The effect of physiological stressors on pilot's decision making during unfavourable simulated conditions: An explorative study

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Abstract: *This paper deals with physiological factors that can easily affect a pilot performance and have negative impact on the flight safety. Our research focuses on the observation of pilot-student's flying abilities during changing conditions for flight tasks in flight simulation training device in order to avoid pilot students' bad decision making caused by uncomfortable conditions for the flight. Pilot error statistics related to the impact of physiologic factors on pilot performance help us to predict which stressors are the most dangerous for flight tasks and they help indeed pilot-students to react properly and make the right decisions in different crisis situations.*

Key Words: *pilot performance, physiological factors, training, heart rate, workload*

1. INTRODUCTION

Many aircraft accidents are related to pilot errors that could happen as a result of misjudgements, wrong decisions and actions caused by different factors, such as lack of adequate training, situational awareness, mental stress or fatigue. Also, a lot of physiological effects are linked with flights and they could jeopardize the flight safety. However, different case studies related to the pilot performance have shown that most of the aircraft accidents were related to human errors depending on physiological conditions during flight tasks. Indeed, there is no conclusive list of pilot stressors as they vary through culture, gender, age and work experience level, etc.

Pilot workload depends on different phases of the flight, for instance, Instrument Flight Rule (IFR) flight creates significantly higher workload than Visual Flight Rule (VFR) flight. Observations show that the biggest pilot workload is related to the Take-off phase or Landing phase compared to Cruise or VFR flight phase. Therefore, it is necessary to highlight this issue and take proper measures to ameliorate this risk that can lead to fatal accidents or incidents.

In addition, physiological factors may cause changing and degradation of basic cognitive abilities and degrade pilot's thinking and concentration.

Also, the pilot distance himself from the emotional side of the critical situation and has to keep his mind cool and clear in order to make a correct evaluation of all flight situations. Indeed, the physiological factors influence the decision making reaction time also affecting the pilot's workload.

2. ASSESSMENT OF SELECTED PHYSIOLOGICAL STRESSORS ON PILOT PERFORMANCE

The human factor is affected by different environmental and operational factors that determine his performance potential. Indeed, the workload can be characterised by physiological, psychological and operational criteria as illustrated in ***Figure 1*** below.

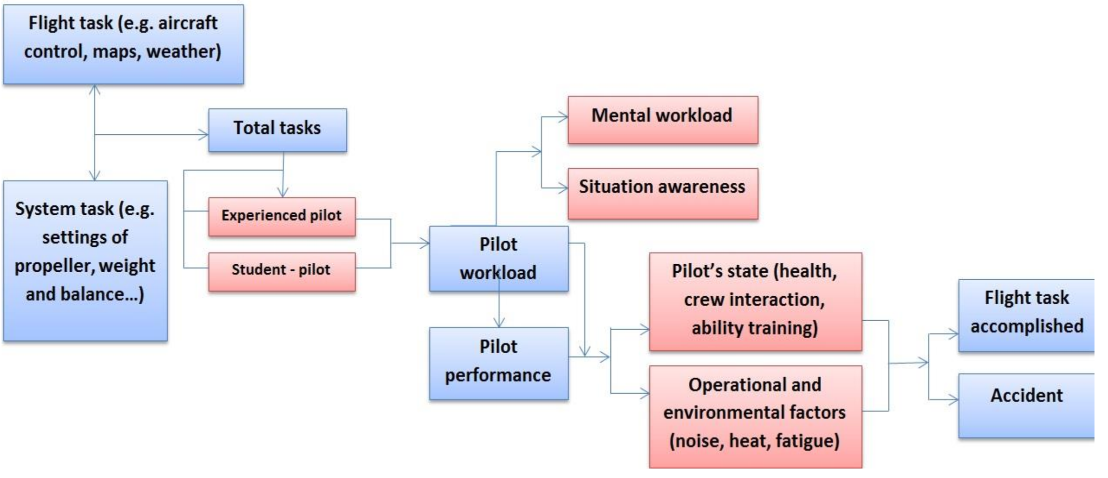

Figure 1. Illustration of algorithm related to pilot performance [compiled by authors]

The effect of physiological stressors on pilot performance and its monitoring play important role in order to ensure the safety of all flight tasks and mitigate the possibility of any risk situations. Therefore, this paper is focused on monitoring the selected physiological factors during predetermined physiological conditions using a flight training simulation device in order to determine the level of successful or unsuccessful flight tasks. During our measurements we deal with psychological and physiological factors, such as heat, noise, hypoglycaemia, fatigue and heart rate in-flight measure.

These factors were chosen in order to easily simulate unfavourable conditions for pilot's flight task in flight training simulation device. Moreover, the pilot workload was increased by determining auxiliary flight tasks and evaluating his performance on the secondary task together with the influence of the additional task's stress on the primary task performance. Therefore, time management and proper sequence of flight tasks are important for the right decision-making.

