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ANALYSIS OF THE IMPACT OF TASK DIFFICULTY ON THE OPERATOR'S WORKLOAD LEVEL

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Abstract. The widely held thesis is that the profession of pilot is one of the most difficult jobs to do. The task of the article was to analyse whether and how the difficulty of the performed task affects the pilot's workload during the flight. The research was carried out using a flight simulator. During the simulator tests, the cognitive load measurements represented by the change in pilot pulse and concentration were used. A finger pulse oximeter was used for the first purpose. The second device was Mindwave Mobile which allows to measure level of pilot's concentration and relaxation. The NASA-TLX questionnaire is used as a subjective method of operator's workload assessment. The examined person assesses the level of his/her load, using six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Five research hypotheses were put forward and verified by the Friedman test. It has been shown that the level of difficulty of individual stages of the study is appropriately differentiated by pulse, concentration, relaxation, and subjective assessment of the respondents' workload. It has been proved that pulse measurement, concentration, and relaxation levels, as well as subjective assessment of load levels, can be successfully used to assess the psychophysical condition of the operator.

Keywords: flight simulator, pilot workload, task difficulty, aviation, Friedman test.

Introduction

The rapid development of the aviation industry poses more and more challenges to researchers. Undoubtedly, the further development of air transport is related to investments in modern technologies, equipment, systems, and training. However, in aviation, the human factor is still mentioned as the most important safety element. Human factors are the weakest and most unpredictable element in the prevention of aviation accidents (Carver et al., 2017; Cekan et al., 2014; Cokorilo, 2013; Cameron et al., 2003). Active involvement of human factors researchers and engineers can lead to evidence – based human factors considerations in standards development (Vu et al., 2020). Pilots are capable of anticipating complex system behaviour but reports of human – automatics situations stress the importance of a shared understanding of situations by pilot and cockpit (Klaproth, 2020a, 2020b). Man is the most flexible, but also the most error-prone component of the pilot-plane-environment system. About 73% of all air accidents are caused by the human factor (CAE Oxford Aviation Academy, 2014). Under these circumstances, it is worthwhile to take scientific research on human factors in civil aviation (Liu et al., 2017). The issue of human factor is therefore addressed in a number of studies that conduct a research on human behaviour and responses to various stressful situations and where appropriate, propose measures that can eliminate potential failures and errors leading to safety risks. The interesting point of view can be found in Kilic article concern on the fatigue among student pilots (Kilic, 2021). In the context of this issue, the main focus is on understanding human capabilities and limitations, and the skilful use of this knowledge. Human errors and inadequate responses to events can happen in all phases of flight, but they occur much more often when the operator's workload is high (Martins, 2016; Vijay Rao & Balas-Timar, 2014). Providing an appropriate sense of safety, comfort, satisfaction, and efficiency is possible when the operator performs specific tasks at the optimal level of load (Biernacki & Zieliński, 2010; Hertzum & Holmegaard, 2012). Increased automation seems to reduce the number of tasks performed by aircraft pilots. However, a reduction in the level of exercise is not always accompanied by a reduction in the level of mental strain. Consequently, the issue of operator load is an ongoing subject of research (Biernacki & Zieliński, 2010; Luximon & Goonetilleke, 2011; Rubio et al., 2004). Despite many

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problems with definition (Cain, 2007; Martins, 2016), workload in its simplest form is defined as the ratio of the resources required to perform a task by the operator to the number of cognitive resources available (Martins, 2016; Patten et al., 2004; Rubio et al., 2004). The right number of cognitive resources is needed to complete the task (Martins, 2016). These resources, however, are limited and can be fully used (Patten et al., 2004). The concept of load is considered to be multidimensional (Cain, 2007). The workload experienced by the operator is the sum of many individual factors (such as the level of skills, experience or strategies used) and the objective requirements imposed by the task itself (Biernacki & Zieliński, 2010; Galant & Merkisz, 2017).

