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PSYCHOPHYSIOLOGICAL FEATURES OF THE DEVELOPMENT OF FATIGUE IN OPERATORS OF UNMANNED AVIATION SYSTEMS

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Introduction. In today's conditions, with the development of scientific and technical progress, new professions are appearing en masse. The profession of an operator of unmanned aircraft systems (UAS) is no exception. Complex work tasks contribute to the intensification of the decision-making process. The switching of attention, which causes the development of fatigue in operators of UAS. The adaptive processes of the body of military pilots largely depend on the level of fatigue development, which must be taken into account when assessing the adaptation reserves and the degree of reliability of the professional activity of these specialists. Considering the lack of similar information about operators of UAS, we can think about a certain similarity regarding the development of fatigue in pilots and operators. However, this question remains relevant, especially in the condition of war, and requires further study.

The aim of the research is to determine the psychophysiological features of the development of fatigue in operators of UAS.

Materials and methods of the research. 225 specialists of the relevant profession under 40 years of age were selected during the period of inpatient flight medical examination at the base of the Military Medical Clinical Center of the Central Region, taking into account their state of health. The examination was carried out with the help of the software and hardware complex for psy-chophysiological research «PPR-2». The organization and methods of examinations were developed on the theoretical and practical approaches.

Results. With the development of fatigue in operators of UAS, a number of psychophysiological parameters deteriorate. The article provides information on such changes according to the main investigated indicators and mean square deviations of the corresponding parameters, taking into account the distance between the vacation and the time of the survey. Among the high-speed psychophysiological characteristics, indicators of functional mobility of nervous processes, balance, the number of leads and delays in the study of the speed of reaction to a moving object with a reliability of $p < 0.05$ were noted. With regard to the characteristics of orientation in space and short-term visual memory, with the reliability of $p < 0.05$, the indicator of the time of correct pointing deteriorated in the study of short-term visual memory. Another group of indicators, represented by the mean square deviations of the corresponding parameters, can indicate the degree of mobilization of the body of the operators during the study of various psychophysiological functions moreover, a decrease in the value of this indicator indicates an increase in the level of mobilization of the body of the operators of UAS, that is, a greater readiness for the high-quality performance of assigned tasks. Thus, among the speed psychophysiological parameters, the following indicators confirm this: mean square deviation and characteristics of omission errors in the study of a complex visual-motor reaction, functional mobility and strength of nervous processes, balance in the study of the speed of reaction to a moving object ($p < 0.05$). With regard to the characteristics of orientation in space and short-term visual memory, the indicator of the number of correctly reproduced geometric shapes in the study of short-term visual memory deteriorated with the reliability of $p < 0.05$.

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Conclusions. It was established that the development of fatigue in operators of UAS leads to the deterioration of a number of psychophysiological characteristics of the operators (indicators of the functional mobility of nervous processes, balance, the number of advances and delays in the study of the speed of reaction to a moving object, the time of correct indication in the study of short-term visual memory) and a decrease indicators of the level of mobilization of the body (mean square deviation and characteristics of omission errors in the study of a complex visual-motor reaction, functional mobility and strength of nervous processes, balance in the study of the speed of reaction to a moving object, the number of correctly reproduced geometric figures in the study of short-term visual memory). Quite a lot of the investigated functions undergo only a tendency to change, which may indicate an unequal rate of deterioration of psychophysiological functions over time. The hypothesis was formulated that the reduction of functional reserves accompanying the development of fatigue causes such in role of individual psychophysiological functions and strengthen their connectivity (correlation coefficient in this case is 0.72). It has been proven that more complex functions of the body undergo the most intense transformation during the development of fatigue (latent period of a simple visual-motor reaction, latent period and mean square deviation of a simple visual-motor reaction, number of correct indications and time of false indication in the study of spatial orientation). At the beginning of the working period after rest, informative psychophysiological indicators determine only 16 % of the fatigue development factor. In tired operators of UAS, informative psychophysiological indicators determine 53.3 % of the variation of professionally important psychophysiological qualities. This indicates a significantly greater influence on the development of the state of fatigue of the analyzed psychophysiological parameters (latent period and the number of omissions of a simple visual-motor reaction, the time of correct pointing during orientation in space and the time of false pointing during the study of short-term visual memory).

