https://doi.org/10.26552/ pas.Z.2022.2.15

THE ISSUE OF GLYCAEMIA AND HEART RATE VARIABILITY OF FLIGHT CREW DURING EMERGENCY SITUATIONS USING HRV CORSENSE ELITE

Alžbeta Pudíková
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina

Iveta Škvareková
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina

Abstract

The purpose of this article is to research the issue of glycaemia and heart rate variability (HRV) of flight crew, while these physiological processes are investigated during emergency and abnormal situations on the flight simulator. Stressful situations, which pose dangerous emergency situations for pilots during the flight, raise blood sugar level to ensure the brain has enough glucose during stressful situations. The attention is also given to assessing the effect of fasting blood glucose on flight crew performance, stress and heart rate variability. We try to focus on the overall evaluation of the impact of the above physiological processes during flights in which selected emergencies occurred in order to increase the level of stress hormone – cortisol, which is produced during workload and stress. The autonomic nervous system and its parasympathetic and sympathetic branches affect the heart functioning and its activity. The methods used to measure blood glucose and heart rate variability are non-invasive methods of measurement. The survey compares the results of measurements from samples of ten pilots studying the field of professional pilot. As proper eating habits are important for safe flight, we are trying to find out how the absence of food for at least 12 hours can affect pilot's performance as well as heart rate variability in the research.

Keywords

anatomy and physiology, diabetes mellitus, glycaemia, flight simulator, nervous system, emergency situations, workload

1. INTRODUCTION

Flight crew members work under immense pressure and demands placed on them by airlines, which can ultimately be the cause of potential negative events, including aviation accidents or incidents. With the ever-increasing trend in the introduction of innovative systems into aircraft, aviation technology professionals are striving to take as much of the burden off the pilot as possible when performing flight-related tasks in order to achieve the highest possible level of safety in the aviation sphere. The pilot, as a key link in the whole aviation industry, is affected by a wide range of physiological, psychological and physical characteristics and, insofar as they can affect the overall performance of the flight crew, they have by their nature a direct impact on the safety of air operations. Safety in aviation is a much debated concept today. Due to its demanding nature, the profession of pilot is one of those professions, in which it is essential to be in perfect physical and mental condition. If we looked back to the not-so-distant in the past, we would found out there were regulations which prohibit pilots from practising this type of profession in the event of a serious illness, such as diabetes mellitus.

Since the issue of glycaemia in flight crew is not a much researched area, for this reason we decided to go deeper into the above mentioned issue and try to explore the area of human performance from multiple perspectives. In aviation research, heart rate monitoring of flight crew members provides an overall index of the workload on pilot. It is with heart rate variability, also known by the acronym HRV, as a promising measure, that we decided to turn out the attention to this important factor as well. Based on a review of the available literature and the research conducted dealing with these two fundamental facts, we decided to set as the subject of our investigation the issue of glycaemia and heart rate variability in pilots during abnormal and emergency situations. The primary objective of the research was to investigate the effect of glycaemia on heart rate variability, and we also wanted to observe how these two parameters behave under the influence of different types of emergency and abnormal situations during flight on the flight simulator. However, it is important to note that we focused our attention to measurements when pilots were in a fasted state, and the time between the last meal consumption and the test flight had to be at least 12 hours.

2. DIABETES MELLITUS AS A HORMONAL AND METABOLIC DISORDER

Humanity has been plagued by diabetes, as a type of hormonal and metabolic disease, practically since time immemorial, for more than 3,000 years. With its unfortunately adverse and unpleasant effects, it particularly affects the daily life of several social segments of the world; the affliction of diabetes mellitus in flight crew is no exception, while the prevalence of the disease in pilots has been a subject of controversy for many years on the ground of inconsistent legislation in different parts of the world. In not so distant times, in aviation all over the world, the diabetic pilot was considered as an oxymoron, because the pilot profession is conditioned by perfect health corresponding to the requirements. When diabetes mellitus occurs in applicants for this type of profession and in pilots who hold an ATPL or other licence, the pilot's medical condition is closely examined by medical supervision, and various restrictions are placed on the issue and granting of restricted certificates to fly. A huge controversy in the field of diabetes diagnosis in insulin-treated pilots has been caused by the potential value of the performance required of pilots to carry out the profession with the utmost professionalism, as there is no space for human error in aviation [1] [2] [3].

To the above characterized multifactorial disease, which affects the human individual throughout life, we could add attributes such as the most economically costly, medically most serious chronic and often disabling disease, limiting all activities of persons with diabetes mellitus, based on its impact and severity [4].

For specific profession of diabetics, a cumulative assessment of exposure to various forms of stress and stressful situations is essential, and the profession of pilot belong among the extremely difficult jobs by virtue of its demanding nature, both physically and mentally. In particular, newly recruited transport pilots who are new to their field are under more stress than pilots who have been with the airline for some time. When a pilot who has been employed by an airline for a short period of time is treated by insulin for diabetes mellitus, he or she may experience fluctuations in glycemic levels due to exposure to a variety of stressors. The general recommendation for such a matter is to change from a job with too much stress to a less stressful type of job, after mutual agreement with a certified aviation doctor [4].

2.1. Metabolic basis

Carbohydrate metabolism in organisms, which biochemically include monosaccharides such as fructose, galactose, and the essential glucose, is characterized by a complex interplay of interactions between certain disorders and enzymatic pathways. Searching for the best definition of diabetes mellitus in relation to the metabolic processes typical for the disease, we came across the definition of the general meaning of the medical term "diabetes mellitus" by the Portuguese Society of Diabetology (PSD). The PSD generally states that it is a dysfunction with multiple aetiologies, in which chronic hyperglycaemia with metabolic disturbances is the typical presenting symptom of the disease. The aforementioned hyperglycaemic symptom is caused by insufficient secretion or even insufficient action of insulin, and if these defective processes continue for a prolonged period of time, degenerative processes occur in the organs, namely the brain, eyes, heart, blood vessels and kidneys, or even organ failures, which, if diabetes mellitus is inadequately, improperly and especially in the absence of treatment, can lead to the extinction of human life [1] [2] [5].