The aim of the study is to answer the research question: Does the difficulty of the task differentiate the level of operator workload. In the similar studies conducted in this area (Yu et al., 2015) the subjective load rating increases with increasing difficulty of the tasks. Also, research results shown that heart rate levels differ significantly between tasks characterized by low and high levels of workload (Charles & Nixon, 2018; Splawn & Miller, 2013). Additionally, concentration represented by the brain activity decreases as the difficulty of the task increases, which is the results obtained in the previous studies conducted so far (Biernacki & Zieliński, 2010; Cain, 2007). Our goal is to prove this using different research methodology.

1. Research methodology

The research was conducted in the Simulation Research Laboratory using a flight simulator CKAS MotionSim5 (Figure 1). This device was produced by Australian company CKAS Mechatronics Pty Ltd. It is a system that uses software and hardware that combines the reliability of a modern desktop computer equipment on a custom-built motion platform, with a cockpit that provides control devices identical or similar to those found on the real aircraft.

The CKAS MotionSim5 trainer is designed to simulate four generic types of light aircraft: a piston single-engine aircraft, a piston twin-engine aircraft, a light twin-engine turboprop aircraft and a light jet (Merkisz et al., 2017; Maciejewska et al., 2019). It is not intended to simulate a particular aircraft model, but rather to represent a typical aircraft of each class in its handling qualities and features. The Flight Simulation Training Device can be certified as an EASA FNPT II MCC Flight Trainer (Flight Navigation and Procedure Trainer Multi Crew Coordination). It means that FSTD allows to take training by two pilots at the same time. The MotionSim5 is a four-seater platform with two sets of flight controls. It requires at least two people to operate: a pilot and an instructor, seated behind the left pilot seat at the Instructor Station. The Instructor Station provides control over the flight simulator environment such as weather, positioning, malfunctions as well as real-time tracking and flight recording. Additionally, it is possible to take operations from and to almost every airport in the World (Nowak et al., 2018; Galant et al., 2019). Flight simulators are mainly used to conduct training for pilots, but they can also be used for research purposes (Boril & Jalovecky, 2012; Galant & Merkisz, 2017).

The measurement of cardiovascular activity was performed with the use of the pulse oximeter (Figure 2a). This equipment provides precise, stable, and fast measurement of oxygen saturation (SpO_2), pulse (PR) and perfusion index (PI). The MindWave device was used to measure brain activity (Figure 2b). The device is a simplified version of the EEG (Electro-encephalography) which represents one of the most popular technique to infer mental workload (Dehais et al., 2019). The device computes and outputs the EEG power spectrums (alpha waves and beta waves). The increased presence of the alpha rhythm indicates an elevated level of relaxation. On the contrary, the predominance of the beta waves determines the increase in the level of concentration. The MindWave enables to record data every second of the experiment, expressing the level of relaxation and concentration on a scale from 0 to 100. The device consists of a headset, an ear clip, and a sensor arm. The headset's reference and ground electrodes are located on the ear clip, whilst the EEG electrode is placed on the sensor arm, resting on the forehead above the eye. Both devices were used as a method of evaluating the operator's workload in an objective manner.

The NASA-TLX questionnaire was used as a subjective method of examining the operator's workload. This tool provides an overall workload score based on weighted average of ratings on six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration level (Biernacki & Zieliński, 2010; Luximon & Goonetilleke, 2011; Rubio et al., 2004). The subjective load assessment procedure consists of two parts. In the first stage, a participant completes a pairwise comparisons task in order to evaluate the relevance of each factor to the workload of a specific exercise. The respondent is asked to

Figure 1. CKAS MotionSim5 simulator

a) b)

Figure 2. Research devices: (a) pulse oximeter, (b) MindWave mobile

select (in each of the fifteen combinations of pairs) the category which, in his opinion, was felt more strongly during the task (Biernacki & Zieliński, 2010). The second part of the examination is to evaluate each of the six dimensions of the workload using a 20-point rating scales. The scale is bipolar, and the extreme points of the scale contain descriptions of opposite meaning: low – high, good – poor. The result of this part of the questionnaire is expressed using a scale from 0 to 100, where each of the 20 intervals is assigned 5 points (Biernacki & Zieliński, 2010). The primary motivation for applying the NASA-TLX questionnaire in the research was that it is one of the most reliable tools for subjective measurement of the task load. This method has been successfully used in simulated aviation tasks (Rubio et al., 2004).

