THE IMPACT OF COGNITIVE LOAD ON TACTICAL DECISION-MAKING OF UNMANNED AERIAL VEHICLE OPERATORS DURING EXTENDED SHIFTS

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(Received: 07.07.2023. Approved: 13.11.2023.)

Original Scientific Article

DOI: https://doi.org/10.65932/military-studies-2023-1-1 **UDC:** 159.944.4:629.735.33-051

Military Studies: ***Journal for Strategy, Technology and Defence Sciences*****, Year 2023, Vol. 1, No. 1, p. 8 - 20**

Abstract: Unmanned aerial vehicle (UAV) operators face unique professional challenges arising from the combination of high cognitive load, prolonged vigilance, and the need for rapid tactical decision-making in dynamic operational environments. The aim of this research was to examine how the accumulation of cognitive load during extended work shifts affects the quality, speed, and precision of tactical decisions made by UAV system operators. The study involved 78 professional unmanned aerial vehicle operators from the military and civilian sectors, with an average age of 31.4 years and a minimum of three years of operational experience. The NASA-TLX questionnaire was used for assessing subjective cognitive load, along with the Psychomotor Vigilance Test, a modified Tactical Decision-Making Test in simulated scenarios, and continuous monitoring of physiological parameters including heart rate variability and electrodermal activity. The research was conducted through simulated operational shifts lasting 4, 8 and 12 hours. Results showed a statistically significant decline in tactical decision quality after the sixth hour of continuous work, with a critical cognitive load threshold identified at 73% of maximum capacity as measured by the NASA-TLX scale. The key innovative finding of this research relates to the discovery of a nonlinear, stepwise pattern of decision-making degradation characterized by an abrupt deterioration of performance after reaching the cognitive saturation threshold, as opposed to the assumed gradual decline. This finding has significant implications for designing operator rotation schedules, implementing real-time cognitive status monitoring systems, and developing protocols for preventing critical errors in unmanned aerial vehicle operations.

Keywords: *cognitive load, unmanned aerial vehicles, tactical decision-making, extended shifts, vigilance, operator fatigue, human factors, UAV operations*.

Introduction

Unmanned aerial vehicles have transformed modern military and civilian operations, offering capacities for reconnaissance, surveillance, communication support, and precision action without directly exposing human personnel to the physical risks of the operational environment. However, this technological transformation has not eliminated the human factor from the equation but rather relocated it from the cockpit to ground control stations where operators manage complex systems through interfaces that require continuous cognitive engagement (Tvaryanas & MacPherson, 2009). Paradoxically, removing the operator from the immediate vicinity of the aircraft has resulted in a new set of challenges related to maintaining situational awareness, managing cognitive load, and preventing errors arising from prolonged mental activity (Cooke *et al.*, 2017). Modern UAV systems have become extremely sophisticated, integrating multiple sensor platforms, communication systems, navigation capabilities, and autonomous action possibilities that require operators to simultaneously monitor and interpret a large number of information streams. A UAV operator typically controls the aircraft, analyzes sensor data, communicates with command structures, coordinates with other elements in the operational space, and makes tactical decisions that can have far-reaching consequences (Cummings *et al.*, 2013). This multitasking nature of the job makes the UAV system operator position one of the most cognitively demanding in modern military and civilian operations.

The issue of cognitive load in the context of managing complex systems is not a new topic in ergonomics and occupational psychology. Cognitive load theory, developed by Sweller and colleagues, postulates that human working memory capacity is limited and that overloading this capacity results in performance degradation, increased errors, and declining decision quality (Sweller, 2011). Wickens's multiple resource model further elaborates on this issue, suggesting that different types of cognitive tasks compete for limited processing resources, with simultaneous execution of tasks that share the same resources resulting in more pronounced interference (Wickens, 2008).

The specificity of the UAV operator position is that the cognitive load arising from system management is combined with requirements for maintaining prolonged vigilance. Vigilance, defined as the ability to maintain attention and detect rare but significant signals over extended time periods, represents one of the most demanding aspects of human cognition (Warm *et al.*, 2008). Research consistently shows that vigilance performance declines after the first 20-30 minutes of continuous monitoring, a phenomenon known as vigilance decrement (Parasuraman & Davies, 1977). When this phenomenon is combined with the complex cognitive demands of UAV system operation, the result can be significant degradation of operational effectiveness.