Key words: operator of unmanned aircraft systems, psychophysiological parameters, fatigue, level of mobilization

Introduction

Nowadays the role of scientific and technological progress is increasing, which fundamentally transforms professional activity: new professions emerge, and the activity of existing ones is being transformed. The state of war intensifies the processes of such transformations. One of the modern professions is the personnel of unmanned automated technology management. According to some authors [7, 8, 18], unmanned aerial vehicles, UAVs are a type of aviation that is developing most actively in the world and can significantly change the tactical situation on the battlefield.

The main workload on UAV operators is determined by the action of information and emotional factors. The workplaces of UAV operators are equipped with various complex systems for displaying information and management, which allow to take into account the content and duration of tasks to be performed [7, 8, 12]. Complex work tasks contribute to the acceleration of decision-making, attention switching, which, in turn, leads to the development of fatigue in UAV operators [7].

Professional reliability and effectiveness are the most important indicators of psychophysiological readiness to perform professional tasks under conditions of professional stress, which undoubtedly occur in aviation [3]. According to some scientists [4], the intensification of fatigue development processes varies among servicemen with different personal qualities. The health status and level of psychophysiological qualities of a military pilot are closely related [17, 20] and depend on the type of aircraft [19], workload [15], presence of stressful situations, and so on. The adaptational processes of the body of military pilots largely depend on the level of fatigue development, which must be taken into account when assessing the reserves of adap-

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tation and the degree of reliability of the professional activity of these specialists [9]. Given the absence of identical information regarding UAV operators, it is possible to assume a certain similarity in the development of fatigue in pilots and operators. This issue is relevant in modern conditions, especially in wartime, and requires further study.

Taking into account the tactical and technical characteristics of class I unmanned aerial vehicles used for reconnaissance on the front line and having a small radius of action and range, as well as flight duration, it can be assumed that stressful situations for such operators are not uncommon and, accordingly, fatigue develops somewhat differently for them. Therefore, when organizing monitoring of psychophysiological qualities, it is necessary to carefully study the functional state to minimize possible errors during psychophysiological examination [4, 16].

Given the above, determining the characteristics of fatigue development in operators of UAV is extremely relevant.

The aim of the research is to determine the psychophysiological features of fatigue development in operators of UAV.

Materials and methods of the research

To identify the psychophysiological features of fatigue development in UAV operators, 225 such specialists aged up to 40 years were selected during stationary medical and flight examinations at the Military Medical Clinical Center of the Central Region (MMCC CR), taking into account their health status. The examination was carried out using a software and hardware complex for conducting psychophysiological research, «PFI-2» [13], registered in the register of persons responsible for introducing medical devices, active medical devices, implantable medical devices, and medical devices for *in vitro* diagnostics in Circulation No. 5850 of the Ministry of Health of Ukraine. The organization and methods of the examinations were developed on the basis of theoretical and practical approaches [10, 11]. The following parameters were recorded: critical flicker fusion frequency (CFFF) for green color in the right (rCFFF) and left (lCFFF) eye; latent period of simple visuomotor reaction (lSVMR), mean square deviation of SVMR (σSVMR), errors of omission of SVMR (eoSVMR); latent period of complex visuomotor reaction (lCVMR), mean square deviation of CVMR (σCVMR), errors of omission of CVMR (eoCVMR), instruction errors of CVMR (ieCVMR); functional mobility of nervous processes (FMNP), strength of nervous processes (SNP), number of FMNP tasks (nFMNP), dynamics of nervous processes (DNP) [1]; equilibrium in determining reaction time to a moving object (RMO) as the ratio of the number of delays to the number of anticipations, anticipation time (atRMO) and delay time (dtRMO) of RMO, number of anticipations (naRMO) and delays (ndRMO) of RMO (clock speed during RMO measurement is 2 rotations per minute); number of correct (cAC), incorrect (iAC) and missed (mAC) marks in performing a task on attention concentration (AC), time spent on performing the AC task (tAC); time of correct (tcSO) and incorrect (tiSO) indications during spatial orientation (SO), number of correct (ncSO) and number of incorrect (niSO) judgments; time of correct (tcSTVM) and incorrect (tiSTVM) indications during short-term visual memory (STVM) study, number of correct (ncSTVM) and incorrect (niSTVM) marks during STVM study, and so on.

Statistical data analysis was performed using parametric statistical methods and stepwise

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multiple correlation-regression analysis using the software package STATISTICA 13.3 (license AXA905I924220FAACD-N).

