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THE RISK RELATED TO THE INFLUENCE OF SLEEP DEPRIVATION ON THE RELIABILITY OF HUMAN ON THE EXAMPLE OF PILOT

Ryzyko związane z wpływem deprywacji snu na niezawodność człowieka na przykładzie pilota

Abstract: *The purpose of this publication is to discuss the issues related to the operator sleep deficiency, its effects and the resulting risk. The issue is discussed on the example of a pilot, as a position in which the probability of occurrence of the phenomenon is high, with consequences of its occurrence that can be very severe. Despite the fact, the authors try to present the issues in a universal way enabling reference to a wide spectrum of different types of operators. In the article, concepts such as risk and fatigue are characterized. Furthermore, short and long-term fatigue are discussed, as well as the impact of shift work on human health and reliability. The second part presents methods of fatigue monitoring useful in aviation. The summary emphasizes the need for a holistic approach to the issue of crew fatigue in the management and the need for actions before commencing with work.*
Keywords: human factor, risk, sleep deprivation, fatigue, safety of flights

Streszczenie: *Celem publikacji jest omówienie zagadnień związanych z niedoborem snu operatora, jego skutków oraz wynikającego z nich ryzyka. Powyższe zagadnienie omawiane jest na przykładzie pilota jako stanowiska, na którym prawdopodobieństwo wystąpienia zjawiska jest wysokie, a konsekwencje jego wystąpienia mogą nieść za sobą bardzo dotkliwe skutki. Mimo to autorzy starali się przedstawić problematykę w sposób uniwersalny, umożliwiając odniesienie treści do szerokiego spektrum różnego rodzaju operatorów. W pierwszej części artykułu scharakteryzowane zostały takie pojęcia jak ryzyko i zmęczenie. Omówiono także rodzaje zmęczenia: krótkotrwałe i długotrwałe oraz wpływ pracy zmianowej na stan zdrowia i niezawodność człowieka. W drugiej części zaprezentowano metody monitorowania zmęczenia użyteczne w lotnictwie. W podsumowaniu podkreślono konieczność holistycznego podejścia do zagadnienia zmęczenia załóg w zarządzaniu oraz podejmowania działań jeszcze przed rozpoczęciem wykonywania pracy.*
Słowa kluczowe: czynnik ludzki, ryzyko, deprywacja snu, zmęczenie, bezpieczeństwo lotów

1. Introduction

The pilot's workstation has special characteristics due to pilot's high psychological load, exposure to stress, specific microclimatic conditions, multitasking, variability of tasks, the need to quickly make difficult decisions or controlling many parameters at the same time. The fatigue factor, which is directly dependent on an adequate rest, has an indispensable impact on reliability during the performance of tasks. The amount and quality of operator sleep enabling adequate regeneration of the body is indispensable in this matter, and its deficiency significantly reduces human psychophysical capabilities and is a serious hazard to flight safety [3, 4, 11].

2. Risk

There are many descriptions of risk. Generally, the risk is defined as a combination of the probability of occurrence and the severity of its effects. Risks associated with sleep deprivation include short and long-term effects [4].

Short-term effects include the threat of a single flight operation or a flight cycle. They are directly related to the impact of sleep deprivation on the operator's day-to-day operation in the cockpit. Long-term effects include overall damage to the reliability and health of the pilot. They include not only the ability to perform the current task, but also the ability to perform aviation activities in the perspective of many years. Long-term effects of fatigue can have various consequences with deterioration of health, up to to the extent that can disqualify a crew member from receiving a positive medical certificate.

When considering the above elements, the concept of fatigue plays a primary role, because it is inseparable from a rest, with its primary form in the form of sleep. Sleep deprivation causes fatigue, while it is the most important way to reduce fatigue [8].

3. Fatigue

There are many definitions of fatigue. Most often they are defined as an internal state, which consists in reduced work capacity as a result of previous effort. Some definitions of fatigue refer to subjective feelings, such as a feeling of being unwell or being reluctant to carry out a task.