2. Participants and procedure

Six respondents from age 21 to 24 participated in the study. The mean age in the research group was equal to 22 years. Subjects were divided into three groups according to their flight experience. Group A consisted of people with the Private Pilot License – PPL(A). Group B comprised of participants who were not licensed and don't have flight training. Nevertheless, selection criterion was established based on their experience in piloting a flight simulator and basic aviation knowledge obtained during aviation studies. The subjects who did not have any aviation experience were included in group C. The selection of the sample was deliberate, as the units were selected in relation to a specific criterion (Miszczak & Walasek, 2013). Each of the tests was carried out during the day, in the morning hours. It is caused, among others, by the willingness to maintain comparable conditions for all respondents and the fact that daytime promotes a lower workload for pilots compared to the night time. It has been proven that the accident rate increases eightfold at night (Kilic, 2021). In addition, the aforementioned study proved that the most important factors contributing to accidents during night flights in commercial aviation carriers, are physical conditions, errors resulting from skills as well as decision and perceptual errors in descending order. The tests were divided into three stages. In the first stage of the study ("easy task"), the task was to perform a take-off and to climb the aircraft to an altitude of 2000 ft. The second task ("moderate difficulty") was to execute a take-off, to climb the aircraft to 2000 ft and to make aerodrome traffic circuit. This stage of the study was completed after the location of the airplane indicated that it was above the airport. Participants experienced CAVOK (cloud and visibility OK) weather conditions while performing the second task. Meanwhile, the third stage of the study ("difficult task") consisted of repeating the task of the second stage in bad weather conditions (the wind from the direction of 220° at 15 knots and moderate rain). Subjects participating in the study were informed about the purpose and the procedure of the research, as well as about the possibility of withdrawing from further participation at any time. Before the beginning of each stage, the participants were informed about the tasks they had to perform along with prevailing weather conditions. The participants controlled the altitude and airspeed together with the flight course. The levels of concentration, relaxation and pulse of the pilots were recorded during the entire study. For the purposes of the following analysis, fragments representing individual stages of the study have been selected. The pulse oximeter was placed on the left middle finger of every subject, as recommended for obtaining reliable measurement. The MindWave device was used to measure the level of concentration and relaxation. After completing each of the three stages, the participant received a NASA-TLX questionnaire translated into Polish. In the first part, the respondent was asked to make pair-wise comparisons of the six scales, choosing the member of each pair that contributed more to the workload. The participant then assessed the load level in all six dimensions. While completing the questionnaire each subject was provided with a definition sheet which contained descriptions of the individual dimensions. At the end of the study, the participants were asked to complete a post-questionnaire which evaluated the level of difficulty of all three stages.

3. Analysis of research result

Statistical analyses of the quantitative data were performed with the use of IBM SPSS Statistics version 25. In this study, the results were considered statistically significant when the significance level was $p < 0.05$. Values considered statistically significant are marked in bold. The independent variable of the study was task difficulty level. The dependent variables were pilot's pulse, concentration level, relaxation level, subjective load assessment (NASA-TLX) and the assessment of the difficulty of three study stages. Table 1 presents the basic descriptive

Table 1. Basic descriptive statistics of quantitative variables

Variable	M	SD	Mdn	Min	Max	Skewness	SES	Kurtosis	SEK
Pilot's pulse	82.39	11.96	80.00	32.00	123.00	0.417	0.008	0.453	0.016
Concentration level	46.82	18.24	47.00	1.00	100.00	0.087	0.008	–0.147	0.016
Relaxation level	52.91	15.06	53.00	1.00	100.00	–0.066	0.008	0.082	0.016
NASA-TLX	45.18	19.18	48.17	10.67	86.00	0.132	0.181	–0.488	0.360

Note: M – mean, SD – standard deviation, Mdn – median, Min – minimum value, Max – maximum value, SES – standard error of skewness, SEK – standard error of kurtosis.

statistics of quantitative variables based on data collected from all participants at each stage of the study.