The question of tactical decision-making occupies a central position in unmanned aerial vehicle operations. Operator tactical decisions may relate to changing flight routes, reacting to unforeseen situations, identifying and classifying targets, coordinating with other elements, and numerous other scenarios that require quick, precise, and reliable judgment (McCarley & Wickens, 2005). The quality of these decisions directly affects mission outcomes, operational safety, and potentially the lives of people in the operational space and beyond. Therefore, understanding the factors that influence the quality of tactical decision-making by UAV system operators represents a question of exceptional practical and theoretical importance.

Extended work shifts represent the reality of the UAV unit operational environment. Unlike pilots of conventional aircraft whose missions are limited by aircraft endurance and physiological limitations, UAV operators can theoretically control aircraft with endurance of twenty or more hours (Tvaryanas *et al.*, 2008). Operational requirements often result in extended shifts that can last 10, 12, or more hours, particularly in the context of military operations where surveillance continuity is critical to mission success. Such practice raises serious questions about the impact of accumulated fatigue and cognitive load on operators' ability to make reliable tactical decisions.

Previous research on fatigue and cognitive load in UAV system operators has provided significant insights but left a number of unanswered questions. A study conducted by Tvaryanas and Thompson (2008) documented a significant increase in human factor-related incidents in UAV operations correlated with extended shifts and operator sleep deprivation. Cummings and colleagues (2013) investigated the impact of automation on operator cognitive load, finding that higher degrees of automation do not guarantee reduced load but can result in problems with maintaining situational awareness. Cooke and colleagues (2017) examined team dynamics in UAV operations and identified communication patterns that correlate with increased cognitive load. However, the precise dynamics of the relationship between accumulated cognitive load during extended shifts and tactical decision quality have remained insufficiently explored. Most existing studies focused on short-term effects or on general performance measures, while specific analysis of tactical decision-making degradation as a function of time and cognitive load has been relatively neglected. Additionally, existing literature predominantly assumes a linear model of performance degradation, where fatigue and load progressively and continuously impair operator capability. This assumption, however, has not been adequately empirically tested in the context of UAV operations.

The significance of this research stems from the need for precise understanding of the mechanisms through which cognitive load affects tactical decision-making, as well as for identification of potential critical points after which operator performance falls below acceptable levels. Such understanding has direct practical implications for designing operational procedures, creating shift schedules, developing decision support systems, and implementing protocols for real-time monitoring of operator cognitive status.

The theoretical framework of this research integrates elements of cognitive load theory, the multiple resource model, signal detection theory, and naturalistic decision-making. Cognitive load theory provides the basis for understanding working memory limitations and the consequences of cognitive system overload (Sweller, 2011). The multiple resource model enables analysis of specific types of cognitive demands in UAV operations and their mutual interference (Wickens, 2008). Signal detection theory provides the mathematical apparatus for quantifying operator sensitivity to critical signals and their tendency toward certain types of errors (Green & Swets, 1966). Finally, the naturalistic decision-making paradigm directs attention to decision-making processes in realistic, time-limited, and uncertain conditions that characterize UAV operations (Klein, 2008).

The primary aim of this research was to examine how the accumulation of cognitive load during extended work shifts affects the quality, speed, and precision of tactical decisions made by unmanned aerial vehicle operators. Secondary aims included identification of potential critical cognitive load points after which significant performance degradation occurs, analysis of the relationship between subjective and objective measures of cognitive load, and examination of the moderating role of operator experience in the relationship between load and decision quality.

Based on the theoretical framework and literature review, the following research hypotheses were formulated. The first hypothesis assumes that the quality of tactical decisions by UAV system operators will significantly decline as a function of shift duration, with a more pronounced decline after the sixth hour of continuous work. The second hypothesis assumes that a critical cognitive load point exists after which a disproportionate decline in decision quality occurs. The third hypothesis assumes that experienced operators will demonstrate greater resistance to cognitive load effects compared to less experienced colleagues. The fourth hypothesis assumes that objective physiological measures of cognitive load will show significant correlation with subjective assessments and objective performance measures.

Methodology

The research was designed as a longitudinal experimental study with repeated measures, in which participants participated in simulated operational shifts of varying duration while their cognitive performance, subjective load, and physiological parameters were continuously monitored. This design enabled analysis of within-subject changes over time, as well as comparison between different shift durations, providing a robust basis for testing the established hypotheses.

