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AGE CHARACTERISTICS OF THE FORMATION OF FATIGUE IN MILITARY HELICOPTER PILOTS

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Introduction. In the modern war, aviation occupies a leading place, therefore, all issues that increase the quality of the professional activity of the State Aviation acquire primary importance. During the operation of the aircraft, the pilot develops a state of fatigue, which integrally reflects the influence of a complex of harmful factors and the deterioration of the quality of information processing, reduces attention, the speed of their reactions, and thus the risk of fatal errors arises. A new modern factor that burdens the functional condition of flight crew and aviation personnel is the time awake at night, due to the active use of their mobile phones and tablets to connect to Facebook, Twitter, Instagram and other social networks. Today, fatigue is not considered a condition that is a contraindication to flight clearance. This is due to the lack of reliable methods for assessing the level of fatigue, especially in people of different ages, the absence of approved legal acts for determining acceptable levels of fatigue, the lack of trained specialists for assessing the level fatigue, etc. Now when martial law is in force, there is an urgent need to assess the level of fatigue of flight crew members and aviation personnel who are actively performing combat tasks. The importance of the discussed problem increases due to the involvement in flights of pilots of various ages, qualifications and experience of working in combat conditions, which is reinforced by the shortage of personnel and the state policy, aimed at the maximum protection of life and health of servicemen. Considering the above, the study of the age-related features of the formation and development of fatigue in military pilots is an urgent issue today.

The aim of the research is to generalize the experience of psychophysiological reactions associated with the development of fatigue in military helicopter pilots of various ages, taking into account their professional activities in a real theater of war.

Materials and methods of the research. In order to identify the age-specific features of the development of fatigue in military helicopter pilots, 573 relevant specialists aged 22 years to 59 years were selected during the period of inpatient medical-flight examination based on the Department of Psychophysiology and Psychology of the Military Medical Clinical Centre of the Central Region. The examination was carried out with help of the «PFI-2» software and hardware complex for psychophysiological research. The organization and methods of examinations were developed on the basis of theoretical and practical approaches.

Results. An external indicator, which to some extent is reflected in the development of fatigue in military helicopter pilots, from the moment after the end of vacation to the moment of the examination, excluding the initial phase of training and stabilization of the level of work capacity, reflects the tendency of the loss of functional reserves of the pilots` body. It is worth noting that in helicopter pilots of different ages, the process of fading functional reserves and increasing the level of fatigue can occur at a fairly different speed. In order to exclude the influence of fatigue mechanisms implemented in other age groups, four separate age ranges were analyzed:

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20—29 years, 30—39 years, 40—49 years and 50—59 years. In the age range of 50—59 years, the largest number of informative indicators is observed, 8.75 % of which refer to speed characteristics. The remaining parameters relate to concentration of attention (12.5 %) and short-term visual memory (12.5 %). The coefficient of multiple correlation in this case is R = 0.62 (p = 0.005). The next age range 40—49 years has a smaller number of informative indicators (6). Among them, 33.3 % are speed characteristics, 50.0 % are indicators of reaction to a moving object, and 16.7 % are indicators of short-term visual memory. The multiple correlation coefficient between these psychophysiological parameters is R = 0.27 (p = 0.04). The development of fatigue in helicopter pilots in the age range of 30—39 years has 5 informative indicators. Among them, 60.0 % refer to speed characteristics and 40.0 % to spatial orientation indicators. The multiple correlation coefficient between these psychophysiological parameters is R = 0.29 (p = 0.013). The age range of 20—29 years is represented by 6 informative indicators. An interesting fact is that among these indicators, only 16.7 % belong to the group of speed reactions, 50.0 % of indicators characterize spatial orientation, and 33.3 % of psychophysiological characteristics relate to the assessment of short-term memory. The multiple correlation coefficient between these psychophysiological indicators is R = 0.32 (p = 0.006). Summarizing the obtained results for all age groups, it is worth noting that the percentage of use of fast reactions associated with fatigue tends to decrease in helicopter pilots from older to younger age. This trend is especially noticeable in the 50—59 and 20—29 age groups. It turns out that at an older age, speed reactions suffer the most. Therefore, fatigue, which manifests itself to a greater extent at the age of 50—59, is closely related to the speed reactions that are most vulnerable for this age, and vice versa, qualitative and stable speed reactions are more characteristics at a young age. The contribution of cognitive functions in the discussed range of age groups has the opposite trend. That is, with a decrease in age in the analyzed groups, there is an increase in the contribution of cognitive functions associated with the development of fatigue. Both noted trends are proof of the fact of a gradual decrease in speed characteristics with age and an increase in the contribution of cognitive functions in young helicopter pilots. Another important feature of the development of fatigue emerges from the conducted multiple stepwise correlation-regression analysis. The calculated correlation coefficients are structured in the following series: 0.62 (50—59 years), 0.27 (40—49 years), 0.29 (30—39 years), 0.32 (20—29 years). Such a profile of the change in correlation coefficients can be explained by greater intensity of fatigue formation processes in older age groups of helicopter pilots, when the reduction of their speed capabilities is more closely related to a violation of the functional state; the degree of connection of psychophysiological functions with pronounced fatigue is approximately the same in all other age groups and is at an average level, which indicates the presence of significant compensatory capabilities in helicopter pilots aged 20—49 years. Thus, each age group of helicopter pilots has its own specifics of the development of fatigue, but the general pattern of changes in a number of individual psychophysiological characteristics with age is maintained.