Results of the research and their discussion

The presence of prolonged hostilities significantly affects the functional state of both military personnel and the entire population of Ukraine. This phenomenon is caused by many factors. Firstly, there is high emotional tension that is formed in all people who in one way or another take part in the material and intellectual levels of providing hostilities [2]. The emotional state of the entire population of Ukraine somehow affects them. Secondly, in martial law, leaves of military personnel are prohibited, which reduces the functional reserves of the bodies of these individuals. Thirdly, the military actions have made their adjustments to the lifestyle of most of the population of Ukraine (internal and external mass displacement of persons associated with changes in the combat situation, changes in the structure of education of children and youth, destruction of homes, energy facilities, schools, hospitals, and other socially important infrastructure), which has increased the already high level of tension in the population. All of the above significantly affects the functional state of military personnel, increasing the level of their nervous and emotional tension, which leads to accelerated development of fatigue in them.

Previous studies have shown that a pilot's current functional state significantly affects their performance in tasks related to examining their psychophysiological status, which in turn depends on the time elapsed since the pilot's last vacation [14], during which their psychophysiological parameters are restored [5]. Therefore, as a factor that reflects fatigue development in UAV operators to some extent, the distance between the vacation and the examination was chosen. It has been proven that this factor affects the psychophysiological characteristics of military pilots [5]. Hence, it can be inferred that the distance between vacation and examination will also have an impact on the psychophysiological characteristics of UAV operators. According to the findings of this study presented below, several psychophysiological characteristics of UAV operators deteriorate with an increase in the time elapsed since the vacation. Additionally, the duration after the vacation is significantly ($p < 0.05$) correlated with psychophysiological indicators, such as the number of anticipations and delays in testing the reaction to a moving object, as well as the time of correct indication in the study of their short-term visual memory using the «geometric figures» method.

Shifts in psychophysiological functions are observed when comparing the period after vacation (up to 100 days) with the indicators of these functions registered after 250 days from the end of vacation. These data are presented in Table 1.

Fatigue in UAV operators is manifested both by the mean values and by the variability of psychophysiological parameters. The former indicate a deterioration in the corresponding functions. As fatigue develops, functional mobility and nervous process strength decrease by 6.8 % and 4.5 %, respectively, and the number of anticipations in RMO research increases by 35.7 %. The number of delays in RMO research increases by 17.5 %, while the balance of nervous processes (91.7 %) improves due to a reduction in nervous process activation during fatigue development in UAV operators.

The second group of indicators, represented by the standard deviations of the corresponding parameters, may indicate the degree of mobilization of operators' organisms during the study of various

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Table 1

Transformation of speed characteristics of UAV operators with the development of fatigue

Indicators	Mean values of indicators in different periods after vacation			Mean standard deviations of indicators in different periods after vacation (σ)		
	1–100 days, n = 103	> 250 days, n = 36	p	1–100 days, n = 103	> 250 days, n = 36	p
SVMR, ms	269.8	266.7	0.57	28.44	27.67	0.88
σSVMR, ms	22.8	20.2	0.25	12.42	9.43	0.07
CVMR, ms	407.8	405.8	0.83	45.68	52.63	0.28
σCVMR, ms	71.7	72.7	0.85	25.30	35.42	0.01*
eoCVMR, number	0.69	0.72	0.93	2.13	1.58	0.049*
FMNP, ms	327.2	349.6	0.02*	37.89	71.65	0.000001*
SNP, ms	414.8	433.3	0.10	41.36	91.36	0.0000001*
DNP, units	-0.002	-0.0023	0.36	0.00122	0.00121	0.97
Equilibrium in determining RMO, units	4.6	2.4	0.04*	5.92	3.43	0.0008*
naRMO, number	5.6	7.6	0.049*	5.20	4.97	0.77
ndRMO, number	13.4	11.4	0.049*	5.20	4.97	0.77

*Notes. *The significance of the difference between the indicators of non-fatigued and fatigued UAV operators is at the level of $p < 0.05$.*

psychophysiological functions. Moreover, a decrease in the magnitude of this indicator indicates an increase in the degree of mobilization of the UAV operator's organism, i.e., a greater readiness to perform tasks effectively. In this case, fatigue leads to an increase in fluctuations in the σCVMR index by 40.0 %, as well as in functional mobility and nervous process strength by 89.1 % and 120.9 %, respectively. At the same time, the level of mobilization of UAV operators' organisms increased according to the following indicators: balance of nervous processes by 72.6 % and the number of missed errors in CVMR research by 34.8 %. Therefore, it can be assumed that in some cases, a decrease in organism activation caused by fatigue leads to more careful instruction following during psychophysiological testing. However, such phenomena require additional research and discussion.