Fatigue affects all aspects of human life. It can affect the quality of its interpersonal relationships, the functioning of the immune system, a general sense of well-being and many other issues. From the safety point of view, the impact of fatigue on the work is crucial. Fatigue symptoms are clearly visible in the case of operators who perform tasks

with direct and immediate impact on the environment. This group of operators includes persons controlling machines in motion, such as drivers and pilots. Constant observation of the environment, parameters, their analysis, responding to them, predicting their consequences, forecasting possible external factors requires maintaining high concentration at time of work, which is a heavy burden and requires proper hygiene.

Fatigue has a significant impact on the speed of response and correctness of decisions, affecting the quality of the tasks performed by the operator. Short-term sleep deprivation has a direct impact on the decrease of employee's efficiency. A person who is deprived of over 40 hours of sleep has a decrease in efficiency of about 60%.

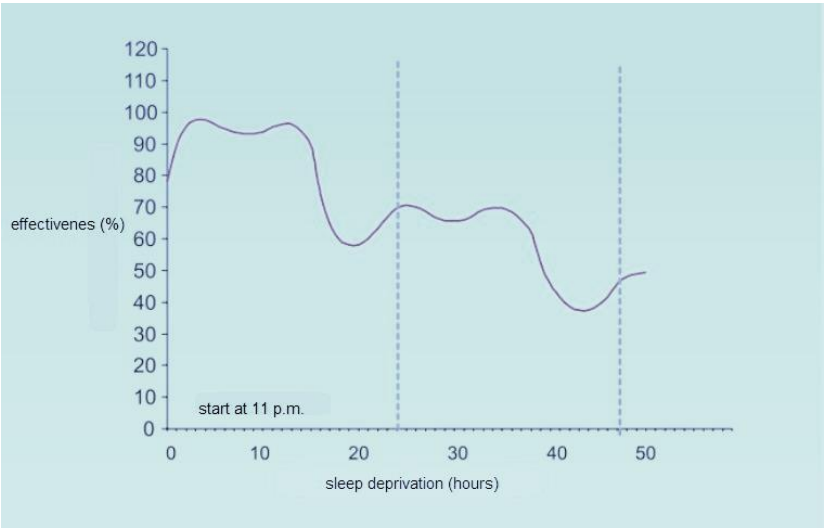


Fig. 1. The curve of operator's efficiency curve versus sleep deprivation in time [15]

Sleep deprivation can generate financial losses for the company and very high social costs, especially in the event of an accident (costs of compensation, pensions, medical treatment, rehabilitation benefits).

In the context of a pilot, fatigue is often mentioned as a contributing factor of an accident. It is a consequence not only of tasks performed in the air, but also other aviation activities such as preparation for flight (pre-flight review, meteorological situation analysis, flight planning, etc.) and post-flight activities (organization of the workplace, completing documentation, reporting , flight overview). Fatigue also includes factors related to the work performed, but not in the form of aviation activities, e.g. stress and atmosphere at work or proper nutrition (often difficult in working conditions).

The private situation of the operator is often a overlooked factor, but no less important. Renovation of the apartment, moving house, family problems such as divorce, death of a family member, upbringing problems can be the cause of fatigue, although it is difficult to grasp by people from the aviation organization. The occurrence of positive load-generating

events such as the birth of a child, marriage and absorbing hobbies should also be taken into account.

In order to counteract the negative effects of fatigue, many measures are taken, such as: working time limits, reporting of a current flight readiness, medical and aviation tests, distribution of the crew's task between many persons, limits on the number and time of operations performed during the day, month, year, appropriate arrangement of a flight schedule.

Summing up, the factors causing fatigue can be divided into: directly related to the performance of aviation activities, dependent on the external environment, and the organization of work, related to the pilot. They can cause physical (muscular) fatigue or mental (sensory, mental and emotional) fatigue [2, 6, 13, 14, 16, 20].

3.1. Short-term fatigue

It is caused by a lack of sleep, rest and the load occurring during the last several dozen hours. It may also coexist with long-term fatigue, but the focus of this description is on short-term fatigue that is self-existing.

The most important factors causing short-term fatigue include: static load, mental load, load on sensory organs. To a large extent they depend on external factors. These include, among others: temperature, humidity, air flow, vibrations, improper organization of work (flight duration and flight activities), frequent work at night.