Conclusions. Specific features of the development of fatigue in military helicopter pilots who directly participated in hostilities have been determined. It is shown that each age group has a specific connection for this group with a complex of psychophysiological functions aggregated with the state of fatigue. This effect is especially evident in older (50—60 years) by speed functions and younger (20—29 years) by cognitive functions. A complex of informative indicators related to the development of fatigue in helicopter pilots of various ages was identified, on the basis of which equations were constructed to estimate the level of fatigue. Ways of practical application of the invented psychophysiological effects in practice by assessing the level of fatigue in military helicopter pilots to determine the strategy for restoring their psychophysiological status and training the relevant psychophysiological functions, taking into account their age criteria, are discussed.

Key words: age characteristics, fatigue, psychophysiological characteristics, military helicopter pilots, speed reactions, cognitive functions

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Introduction

In the context of modern warfare, aviation holds a pivotal role, and enhancing the quality of professional performance within the State Aviation becomes paramount. In this context, it is essential to acknowledge that human operators are a critical element in the «man-aircraft» system, subject to numerous detrimental factors during aircraft operation. Consequently, pilots experience fatigue as a cumulative effect of this intricate mix of adverse influences. Fatigue poses a severe threat to aviation safety [14]. It diminishes information processing efficiency, impairs attention and reaction speed, and heightens the risk of fatal errors [11]. Notably, about 21 % of aviation accidents are attributed to the human factor, particularly fatigue-related issues [16].

Contemporary literature [23] identifies a constellation of factors that trigger fatigue. These factors encompass heavy workloads, shift work, inadequate sleep quality and quantity, sleep interruption, informational stress, extended working hours, and insufficient rest time [23]. Such factors incite acute or chronic stress, contributing to fatigue development. Acute stress affects cognitive information processing, leading to diminished performance in demanding situations, as seen in contexts like nuclear power plants [17]. It has been demonstrated that 64% of information search productivity variance and 41 % of operation execution time variation can be explained by psychophysiological changes arising from stress and fatigue in workers.

Armed conflicts have a decisive impact on the consequences of stress reactions, among which fatigue takes the leading place [9, 13, 15, 22]. It is emphasized that anticipation, as a response to stress, initiates the process of homeostasis through a chain of reactions that allow the body to resist various threats [21], when the response to stress is activated in a chronic form, in particular, in the form of fatigue. Anticipatory reactions of anxiety, in turn, lead to behavioral, cognitive and psychological disorders [8, 18, 20] and contribute to a decrease in attention concentration and decision-making speed, memory impairment [8, 19], etc.