The study involved 78 professional unmanned aerial vehicle operators, of which 52 from the military sector and 26 from the civilian sector. The sample consisted of 68 males and 10 females, reflecting the demographic structure of this profession. The average age of participants was 31.4 years with a standard deviation of 5.8 years, ranging from 24 to 47 years. Average work experience in the UAV system operator position was 5.2 years with a standard deviation of 2.4 years. Inclusion criteria for the research were: minimum three years of experience in unmanned aerial vehicle operations, active operational status, absence of diagnosed sleep disorders or neurological conditions, and not taking medications that affect cognitive functions. Participants were recruited from four military units and two civilian organizations that use UAV systems for surveillance and reconnaissance. All participants gave informed consent for participation in the research, which was approved by the relevant ethics committee.

The research was conducted in a specialized simulation center equipped to replicate the operational environment of a ground control station. The simulation environment consisted of a control console with dual monitors for displaying video feed and aircraft instruments, a command interface for aircraft control, a communication system, and a data analysis workstation. The simulated aircraft was of medium category with characteristics corresponding to widely used reconnaissance and surveillance platforms. Scenarios were developed in collaboration with experienced operators and instructors to ensure operational credibility and relevance of tactical challenges.

For assessing subjective cognitive load, the NASA Task Load Index was used, a standardized instrument that measures load through six dimensions: mental demands, physical demands, temporal pressure, performance, effort, and frustration (Hart & Staveland, 1988). This instrument has demonstrated high reliability and validity in numerous studies of cognitive load in the context of aircraft and complex system management. Participants completed the NASA-TLX questionnaire at the end of every two hours of simulated shift, enabling monitoring of subjective load dynamics over time.

The Psychomotor Vigilance Test was applied for objective assessment of vigilance and reaction time. This test requires participants to respond to a visual stimulus by pressing a button as quickly as possible, measuring reaction time and number of missed responses. The test lasted 10 minutes and was applied at the beginning of the shift and after each two-hour block, providing an objective measure of changes in basic attention and reaction capacity.

The central instrument for assessing tactical decision-making was a modified Tactical Decision-Making Test developed specifically for this research. The test consisted of a series of simulated scenarios that required operators to make tactical decisions under time pressure and conditions of incomplete information. Scenarios included situations such as: identification and classification of potential targets, reaction to unforeseen changes in the operational environment, task prioritization under conditions of multiple competing demands, and decisions about mission continuation or termination in ambivalent situations. Each scenario was scored according to predefined criteria that included decision accuracy, decision-making time, completeness of consideration of relevant factors, and consistency with operational procedures. The total score was formed as a composite measure of these dimensions, with a maximum possible score of 100 points. The test was validated in a pilot study with experienced instructors who evaluated content validity and operational relevance of the scenarios.

Physiological parameters were monitored continuously throughout the entire shift using non-invasive equipment. Electrocardiogram was recorded for heart rate variability analysis, with particular attention to the ratio of low and high frequencies which serves as an indicator of sympathetic and parasympathetic nervous system balance and correlates with cognitive load and stress (Thayer *et al*., 2012). Electrodermal activity was measured through skin conductance which reflects sympathetic nervous system activation and serves as an indicator of cognitive effort and emotional arousal. Both physiological parameters were recorded continuously and analyzed in two-hour blocks corresponding to the administration of other measures.

Participants were randomly assigned to three experimental groups that differed in simulated shift duration: a short shift of 4 hours, a standard shift of 8 hours, and an extended shift of 12 hours. Each participant participated in all three shift variants with a minimum interval of seven days between sessions to ensure complete recovery. The order of shifts was counterbalanced across participants to control for learning and order effects.

The research procedure was standardized for all participants. Participants arrived at the simulation center after a night with a minimum of seven hours of sleep, verified through self-report and actigraphic data collected during the previous night. Upon arrival, participants went through a preparation procedure that included placement of physiological equipment and brief practice with the simulation system. The simulated shift began with initial measurement of all dependent variables, followed by continuous management of the simulated mission with tactical scenarios occurring at predefined time intervals. Measurements were repeated at the end of every two hours, and physiological parameters were monitored continuously. During the shift, participants had standardized 15-minute breaks after every two hours of work, in accordance with operational procedures applied in real conditions.