Glucose, serving as an essential and indispensable fuel for the major part of human body processes, is taken in the form of complex carbohydrates contained in the consumed food. Into the vital fluid represented in our bodies and in the bodies of animals by the blood, glucose enters by release as a result of the process of digestion, which is transported with the aid of the blood to the end organs of the body, in which it represents a function as a source of necessary fuel. In order to avoid the adverse and severe consequences of unusually low or unusually high blood sugar in living organisms, the healthy body of an individual can normally maintain relatively tight control over the level of glucose found in the blood. The dietary intake of living individuals should be at certain regular intervals, but there are also periods of fasting which human beings have established between regular intervals of eating. But since the human body can adapt itself relatively quickly to the varied external conditions found in the environment, the body of the individual has also been able to adapt itself to this existing fact over the course of several generations. In general, it can be argued that hormone production is dependent on the unit of time, which means that hormones are produced at different times during the day to lower blood glucose levels and to promote the storage of this monosaccharide after the consumption of food, also to raise blood glucose levels and to release it from the so-called "storage sites" during the aforementioned periods of fasting between meals. If we consider a healthy human individual, i.e. an individual without diabetes mellitus of any type, in the manner described above, his body is able to maintain the functioning of normal carbohydrate metabolism, which is accomplished through the coordinated interaction of glucose and the various controlling hormones, and it is insulin, as a complex molecule, that is one representative of these key regulatory hormones serving for the control and supervision of blood glucose [3].

"The harmonious couple in the house on the island"- insulin and glucagon, as the French physician P. J. Lefèbvre called these hormones, are key and important hormonal factors regulating energy metabolism. The β-cells of the Langerhans islets are the cells responsible for the secretion of insulin, initially a precursor of the hormone proinsulin, which is subsequently hydrolysed to give active insulin and, in addition, a metabolically inactive fragment of C-peptide. The β-cell marks the basis for the act of cleavage of proinsulin into insulin with the C-peptide, where this act, better said cleavage, also takes place. After consuming a diet, a person may notice that he or she has an elevated blood glucose level, which acts as a trigger for the next event, which is the release of insulin from the β-cells of the Langerhans islets [3].

Glucose is released into the blood circulation when blood glucose levels are lower, indicating, for example, a fasting state. The origin of this glucose would be found in the breakdown of glycogen internal reserves and in the increased amount of endogenous glucose production. Author D. G. Newman states in his report that there is even slight evidence to show that the kidneys are equally involved and play a function in glucose metabolism. In carrying out an action such as the reduction of excessive glucose contained in the blood of an individual to values belonging to the normal range, it must be emphasized that the mission of insulin in the metabolic control of glucose is to arrange for the progress of this action. The entire course of this action is accomplished through three specific modes of action [3] [6]:

1. insulin facilitates the transport and uptake of glucose from the blood into skeletal muscle and fat cells;
2. it also suppresses the endogenous production and release of glucose from important storage depots located in the liver;
3. intensifies the rate of glycogen synthesis contained in the liver [3].

The predominant effects of insulin are associated with a state of satiation, i.e. a certain state after the consumption of food by a human or other living creature. In the opposite state to the satiated state, which is the fasting state, the effects of other hormones are applied to promote the release of glucose into the body's bloodstream, thereby achieving a marked reduction in insulin levels. It is the failure of these aforementioned processes of metabolic control that leads to metabolic disorders, and diabetes mellitus is unfortunately the result of this failure [3].

2.2. Acute complication of diabetes mellitus – hypoglycaemia

From the whole range of complications associated with diabetes mellitus, which are usually further divided by experts into acute and chronic complications, we will deal with only one type of complications, namely hypoglycaemia, which, according to V. Bartoš, among other complications, represents acute complications of diabetes mellitus [7]. In general, hypoglycaemia (low blood glucose concentration) can be characterised as an immediate life-threatening complication due to its severity and possible recurrence, often in diabetes mellitus type 1 patients (more than 90%), that develops when insulin is over administered into the blood of a diabetic patient or when treated with a wide range of oral antidiabetic drugs, intended only for patients with DM2 because of their mechanism of action. In terms of the complication of insulin therapy, the term "major complication of insulin therapy" is assigned to it [3].

“Hypoglycaemia is generally understood as a pathological state of reduced glucose concentration associated with clinical and other biochemical manifestations.” Regarding the measurement of glycaemic values, in general, the established limit of hypoglycaemia in capillary plasma according to V. Bartos value of 3.3 mmol/l [7]. Laboratories located in hospitals generally work with a glycaemic value of 3.8 mmol/l as the lower limit [8].

The action of a variety of hormones in an attempt to raise blood glucose levels can cause most of the symptoms associated with hypoglycaemia, as the development of a wide variety of symptoms can be rapid and have too great a negative impact on the brain in particular, and therefore it is imperative to take action in hypoglycaemia and to start the required treatment. If such a situation occurs when the diabetic is alone or when he sleeps during the night hours, the vast majority of all cases associated with hypoglycemic coma can usually be regulated and corrected even without proper treatment. The other part of the symptoms associated with hypoglycaemia is caused by impaired CNS function, which is caused by, or causes, insufficient amounts of a key fuel supplied to the central organ of the NS - the brain. Since this organ, which is considered to be the most complex structure observed in human beings, is directly dependent on continuous glucose doses [3] [7] [9].

Various investigations that have been conducted in a more detailed study in relation to hypoglycemia and visual reaction time have led to the findings that during the state of hypoglycemia, complex decision-making abilities are impaired. The literature suggests that brain dysfunction in diabetic patients is caused by exposure to hypoglycemia, but it is generally argued that it is in the close examination and subsequent understanding of the various effects resulting from hypoglycemia and its effects on brain metabolites that may prove helpful to scientific investigators in developing new approaches needed in hypoglycemia to reduce brain damage [3] [10].

3. HEART RATE VARIABILITY

"During depolarization of the heart muscle (when it is irritated), which gradually spreads through the heart from the atria to the ventricles, certain potential differences are generated, the so-called action currents, which also spread to the surroundings of the heart, which are recorded on the surface of the body with the help of a clinical diagnostic device - a galvanometer" [11]. The ECG, as the electrocardiogram is commonly referred to in the medical profession, serves as a way for us to express a graphical record of the bioelectric action potentials of the heart (the electrical activity of the heart) over a specific time span and is an established routine diagnostic tool for irregular heart activity. Five distinct points can be observed on the ECG, representing positive and negative oscillations [11] [12]:

- P wave;

- QRS complex;

- T wave [12].