Environmental factors modulate the response to stress and fatigue. A contemporary factor exacerbating the functional state of aircrews is the amount of nighttime wakefulness resulting from their increased use of mobile phones and tablets to access social media platforms such as Facebook, Twitter, Instagram, and others [14].

Experience, task preparation diligence, troop type, and related factors contribute to the modulation of stress level transformation and fatigue development [6]. Research findings show that fatigue, resulting from the development of stress, was experienced by 2.94 % of transport aircraft crews, 14.28 % of fighter aircraft crews, 20.83 % of helicopter crews, 52.17 % of air traffic control personnel, and 14.28 % of other ground aviation personnel [14].

In the present context, fatigue is not treated as a disqualifying condition for flight clearance. This is due to several factors: the absence of reliable fatigue assessment methods, especially across different age groups; lack of established regulatory standards for permissible fatigue levels; shortage of trained specialists for fatigue assessment; and other related factors. This is particularly relevant to the pilot profession, as pilots operate various aircraft types and engage in a wide array of complex tasks. Information on this topic remains fragmented. Particularly in the conditions of armed conflict, evaluating aviation personnel fatigue levels, especially those actively involved in critical tasks,

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becomes imperative. Given the highest manifestation of fatigue in helicopter pilots (20.83 %), the analysis of fatigue manifestations in military helicopter pilots becomes a pressing priority.

The objective of this research is to comprehensively analyze and synthesize the accumulated knowledge regarding psychophysiological reactions correlated with fatigue development among military helicopter pilots across different age groups, considering the pilots' professional engagement in actual wartime scenarios.

Materials and methods of the research

For the purpose of investigating age-related patterns in fatigue development among military helicopter pilots, a total of 573 specialized professionals aged 22 years to 59 years were selected during the inpatient medical-flight evaluation phase. This evaluation took place at the Department of Psychophysiology and Psychology within the Military Medical Clinical Center of the Central Region. The assessments were conducted utilizing the PFI-2 software and hardware complex, renowned for its effectiveness in psychophysiological research [5]. This complex is registered under No. 5850 by the Ministry of Health of Ukraine as a certified medical device, encompassing both active implantable medical devices and medical devices designed for in vitro diagnostics. The examination methodology was devised in alignment with comprehensive theoretical and practical frameworks [2, 3]. Various indicators were meticulously recorded, encompassing critical frequency of flickering fusion for the color green in both the right eye (1) and left eye (2), latent period of a simple visual-motor reaction (3), mean square deviation of a simple visual-motor reaction (4), omission errors of a simple visual-motor reaction, latent period of the complex visual-motor reaction (5), mean squared deviation of complex visual-motor reaction (6), errors of omission of complex visual-motor reaction (7), and errors of instructions of complex visual-motor reaction, functional mobility of nervous processes (8), strength of nervous processes (9), number of tasks related to functional mobility of nervous processes (10), dynamism of nervous processes (11) [4]; balance in determining the speed of reaction to a moving object as the ratio of the number of delays to the number of overtakings, the time of overtaking (12) and delay (13), the number of overtaking (14) and delays (15) to reaction to a moving object (clockwise speed when measuring a reaction to a moving object is 2 revolutions per minute); the time of correct (16) and false indication (17) during spatial orientation, the number of correct (18) and the number of false (19) judgments; the number of correct (20), false and missed marks when performing the task on concentration of attention, the time spent on performing the task on concentration of attention (21); the time of correct (22) and false indication (23) during the study of short-term visual memory, the number of correct (24) and false (25) indication.

Subsequently, the data underwent rigorous statistical analysis via stepwise multiple correlation-regression analysis using the STATISTICA 13.3 software package (license AXA905I924220FAACD-N).

Results of the research and their discussion

The foundation of this study lies in the selection of a primary indicator of fatigue – an external marker that serves as a starting point. One such indicator could be the period elapsed from the end of vacation to the moment of examination [1]. This temporal span, in a sense, reflects the trend of functional reserves depletion within pilots' bodies, particularly

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after the initial training phase and stabilization of performance levels. However, it's crucial to acknowledge that the rate of functional reserve reduction and fatigue escalation can vary significantly among pilots of different ages and while performing distinct tasks in helicopters. Thus, analyzing data from professionals within the same age group can provide insights into fatigue development.