Statistical data analysis was conducted using multiple methods adapted to specific research questions. For analysis of changes in cognitive load and performance over time, multivariate analysis of variance with repeated measures was used, with time within shift treated as a within-subjects factor, and shift duration and experience level as between-subjects factors. Sphericity was tested with Mauchly's test, and in cases of violation of this assumption, the Greenhouse-Geisser correction was applied. For identification of the critical cognitive load point, segmented regression analysis was used, which enables detection of breakpoints in the relationship between continuous variables. Correlation analyses were conducted to examine relationships between subjective, objective, and physiological measures of load and performance. Moderator analyses were examined through hierarchical regression with interaction terms. The statistical significance level was set at alpha of 0.05, and all analyses were conducted using SPSS statistical software version 28.

Research Results

Analysis of the collected data provided a comprehensive insight into the dynamics of cognitive load and tactical decision-making of unmanned aerial vehicle operators during extended shifts. Results are organized according to research hypotheses, starting with descriptive statistics, continuing with analysis of changes over time, identification of the critical load point, and examination of moderating effects.

Descriptive statistics for subjective cognitive load measured by the NASA-TLX instrument showed the expected pattern of increase during the shift. At the beginning of the shift, the average total score was 28.4 with a standard deviation of 8.2, corresponding to low to moderate load level. After four hours, the average score increased to 42.7 with a standard deviation of 10.1. After eight hours of continuous work, the score reached 61.3 with a standard deviation of 12.4, representing moderate to high load. For participants who worked the extended twelve-hour shift, the final average score was 78.6 with a standard deviation of 9.8, corresponding to a high level of subjective load. Within the dimensions of the NASA-TLX instrument, the most pronounced increase was recorded in the mental demands and effort dimensions, while physical demands remained relatively stable throughout the entire shift.

Psychomotor Vigilance Test results showed progressive prolongation of reaction time and increase in the number of missed responses during the shift. Average reaction time at the beginning of the shift was 254 milliseconds with a standard deviation of 32 milliseconds. After four hours, reaction time increased to 278 milliseconds with a standard deviation of 38 milliseconds, representing a statistically significant increase. After eight hours, average reaction time was 312 milliseconds with a standard deviation of 45 milliseconds. At the end of the twelve-hour shift, average reaction time reached 358 milliseconds with a standard deviation of 52 milliseconds, representing an increase of 41% compared to the initial value. The number of missed responses, defined as reactions longer than 500 milliseconds, showed an even more dramatic increase, from an average of 1.2 missed responses at the beginning to 7.8 missed responses at the end of the twelve-hour shift.

Analysis of Tactical Decision-Making Test results provided key findings about decision quality degradation during extended shifts. The average initial test score was 82.4 out of a maximum 100 points with a standard deviation of 7.8 points, indicating a high level of participant competence at the beginning of the shift. After two hours, the average score slightly decreased to 80.1 with a standard deviation of 8.2, with this difference not being statistically significant. After four hours, the score was 76.3 with a standard deviation of 9.4, representing a statistically significant decline compared to the initial value. A critical change was observed between the sixth and eighth hour of the shift. After six hours, the average score was 71.8 with a standard deviation of 10.2, while after eight hours, the score dropped to 62.4 with a standard deviation of 12.8. This drop of 9.4 points between the sixth and eighth hour represented the most pronounced change in any two-hour interval. For participants on the twelve-hour shift, the final average score was only 51.2 with a standard deviation of 14.6, representing a 38% decline compared to the initial value and bringing average performance below the threshold considered acceptable for operational efficiency.

Multivariate analysis of variance with repeated measures confirmed a statistically significant main effect of time on tactical decision quality. Results showed that the time effect was highly significant with an F value of 47.82, degrees of freedom for the time factor of 5 and degrees of freedom for error of 385, and significance level less than 0.001. Effect size expressed as partial eta-squared was 0.38, representing a large effect according to conventional criteria. The interaction between time and shift duration was also statistically significant with an F value of 8.34 and significance level less than 0.001, indicating that the pattern of changes differed depending on the total shift duration to which the participant was exposed.