The Heart Rate (HR) has been the most widely used method to assess emotional response or stress in an individual and is the most accessible function suitable for us to record a physiological parameter that reflects the autonomic regulation of the human cardiovascular system and in the body as a unified whole [13] [14]. On the other hand, after several investigations have been conducted, it has been shown that the interval between heart beats (RR-interval) is an indicator of the ability to regulate internal and external demands [13] [15].

The promotion of heart rate variability has been that it is a simple, useful and, most importantly, non-invasive measurement method that serves as a general assessment of the influence of ANS on the heart rhythm of an individual and also represents a kind of insight into the overall ability needed to adapt to stimuli occurring in the external environment [16] [17]. Heart rate variability (HRV) provides useful information about certain differences in the length of individual RR intervals not only for medical personnel or researchers, but also for ordinary people [66].

However, the intervals are not constant but vary from heartbeat to heartbeat, the time between each beat of our "life pump" fluctuates slightly and this difference in time is milliseconds [ms]. Simply put, beat-to-beat HRV measures the change, or difference, between two heartbeats compared to two previous heartbeats. By looking at the beat-to-beat intervals, we can see that they are not constant, varying from heartbeat to heartbeat, and if a person has a higher HRV, it only indicates a better overall health, either in terms of physical or mental state [13] [15]. Conversely, if a person or a flight crew member experiences a reduced HRV, we can conclude that the person is more vulnerable to physical and psychological stressors, as well as to various diseases. In general, the effects of stress will result in changes of a different nature, e.g. biochemical or hormonal, which are characterised by their markedness, but even before these changes, changes in the heart rate parameters will first occur in a stressful situation. "HR is most commonly determined by electrocardiac signal with extraction of QRS complexes and duration of RR intervals." [18].

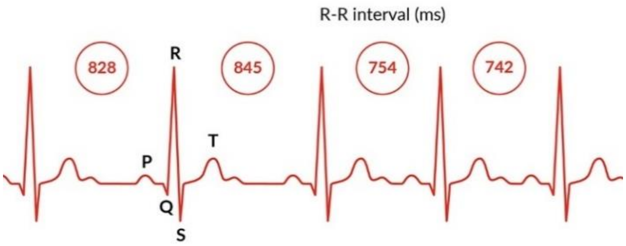


Figure 1 - R-R interval measured in milliseconds as the time between heartbeats that varies from heartbeat to heartbeat [Source: https://www.firstbeat.com/en/blog/what-is-heart-rate-variability-hrv/]

3.1. Heart rate variability and performance of commercial airline pilots during flight simulations

The demands of being a pilot are often closely linked to the stressors that crew members may encounter during the various phases of flight, which can affect pilot performance through their occurrence. A typical stressor in relation to flight performance is the humidity in the cockpit present during the flight, in addition to which fatigue, illness, or death in the pilot's immediate family, as well as many other events, can be a stressor for the pilot. Stress occurring at work, so-called "occupational stress," represents a chronic condition and, together with the workload, can be recognised by various physiological indicators such as salivary cortisol levels, respiratory rate and, for us, the inherently important HRV. In the context of this study, we will encounter the use of HRV to characterize the sympathetic stress response in crew during flight performance [19].

The general assumption for the dependence of HRV on workload in a flight crew member is that the higher the workload, the lower the HRV, or in other words, that the harder the pilot tries, the more regular his heart rate [20]. The participants of the study, conducted from March to May 2017, were active pilots of selected commercial airlines (n = 30 pilots) who voluntarily underwent the subject research. The task of the commercial airline pilots was to perform three flight segments on an A320 flight simulator that was certified by the Federal Aviation Administration (FAA) in the USA. An interesting feature of the study was that in each flight segment, CO2 was present in the cockpit of the flight simulator, the concentration of which varied depending on the flight segment. The research was set up in such a way that pilots had to fly different manoeuvres with varying degrees of difficulty, with the performance of experienced pilots being evaluated by examiners who were pre-determined by the FAA [19].

For the measurement, the authors of the study used the Movisens EcgMove3 sensor, which is a measurement system used for the overall assessment of the ECG and physical activity of a person. The sensor can acquire raw data of single-channel ECG, 3D acceleration, barometric air pressure, as well as temperature, which was then used by the researchers using a software application to calculate HR, HRV, as well as other parameters such as energy expenditure, etc. [19] [21].

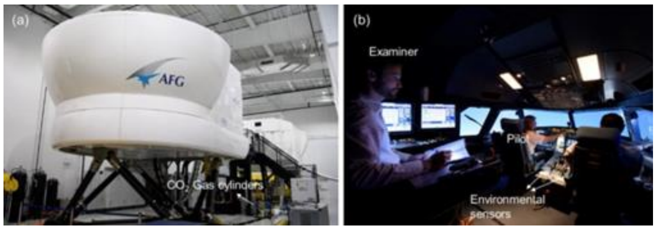


Figure 2 - (a) A320 flight simulator; (b) Flight simulation test [Source:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6352143/]

4. MEASUREMENT METHODOLOGY

When assessing the appropriate choice of research method to best obtain data relevant to the overall evaluation of the issue under study, we judged that the choice of quantitative and qualitative research would be the most appropriate solution for the area under study, based on the research questions posed in the introduction of the thesis. The basis of the quantitative research in collecting the necessary data in connection with the mentioned issue will be a questionnaire with different types of questions and assessment scales, which we had the pilots fill in before and just after the flight, on the basis of which we were able to assess the psychological state of the participant before and after the flight in the flight simulator. In the case of qualitative research, from a range of choices of research methods in data collection, we use scientific observation, which is characterized by planning the observation some time in advance, systematicity and objectivity, through which the results of the research are not influenced by various subjective factors or factors.

The environment in which the scientific observation was carried out can be described as suitable for conducting the research, since it was a bounded environment or space, which, by its boundedness, is considered to have better conditions that are suitable for the observation process. Although no environment is absolutely perfect in its conditions, we have tried to create as objective as possible conditions suitable for the participants of the research for the undisturbed measurement of the necessary variables. To ensure the overall safety of all research participants, but also from a financial point of view, we conducted observations based on flight simulations and abnormal conditions. For the observations, as one type of the research methods, we used short-term direct observation, which was also carried out with the help of the teaching staff needed to operate the simulator from the instructor's workplace. In the flight simulator, we, as observers, were located at a sufficient distance from the subjects during each measurement due to possible disturbance and influence during the participant's flight activity, which would bias the measurement results.