Among factors affecting fatigue, related to the pilot oneself, the following can be distinguished: age, psychophysical and health condition, number of sleep hours preceding the flight, the circadian rhythm, alcohol consumption, medications taken, time of flight.

The decrease in efficiency also correlates with the number of mistakes made and the decrease in psychophysical fitness. The psychophysical performance of a person with fifteen hours of sleep deprivation can be compared to a person with a concentration of alcohol in blood of 0.40 per mil. When deprivation lasts 21 hours, the decrease in fitness can correspond to a concentration of more than 1 per mil of alcohol in the blood [13, 14, 16, 20].

3.2. Long-term fatigue

The basic factor responsible for long-term fatigue is permanent sleep deficiency. It can be caused, among others, by shift work, an unhealthy lifestyle, illness, a sick person or a child's care, stress and other conditions. Operating conditions including vibration, noise, microclimate and exposure to sunlight are also important.

An unhealthy tendency to reduce time of sleep has been observed in recent years. This is mainly due to civilization changes. Electrification, which significantly makes man

independent of the rhythm determined by the presence of sunlight, the use of devices emitting artificial light (computers, telephones, television) and a wide range of cultural and social events causes that people sense lesser requirement for sleep or it appears to be less attractive. Another effect of the above-mentioned factors is the impairment of the natural circadian rhythm. These conditions mean that a person sleeps about 1-2 hours a day shorter than people living 100-200 years ago, on average. The result is widespread chronic fatigue affecting the overall functioning of a human being. This thesis are confirmed by research carried out by Centers for Disease Control, in which, people were asked "How many days in the last 30 days did not you feel rested enough or sleep well?" The research has showed that only 30.7% of respondents said that they were rested every day, 11.1% said that during the last month there was not a single day they would sleep well [17].

At the same time, it should be taken into account that the need for sleep is an individual feature that depends not only on the age of the employee. In the adult group, the need for sleep may range from 6-10 hours. Therefore, in addition to providing the right conditions for rest by the employer, it is crucial to involve the employee himself in conducting adequate sleep hygiene according to his own conditions [13, 14, 16, 20].

4. Shift work

Shift work is most common in the line pilots community. Primarily it is forced by economic factors. Nevertheless, the carriers are able to eliminate its negative effects by proper organization of crews' work.

Negative effects on human operation pursuant to shift work are related to a disturbance of the natural circadian rhythm. The circadian rhythm is the rhythm of changes that occur throughout the body during the day. This includes the changes in parameters such as body temperature, hormone levels, blood pressure, and blood sugar. These parameters are responsible for the feeling of fatigue, ability to perform tasks, drowsiness or a tendency to undertake activities. The changes of some parameters occurring during the day are presented in fig. 2.

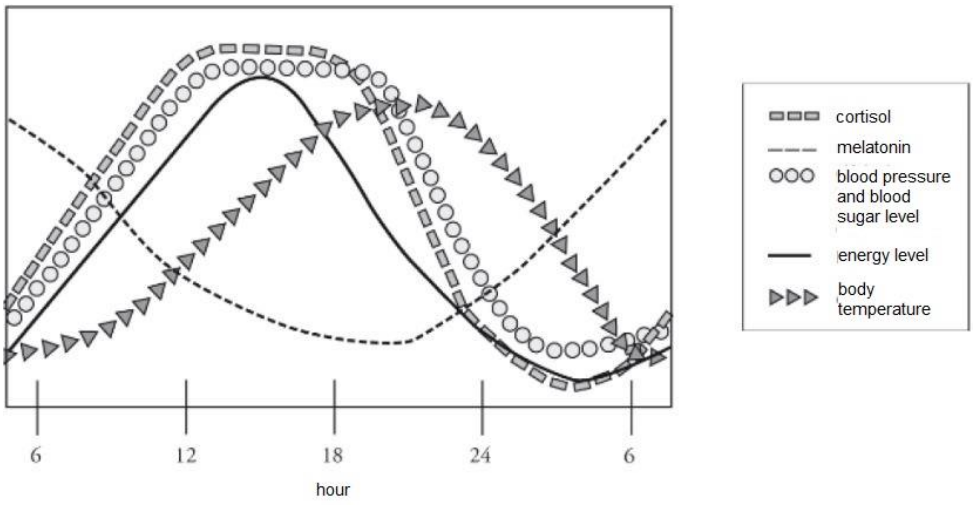


Fig. 2. The course of changes in the level of the selected psychophysiological parameters depending on the time of day [1]