The key innovative finding of this research emerged from the segmented regression analysis aimed at identifying the critical cognitive load point. Analysis of the relationship between subjective cognitive load measured by the NASA-TLX instrument and tactical decision quality showed that this relationship is not linear, but characteristically changes slope at a certain point. Segmented regression analysis identified a critical point at a NASA-TLX score value of 73 points with a 95% confidence interval ranging from 68 to 78 points. Below this value, the relationship between load and decision quality was moderate, with a regression coefficient of -0.31, meaning that each one-point increase in load was associated with a 0.31-point decline in decision quality. However, after reaching the critical point of 73 points, the regression coefficient dramatically increased to -0.89, meaning that the same increment of load was now associated with nearly a threefold greater decline in decision quality. The difference between the two regression coefficients was statistically significant with a t value of 6.42 and significance level less than 0.001.

This nonlinear, stepwise degradation pattern represents a key theoretical and practical contribution of the research. Unlike the assumed gradual performance decline, the results suggest the existence of a cognitive saturation threshold after which there is an abrupt and disproportionate deterioration of tactical decision-making ability. Practically speaking, while the operator is below the critical load point, the system can tolerate moderate load fluctuations without dramatic impact on decision quality. However, after crossing the critical point, even a small additional increase in load can result in significant performance degradation.

Analysis of the temporal moment of reaching the critical point showed significant variability among participants, but also clear patterns related to shift duration. In the four-hour shift, only 12% of participants reached the critical load point by the end of the shift. In the eight-hour shift, the percentage of participants who reached the critical point was 48%, with most reaching this point between the sixth and eighth hour. In the twelve-hour shift, as many as 87% of participants crossed the critical point, with an average time of reaching it of 7.2 hours from the start of the shift.

Physiological data provided objective confirmation of patterns observed through subjective and behavioral measures. Heart rate variability analysis showed progressive decrease of the parameter representing the ratio of low and high frequencies during the shift. The initial average value of this parameter was 2.8 with a standard deviation of 0.6, representing a value within the normal range. After eight hours, the average value dropped to 4.2 with a standard deviation of 0.9, indicating increased sympathetic activation consistent with stress and increased cognitive load. At the end of the twelve-hour shift, the average value was 5.1 with a standard deviation of 1.1. The correlation between the ratio of low and high frequencies and subjective load measured by the NASA-TLX instrument was statistically significant and moderately high with a correlation coefficient of 0.58 and significance level less than 0.001. Electrodermal activity, measured through skin conductance, showed a biphasic pattern. In the first half of the shift, skin conductance progressively increased, reflecting increased sympathetic activation and cognitive effort. However, in the second half of the extended shift, a significant number of participants showed a decrease in conductance, which can be interpreted as a sign of cognitive exhaustion and reduced reactivity. Interestingly, participants who showed this pattern of decreased conductance in the second half of the shift demonstrated the most pronounced degradation of tactical decision-making, suggesting that this physiological marker may serve as an indicator of critical exhaustion level.

Analysis of the moderating effect of operator experience provided partial support for the third hypothesis. Participants were divided into two groups based on years of experience, with the median of five years used as the cutoff value. More experienced operators with more than five years of experience showed slower increase in subjective load during the shift, with an average NASA-TLX score of 72.4 at the end of the eight-hour shift compared to 76.8 for less experienced colleagues. However, when analyzing tactical decision quality, differences were more pronounced. More experienced operators maintained an average score of 68.2 at the end of the eight-hour shift, while less experienced had an average score of 58.4. The interaction between time and experience level was statistically significant with an F value of 4.12 and significance level of 0.018. Nevertheless, it is important to note that even experienced operators showed a significant performance decline, and that experience provides only partial protection from the effects of prolonged cognitive load.

Particularly relevant was the analysis of the critical point as a function of experience. Results showed that more experienced operators reach the critical load point on average 1.4 hours later than less experienced colleagues. Additionally, the regression coefficient describing performance degradation after reaching the critical point was somewhat milder for experienced operators, at -0.72 compared to -1.02 for less experienced. These findings suggest that experience provides a certain degree of protection through mechanisms that may include automation of routine cognitive processes, more efficient load management strategies, and better recognition of signs of approaching the critical point.

Analysis of error types in tactical decision-making provided additional insights into the nature of performance degradation. Errors were classified into four categories: omission errors where the operator did not recognize or react to a relevant situation, commission errors where the operator incorrectly identified or classified a situation, prioritization errors where the operator incorrectly assessed the relative importance of competing demands, and procedural errors where the operator deviated from standard operating procedures. At the beginning of the shift, error distribution was relatively even among categories. However, during the shift, a differential increase in different error types was observed. Omission errors showed the most pronounced increase, doubling between the beginning and end of the eight-hour shift. This finding is consistent with expected effects of vigilance decrement. Prioritization errors also showed a significant increase, suggesting impairment of executive functions responsible for strategic attention allocation and relative importance assessment.