The working hypothesis of this study posits that the mechanisms ensuring necessary work capacity, coupled with fatigue development, gradually evolve with age in helicopter pilots. To investigate the phenomena highlighted in this hypothesis, a stepwise multiple correlation-regression analysis was conducted on the professionally significant psychophysiological attributes of military helicopter pilots. The level of fatigue development was considered the dependent variable, characterized by the time elapsed since vacation termination until examination, accounting for a 100-day interval that covers commissioning and stable performance phases. To isolate the influence of fatigue mechanisms prevalent in other age groups, the analysis was executed separately within four age ranges: 20–29 years; 30–39 years; 40–49 years; and 50–59 years.

The outcomes of the research are illustrated in the Figure. It is important to note that the stepwise multiple correlation analysis not only indicates the degree of association among independent variables but also identifies psychophysiological parameters closely linked to the level of fatigue development.

Commencing the discussion on the age-related transformation of psychophysiological attributes from the older age bracket appears prudent, as it's within this range (50–59 years) that profound changes associated with the age of the helicopter pilots become more apparent. Indeed, this age group exhibits the highest count of informative indicators (8), signifying the complexity of modeling fatigue development within this cohort of helicopter pilots. Of these indicators, 75 % belong to the category characterizing high-speed physiological processes. The remaining two indicators are divided between attention concentration (12.5 %) and parameters assessing short-term memory (12.5 %). The multiple correlation coefficient among these psychophysiological indicators stands at $R = 0.62$ ($p = 0.005$). When calculating the percentage of informative characteristics from the total number of psychophysiological parameters, the distribution of informative speed attributes in helicopter pilots across different age groups (50–59, 40–49, 30–39, 20–29 years old) appears as follows: 24 %, 8 %, 12 %, 4 %. Evidently, the number of informative speed reactions within the 20-29 years age group is six times less than that in the 50–59 years age group. This disparity in linkage holds significance at the $p < 0.04$ level.

Moving on to the subsequent age range of 40–49 years, a reduced to 6 informative indicators is observed. These indicators are distributed as follows: 33.3 % – speed attributes; 50.0 % – reactions to moving objects, combining to form 83.3 %; and 16.7 % – an indicator of short-term visual memory. A substantial discrepancy in the proportion of speed reactions versus cognitive functions is evident ($p < 0.02$). The coefficient of multiple correlation amid these psychophysiological indicators rests at $R = 0.27$ ($p = 0.04$).

For helicopter pilots aged 30–39 years, the development of fatigue involves 5 informative indicators. Among these, 60.0 % relate to speed parameters, while 40.0 % evaluate spatial orientation. A noticeable shift in the balance between speed and cognitive components of informative