The average heart rate in the study is 82.39. The standard deviation value is 11.96. The median is 80. This means that half the results for the study are 80 or less and the other half are 80 or greater. The minimum heart rate is 32 beats per minute and the maximum value is 123 beats per minute. Dividing the standard deviation by the mean, the value of the coefficient of variation is obtained and it equals to 15%. It indicates a relatively small value of variability. The absolute skewness value is 0.417, which is greater than the double standard error of skewness (SES). Therefore, it was found that the distribution of the variable "Pulse" is right skew (positive skew). The absolute value of kurtosis is 0.453 and is greater than double the standard error of kurtosis (SEK). The distribution of the variable "Pulse" is leptokurtic (positive kurtosis). The distribution of the "Pulse" variable has been placed in the histogram (Figure 3) containing all the results recorded in the study of six participants for each of the three phases.

The average level of concentration in the research is 46.82. The standard deviation value is 18.24. The median has a value of 47. The minimum value of the concentration level is 1 and the maximum value is 100. The coefficient of variation is 0.39, which indicates a small value of variation. The skew value is 0.087. The kurtosis value is –0.147. The absolute value of both skewness and kurtosis exceeds doubled corresponding standard errors. The distribution of the variable "Concentration level" is therefore right skew (positive skewness) and platykurtic (negative kurtosis). The histogram (Figure 4) presents the distribution of the variable "Concentration level", containing all the results recorded in the study of six participants for each of the three phases.

For the purposes of further analysis, the Kolmogorov-Smirnov test was performed for all quantitative variables. The significance level of the variables is lower than 0.001. This means that the empirical distribution of all four variables does not follow the normal distribution. Due to the properties of the results, a non-parametric test was used.

In order to answer the research question (Does the difficulty of the task differentiate the level of the operator's

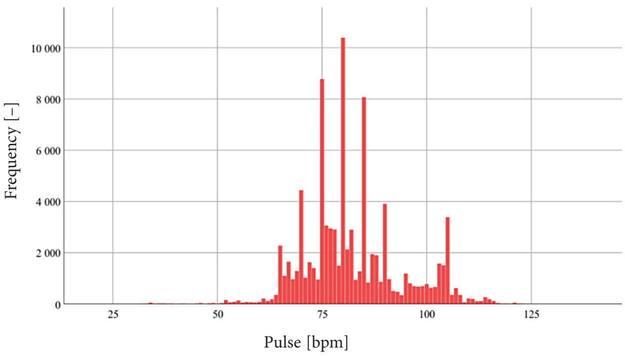

Figure 3. The distribution of the "Pulse" variable

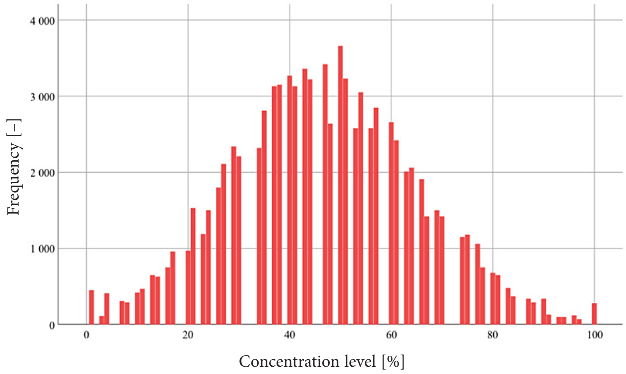

Figure 4. The distribution of the "Concentration level" variable

workload?), the following five research hypotheses were formulated:

1. Hypothesis 1: The level of difficulty of each stage of the study is differentiated by the average heart rate of the respondents.
2. Hypothesis 2: The level of difficulty of each stage of the study is differentiated by the average level of concentration of the respondents.
3. Hypothesis 3: The level of difficulty of each stage of the study is differentiated by the average level of relaxation of the respondents.
4. Hypothesis 4: The level of difficulty of each stage of the study is differentiated by the subjective assessment of workload of the respondents.
5. Hypothesis 5: Each stage of the study differs in the assessment of difficulty made by the respondents.