4.1. Measurement methodolody

For the measurements performed on the flight simulator provided by LVVC, we focused not only on objective but also on subjective measurement methods, the results of which we evaluate and analyse in the following chapter. We decided to use objective (measuring devices, HRV applications) and subjective measurement methods (questionnaire) based on the fact that by obtaining the results of both measurement methods we would obtain comprehensive results that would complement each other, thus also obtaining the pilots' subjective view to assess the possible influence of fasting glycaemia after at least 12 h of fasting and the influence of this measurement parameter on the other measured variables.

Prior to the actual measurements, all participants were briefed and informed about the subject of the investigation. Always the day before the flight simulator measurements, the pilots were instructed when they could take their last meal and from that meal onwards they were not allowed to take any food for a minimum of 12 h. As far as liquids were concerned, only plain water intake was allowed.

One type of reference measurements in the pilot was 2 h after a meal and without the occurrence of an emergency situation, and the second reference measurement was also 2 h after eating a meal, but already with the occurrence of an abnormal or emergency situation. As for the second type of reference measurements, these were performed with the pilot in a fasted state, where the pilot was not allowed to take any food for at least 12 h, the exception being the intake of fluids in the form of unsweetened (plain) water. In the first and second type of measurements, no abnormal in-flight situation had yet occurred, but in the remaining measurements an abnormal or emergency situation had already occurred, but the pilots were not informed in advance of the exact time of the occurrence of this situation, nor on which flight such a situation would occur.

Before measurements started, the participants were asked to fill in a questionnaire that contained different types of questions that allowed us to find out basic information about the participant (gender, age, weight), about his/her family history, and about his/her current condition, where we assessed the length of the pilot's sleep per night, the last time he/she consumed it, and other parameters. Once the pilot completed the pre-flight questionnaire, his blood pressure and glycemia were measured using a glucometer. After the ground training was done, the HRV meter was put on the participant's index finger. We started recording HRV in the Elite HRV mobile app when the pilot was ready for flight. During the flight, we were careful to conduct ATC communications. HRV recording was initiated from pre-flight operations and continued until the aircraft stopped on the runway after landing at LZZI. After the HRV recording was completed, the pilot was given another questionnaire to complete, in which we focused on his/her psychological and medical condition after the flight and to assess whether the fasting glycaemia and the abnormal or emergency situation had a possible influence on the pilot's medical or psychological condition and the possible occurrence of errors during the flight. As well as before and after the flight, we performed blood pressure and blood glucose measurements on the pilot, which were later used to assess the possible influence of emergency situations on glycaemia.

4.2. Pilots

A total of ten pilots underwent the measurements on a voluntary basis and were informed in advance about the course of the individual measurements and the subsequent procedures. All research participants were KLD students undergoing pilot training at LVVC (mainly students in the professional pilot program), with each participant having a different number of flight hours. The fundamentals of IFR flying theory were the criterion for selecting the research participants, which were required to perform flights in different conditions.

The participants were predominantly male, as one female pilot participated in the research. Expressing the gender representation of the participants as a percentage, 90% of the participants were male (pilots, n = 9 participants) and 10% of the participants were female (female pilot, n = 1 participant). The mean age of the participants is a figure of 23.30, the youngest research participant was only 20 years old and the oldest participant was 26 years old. The basic data of the participants such as age and BMI value were shown in Table based on their statistical processing using arithmetic mean, median, maximum (max) and minimum (min) values.

Table 1 - Basic statistics on research participants [Source: Author]

	Arithmetic mean	**Median**	**Max**	**Min**	
Age	23,30	23,00	26,00	20,00	
BMI	23,04	23,43	26,69	19,41	

Through the questionnaire, we also collected other data about the pilots, such as the prevalence of certain diseases in the pilot, including family history, which may relatively affect the HRV results. It is important to note that no pilot is being treated for diabetes mellitus or cardiovascular disease.

Table 2 - Basic data of pilots [Source: Author]

Pilot	**Flight hours**	**Weight**	**Height**
Pilot 1	100 - 150	76 kg	160 cm
Pilot 2	100 - 150	66 kg	178 cm
Pilot 3	100 - 150	82 kg	185 cm
Pilot 4	> 200	65 kg	183 cm
Pilot 5	150 - 200	65 kg	175 cm
Pilot 6	50 - 100	60 kg	158 cm
Pilot 7	> 200	74 kg	178 cm
Pilotka 8	50 - 100	55 kg	153 cm
Pilot 9	150 - 200	65 kg	178 cm
Pilot 10	150 - 200	74 kg	176 cm

4.3. L-410 UVP-E20 flight simulator

The choice of the flight simulator to conduct the research was conditioned by several criteria. In order to assess the impact of abnormal situations on the pilot's glycaemic value and workload, it was necessary to have a wide selection of different types of AS and NS and to model different adverse conditions that would affect the crew's performance. Another criterion was realistic cockpit dimensions in 1:1 scale and general use of the simulator in the wide sphere of the investigated areas. After evaluating the options, the above criteria were met by the L-410

UVP-E20 simulator, a twin turboprop simulator that, by its design and implemented functionality, meets the requirements of the "FTD Level 2" qualification and, in addition, the "FNPT II MCC." When performing flights, there is also the possibility of obtaining audio and video outputs from the course of the flight, from which a number of elements can be subsequently evaluated in the assessment of the pilot's performance [22].

Figure 3 - Flight simulator interior [Source: University Science Park, Flight Simulator]

4.4. Rearch measurement technique

The selection of the types of equipment used was made on the basis of the research questions posed in the introduction to the thesis. Taking into account the ease of use of the instrumentation and the wide choice of measurement equipment needed for the research available on the current market, we decided to use the following measurement devices: the Contour Plus One glucose meter (with kit) and the HRV CorSense with ELITE HRV app.

4.5. LZZI airport and flight trajectory

All participants - pilots who were included in the research are pilots - students at LVVC and for the reason of greater unburdening of pilots we chose LZZI as the aerodrome, although the original plan of the research was to use several aerodromes (LZTT, LZIB), which would have allowed us to induce a greater load on the pilots, including the occurrence of an abnormal or emergency situation just before landing, after take-off, etc. Prior to each flight, pilots were given instructions in relation to the flight. SID (Starndard Instrument Departure) and STAR tracks (Standard Instrument Arrival) were flown.