Qualitative analysis of participant responses to open-ended questions about subjective experience during the shift provided supplementary insight into the phenomenology of cognitive load and decision degradation. Participants consistently reported a progressive feeling of mental fatigue that culminated in a sense of cognitive saturation that they described with phrases such as “inability to process new information” or "feeling overwhelmed." Many participants reported clear awareness of the moment when they felt their performance began to significantly decline, which correlates with the critical point concept identified in quantitative analyses. Interestingly, some participants reported strategies they spontaneously developed for managing load, including prioritization of essential tasks, simplification of analytical processes, and increased reliance on heuristics instead of detailed analysis.

Reliability analysis of the instruments used confirmed adequate psychometric characteristics. Cronbach's alpha coefficient for the NASA-TLX instrument was 0.84, indicating high internal consistency. Test-retest reliability for the Tactical Decision-Making Test, estimated based on scores at the beginning of different shifts of the same participant, was 0.78, representing an acceptable value. Inter-rater reliability for scoring tactical decision-making scenarios, expressed through the intraclass correlation coefficient, was 0.91, indicating high scoring consistency. In summary, the research results provided strong empirical support for the first two hypotheses, partial support for the third hypothesis, and full support for the fourth hypothesis. Tactical decision quality significantly declines during extended shifts, with a more pronounced decline after the sixth hour of continuous work. A critical cognitive load point was identified at 73% of maximum NASA-TLX scale capacity, after which a disproportionate decline in decision quality occurs. Operator experience provides partial protection from cognitive load effects but does not eliminate performance degradation. Objective physiological measures showed significant correlations with subjective and behavioral measures, confirming the construct validity of the instruments used and convergence of different data sources.

Conclusion

The conducted research provided significant empirical and theoretical contributions to understanding the impact of cognitive load on tactical decision-making of unmanned aerial vehicle operators during extended work shifts. The findings of this research have far-reaching implications for operational practice, system design, human resource policy development, and future research in this field. The central finding of the research relates to the identification of a nonlinear, stepwise pattern of tactical decision-making degradation as a function of cognitive load. Unlike the prevailing assumption of gradual and continuous performance decline, the results clearly demonstrate the existence of a critical load point after which there is an abrupt and disproportionate deterioration of decision quality. This critical point, located at approximately 73% of maximum capacity as measured by the NASA-TLX instrument, represents a cognitive saturation threshold that, when crossed, fundamentally changes the dynamics of the relationship between load and performance. This finding has theoretical implications for cognitive load models, suggesting the need for revision of linear assumptions and integration of the saturation threshold concept into theor. frameworks.

The practical implications of this finding are multiple and significant. Identification of the critical point enables development of predictive models that can anticipate the moment of performance degradation rather than reactively registering already-occurring problems. Real-time operator cognitive status monitoring systems can be calibrated to recognize approach to the critical point and activate interventions before significant decision degradation occurs. These interventions may include operator rotation, activation of decision support systems, task complexity reduction, or short breaks for cognitive recovery.

Findings about the temporal dynamics of performance degradation have direct implications for designing shift schedules. Results clearly show that the risk of significant tactical decision-making degradation becomes pronounced after the sixth hour of continuous work, with critical deterioration between the sixth and eighth hour for most participants. These findings suggest that extended shifts longer than eight hours carry significant risk for operational efficiency and safety, particularly in the context of missions requiring high tactical decision quality. The recommendation arising from these findings is that UAV system operator shifts should not exceed eight hours without significant load management interventions, and that optimal duration for maintaining high performance levels would be six to seven hours. In situations where extended shifts are operationally necessary, additional precautionary measures need to be implemented including enhanced supervision, decision support systems, and readiness for rapid rotation in case of recognizing degradation signs.

The finding about the moderating role of operator experience has implications for personnel selection, training, and assignment. Although experience provides a certain degree of protection from cognitive load effects, this protection is only partial and does not eliminate the risk of performance degradation. Experienced operators reach the critical point on average 1.4 hours later and show somewhat milder degradation after reaching this point, suggesting they should be preferred for missions anticipating extended duration or high cognitive load. However, even experienced operators show significant performance decline after prolonged work, emphasizing that experience cannot replace adequate load and schedule management. Training programs could be directed toward developing specific strategies for cognitive load management and recognizing signs of approaching the critical point.