The human body has the ability to adapt to the change of time zone relative to the current circadian rhythm by about 1 hour a day. The greater changes in the time of work and rest, the greater desynchronization of the circadian rhythm, which intensifies the severity of the negative effects of shift work. We divide them into:

- sociological effects regarding: participation in social and political life, the use of forms of institutionalized rest, social activity, family life;
- biological effects including: inconsistency of phases of physiological rhythms (unusual times of meals, inconsistencies of digestion and digestive tract), changes in the characteristics of circadian rhythms (e.g. amplitude, acrophase, period), sleep is "defective";
- health effects: gastrointestinal disorders (heartburn, epigastric pain, intestinal motility disorders, metabolic syndrome, peptic ulcer disease), oncological diseases, cardiovascular diseases (hypertension, coronary artery disease), neuropsychiatric disorders (anxiety, neurotic disorders, depression, medication).

Shift work, especially at night and for a long time significantly affects the risk of accidents. The results of the accident analysis among shift workers indicate that the risk of accident and injury during subsequent nights of shift work is about 6% higher on the second night, 17% higher on the third night and 36% higher on the fourth night [21].

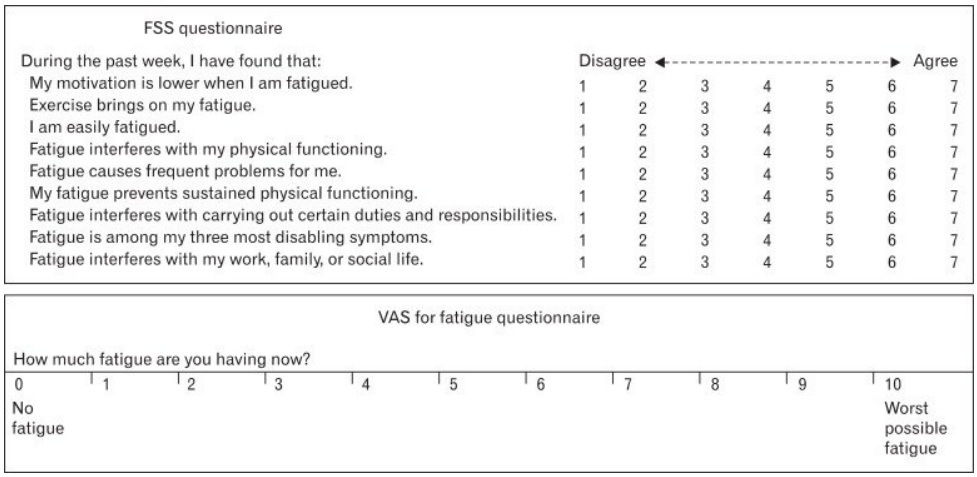
Also the time of day itself has an impact on employee's reliability. This dependence is presented in figure 3. The figure shows the time of serious disasters, in which the total number of fatalities amounted to several thousand people [13, 14, 18, 20, 21].

Fig. 3. Operator error curve during the day [10]

5. Measurement methods

Among the measuring methods assessing the level of fatigue, we can distinguish subjective methods in which the operator independently assesses his sense of fatigue and objective methods in which the level of fatigue is assessed based on changes in physiological parameters and body response.

An example of a subjective method is the Fatigue Severity Scale questionnaire method in which the operator assesses the level of one's fatigue. The test result is a rating on a 10-point scale, in which a score of 0 corresponds to the absence of fatigue, and a score of 10 to the existence of the greatest fatigue.