The Friedman test was used to verify all five hypotheses. Table 2 presents the test results for quantitative and ordinal variables.

The obtained significance level for the variable "Pulse" ($p < 0.001$) allows to accept the Hypothesis 1. The level of difficulty of individual stages of the study is differentiated by the average pulse of the respondents. The obtained level of significance for the variable "Concentration level" ($p < 0.001$) allows to accept the Hypothesis 2. The level of difficulty of individual stages of the study differentiates the average level of concentration of the respondents. The obtained significance level for the variable "Relaxation level" ($p = 0.001$) allows to accept the Hypothesis 3. The level of difficulty of the individual stages of the study differentiates the average relaxation level of

Table 2. Friedman test results

Variable	χ^2	Relevance
Pilot's pulse	53.333	$p < 0.001$
Concentration level	43.333	$p < 0.001$
Relaxation level	13.333	$p = 0.001$
NASA-TLX	83.333	$p < 0.001$
Difficulty	72.381	$p < 0.001$

the respondents. The obtained significance level for the variable "NASA-TLX" ($p < 0.001$) allows to accept the Hypothesis 4. The level of difficulty of individual stages of the study differentiates the subjective assessment of workload the respondents. The obtained significance level for the variable "Difficulty" ($p < 0.001$) allows to accept the Hypothesis 5. The individual stages of the study differ in the assessment of difficulty made by the respondents. Further analysis is based on making intergroup comparisons. For this purpose, Dunn's tests were used. The significance value for Dunn's tests was corrected by the Bonferroni method. The mean ranks of the individual study stages are given in parentheses. Table 3 presents the results of the intergroup comparisons for the variables: "Pulse", "Concentration level", "Relaxation level" and "NASA-TLX".

Dunn's tests performed for the variable "Pulse" show that at each stage of the study there is a significant change in the intensity of this variable. The average pulse of the respondents at stage 2 (1.41) is significantly lower than the average pulse of the respondents at stage 1 (2.12) and at stage 3 (2.47). The average heart rate of the respondents at stage 1 (2.12) is significantly lower than the average pulse of the respondents at stage 3 (2.47). The pairwise analysis makes it possible to state that the average concentration level of the respondents is lower at stage 3 (1.33) than at stage 1 (2.50) and at stage 2 (2.17). Dunn's tests performed for the variable "Relaxation Level" show that the mean level of this variable is significantly higher in Stage 1 (2.33) than in Stage 2 (1.67). The pairwise analysis shows that at each stage of the study there is a significant change in the pilot's assessment of workload. The load assessment in stage 2 (2.00) is significantly higher than the load assessment in stage 1 (1.17). The load assessment at stage 3 (2.83) is significantly higher than the assessment at stage 1 (1.17) and at stage 2 (2.00). The assessment of workload increases in the subsequent stages of the study. Intergroup comparisons for the "Difficulty" variable (final questionnaire) show that the difficulty rating of stage 3 (2.83) is significantly higher than the difficulty rating of stage 1 (1.50) and stage 2 (1.67). Table 4 presents the results of Dunn's test for the variable "Difficulty".

Table 3. Dunn's test results for four quantitative variables

Pilot's pulse			
N/A	N/A	Z	Relevance
Stage 1	Stage 2	7.303	p < 0.001
Stage 2	Stage 3	−3.651	p = 0.001
Stage 3	Stage 1	3.651	p = 0.001
Concentration level			
N/A	N/A	Z	Relevance
Stage 1	Stage 2	1.826	p = 0.204
Stage 2	Stage 3	4.564	p < 0.001
Stage 3	Stage 1	6.390	p < 0.001
Relaxation level			
N/A	N/A	Z	Relevance
Stage 1	Stage 2	3.651	p = 0.001
Stage 2	Stage 3	−1.826	p = 0.204
Stage 3	Stage 1	1.826	p = 0.204
NASA–TLX			
N/A	N/A	Z	Relevance
Stage 1	Stage 2	−4.564	p < 0.001
Stage 2	Stage 3	−4.564	p < 0.001
Stage 3	Stage 1	−9.129	p < 0.001

Table 4. Dunn's test results for "Difficulty" variable

Difficulty			
N/A	N/A	Z	Relevance
Stage 1	Stage 2	−0.913	p = 0.001
Stage 2	Stage 3	−6.390	p < 0.001
Stage 3	Stage 1	−7.303	p < 0.001

Conclusions

The aim of the study was to answer the research question formulated at the beginning of this work: Does the difficulty of the task differentiate the level of operator workload?