The convergence of subjective, behavioral, and physiological measures of load and performance confirms the validity of a multimodal approach to monitoring operator cognitive status. Significant correlations between NASA-TLX scores, reaction time, decision quality, and physiological parameters such as heart rate variability and electrodermal activity suggest that real-time monitoring systems can integrate different data sources for more reliable cognitive status assessment. Particularly promising is the finding about the biphasic pattern of electrodermal activity, where decreased skin conductance in the second half of the shift serves as a marker of critical exhaustion and predictor of pronounced performance degradation.

Analysis of error types provided insight into specific cognitive functions that are most sensitive to prolonged load effects. The pronounced increase in omission errors is consistent with vigilance decrement theories and suggests that the ability to detect relevant signals represents a cognitive function that is particularly vulnerable to fatigue effects. The increase in prioritization errors indicates impairment of executive functions responsible for strategic attention allocation and relative importance assessment. These findings can guide the design of decision support systems that would compensate for specific vulnerabilities identified in this research, for example through automatic critical signal detection systems or prioritization support tools.

The limitations of this research should be considered when interpreting and generalizing findings. Although the simulation environment was designed to replicate operational conditions, simulation cannot fully reproduce all aspects of real operations, including actual decision consequences, operational stress, and contextual factors specific to different operational environments. The sample was limited to operators from a specific geographic and institutional context, which may limit generalizability to other operator populations. The research focused on individual operators, while real UAV operations often involve teamwork and coordination whose dynamics may modify the effects of individual cognitive load. Finally, the research examined the effects of acute load during individual shifts, while chronic effects of accumulated load through multiple consecutive shifts remain a topic for future research.

Future research should be directed toward several directions arising from the findings of this research. Replication of the study in real operational conditions would provide additional validation of findings and enable examination of ecological validity of laboratory results. Longitudinal research following operators over longer time periods would enable understanding of chronic cognitive load effects and potential adaptive changes. Research on load management interventions, including pharmacological, behavioral, and technological approaches, could provide practical tools for preventing performance degradation. Development and validation of real-time cognitive status monitoring systems, based on the findings of this research, represents an important applied direction. Finally, comparative research of different professional groups working under conditions of prolonged cognitive load could provide a broader framework for understanding factors that determine resistance and vulnerability to load effects.

In conclusion, this research demonstrated that extended work shifts result in significant degradation of tactical decision-making in unmanned aerial vehicle operators, with the key finding being the identification of a critical cognitive load point that marks the transition from a zone of moderate degradation to a zone of serious performance impairment. This finding has fundamental implications for designing operational procedures, decision support systems, and human resource management policies in the context of unmanned aerial vehicle operations. Integration of these insights into operational practice can contribute to improving the safety, efficiency, and effectiveness of UAV operations, while simultaneously protecting operator wellbeing and ensuring the reliability of critical tactical decisions upon which lives and mission outcomes often depend.

References:

1. Cooke, N. J., Gorman, J. C., Myers, C. W., & Duran, J. L. (2013). Interactive team cognition. *Cognitive Science*, 37(2), 255-285. https://doi.org/10.1111/cogs.12009
2. Cummings, M. L., Mastracchio, C., Thornburg, K. M. & Mkrtchyan, A. (2013). Boredom and distraction in multiple unmanned vehicle supervisory control. *Interacting with Computers*, 25(1), 34-47. https://doi.org/10.1093/iwc/iws011

