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THE ROLE OF SIMPLE VISUAL-MOTOR COGNITIVE INDICATORS IN FLIGHT SAFETY

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Summary: *Pilot psychophysiological performance is a critical determinant of flight safety in modern aviation, with 70-80% of aviation accidents attributed to human factors [6,7]. Assessment based solely on cardiovascular parameters and stress indices is limited in evaluating pilot stress and emotional strain and does not fully reflect real-time cognitive readiness. In this study, simple visual-motor reaction (SVMR) indicators of Azerbaijan Airlines pilots were evaluated using a dual-task simulator model. While performing primary flight tasks, pilots also completed additional visual-motor tasks, allowing assessment of the impact of cognitive load on psychophysiological performance.*

The results showed that under dual-task conditions, cognitive indicators were highly sensitive: mean reaction time increased, root mean square deviation (RMSD) rose, and attention stability and concentration changed, predominantly remaining at moderate and low levels. The Whipple accuracy coefficient decreased, the number of errors increased, and mean reaction time values rose. The marked increase in reaction time and other cognitive changes observed in Table 1 indicate that even when autonomic stress remains near normal, changes in cognitive functions during the initial stage of the experiment may increase the likelihood of future compromises in flight safety. Statistical calculations presented in Table 2 confirm these results.

Keywords: *Pilot, flight safety, dual-task simulator model, simple visual-motor reaction (SVMR), cognitive load, human factor*

Introduction

Human factors play a central role in ensuring flight safety, as issues related to pilot decision-making, accuracy, attention, and stress tolerance are among the primary causes of aviation accidents and incidents [1]. Recent research indicates that assessments based solely on cardiovascular parameters or subjective self-report measures do not fully capture pilots' functional and cognitive readiness in real time [5].

Fundamental research in aviation physiology has demonstrated that declines in pilot performance is often associated with frequent tension and cognitive–volitional overload [2]. The evaluation of pilots' cognitive indicators is considered an essential component of safety monitoring. In particular, the dual-task method and the measurement of simple visual-motor reactions (SVMR) reflect performance changes when pilots perform tasks under additional, non-standard conditions and allow the identification of human factor risks during aviation accidents.

To date, studies have mainly assessed simple visual-motor reactions under laboratory conditions or through general psychomotor

tests, while their integrative and biomarker-based application in real flight conditions has not been sufficiently investigated [3].

The novelty of this study lies in measuring SVMR indicators in real time under modern, standards-compliant flight simulator conditions, enabling the assessment of pilots' cognitive and psychophysiological readiness levels. This approach provides a scientific basis for transitioning to a human factor–based flight safety model in modern aviation.

Material and methods

The study was conducted on pilots using various simulators, including Boeing and Embraer systems. Simple visual-motor reaction (SVMR) assessments were performed using the «NS-Psychotest» computer-diagnostic system and the «Accordix» telemetry system, with results evaluated as mean values. While performing primary flight tasks, pilots simultaneously completed additional SVMR tasks, following the established methodology for assessing cognitive indicators via SVMR. Execution of the additional tasks without affecting the quality of the primary flight task was considered a standard criterion for evaluating sustained attention and attention concentration.

To obtain more comprehensive information about the characteristics and functional state of the central nervous system, additional indicators were analyzed based on the results of this methodology, particularly the Whipple's accuracy coefficient (AC). The Whipple accuracy coefficient determines the ratio between errors and correct keyboard responses and is calculated using the formula:

$$AC = \frac{N - R}{N + P},$$

where N represents the total number of measurements (presented signals), R is the number of correct responses, and P is the number of errors.

Red light signals were presented at the center of the monitor screen. Upon the appearance of a signal, pilots were required to press the corresponding keyboard key as quickly and accurately as possible, enabling assessment of both reaction speed and accuracy. The interval between signals varied from 0.5 to 2.5 seconds. The first 5–7 signals were considered trial stimuli and were not included in the analysis. A total of 70 signals were presented during each examination.