FSS questionnaire

During the past week, I have found that:	Disagree ◄						► Agree
My motivation is lower when I am fatigued.	1	2	3	4	5	6	7
Exercise brings on my fatigue.	1	2	3	4	5	6	7
I am easily fatigued.	1	2	3	4	5	6	7
Fatigue interferes with my physical functioning.	1	2	3	4	5	6	7
Fatigue causes frequent problems for me.	1	2	3	4	5	6	7
My fatigue prevents sustained physical functioning.	1	2	3	4	5	6	7
Fatigue interferes with carrying out certain duties and responsibilities.	1	2	3	4	5	6	7
Fatigue is among my three most disabling symptoms.	1	2	3	4	5	6	7
Fatigue interferes with my work, family, or social life.	1	2	3	4	5	6	7

VAS for fatigue questionnaire

How much fatigue are you having now?

0	1	2	3	4	5	6	7	8	9	10
No fatigue										Worst possible fatigue

Fig. 4. Fatigue Severity Scale questionnaire [17]

Electroencephalography is a non-invasive diagnostic method. The study allows to register the bioelectrical in the brain and various types of its activity [8]. There are basic types of brain waves:

- Delta (δ) waves with frequencies up to 4Hz most often occurring at time of sleep
- Theta (θ) waves with frequencies of 4-8 Hz characteristic to the state of deep relaxation or inner focus
- Alpha (α) waves with a frequency of 8-13 Hz associated with the state of relaxation and reduced cognitive activity,
- Beta (β) waves with a frequency of 12-35 Hz occurring at time of moderate activity
- Gamma (γ) waves with a frequency of 26-100Hz occurring in a state of high concentration and attention

It requires the placement of about 20 electrodes on the surface of the skull skin recording the changes in the electric potential. Electroencephalography is widely used in medicine, including diagnostics of sleep disorders, epilepsy or organic brain diseases. Interpretation of data requires a lot of knowledge and experience, therefore this method is used primarily in simulation research. In recent years, many simulation studies have been carried out on the reliability of drivers and the impact of fatigue on road safety. Due to the difficulties associated with interpretation of test results and the discomfort associated with placing a large number of electrodes on the subject's head, the use of this method on a large scale is impossible.

An alternative to the full EEG examination may be simplified biofeedback devices. They are currently used primarily in marketing research and as a support in the treatment of children with learning disorders or hyperactivity disorder characterised with attention

deficit. The use of a simplified EEG apparatus most often requires the use of three electrodes with means of a headband or a headphone rack.

An important group of parameters illustrating the changes in human load are methods examining the level of pulse and blood oxygenation. These include, among others, an ECG test, but simple pulse measuring devices such as a pulse oximeter or a sports heart rate monitor can also be successfully used. The methods related to heart rate measurement are described in more detail in the article "Overview of the Workload Assessment Methods in the Aspect of Improvement of the Operator-Technical Subsystem Relations on the Example of a Pilot" [4].

The PERCLOS (Percentage eye openness tracking) system is another useful method. It allows the operator to assess fatigue based on the percentage of eyelid closure in time during the task. It is 100% for fully closed eyelids and 0% for fully opened eyelids, intermediate states are also recorded. The most recognized method of fatigue evaluation with means of the PERCLOS system is the measurement of duration of the interval in which the eyes are closed in the range of 80-100% [1]. This concept is used in many systems applicable for monitoring fatigue or eye tracking. There are many driver fatigue monitoring systems on te market, among others, that trigger an alarm (acoustic, visual or vibration-generating) when a driver is at risk of falling asleep. The systems based on eyeball tracking are also used to train pilots on Full Flight Simulator (FFS) devices. Many events result from incorrect division of attention between the activities and monitoring of individual flight parameters. The use of methods imaging the path, which the pilot follows with his eyes, helps in the diagnosis of instrument tracking by crew members and allow the instructor to take action for correction of any errors. Based on the observation, the system can generate a warning about a too high level of fatigue [23].