After takeoff, the pilots proceeded toward the BILNA point and then the ILS for Runway 06 (RWY 06) was flown. The flight, without the occurrence of an abnormal or emergency situation, lasted approximately 20 to 30 min on average. A flight during which an unexpected emergency (NS) or abnormal situation (AS) occurred lasted depending on the pilot's handling of the situation, his experience and the phase of the flight in which the AS or NS occurred. When an AS or NS occurred, pilots used all available navigational aids as a source of situational awareness, ranging from magnetic compass to DME, NDB, and GPS position to ILS. Abnormal or emergency situations occurred at different phases of the flight; we mostly focused on the occurrence of these situations just after takeoff, in the turn, and during the approach to landing. We could see the effect of the pilot's alert state and the occurrence of these situations on the HRVs, which was reflected in the results.

In selecting specific abnormal and emergency situations, we focused on several types of malfunctions, whether aircraft electrical systems, navigation, hydraulic, etc. In most cases, we simulated a left or right engine failure, engine fire in individual measurements. Each pilot flew 8 flights, of which in some flights, the so-called reference measurements, there were no AS or NS. Each pilot had a combination of simulated failures during measurements of the effect of AS or NS on glycaemia and HRV. In some cases of simulated combination of failures and under reduced meteorological conditions, CFIT (Controlled Flight Into Terrain) occurred. In addition to the various disturbances, we also simulated degraded meteorological conditions for the pilots (15 kts winds, occurrence of turbulence, thunderstorms, etc.).

5. RESULTS OF MEASUREMENTS AND ANALYSIS

5.1. Processing blood glucose concentration results from Contour Plus One glucose meter

The results of the blood glucose levels of the research participants were recorded after each measurement in pre-prepared tables, where, in addition to the values of the blood glucose concentrations of the pilots, we also wrote down other necessary data that were related to the specific measurement and could also have a significant influence on the results. In the tables, we also recorded the time of glucose measurement before and after the flight in the simulator, the participant's blood pressure also measured before and after the flight. Of particular importance was the time elapsed since the last meal, and for the fasting measurements we required that the pilot had not eaten for at least 12 h prior to the simulator measurements.

For each glucometer reading, we recorded whether the pilot had experienced an abnormal or emergency situation during the flight, and since pilots experience stress during emergency and abnormal situations, the effect of stress, which increases heart rate as well as glycemia, should be evident in the research results. The glycemia results from the tables were processed for each pilot separately in the form of a graph. We have plotted the glycemia results in the form of two graphs, one graph showing the glycemia results of a particular pilot during all the measurements taken and the other graph focusing on the glycemia value in relation to the occurrence of AS and NS during the flight. Based on the graphs, we can compare the pre-flight and post-flight glycaemia values for the pilots represented by the blue and orange bars in the graphs.

5.2. Processing HRV results with Kubios HRV

The high HRV values we measured in our research using the CorSense HRV sensor reflect the ability of the ANS to adapt to the stressors acting on the pilot at any given moment. These higher values are just a result of the pilot's good health style and are also related to the performance of executive functions. On the contrary, its low values, which can even fall into negative numbers, are a huge disadvantage associated with the poor adaptability of the ANS, while it is related to fatigue, the occurrence of stress and exhaustion. We transferred the HRV results obtained for the pilots during the simulator measurements from the Elite HRV mobile app to a computer and analyzed the results using an innovative and easy-to-use software presented by Kubios HRV. Since we can obtain data through the software that are commonly parameters in HRV, especially in the time and frequency domain, the values that are particularly important for our research are those related to the sympathetic and parasympathetic branches of the pilot, marked in the results sheet as PNS Index for the parasympathetic branch and SNS Index for the sympathetic branch.

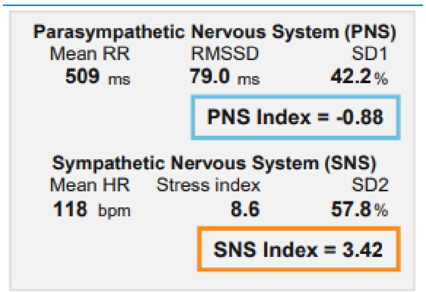


Figure 4 - Illustrative example of PNS and SNS Index results for pilot 10 [Source: Author]

From the above figure you can notice that in the graphs on the left part of the figure we can see the parameters or better said factors like mean RR, RMSSD, SD1 which are associated with parasympathetic and the part of the graph where sympathetic is shown we can see the factors mean HR, stress index and SD2. These are the factors that affect the aforementioned indices that are important for our research - PNS Index and SNS Index. The basic characteristics of the factors that influence parasympathetic and sympathetic are:

Influencing factors of PNS

- Mean RR - mean RR value, longer mean RR interval means lower heart rate and higher activation of cardiac parasympathetic;
- RMSSD - root mean squared difference of consecutive RR intervals, captures rapid changes in RR interval from beat to beat, strongly associated with the magnitude of the RSA component, high values indicate a strong RSA component and high parasympathetic activation of the heart;
- SD1 - Poincaré graphical index in normalized units, to estimate sympatho-vagal balance of ANS, calculate the ratio of low (LF) to high (HF) frequency power from HRV, reflects short-term variability.

Influencing factors of SNS

- Mean HR - mean HR (heart rate), higher heart rate is associated with higher cardiac sympathetic activation;
- Stress index (SI) - stress index, a geometric measure of HRV, reflects stress on the cardiovascular system, high values indicate reduced variability and high sympathetic activation of the heart;
- SD2 - describes long-term variability, use to project points onto a Poincaré plot.

The tables show us the PNS and ANS Index values for specific pilots. Specifically, the first table is a summation of these indices at the reference measurements that we took for each pilot in the research, for a total of 4 reference measurements, against which we then compared the index values when AS or NS occurred in flight. Due to the large number of measurements performed on the flight simulator, in this part of the paper we present the results of only those pilots for whom we found interesting values (pilot 3) and due to the influence of gender on HRV we also present the results of woman - pilot 8. We give a general assessment of the results of all pilots in the conclusion of the paper. For the reference measurements, pilot No. 10, who was fasted and had an occurrence of an abnormal or emergency situation during the flight, had low quality data. Also, one measurement for pilot #8 in the fasted condition with the occurrence of an emergency or abnormal situation had low data quality. Results with low data quality will not be evaluated. In the tables with PNS and SNS index values, these measurements with low data quality are marked in orange.