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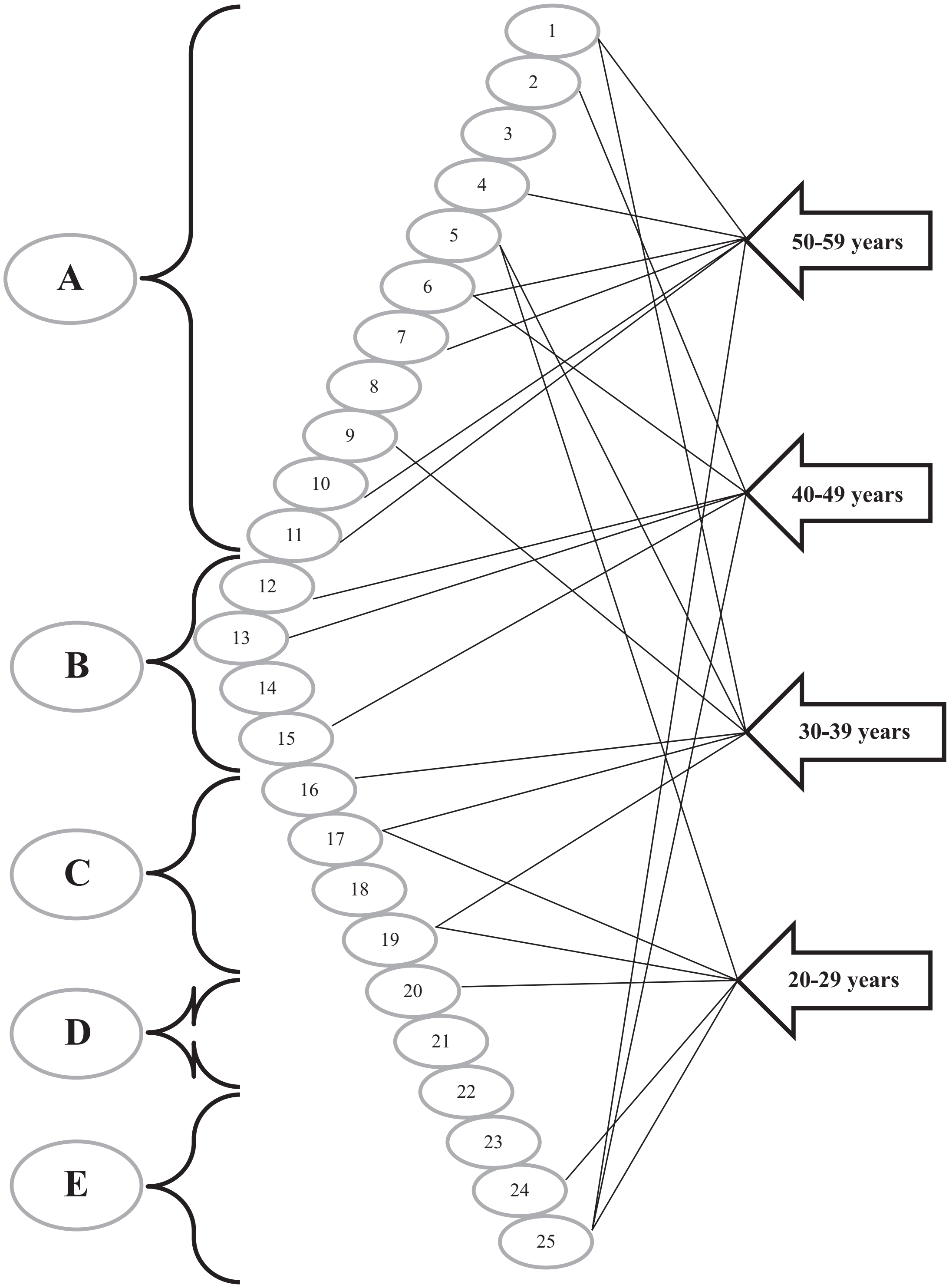

Figure. Correlation structure of psychophysiological parameters in military helicopter pilots of various ages with the duration of work period post-leave until examination:

(A) Speed Characteristics; (B) Reactions to a Moving Object; (C) Spatial Orientation Characteristics; (D) Attention Characteristics (Corrective Test); (E) Visual Memory Characteristics.

The numbers in circles have been explained in Materials and methods section

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characteristics is apparent. The coefficient of multiple correlation between these psychophysiological indicators is R = 0.29 (p = 0.013).

Within the 20–29 years age group, 6 informative indicators are identified. Remarkably, only 16.7 % of these indicators pertain to speed attributes; 50.0 % characterize spatial orientation; and 33.3 % assess short-term memory – in sum, cognitive responses comprise 83.3 % of the total. Notably, a significant difference in the weightage between speed reactions and cognitive functions is evident (p < 0.02). The multiple correlation coefficient amid these psychophysiological indicators is R = 0.32 (p = 0.006).