During the application of the methodology, the functional state of the examinee and the testing conditions significantly influenced the results. Therefore, SVMR measurements were performed before the flight, during the flight, and after the flight in order to comprehensively evaluate the dynamics of reaction time and changes in accuracy among pilots.

Thus, the SVMR methodology enables early detection of the pilot's actual functional readiness, potential stress development, attention deficits, accuracy levels, error frequency, and other relevant indicators. Research conducted using this methodology ensures objective real-time assessment of the human factor and creates new perspectives for evaluating flight safety based on biomarkers.

Discussion of Results

The evaluation of the study results was carried out based on cognitive indicators, including mean reaction time, standard deviation, accuracy, and other related parameters. The mean value reflects the average speed of simple visual–motor reactions (SVMR) characteristic of an individual: the lower the mean reaction time, the higher the reaction speed. The standard deviation serves as an indicator of the stability of the sensorimotor response: the smaller the standard deviation, the more stable the sensorimotor reaction speed under conditions of time constraint and simulated emergency situations.

The lower the Whipple accuracy coefficient, the greater the number of errors and the lower the degree of sustained attention, which, in turn, is determined by the strength and balance of nervous processes.

In previous studies, the psychophysiological state of pilots during flight was primarily assessed using heart rate, the LF/HF (low frequency/high frequency) ratio, and ECG stress indicators [4]. These methods employ Baevsky's Stress Index (SI) and the RSAI (Regulatory Sys-

tems Activity Index) to determine stress and emotional tension in pilots, however, they do not directly measure the dynamics of attention reserves or sensorimotor performance.

The novelty of the present study lies in the simultaneous assessment of simple visual–motor reactions (SVMR) alongside the evaluation of pilots' psychophysiological stress both in the simulator and during actual flight conditions.

Through SVMR measurements, the real-time state of pilots' cognitive resources was objectively assessed, including parameters such as reaction speed and error rate while performing additional tasks in parallel with primary flight operations.

A comparative analysis of SVMR indicators of the examined pilot before and during flight under different operational conditions (Table 1) demonstrated that the increase in standard deviation from 151 ms to 296 ms indicates a decrease in the stability of sensorimotor reactions. This change confirms that while performing additional tasks, pilots exhibit greater variability in sensorimotor performance and an increased potential risk of errors. The Whipple accuracy coefficient decreased from 0.88 to 0.68, which was accompanied by an increase in the number of errors. This finding may be explained by elevated stress levels during flight.

Table 1

Comparative analysis of SVMR indicators of the examined pilot before and during flight under different operational conditions

Dimensions	Pilot examined "Pre-flight and In-flight conditions"				
	Stress indicators			SVMR cognitive indicators	
	Heart rate	ECG			
Pre-flight	Mean: 93 beats/min. Maximum: 109 beats/min.	LF/HF	4,82	Mean reaction time	317
				Attention stability	1,07 O
		Sİ	67,0	Attention concentration	0,84 O
				Standard deviation	151
		RSAI	4	Anticipatory errors	2
				Delayed errors	7
				Whipple accuracy coefficient	0,88
In-flight	Mean: 96 beats/min. Maximum: 113 beats/min.	LF/HF	5,47	Mean reaction time	588,6
				Attention stability	1,2 O
		Sİ	96,4	Attention concentration	1,01 A
				Standard deviation	296
		RSAI	4	Anticipatory errors	4
				Delayed errors	20
				Whipple accuracy coefficient	0,68

Indicators:
LF/HF ratio - relative high- and low-frequency indicators
Baevsky's Stress Index (SI)
RSAI - Regulatory Systems Activity Index

The parameters of the pilot mentioned in the table show that the performance of additional tasks (SVMR) and the increase in cognitive load during flight have a significant impact on the results (Table 1). The increase in reaction time, the increase in the mean square deviation and the decrease in the Whipple accuracy coefficient indicate that the pilot is operating at the limit of his attentional resources, which weakens sensorimotor stability.