Table 3 - PNS and SNS Index values for reference measurements [Source: Author]

Reference measurements					
		After eating without AS/NS	Fasting state without AS/NS	Fasting state with AS/NS	After eating with AS/NS
Pilot 1	PNS Index	-0,13	-0,07	1,77	-0,92
	SNS Index	0,81	1,15	1,14	2,02
Pilot 2	PNS Index	-0,08	-0,62	1,85	-1,50
	SNS Index	1,10	1,64	0,62	2,80
Pilot 3	PNS Index	-1,05	-0,44	0,76	1,39
	SNS Index	1,46	1,20	0,83	1,94
Pilot 4	PNS Index	-2,01	-1,51	0,13	0,13
	SNS Index	3,05	1,65	0,96	0,53
Pilot 5	PNS Index	2,26	2,15	1,12	0,82
	SNS Index	1,87	0,79	1,49	1,69
Pilot 6	PNS Index	-0,13	1,24	1,68	1,80
	SNS Index	1,36	0,21	-0,43	0,33
Pilot 7	PNS Index	-0,62	-0,47	3,96	0,13
	SNS Index	2,38	1,73	-0,28	2,29
Pilot 8	PNS Index	4,86	2,87	2,09	3,13
	SNS Index	-0,15	-0,19	-0,35	-0,58
Pilot 9	PNS Index	1,66	1,89	1,49	3,78
	SNS Index	0,50	0,63	1,13	0,74
Pilot 10	PNS Index	-1,02	-1,78	-0,27	1,57
	SNS Index	3,06	2,68	1,79	2,27

Table 4 - PNS and SNS Index values for AS/NS occurrence during flight [Source: Author]

Measurements with AS/NS					
		Fasting state	Fasting state	Fasting state	Fasting state
Pilot 1	PNS Index	-0,62	1,39	-0,9	-0,27
	SNS Index	2,21	1,22	2,16	1,93
Pilot 2	PNS Index	0,42	-1,09	0,07	0,77
	SNS Index	1,4	3,54	0,82	1,02
Pilot 3	PNS Index	1,57	-0,05	-0,4	0,06
	SNS Index	0,91	0,99	0,92	0,84
Pilot 4	PNS Index	-0,62	-1,8	-0,68	-0,33
	SNS Index	2,21	3,51	2,04	1,28
Pilot 5	PNS Index	2,36	0,31	1,86	1,86

Measurements with AS/NS					
		Fasting state	Fasting state	Fasting state	Fasting state
	SNS Index	0,21	0,43	-0,01	0,28
Pilot 6	PNS Index	0,86	-1,02	0,13	1,65
	SNS Index	1,69	2,51	2,29	0,5
Pilot 7	PNS Index	3,96	1,96	0,87	0,85
	SNS Index	-0,28	0,11	0,02	0,38
Pilot 8	PNS Index	4,12	4,66	-1,02	3,43
	SNS Index	-0,43	-0,39	3,06	-0,15
Pilot 9	PNS Index	2,76	1,41	2,88	3,73
	SNS Index	0,53	1,43	0,92	0,65
Pilot 10	PNS Index	-0,79	-0,88	-1,3	-0,66
	SNS Index	4,25	3,42	4,25	3,81

5.3. Results of pilot 3

Because of the number of hours flown in training, Pilot 3 is a relatively experienced pilot and, based on experience, should not be expected to have a greater workload when abnormal or emergency situations occur than pilots with fewer hours flown. The first measurement was the reference measurement, which was taken 2 h after eating a meal. The measurement lasted for 20 min and 42 s, and no AS or NS occurred during the measurement; both the SNS Index and PNS Index values were within standard values. As the pilot was not under any stress load during the flight that could be felt due to hunger or the occurrence of AS or NS, the PNS and SNS values are relatively within normal limits, however, the PNS Index is already in negative values at the reference measurement, indicating an increase in the workload. Regarding the glycaemia values, the pilot took a meal 2 h before the first measurement and the glycaemia value was 5.3 mmol/l before the flight and dropped to 5.0 mmol/l during the flight. The pilot was not exposed to a stressful situation during the flight, therefore, the pilot was not expected to have an increase in glycaemia due to the applied stress, although the PNS Index value speaks of a moderate stress.

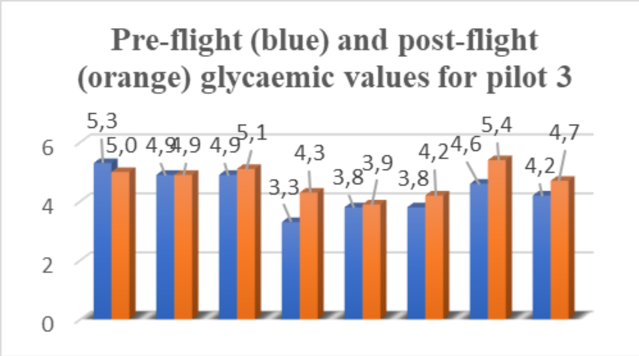
The second measurement (15 min and 19 s) was a fasting measurement, i.e., in a state where the pilot had last taken a meal at least 12 h prior to the measurement. No AS and NS occurred during the flight. PNS and SNS Index were within normal limits, even in this measurement both index values were better than in the 1st measurement. For this measurement, we expected a greater load to be exerted on the pilot due to the fasted state, however, compared to the reference measurement, the PNS Index value increased (Δ 0.61) and the SNS Index decreased slightly (Δ 26). The blood glucose values in this measurement remained at the same pre-flight and post-flight concentrations with a value of 4.9 mmol/l.

During the third measurement, the pilot experienced an abnormal situation, which consisted of a right engine stall, TCAS alert - TA (traffic advisory), and AHRS and HSI stall. The PSI Index was 1.39 and the SNS Index was 1.94. The pilot was 2 h after consuming food with a pre-flight glycaemic value of 4.9 mmol/l and a post-flight value of 5.1 mmol/l. We expected a slight increase in glycaemia after the occurrence of stressful situations, which is also visible in the graph, as the action of stress can increase glycaemia. Comparing this measurement with the first reference measurement, the PNS Index and SNS Index increased compared to the first measurement.

The next measurement, the fourth measurement, was the measurement when the pilot was fasted and the same abnormal situations occurred during the flight as in the third measurement, with one difference, that instead of a TCAS - TA alert, a GPS ejection occurred. The PNS Index and SNS Index values were in positive numbers, namely PNS Index = 0.76 and SNS Index = 0.83. The results of these values can be compared with the third measurement, which is our reference in this case (after eating a meal, with the occurrence of AS). We find that the PNS Index decreased compared to the third measurement, and the same was the case for the SNS Index. The pilot's glycaemia increased more significantly after the flight (Δ 1 mmol/l), which was expected as the pilot experienced AS. Before the flight, the pilot had a lower glycaemia than the first measurement as he was fasting, whereas before this flight the pilot had the lowest glycaemia value of all his measurements (3.3 mmol/l).

