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THE CHOICE OF INFORMATIVE PHYSIOLOGICAL INDICATORS FOR EVALUATINING FUNCTIONAL STATE OF THE OPERATOR UNDER LIMITED MOBILITY CONDITIONS

The paper considers methods for operator's functional state evaluation according to physiological indicators. An approach to evaluating informativeness and the influence of physiological indicators on the operator's functional state is presented. Practical implementation of the new approach to the operator's functional state evaluation is described. Requirements to the equipment, namely, to the sensors and primary biomedical (physiological) converters for the approach implementation, are presented.

Keywords: *physiological indicators, functional state evaluation, functional state of the operator, limited mobility, functional state determination.*

Introduction

Pulse rate at each definite time moment is known to be resulted from a cumulative influence of the parasympathetic and sympathetic branches of the autonomic nervous system on the cardiovascular system (CVS). Dominance of the parasympathetic effects causes slowing of the heart rate in lying position, which makes it possible, to a certain extent, to evaluate tone condition of the autonomic nervous system. Excitation of the parasympathetic branch can be evaluated by the Aschner test and the sympathetic branch excitation – by orthostatic test. The stronger reaction to the stimulation, the higher excitation [1].

Such a complex indicator as blood circulation efficiency, which can be considered to be an objective sign of the functional state (FS) worsening that is the evidence of the operator tiredness, is a more sensitive FS state indicator than the values of the heart rate (HR) and arterial pressure (AP) themselves [2]. A. M. Lukyanov and M. V. Frolov believe that continuous operator's FS monitoring can be conducted according to the two most significant manifestations of the changes in the coordination of psychological processes and functions of human activities: characteristics of attention and emotional tension [3]. It should be noted that the authors use physiological methods to determine both said characteristics.

One of the known methods for human organism FS evaluation by physiological indicators consists in simultaneous measurements of HR, system AP, oxygen content in arterial blood and minute blood volume. Then the complex indicator K is found by the formula:

$$К = 100(2{,}4 - \frac{A_n}{A_o} - 0{,}8\frac{B_n}{B_o} + 0{,}4\frac{C}{C_o} - \frac{Д}{Д_o}),$$

where: n – current value поточне значення; o – initial value початкове значення; A – AP; B – minute volume; C – heart rate; $Д$ – oxygen content in arterial blood (before and after therapeutic influence): if $К \geq 110$, it is an extremely serious condition; $80 \leq К \leq 100$ – grave condition; $64 \leq К \leq 80$ – moderate severity condition; <64 – satisfactory condition [4].

It should be also noted that complex processing of the electrocardiogram, rheogram and breath curve makes it possible to obtain a number of indicators which give a rather comprehensive characteristic of the state of the operator's cardiovascular system [5]. The indicators include:

1. EKG – amplitudes of the R, T waves, $R-R$, $R-T$ intervals;
2. Rheogram $-(\frac{dz}{dt})_{max}$, interval $\tau = \left\{ R - (\frac{dz}{dt})_{max} \right\}$;
3. Breath curve – peak inspiratory flow rate – W, peak expiratory flow rate – WW; breathing cycle

duration – *Д* – *Д*.

The chosen set of indicators makes it possible to evaluate electrical and mechanical activities of the cardiac and respiratory systems: $(\frac{dz}{dt})_{\max}$ value in combination with indicator τ enables evaluation of the relative changes in the cardiac output, which follows from the expression:

$$\Delta V = \rho(\frac{l^2}{z^2})T \cdot (\frac{dz}{dt})_{max} ,$$

where ΔV – stroke volume; ρ – specific blood resistance; l – distance between the electrodes; T – expulsion phase. As *l, p, z* remain practically unchanged during investigation, and T is proportional to τ interval, judgments about changes of ΔV can be made.

Increased working load on the operator and corresponding nervous and emotional tension leads to significant (two-time) reduction of the daily amplitude of the body temperature and CVS indicatorsvariations. At the same time average daily values of the body temperature remain practically unchanged and changes of PR values are insignificant [6].

ST segment of the electrocardiogram reacts operatively to the processes of the correct and incorrect information flow remembering [7]. Limiting of the operator's mobility causes reduction of the body temperature and PR by the end of the shift. It is also expedient to take into account changes of PR indicators caused by daily rhythms and hypokinesia [2].

The most sensitive method for normal and pathological brain state evaluation is the use of submicrovolt short-latency evoked brain potentials (SSLEBP) of acoustic and somatosensory stimulation. Summing up multiple brain potentials, evoked by acoustic and pain stimuli, enable PC registration of the signal with the amplitude smaller than the noise of electrocardiogram itself (about 2 – 3 μV). At the same time the electrocardiogram amplitude is more than 100 times that of SSLEBP.

SSLEBP make it possible to determine the speed of excitation conduction through the auditory pathway of the brain and somatosensory pathway of the brain and spinal cord. Besides, these potentials make it possible to evaluate the condition of separate relay nuclei of both auditory and somatosensory pathways [8].

The operator's state diagnostics is often associated with the analysis of EEG [9, 10]. In this case three types of EEG are considered possible to be used: desynchronized, transient and that synchronized with an external stimulation. These EEG types could serve as a criterion of the functional state of the operator's CNS. Except EEG, EMG, EKG and pneumogram (PG) are used, which are taken into account for the operator's state evaluation according to boundary values determined using the calculation algorithm based on statistical methods [11].

Condition of the seamen brain vessels during sea voyages was studied by the method of rheoencephalography (REG) for frontomastoidal arrangement of the electrodes. CNS fatigue was determined according to the critical frequency of light blinks fusion (CFLBF), performance – according to the seamen speed of response to emergency signal (ES) [12]. The condition of brain vessels was evaluated by the amplitude maximum of rheographic wave that closely correlates with the intensity of central blood flow.