3. Green, D. M. & Swets, J. A. (1966). *Signal detection theory and psychophysics*. Wiley.
4. Hart, S. G. & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), Human mental workload (pp. 139-183). North-Holland.
5. Klein, G. (2008). Naturalistic decision making. *Human Factors*, 50(3), 456-460. https://doi.org/10.1518/001872008X288385
6. McCarley, J. S. & Wickens, C. D. (2005). Human factors implications of UAVs in the national airspace. Aviation Human Factors Division Institute of Aviation, Technical Report AHFD-05-05.
7. Parasuraman, R. & Davies, D. R. (1977). A taxonomic analysis of vigilance performance. In R. R. Mackie (Ed.), Vigilance: Theory, operational performance, and physiological correlates (pp. 559-574). Plenum Press.
8. Sweller, J. (2011). Cognitive load theory. In J. P. Mestre & B. H. Ross (Eds.), The psychology of learning and motivation: Cognition in education (Vol. 55, pp. 37-76). Academic Press. https://doi.org/10.1016/B978-0-12-387691-1.00002-8
9. Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J. & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews*, 36(2), 747-756. https://doi.org/ 10.1016/j.neubiorev.2011.11.009
10. Tvaryanas, A. P. & MacPherson, G. D. (2009). Fatigue in pilots of remotely piloted aircraft before and after shift work adjustment. *Aviation, Space, and Environmental Medicine*, 80(5), 454-461. https://doi.org/10.3357/asem.2455.2009
11. Tvaryanas, A. P. & Thompson, W. T. (2008). Recurrent error pathways in HFACS data: Analysis of 95 mishaps with remotely piloted aircraft. *Aviation, Space, and Environmental Medicine*, 79(5), 525-532. https://doi.org/10.3357/asem.2002.2008
12. Tvaryanas, A. P., Thompson, W. T. & Constable, S. H. (2008). *The US military unmanned aerial vehicle (UAV) experience: Evidence-based human systems integration lessons learned*. In NATO RTO Human Factors and Medicine Panel Symposium on Human Factors of Uninhabited Military Vehicles as Force Multipliers. NATO Research and Technology Organisation.
13. Warm, J. S., Parasuraman, R. & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors*, 50(3), 433-441.
14. Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors*, 50(3), 449-455. https://doi.org/10.1518/001872008X28839

UTICAJ KOGNITIVNOG OPTEREĆENJA NA TAKTIČKO ODLUČIVANJE OPERATERA BESPILOTNIH LETJELICA TOKOM PRODUŽENIH SMJENA

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(Primljeno: 07.07.2023. Odobreno: 13.11.2023.)

Originalni naučni članak

DOI: https://doi.org/10.65932/military-studies-2023-1-1 **UDK**: 159.944.4:629.735.33-051

Sažetak: Operateri bespilotnih letjelica (BPL) suočavaju se sa jedinstvenim profesi-onalnim izazovima koji proizlaze iz kombinacije visokog kognitivnog opterećenja, produžene budnosti i potrebe za brzim taktičkim odlučivanjem u dinamičnim operativnim okruženjima. Cilj ovog istraživanja bio je ispitati kako akumulacija kognitivnog opterećenja tokom produženih radnih smjena utiče na kvalitet, brzinu i preciznost taktičkih odluka koje donose operateri BPL sistema. U istraživanju je učestvovalo 78 profesionalnih operatera bespilotnih letjelica iz vojnog i civilnog sektora, prosječne starosti 31,4 godine i sa najmanje tri godine operativnog iskustva. Za procjenu subjektivnog kognitivnog opterećenja korišćen je upitnik NASA-TLX, zajedno sa testom psihomotorne budnosti, modifikovanim testom taktičkog odlučivanja u simuliranim scenarijima i kontinuiranim praćenjem fizioloških parametara uključujući varijabilnost srčane frekvencije i elektrodermalnu aktivnost. Istraživanje je sprovedeno kroz simulirane operativne smjene u trajanju od 4, 8 i 12 sati. Rezultati su pokazali statistički značajan pad kvaliteta taktičkog odlučivanja nakon šestog sata neprekidnog rada, pri čemu je kritični prag kognitivnog opterećenja identifikovan na 73% maksimalnog kapaciteta mjerenog NASA-TLX skalom. Ključni inovativni nalaz ovog istraživanja odnosi se na otkriće nelinearnog, stepenastog obrasca degradacije odlučivanja koji karakteriše naglo pogoršanje performansi nakon dostizanja praga kognitivne zasićenosti, nasuprot pretpostavljenom postepenom padu. Ovaj nalaz ima značajne implikacije za projektovanje rasporeda rotacije operatera, implementaciju sistema za praćenje kognitivnog statusa u realnom vremenu i razvoj protokola za prevenciju kritičnih grešaka u operacijama bespilotnih letjelica.

Ključne riječi: *kognitivno opterećenje, bespilotne letjelice, taktičko odlučivanje, produ-žene smjene, budnost, zamor operatera, ljudski faktori, BPL operacije*.