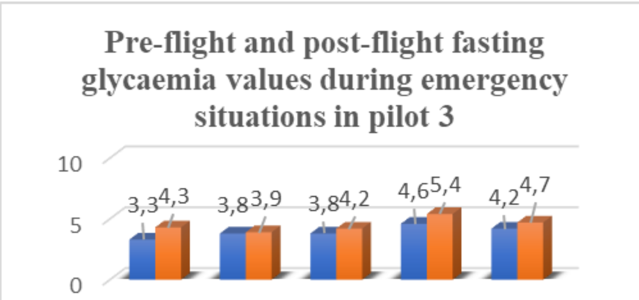
The PNS and SNS Index values at the fifth measurement were PNS Index = 1.57 and SNS Index = 0.91. The PNS Index increased compared to the second measurement and the opposite was true for the SNS Index, which decreased. During this flight, the pilot was fasting when a combination of several ASs occurred, the most serious of which were the following: left engine stall, GPS stall, altimeter stall, artificial horizon stall, AHRS stall, and the occurrence of turbulence with crosswinds and snow. Fasting glycaemia before the flight was 3.8 mmol/l and after the flight was 3.9 mmol/l, but we expected a larger increase in glycaemia due to exposure to more AS. The pilot felt an increased workload especially during the left engine stall that occurred after takeoff, which was later joined by the GPS stall along with the altimeter. The pilot had a higher HR when multiple ASs were combined.

From the tables with PNS and SNS Indices and from the graphs below with fasting glycaemia during AN we can assess that at the sixth and seventh measurements the value of both indices was similar. Compared to the reference second measurement (fasting, no AS), we can conclude that the PNS Indices slightly increased and the SNS Indices slightly decreased. In the sixth measurement, the pilot felt slight effects due to hunger, which manifested itself in a slight distraction and during the flight he started to have a slight headache and felt fatigue. At the seventh measurement, there was a steeper increase in post-flight glycaemia than was the case at the sixth measurement, as at the seventh measurement the pilot had a greater combination of ASs, the most severe of which he considered to be L engine, AHRS and artificial horizon deployment. He experienced an increase in glycaemia as a result of the increased workload imposed by the combination of multiple ASs.



Graph 1 - Glycaemia value for pilot 3 during all measurements [Source: Author]

In the last measurement, which was his eighth measurement, the PNS Index increased to positive values compared to the second measurement, which was fasted and without AS. There were a number of AS and adverse meteorological conditions encountered on this flight. On final, we simulated a left engine (L engine) failure for the pilot. We found the L engine failure to be a more burdensome AS for this pilot than the right engine (R engine) failure. For the adverse weather conditions, we simulated turbulence for the pilot during level flight and just prior to landing, in addition to rain. As for glycaemia, its value increased after the flight, which was the result of the action of several AS as a stressor on the pilot.



Graph 2 - Glycaemia value in pilot 3 during emergency situations (fasting) [Source: Author]

5.4. Results of woman-pilot 8

This pilot was the only woman who participated in our research focusing on glycemia and heart rate variability along with emergency situations.

For the first - reference measurement, the female pilot arrived 2 hours after the meal, and just before the measurement flight she performed a familiarization flight around the circuit to better master the measurements needed for the research. Before the flight, the pilot's glycaemia level was found to be 4.9 mmol/l, after the flight this value increased by 0.02 mmol/l to a value of 5.1 mmol/l. The PNS Index for the first reference measurement was -1.02 and the SNS Index was 2.51, the highest SNS Index measured so far during the reference measurement. It is important to note that no AS/NS occurred during this reference measurement.

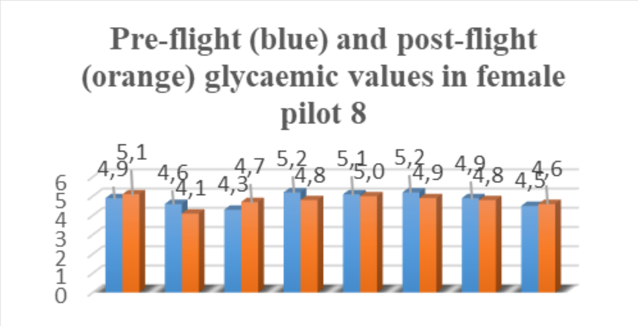
The second flight was characterized by the occurrence of abnormal and emergency situations for which the pilot was not very prepared. It had been 2 hours since the last meal was consumed. The pre-flight glycaemia was 4.6 mmol/l and after the AS/NS flight this dropped to 4.1 mmol/l, which was unforeseen as we expected the glycaemia to rise after the AS/NS. The PNS and INS Index values for this flight are shown in the table.

The next flight, the third flight in the series, was a fasting flight with AS/NS occurrence. During the flight, common abnormal and emergency situations occurred that were also experienced by other participants, so that we can also compare the greatest impact of given types of emergency situations on individual pilots. For the female pilot, in this reference measurement of a fasted AS/NS occurrence, we found that the greatest impact on the female pilot's HRV values was an engine fire that occurred during the approach to landing.

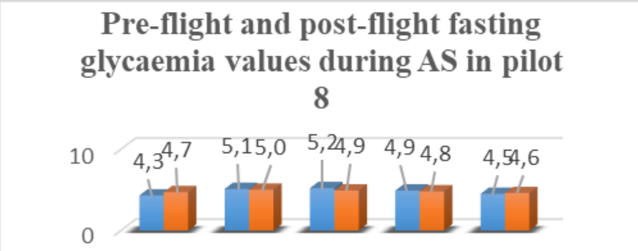
For flights four through seven, these were normal flights during which glycemic levels rose after the flight when the emergency occurred. No emergency or abnormal situation occurred during flight four, as the fourth measurement was a reference measurement for the pilot in the sense that it was a measurement when the pilot was in a fasted state with no AS/NS occurring. We later compared the other flights with this measurement in our overall general performance evaluations.