Five hypotheses were formulated based on the pilot's pulse, concentration level, relaxation level, subjective load assessment (using the NASA-TLX questionnaire) and the assessment of the difficulty of individual study stages (using the final questionnaire). Since the empirical distribution of four quantitative variables does not follow normal distribution, the nonparametric test was used to verify hypotheses.

Each of the three stages of the study was characterized by a different level of difficulty. The task of the first stage was defined as an easy task. The task of the second stage was characterized by a moderate degree of difficulty. The third stage of the study was defined as a difficult task. Only for two dependent variables the results were statistically significant between all three stages of the study. The subjective load rating increases with increasing difficulty of the tasks. The result of this study is the expected result, confirmed by a similar study conducted in this area.

The average pulse of the respondents is characterized by a different relationship. Initially, between an easy task and a task with a moderate degree of difficulty, the average level of the pilots' heart rate decreases. In the further part of the study, between the task with a moderate degree of difficulty and the difficult task, the average pulse of the respondents increases, reaching a value higher than the value obtained in the easy task. A possible explanation for this type of phenomenon is greater agitation of the respondents at the first stage of the study, while performing an easy task. Agitation gradually decreases as subjects get used to task conditions (stage 2), despite the increasing difficulty of the task. The increase in heart rate between the second and third stages indicates a greater load on the subjects in a situation where the weather conditions have deteriorated. The pulse rate of the respondents increases significantly between the first and third stage. This is also compatible with research cited in the beginning of this work. The compliance of the obtained results with previous publications in the field of task load assessment confirms the correctness of the implementation of methods used in ergonomics and the possibility of their application in human research in the aspect of aviation. In particular, to assess the task load of flying personnel.

The average level of concentration in the task defined as difficult turned out to be significantly lower than the average level of concentration in the easy task and in the task of moderate difficulty. The mean relaxation level decreased significantly between the easy task and the moderate difficulty stage. The obtained results indicate that concentration, decreases as the difficulty of the task increases, which is related to the investigation cited in the introduction. The respondents' own assessment of the level of task difficulty was significantly higher at the third stage than at the first and second stages. Half of the respondents considered the first stage very easy. The second stage of the study was characterized by a moderate degree of difficulty. Half of the respondents described it in this way. The task of the third stage was considered difficult by 50% of the respondents. The aim of the article was to analyse whether and how the difficulty of the performed task affects the pilot's workload during the flight. There were some limitations in the research, mainly regarding financing and availability of equipment. Due to the lack of equipment and time, no reference measurement was carried out. It should also be noted that these were basic research, not carried out under any scientific or research project. As part of the research carried out it has been shown that the level of difficulty of individual stages of the study is appropriately differentiated by pulse, concentration, relaxation, and subjective assessment of the respondents' workload. As part of further directions of work, it is planned to extend the assessment of the pilot's task load using the analysis of eye movement and significantly enlarge the research group. In future works, our focus will be on the level of the pilot's task load depending on his experience. The study to compare groups of experts and novices in various tasks during flight are planned. The simulator will be used and it can be possible to create various, even for dangerous situations without endangering the repondents health and life.

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All authors agree to authorship in the manuscript.

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Author contributions

Marta Galant-Gołębiewska and Marta Maciejewska conceived the study and were responsible for the design and development of the data analysis. Barbara Mika was responsible for data collection and analysis. Marta Galant-Gołębiewska were responsible for data interpretation. Marta Maciejewska wrote the first draft of the article.

Disclosure statement

All authors declare, that they have not any competing financial, professional, or personal interests from other parties.

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