As a rule, fatigue development in UAV operators leads to a deterioration of a range of psychophysiological characteristics in UAV operators by 4.5–35.7 % and a decrease in mobilization levels by 40.0–120.9 %. This indicates that the volitional qualities of a person are primarily impaired during fatigue development. Some functions of the body can be compensated for by improving certain parameters.

Other psychophysiological characteristics of UAV operators also play a corresponding role in the process of diagnosing fatigue. Data on the transformation of orientation and short-term visual memory characteristics are presented in Table 2. This table shows that fatigue in operators does not generally lead to a significant deterioration of the examined psychophysiological characteristics. There is a slight decrease in the time for correctly reproducing a

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Table 2

Transformation of psychophysiological parameters of UAV operators that characterize spatial orientation and short-term visual memory

Indicators	Mean values of indicators in different periods after vacation			Mean standard deviations of indicators in different periods after vacation (σ)		
	1–100 days, n = 103	> 250 days, n = 36	p	1–100 days, n = 103	> 250 days, n = 36	p
tcSO, s	10.8	10.6	0.84	6.37	5.18	0.16
tiSO, s	11.6	9.6	0.35	10.17	7.40	0.07
ncSO, number	18.4	18.2	0.37	1.23	1.41	0.30
niSO, number	1.6	1.8	0.37	1.23	1.41	0.30
tcSTVM, s	11.5	10.0	0.01*	3.04	2.72	0.46
tiSTVM,s	10.5	13.5	0.12	9.64	8.02	0.26
ncSTVM, number	15.8	15.2	0.08	1.30	2.28	0.000011*
niSTVM, number	1.9	2.2	0.27	1.36	1.59	0.22

*Notes. *The significance of the difference between the indicators of non-fatigued and fatigued UAV operators is at the level of $p < 0.05$.*

symbol that was memorized by 15.0 % and a decrease in mobilization levels of the operator's body when performing memory tests for the parameter of the number of correctly reproduced geometric shapes by 75.4 %. In this case, the decrease in mobilization levels, in the context of decreasing levels of organism activation during fatigue development in UAV operators, is probably a useful compensatory reaction that allows the body to more qualitatively and quickly reproduce geometric shapes that were previously memorized. However, this statement requires further development.

Based on the data provided, it can be concluded that most of the psychophysiological functions that undergo transformation reliably deteriorate over time after a vacation. However, the interpretation of changes in certain characteristics is somewhat contradictory and requires further clarification. Nevertheless, many of the studied functions only show trends towards change, which may indicate varying rates of deterioration of psychophysiological functions over time. It can be hypothesized that the reduction of functional reserves that accompanies the development of fatigue triggers compensatory changes in the human body that affect the decrease or increase of the role of individual psychophysiological functions. Therefore, it is useful to analyze the strength of the relationships between individual psychophysiological characteristics during different periods after a vacation. This study was conducted using stepwise multiple correlation analysis (Figure), with the period after leaving the vacation until the moment of examination as the dependent variable, and the studied psychophysiological indicators as the independent variables.

The analysis of the obtained results revealed that, firstly, most informative indicators at the beginning of work and during the development of fatigue do not completely coincide. The exception is the SVMR parameter, which represents the simplest reaction of the body to a stimulus. Therefore, more complex functions of the body undergo the

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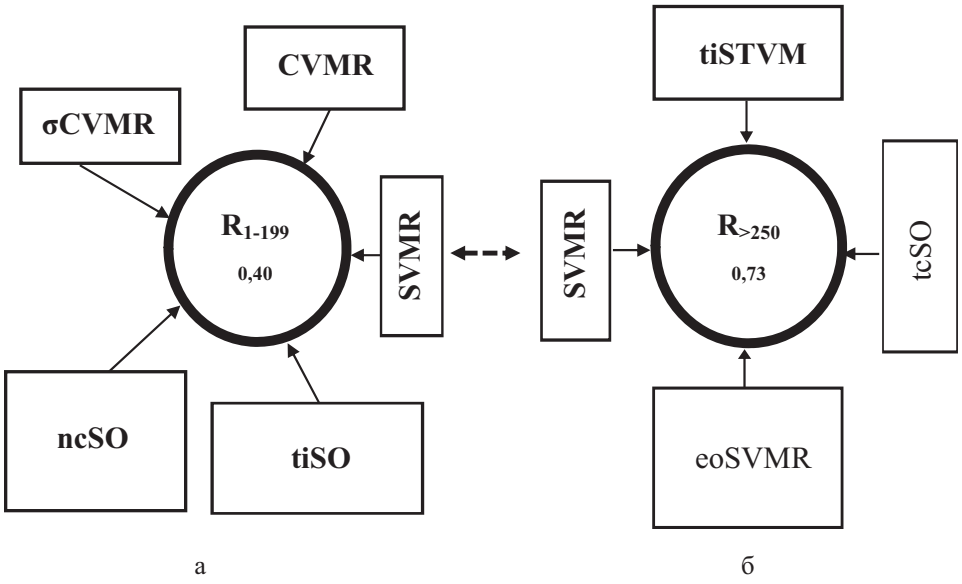