In our experiments, we have extensively investigated the objective assessment of psychophysiological cognitive indicators by measu-

ring stress indicators (HB, LF/HF, ECG) and real-time measurement of simple visual motor responses (SVMR). This methodology accurately determines changes in the pilot's cognitive resources and performance when performing additional tasks.

The sharp increase in reaction time and the increase in errors, especially in pilots, indicate that an increase in cognitive load during flight can result in a decrease in psychophysiological cognitive indicators to a low level, even if vegetative indicators are close to normal. This fact proves that an assessment based solely on cardiovascular parameters is not sufficient.

Based on the analysis conducted, the statistical analysis of the SVMR figures of 59 pilots is shown in Table 2. The main scientific novelty of the study is that for the first time, the SVMR parameters of pilots were analyzed integratively in flight simulators (IL-76, Boing, Cessna) and cognitive parameters were identified as the main objective indicators of the pilot's performance in flight (Table 2). Statistical studies have shown the accuracy of the figures. Thus, the trend of the direction of change of cognitive indicators (Table 1) was statistically confirmed (Table 2).

Table 2

Statistical analysis of the experiment on cognitive indicators during flight

Statistical results of experiments on cognitive indicators												Errors committed during the flight			
Indicators		Mean reaction time		Attention stability		Attention concentration		Standard deviation		Accuracy (Whipple's coefficient)		Anticipatory errors		Delayed errors	
		person	percent	person	percent	person	percent	person	percent	person	percent	person	percent	person	percent
results: incompatible indicators	-	16	27,118 %	14	23,728 %	12	20,338 %	13	22,033 %	4	6,779 %	15	25,423%	8	13,559%
results: constant indicators	0	2	3,389 %	15	25,423 %	23	38,983 %	2	3,389 %	16	27,118 %	13	22,033%	9	15,254%
results: variable indicators	+	41	69,491 %	30	50,847 %	24	40,677 %	44	74,576 %	39	66,101 %	31	52,542%	42	71,186%

Conclusion

Ensuring flight safety cannot rely solely on standard medical examinations or conventional cardiovascular monitoring indicators, as these are not sufficiently informative. In this regard, the results of our study demonstrate that a pilot's actual level of readiness is directly associated with cognitive parameters, particularly the speed of simple visual-motor reaction (SVMR).

The application of the SVMR method used in our research enables objective assessment of a pilot's actual cognitive readiness for flight, allowing early detection of reduced attention resources, increased reaction time accompanied by growth in standard deviation, a decline in the critically important accuracy coefficient, and a rise in error frequency. This approach also provides a basis for predicting potential accident risk and for developing individualized systems for monitoring psychophysiological and cognitive indicators.

In conclusion, flight safety should be determined not only by the reliability of technical systems but also by the pilot's psychophysiological and cognitive state measurable in real time. Thus, the integration of simple visual–motor reaction (SVMR) assessment establishes a new biomarker-based direction for evaluating flight safety and offers a promising scientific platform for the objective monitoring of the human factor in aviation safety.

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PİLOTLARIN SADƏ GÖRMƏ MOTOR KOQNİTİV GÖSTƏRİCİLƏRİNİN UÇUŞ TƏHLÜKƏSİZLİYİNDƏ ROLU

