0.05$). The dependence between FMNP and latency P2 of the cognitive induced potential P_{300} was found at the level of $Rs=0.31$ ($P \leq 0.05$). The relationship between CA and FMNP was equal to $Rs=0.25$ ($P \leq 0.05$).

Discussion

Thus, the link between integrative activity of brain and heart rate was revealed iin athletes. We applied cluster analysis which allowed us to identify the peculiarities of ensuring the processing of information (Fig. 2). It was established that information processing was carried out by a functional system that had several components (clusters). The completeness of the hemovegetative cluster indicates that the process of information processing is accompanied by activation of the sympathetic regulation channel of HR, reciprocal increasing in the activity of the renin-angiotensin system, vascular resistance, and increasing TPVR (25). Neurovegetative cluster reflects the existence of a connection between the properties of the main nervous processes to maintain an unmistakably high rate of differentiation of stimuli and the level of functioning of the CS, demonstrating the probable "price" of information processing (Makarenko et al., 2007).

From literature it is known that the corresponding conditions of activity (Kundiiev et al.,2013) or the existence of cardiovascular pathology (Fox et al.,2008; Kolloch et al.,2008) can cause activation of the sympathetic department of the autonomic nervous system. The integrative cluster, combining FMNP, hemodynamic and neurophysiological characteristics, indicates the importance of FMNP in the performance of the activity and its effect on the functions of the brain and heart in athletes.

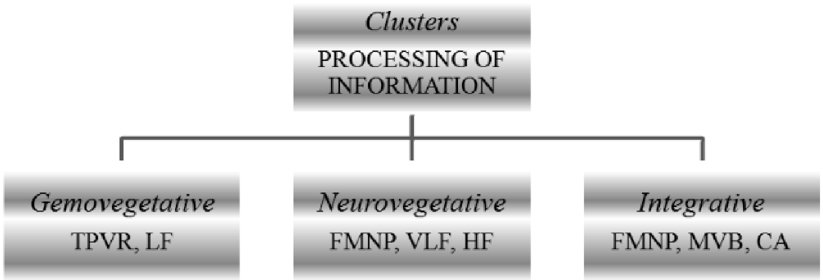

Fig. 2. Cluster structure of functional system which support of neurophysiological and vegetative provision of information processing in athletes

Consequently, the systemic interaction of the brain and heart in the context of information processing is organized in the form of gemovegetative, neurovergetative and integrative clusters that use various mechanisms for maintaining homeostasis and regulating the functional state of the organism in athletes. According to established beliefs, the morpho-functional indicator of mental load performance is the emergence of new neural structures, changes in the activity of frontal lobes, which form the foundation of a new behavior that is adequate to the conditions (O'connell et al., 2012). However, the analysis of indicators of neurophysiological and vegetative functions of the surveyed persons indicates that during the processing of information, the interaction of the brain and the cardiovascular system of human was determined by the level of individual and typological properties of the higher parts of the CNS. This is manifested in athletes also during physical load (Damirchi et al., 2009; Zadorozhna et al., 2018). Perhaps it is connected with the fact that the individuals of the group I of athletes during the processing of information revealed significantly higher cerebellar activation in the concerned areas of the brain, the higher overall capacity of the channels of regulation of HR and mechanisms of CH and CbH, lower tone of large arteries of the brain, shorter latency and greater amplitude of P300 in the comparative to the athletes of the group II.

It is known that the process of information processing in brain level has several successive stages: from the perception of information, the allocation of necessary and significant elements of it to its actual processing, which passes the stages of identification, evaluation, comparison, forming a holistic representation, analysis and selection of material for further storage or abolition. To the next the decision is made, its implementation and final control over the implementation of the action, which is corrected by feedback with the central nervous system (Korobeynikov et al., 2017). Taking into account that the individual features of neurodynamic functions determined the level of activation of the brain and autonomic mechanisms during the differentiation of auditory stimuli, we believe that the properties of FMNP, SNP and ENP participate in the synergy of the information processing and the expected performance of the activity. This related with real situation in sport activity.

The obtained correlations allow asserting about the creation of a wide area in order to achieve a useful result on the basis of a certain number of combinations of selectively involved and interconnected components by the individual-typological properties of the higher parts of the CNS. It should be assumed that FMNP is one of the mechanisms for ensuring the dynamism of processes, and its level determines the degree of plasticity of the entire system, serving as its flexible link (Bechtereva et al., 2005). It is possible that the level of neurodynamic properties of a person is one of the limiting baseline factors in providing the organization of functional systems that may differ in their hierarchical structure. So, a strong, mobile nervous system is a physiological precondition for processing a larger amount of information in a shorter time interval. This is very important for selection and orientation in sport. While a weak and inert one reduces and limits its capabilities. With a strong nervous system a wider band (focusing area) appears, and with a weak nervous system appears narrow one (Makarenko et al.,2007). Therefore, it is likely that athletes with a genetically inert, weak, and unbalanced nervous system were simultaneously receiving less information (II group), than athletes with strong and mobile nervous processes (I group). Received results showed that athletes with strong nervous system may be more successful in sprint distance, but athletes with low level of mobility of nervous system will be more successful in slayer program.

We assert that the existence of the connections of the FMNP with hemodynamic, vegetative, neurophysiological properties is evidence of the belonging of genetically determined neurodynamic functions to the processes of self-perfection and self-regulation of the organism, which proves their importance and irreplaceability during the information processing. We believe that individual-typological properties of mobility, strength and balance of the nervous processes involved in the integrative activity of the brain are one of the basic in the structure of the systemic interaction of the brain and the heart and cause various modifications to it.

Conclusions

Consequently, the systemic interaction of the brain and the heart in the context of information processing is organized in the form of gemovegetative, neurovergetative, and integrative clusters that use different mechanisms for maintaining homeostasis and regulating functions in athletes. It was established that the systemic interaction of the brain and the CS during the processing of information is conditioned by the individual-typological properties of the higher parts of the CNS in athletes. The surveyed athletes with low levels of FMNP, SNP and ENP during the processing of information were characterized by significantly lower cerebral activation, the power of sympathetic and parasympathetic channels of regulation of HR, CH, CbH and progression rates, compared with those people that had high values of the studied individual properties of higher CNS. The correlates of highly genetically-determined neurodynamic individual-typological properties of the higher CNS are the characteristics of the electrical activity of the brain, the latency of the P2 component of the cognitive potential P300, the parameters of the cardiac function, CH, CbH, and the success of the studying. The typological and individual features of the structure of the functional system of information processing are substantiated. The obtained results can be useful during the sport orientation and selection of candidates in sport specialties, which require an increased psycho-emotional stress. The established features of the interaction of the brain and the heart can be used in the clinic as a prognostic criterion for cardiovascular and neurological deviations and be taken into account during rehabilitation measures and for the construction of individual health programs.

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