Summarizing the obtained outcomes across all age groups, it becomes evident that the utilization of fast reactions linked to fatigue tends to decline with deviations from older to younger helicopter pilots. This trend is particularly pronounced in the 50–59 and 20–29 age groups. Hence, advanced age predominantly impacts speed reactions. Consequently, fatigue, more pronounced in older age groups, is intrinsically tied to the vulnerability of speed functions within this cohort. Conversely, robust and stable speed reactions are more characteristic of the younger age group, resulting in their exclusion from the list of informative indicators.

On the contrary, the contribution of cognitive functions within the analyzed age groups follows an opposite trajectory. Specifically, as age decreases, there is an increase in the significance of cognitive functions in relation to the development of fatigue. Both these observed trends substantiate the gradual reduction of speed characteristics with advancing age and an augmented reliance on cognitive functions in young helicopter pilots, possibly attributed to their relative lack of professional experience.

Another noteworthy insight from the conducted multiple correlation analysis emerges. The computed correlation coefficients follow this sequence: 0.62 (for ages 50–59), 0.27 (for ages 40–49), 0.29 (for ages 30–39), 0.32 (for ages 20–29). Two key observations can be gleaned from these results. Firstly, the relationship between fatigue level and psychophysiological functions is most pronounced within the 50–59 years age group. This can be attributed to the heightened intensity of fatigue development processes in senior helicopter pilots, where the degradation of the helicopter's speed capabilities is more closely associated with a disruption in its functional state. Secondly, the degree of correlation between psychophysiological functions and fatigue intensity is relatively uniform across the other age groups, hovering at an intermediate level. This suggests the presence of considerable compensatory capacities within helicopter pilots aged 20–49 years. This sustained level of helicopter functionality must be sustained as long as feasible.

The research culminated in the construction of regression equations, enabling the estimation of fatigue development levels within each age group.

The central aim of this study was to analyze the psychophysiological responses tied to the progression of fatigue in military helicopter pilots of varying ages, in the context of their operational engagements within a real theater of war. This quandary was approached via different avenues. Initially, subjective methodologies were employed including interviews, diary analyses, and questionnaires [7, 10, 12]. These techniques are straightforward and expedient in obtaining results. However, they tend to overlook the intricate psychophysiological mechanisms behind fatigue development.

An alternative approach hinges on analyzing the energy facet of bodily functioning – exploring

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heart rate variability, for instance. For instance, an investigation into military personnel [6] illuminated that stress can result in psychosocial and psychophysiological adversities. Nonetheless, even in this scenario, the cognitive processes linked to fatigue development remain understudied.

This study delved into the informational facets of fatigue development among helicopter pilots spanning different age brackets. A discernible variance was uncovered in the way fatigue evolves across diverse age groups of helicopter pilots. Informative indicators for diagnosing fatigue levels were identified, and equations devised for estimating fatigue levels across various age cohorts.

A key constraint of this study, tempering the precision of fatigue assessments, is the lack of a sufficiently extensive cohort of military personnel across various ages, undergoing comprehensive assessments.

However, it is surmised that beyond the evaluation of fatigue's effects in helicopter pilots of varying ages, the findings of this study can be utilized in structuring the training of specific psychophysiological attributes in helicopter pilots, targeting their developmental gaps across different age brackets.

Conclusions

1. The study provides valuable insights into the development of fatigue among military helicopter pilots actively engaged in combat operations. Notably, distinct patterns have emerged across different age groups, revealing specific connections between fatigue and aggregated psychophysiological functions. This phenomenon is particularly pronounced in individuals aged 50 to 60, where speed-related functions exhibit a significant association, while in the 20 to 29 age group, cognitive functions play a prominent role.
2. The research has successfully identified a comprehensive set of informative indicators that are closely tied to the progression of fatigue in helicopter pilots across various age brackets. Equations have been formulated based on these indicators, enabling the estimation of fatigue levels with reasonable accuracy.
3. The practical implications of these findings can refine fatigue assessment among military helicopter pilots by leveraging these psychophysiological insights. This, in turn, offers a strategic advantage in determining effective strategies to restore their psychophysiological status. Moreover, these age-specific criteria can be integrated into training regimens, tailoring psychophysiological function enhancement to the unique requirements of each age group.

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