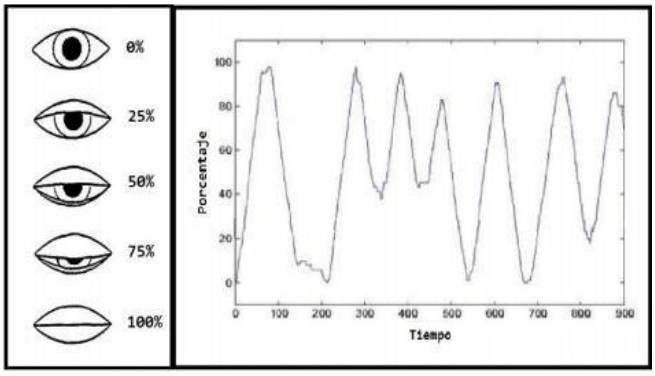


Fig. 5. PERCLOS system operation diagram [19]

The next very interesting method of fatigue measurement is speech analysis. Using speech analysis have been growing. These methods allow to diagnose fatigue by detecting

changes in pause duration, pace of speech, change of frequency and other parameters resulting from the work of the speech apparatus.

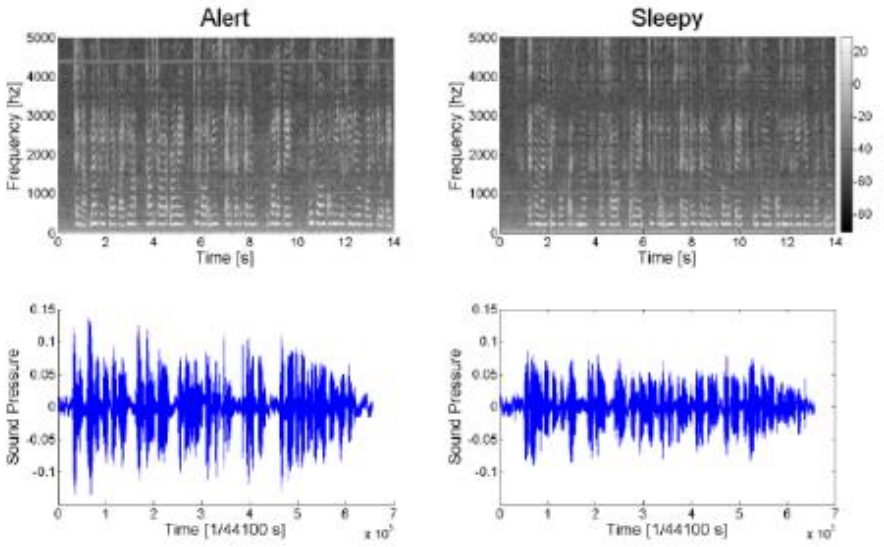


Fig. 6. Spectrum and waveform of speech when the operator is alert and during fatigue [12]

The methods based on speech analysis can be particularly useful in positions where the operator is required to communicate by voice. In the case of flight crews, an example may be operations requiring continuous two-way radio communication or multi-crew operations. Other methods are also worth noting, such as the measurement of Eye Closure Degree (ECD), or the methods based on biofeedback, such as GSR testing the skin-galvanic reaction based on the measurement of electric current resistance depending on the activity of sweat glands, and EMG testing the level of stress based on the measurement of muscle tension. Yawning may also be an indicator of fatigue. Due to the limited volume of the publication, the authors decided to limit themselves explicitly to the list of above methods.

6. Summary

Sleep deprivation significantly affects the functioning of the pilot in the cabin, in his private life and on his long-term ability to perform flights. Comprehensive approach to all factors is a very difficult task, even impossible, but organizations should strive to diagnose risk factors and reduce them as low as possible, assessing fatigue as accurately as possible. The most important goal should be the provision of adequate sleep quantity and quality. Only a holistic approach involving the multi-dimensional functioning of the operator can

effectively reduce the risk associated with sleep deprivation. This requires comprehensive reactive and proactive as well as predictive actions before the pilot undertakes the task. As a supplement to the effective management, it is appropriate to use the methods that diagnose pilot fatigue by monitoring psychophysiological responses of crew members already during the performed task. The results obtained by the monitoring devices can be used to warn crews about the occurrence of fatigue during the flight, but also can be used as a tool for validation of the introduced risk reduction measures. To be successful, the awareness and involvement of the operators themselves is essential.

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