We consider it important to note about the influence of the fasted state on the female gender. Already during the measurements we took during the summer before the actual research on the flight simulator, which also belongs to the LVVC, we had another female pilot who also felt the effects of the fasted state on her in a big way. In the case of the measurements of female pilot #8, this was the sixth measurement in a row where the female pilot felt a large impact of the fasted state on her health and psychological state. However, the last time the pilot had consumed food was over 20 hours ago. The measurement on that day took place on the simulator in the afternoon. The pilot was experiencing a nervousness that resulted in a slight inattention during the flight when the pilot was distracted. Based on the evaluation of the questionnaire, we found that the pilot was experiencing fatigue, exhaustion, and irritability in addition to hunger. In addition, she also complained of headaches.

The last measurement for this female pilot was taken in the morning, with a total flight time of 5 minutes and 27 seconds. During the flight, abnormal situations such as right engine ejection together with left engine ejection occurred at different stages of the flight. The engine drop occurred in the first turn and just before landing the second engine was also dropped, while a crosswind was simulated before the descent to the runway, when the pilot failed to control the situation and the aircraft rolled over on the runway. The glycaemic value rose by a minimal amount after such a flight.



Graph 3 - Glycaemia value for pilot 8 during all measurements [Source: Author]



Graph 4 - Glycaemia value in pilot 8 during emergency situations (fasting) [Source: Author]

6. CONCLUSION

In the case of our research, carried out on a sample of 10 pilots who are students of the University of Žilina, we reached several results. The primary component of the research consisted of abnormal or emergency situations and fasting glycaemia values. During the emergency situations that we simulated for the pilots during the measurements at different phases of the flight, we found that glycaemia rose in the pilots in several cases after the flight. Gender also has a significant effect on fasting glycaemia, which also influences the pilots' response during abnormal and emergency situations.

However, each person is a unique creature and we believe it is only a matter of training and pilot skill to fly a flight with the occurrence of an emergency situation even in a better state of psychological well-being. Through research we wanted to find out which abnormal or emergency situations have a greater impact on the pilot. Much more stress was felt by the pilots during audio distress signals and during emergency situations that are not very likely to occur, such as one engine failure in a turn and the other engine failure in the approach phase of a landing. By comparing our results with those of other studies, we concluded that fasting glucose levels increase or decrease in healthy people (pilots) exposed to an abnormal situation.

REFERENCES

[1] VOZÁR, J. – KREZE, A. – KLIMEŠ, I. 1998. Diabetest Mellitus. 1. ed. Bratislava : SAP – Slovak Academic Press, 1998. p.286. ISBN 80-88908-20-5.

[2] JÚNIOR, W. P. DA C. – DA SILVA, T. A. 2020. Diabetes Mellitus: Main Characteristics And Perspectives For Civil Aviation. [online].

[3] NEWMAN, D. G. 2005. Diabetes mellitus and its effects on pilot performance and flight safety: A review. [online].

[4] HERCEG, P. a kol. 2019. Dia šlabikár+. 1. ed. Košice : Graphics Studio s.r.o., 2019. p. 383. ISBN 978-80-973473-0-7.

[5] BRITANNICA. 2022. Disorders of carbohydrate metabolism. [online].

[6] LEFÈBVRE, P. 2011. Diabetes as a Paracrinopathy of the Islets of Langerhans. [online].

[7] BARTOŠ, V. – PELIKÁNOVÁ, T. et al. 2003. Praktická diabetologie. 3. ed. Praha : MAXDORF s.r.o., 2003. p. 479. ISBN 80-85912-69-4.

[8] MOKÁŇ, M. 2008. Hypoglykémia. In Vnitřní lékařství. ISSN 1801–7592, 2008, y. 54, n. 4, p. 387-394.

[9] GANONG, W. F. 2005. Přehled lékařské fyziologie. 20. vyd. Praha : Galén, 2005. p. 890. ISBN 80-7262-311-7.

[10] REHNI, A. K. – DAVE, K. R. 2018. Impact of Hypoglycemia on Brain Metabolism During Diabetes. [online].

[11] BADA, V. 2002. Základy klinickej elektrokardiografie. 3. ed. Bratislava : Univerzita Komenského Bratislava, 2002. p. 124. ISBN 80-223-1718-7.

[12] YOUNG, K. A. – WISE, J. A. – DESAIX, P. et al. 2013. Anatomy & Physiology. [online].

[13] HAYLEY, Y. – BENTON, D. 2018. Heart-rate variability: a biomarker to study the influence of nutrition on physiological and psychological health? [online].

[14] FEDOTOV, A. A. – AKULOV, S. A. – TIMCHENKO, E. V. 2020. Methods of Mathematical Analysis of Heart Rate Variability.

[15] JAVORKA, K. et al. 2008. Variabilita frekvencie srdca. Mechanizmy, hodnotenie, klinické využitie. 1. ed. Martin : Osveta, 2008. p. 204. ISBN 978-80-8063-269-4.

[16] MACIEJEWSKA, M. – GALANT-GOŁĘBIEWSKA, M. 2021. Case study of pilot's Heart Rate Variability (HRV) during flight operation. [online].

[17] JAMES, D. V. B. – MUNSON, S. C. – MALDONADO-MARTIN, S. et al. 2013. Heart Rate Variability: Effect of Exercise Intensity on Postexercise Response. [online].

[18] FEDOTOV, A. A. – AKULOV, S. A. – TIMCHENKO, E. V. 2020. Methods of Mathematical Analysis of Heart Rate Variability. [online].

[19] CAO, X. – MACNAUGHTON, P. – CADET, L. R. et al. 2019. Heart Rate Variability and Performance of Commercial Airline Pilots during Flight Simulations. [online].

[20] WISE, J. A. – HOPKIN, V. D. – GARLAND, D. J. 2009. Handbook of Aviation Human Factors. [online].

[21] MOVISENS. 2022. EcgMove 3 – ECG and Activity Sensor. [online].

[22] NOVÁK, A., TOPOĽČÁNY, R., BRACINÍK, T. 2009. Výcvik leteckých posádok s využitím nových technológií. Žilinská univerzita, Fakulta prevádzky a ekonomiky dopravy a spojov, 2009. - 94 s. ISBN 978-80-554-0108-9.

[23] NOVÁK SEDLÁČKOVÁ, A., PITOR, J., MRÁZOVÁ, M. 2015. Crisis management in aviation. 1. vyd. - Bratislava : DOLIS, 2015. - 152 s., ilustr. - ISBN 978-80-8181-000-8.