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Xülasə: *Pilotun psixofizioloji fəaliyyəti müasir aviasiyada uçuş təhlükəsizliyinin həlledici amilidir, məhz buna görə aviasiyada uçuş qəzalarının 70–80%-i insan faktoru ilə əlaqələndirilir [6] [7]. Yalnız Ürək-damar göstəricilərinin və gərginlik indeksinin öyrənilməsi pilotun stres və emosional gərginliyini qiymətləndirməkdə məhduddur və real vaxtda koqnitiv hazırlığı tam əks etdirmir. Bizim tədqiqatımızda "Azərbaycan Hava Yolları" pilotlarının sadə görmə motor reaksiyaları (SGMR) göstəriciləri öyrənilmişdir. Belə ki, koqnitiv göstəriciləri simulyator şəraitində "ikili tapşırıq" modelindən istifadə edilərək qiymətləndirilmişdir. Pilotlar əsas uçuş tapşırıqlarını yerinə yetirərkən, əlavə görmə motor tapşırıqları icra etmiş, bunun nəticəsində koqnitiv yükün psixofizioloji göstəricilərə təsiri öyrənilmişdir.*

Tədqiqatların nəticəsi göstərir ki, əlavə tapşırıqları yerinə yetirərkən, koqnitiv göstəricilər çox həssas olurlar: reaksiya vaxtının orta qiyməti artır, ortokvadratik sapma yüksəlir, diqqətin davamlılığı və konsentrasiyası dəyişilir. Diqqətin göstəriciləri, əsasən, orta və aşağı səviyyələrdə müşahidə olunur. Uippl dəqiqlik əmsalı azalır, səhvlər isə artır. Bundan başqa 1-ci cədvəldə pilotun göstəricilərində reaksiya vaxtının kəskin artması və digər koqnitiv dəyişikliklər müəyyən edilmişdir. Vegetativ gərginlik normaya yaxın səviyyədə olsa belə, ilk eksperiment mərhələsində koqnitiv göstəricilərdəki dəyişikliklər gələcəkdə uçuş təhlükəsizliyinin pozulma ehtimalını yüksəldə bilər. 2-ci cədvəldə isə verilən statistik hesablamalar alınan nəticələri təsdiqləyir.

Açar sözlər: *pilot, uçuş təhlükəsizliyi, ikili tapşırıq modeli, sadə görmə motor reaksiya (SGMR), koqnitiv yük, insan amili*

РОЛЬ ПРОСТЫХ ЗРИТЕЛЬНО-МОТОРНЫХ КОГНИТИВНЫХ ИНДИКАТОРОВ В БЕЗОПАСНОСТИ ПОЛЕТОВ

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Аннотация: *Психофизиологические показатели пилота являются критическим фактором безопасности полетов в современной авиации, при этом 70–80% авиационных происшествий связаны с человеческим фактором [6,7]. Оценка, основанная исключительно на сердечно-сосудистых параметрах и показателях стресса, ограничена в оценке стресса и эмоционального напряжения пилота и не в полной мере отражает когнитивную готовность в реальном времени. В данном исследовании оценивались показатели простой зрительно-моторной реакции (ПЗМР) у пилотов «Азербайджанских авиалиний» с использованием симулятора с методикой «двойного выполнения» задания. При выполнении основных задач полета пилоты одновременно выполняли дополнительные зрительно-моторные задачи, что позволило оценить влияние когнитивной нагрузки на психофизиологические показатели.*

Результаты показали, что в условиях "двойного задания", в полете среднее время реакции увеличилось, среднеквадратическое отклонение повысилось, а концентрация и устойчивость внимания снизились и преимущественно находились на умеренном и низком уровнях. В то же время коэффициент точности Уиппла снизился в результате количество ошибок увеличилось, а средние значения времени реакции возросли. Заметное увеличение времени реакции и другие когнитивные изменения, наблюдаемые в таблице 1, указывают на то, что даже когда уровень вегетативного стресса остается близким к норме, на начальном этапе эксперимента изменения когнитивных функций могут повысить вероятность будущих нарушений безопасности полетов. Данные в таблице 2 статистические вычисления подтверждают полученные результаты.

Ключевые слова: *пилот, безопасность полетов, модель двойной задачи, простая зрительно-моторная реакция (ПЗМР), когнитивная нагрузка, человеческий фактор*