The coefficient of correlation between the pulse blood filling A, CFLBF and emergency signal was calculated using the method of Spearman's rank correlation method [12]. It was found that along with the reduction of blood filling of the brain vessels, a simultaneous reduction of CFLBF sensing threshold and increased latent period of the operator's response to emergency signal are observed. .

There is a slight correlation between the indicators of pulse blood filling, CFLBF and the speed of response to emergency signal, which grows as voyage duration increases [12]. Hypodynamia in combination with other voyage conditions could cause violation of blood circulation regulation, reduction of brain vessels blood filling and faster fatigue development [12].

Influence of a set of unfavorable factors, the main of which are increased temperature and high CO_2 concentration in the air within a very short time, leads to worsening of the organism functional state. The longer their influence, the stronger manifestations of the subjective status irregularities and changes of FPR are. REG analysis has shown that a certain regular growth of the REG wave period occurs [13]. The pulse was slowing up to the end of the voyage, systolic AP was lowering beginning from the tenth day and to the end of the voyage its certain pronounced growth was observed. A well-pronounced growth of diastolic AP level was also observed.

Diastolic and dicrotic indices were gradually increasing towards the end of the voyage. REG change dynamics is the evidence of increased elastic-viscous properties of the brain arterial vessels while changes of diastolic and dicrotic indices indicate that as a result of long-time hypodynamia along with the increase arterial tonus, a well-pronounced increase of the tonus of brain veins is also observed [13].

Operator's FS evaluation according to physiological indicators must take into account the type of operator's activity, working conditions, the nature of external influences and, on the one hand, be maximally informative and accurate and, on the other hand, have minimal number of physiological indicators that provide achieving the required informativeness and accuracy of operator's FS evaluation.

Taking the above-mentioned into account, the table of informativeness and the influences of physiological indicators on the operator's functional state can be represented in the form given below (Table 1). Criteria for the operator's working activity evaluation are of continuous character, which requires discrete continuous monitoring of his physiological and psychological indicators. If the criteria quality changes in the worsening direction, the control system forms such test influences, which make it possible to assess the state of human operator without interfering with the working process.

Table 1

Evaluation of informativeness and the influence of physiological indicators on the operator's functional state

Registered indicator	Calculated indicators	The degree of informativeness and influence
1	2	3
1. Electrocardiogram, chest leads	HR; standard HR deviation; shift of ST segment; amplitudes of P, R, Q and ST waves; R-R, P-R and S-T intervals	Tension of the operator's work; correctness of the information flow retention; ability to perform working functions
2. Arterial pressure	Systolic (APS), diastolic (APD), average dynamic	APS – reduces at the beginning of the voyage and increases towards the end; APD – increases towards the end of the voyage
3. Tetrapolar rheogram	$(\frac{dz}{dt})_{\max}$; specific blood volume; minute blood volume; stroke volume; P_{lv}; coefficient of blood circulation efficiency	Cardiovascular system condition characterizes worsening of the operator FS

1	2	3
4. Electroencephalogram	α-rythm θ-rythm	Characterizes emotional stability, activity level, ability to take decisions; characterizes the index of emotional excitement
5. Rheoencephalogram	Dicrotic and systolic indices, maximal amplitude of the rheographic wave	Increases gradually towards the end of the voyage; characterizes the condition of brain vessels
6. Critical frequency of light blinks fusion (KFLBF)	Current value	Characterizes CNS fatigue degree
7. Speed of response to the emergency warning signal (EWS)	Speed of response	Characterizes the operator's performance
8. Spearman's rank correlation procedure	Correlation coefficient between the pulse strength A, CFLBF and APS.	With pulse strength reduction, CFLBF perception threshold decreases and latent period of response to EWS increases.

Practical implementation of the proposed approach to the operator's functional state evaluation is possible if the sensors and primary transducers of biomedical (physiological) signals meet a set of new requirements resulted from such an approach.

The first of these requirements is universality of electrodes and sensors, which enables the use of the same electrodes for registering biomedical signals of different origin.

On our opinion, it makes sense to introduce a requirement of autonomy and consider it as a functionally conditioned and constructive-informational autonomy, FCA and CIA, respectively.

Functionally-conditioned autonomy is an obligatory capability of the input converter (module) to perform its functions as a part of the system and outside it if an autonomous power source is available.

Constructive-informational autonomy is realization of primary and secondary converters, FCA and CIA, in a single constructive. At the input transducer output they generate normalized values of the registered signals, which provide its communication with other units of the system using spatio-temporal logic relationships.

Controllability of the input module is its capability to react to the control signals supplied from the outside or from the computation unit of the system [14].

This requirement has certain special features, which should be taken into account when it is used:

– input transducer must have all the necessary channels for receiving control signals, otherwise it is not capable to perform its functions;

– changes of the program, parameters and operating modes is set, as a rule, by the computation unit of the system but only if the above requirement is satisfied;

– if this definition provides the possibility of manual or remote control, then this is not only the controllability issue, but also the issue of psychological compatibility of the "doctor – PC operator" complex.

Conclusions

Medical data bases for operator's functional state evaluation, arrays of reference values of physiological indicators for each level of the operator's functions are determined by the experimental research results, statistically obtained data and are refined at the stage of determining operator's functional activities and controlled physiological indicators.

Designing effective multifunctional hardware-software means for operator's FS evaluation can be achieved on the condition of the obligatory correspondence of the operator's FS level to the levels of hardware-software means, which provide normal performance of the operator at each operator FS level.

When choosing electrodes and biomedical information sensors for hardware-software means for evaluating functional state of the operators, working under limited mobility conditions, it is recommended to take into account their correspondence to the requirements of autonomy and controllability of input modules.

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