Figure. Transformation of the structure of connections of psychophysiological characteristics of UAV operators during the development of fatigue:

a – during the period of professional activity from 1 to 100 days after vacation (beginning of work);
b – during the period of professional activity from 250 days after vacation (presence of fatigue).

most intensive transformation during the development of fatigue. Secondly, the relationship between the period of fatigue development and the studied psychophysiological indicators is significantly different. At the beginning of the work period after rest (Figure, a), the coefficient of multiple correlation is 0.40. This means that informative psychophysiological indicators determine only 16 % of the fatigue development factor. In fatigued operators (Figure, b), the coefficient of multiple correlation is 0.73. This means that informative psychophysiological indicators determine 53.3 % of the fatigue development factor. This indicates a significantly greater influence of the analyzed psychophysiological indicators on the development of fatigue state.

The obtained phenomena should be discussed from the perspective of the theory of complex systems. As is known, a working person is a complex dynamic system that contains a corresponding number of subsystems related in a certain way. In the analyzed case, these are psychophysiological functions. To ensure the functioning of this system, the body involves a complex of interrelated psychophysiological components. Immediately after the vacation, when the physiological reserves of the body are «filled», their connection with other subsystems of the body is not very great, since the operator's body does not require additional activation of its reserve capabilities to perform its professional duties. Fatigue development leads to a decrease in the functional reserves of the body and reduces the synchronicity of the work of its individual subsystems. In this case, the body is forced to increase its capabilities at the expense of other subsystems. In the process of this transformation, connections with some psychophysiological functions weaken, and with some, they strengthen, which leads to the involvement of new ones.

In the literature, there are certain pieces of evidence for the enhancement of correlation between distinct psychophysiological parameters during fatigue development. It has been proven that there

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is a change in the structure of correlation links between rapid psychophysiological indicators in combatants after a ten-day recovery period under MMCC CR conditions [6].

Conclusions

1. It has been established that the development of fatigue in UAV operators leads to a deterioration in a number of psychophysiological characteristics of the operators (indicators of the functional mobility of nervous processes, balance, the number of anticipations and delays in studying reaction speed to a moving object, and the time to correctly indicate short-term visual memory) and a decrease in indicators of the level of mobilization of the organism (mean square deviation and error rate in studying a complex visual-motor reaction, functional mobility and strength of nervous processes, balance in studying reaction speed to a moving object, and the number of correctly reproduced geometric figures in studying short-term visual memory). Many of the studied functions only show a tendency to change, which may indicate unequal rates of deterioration of psychophysiological functions over time.
2. A hypothesis has been formulated that the reduction of functional reserves accompanying the development of fatigue in the human body causes compensatory restructuring that affects the decrease or increase in the role of certain psychophysiological functions and enhances their coherence (the correlation coefficient in this case is 0.72).
3. It has been proven that more complex organism functions undergo the most intensive transformations during the development of fatigue (latent period of a simple visual-motor reaction, latent period and mean square deviation in the study of a complex visual-motor reaction, the number of correct and time of incorrect indications in the study of spatial orientation). At the beginning of the working period after rest, informative psychophysiological indicators determine only 16 % of the fatigue development factor. In fatigued UAV operators, informative psychophysiological indicators determine 53.3 % of the variation in professionally important psychophysiological qualities. This indicates a significantly greater influence on the development of fatigue state of the analyzed psychophysiological parameters (latent period and number of misses in the study of simple visual-motor reaction, time of correct indication in spatial orientation and time of incorrect indication in the study of short-term visual memory).

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