However, the pilot workload is affected by their different levels of operating skills, as the pilot-students have different workload even though they perform the same flight tasks. Moreover, according to (Roscoe AH, 1993) the Take-off to Climb phase and Final Approach to Landing phase are among the most difficult phases during the entire flight while the Cruise phase is known as the easiest one.

In addition, at Final Approach to Landing phase, the pilots continuously fly down in accordance with the 3° glide path. The increase in gliding angle into 4.5° decreases the distance covered in Final Approach to Landing phase. This decrease in distance would put time pressure on the pilots, where time pressure can increase or decrease the pilot's performance and efficiency in different conditions. Moreover, it is necessary to realise that the relationship between time pressure and performance is not linear but curvilinear. Therefore, the subjects of our research were seven pilots with different amount of flying hours that started from 40 through 270 hours of flight. The flight has been divided into 2 phases – initial and intermediate approach segment as first phase and second phase covered the final approach segment.

For the pilot's measurement we used a flight simulator where we chose ILS approach procedure at the Airport Zilina – Dolny Hricov (LZZI) for runway 06. This procedure was chosen for different reasons.

Firstly, in this procedure there are segments with prescribed flight altitude and final approach segment with a clearly defined glide path angle with measurable deviations from the glide scope and localizer.

Secondly, these procedures are familiar for pilots, as they are actively flying this approach procedure during their training flights at Air Training and Education Centre of the University of Zilina.

FNPT II MCC FLIGHT SIMULATION TRAINING DEVICE

Since 2013, Air Training and Education Centre of University of Zilina uses FNPT II MCC dual pilot flight training simulation device for the purpose of multi-crew coordination processes. The ELITE S923 FNPT II MCC is configured as Beech King Air B200 turbine engine aircraft.

The cockpit of the simulator is partly closed and it is an identic copy of the B200 aircraft, where the system of visual orientation is on very high level and it also displays the effect of aircraft flaring and its touch-down (*Figure 2* below).

The system is operated from the instructor's position that can predetermine different meteorological conditions by computer, such as level of cross-wind, aircraft icing, and turbulence, different way of cloudiness or wind speed.

For the more realistic training it is also possible to set the conditions for the flight during the day, night, dawn or twilight and the control forces are the same as in Beech King Air B200 aircraft.

The simulator visualisation is running through data-projection in pilot's vision angle about width of 180° in horizontal line and 37.5° in vertical line.

Figure 2. Illustration of FNPT II MCC [author]

Simulation device is equipped by these systems for IFR flights:

a) 1 DME Indicator,

b) 1 Transporter,

c) 2 Nav/Comm,

d) 2 ADF,

e) 1 Altitude Proselector,

f) 1 Autopilot System / Flight Director,

g) 1 Audio Control Panel.

Also, the conditions for the take-off and landing phase are realised at the airport CAT1 (it is the airport category), where the decision altitude covers the value of 200 feet with the possibility of automatic approach.

DETERMINATION OF CONDITIONS FOR THE PURPOSE OF RESEARCH

In the case of hypoglycaemia measurements, during 24 hours before measurements the pilots were without food-intake and they also have a limited consumption of sugar (blood sugar has been measured and the results are described in following subchapters). The noise measurement was simulated by enhanced engine working (especially during the take-off phase and landing phase were used thrust reversers for the purpose of making noise) and supported by ongoing communication from the air traffic controllers where pilots have to confirm the dispatcher's instructions.

Moreover, the fatigue measurement was performed after increased physical and also mental pilot workload (it was simulated after at least 24 hour conditions that were based on continuous wakefulness) and it has caused the individual's lower concentration during flight tasks and indeed, it also delayed right decision making during simulated aggravated crisis situations.

In the case of heat measurements we used conditions that were based on continuing incensement of air temperature inside the simulation training device's cockpit (we used a heater where we achieved about 47°C with the aid of an external heat exchanger at 9 kW that was used for heating the air of the engine during winter season).

NOTE: For the purpose of this paper we focused mostly on measurement of heart rate in-flight measure that is described in more detail in the next chapters.

3. HEART RATE AS AN IN-FLIGHT MEASURE OF PILOT WORKLOAD

Heart rate or also called heart pulse is the speed of the heartbeat measured by the number of poundings of the heart per unit of time (usually per minute). Also, the heart rate can vary according to the body's physical needs, including the need to absorb oxygen and excrete carbon dioxide.

Moreover, there are some activities that can cause these changes, such as sleep, anxiety, stress, etc. In addition, the basal or resting heart rate is defined as the heart rate when a person is awake without any effect of stress or surprise. The typical resting heart rate in adults is 60-100 beats per minute [1].

All operations leading to ensure a safe flight require the brain to collect, filter and process information quickly and correctly.

Monitoring heart rate during realisation of flight tasks shows that it tends to increase during flight especially during the take-off or landing phases.

For instance, some studies explained that the increase in heart rate corresponds to an increase of the approach angle; for instance a rate of 104 beats per minute corresponds to an angle of 3° and consequently a rate of 108 beats per minute corresponds to an angle of 6° and a rate of 115 beats per minute corresponds to an angle of 9°.

However, the heart beats depend on different level of pilot workload, therefore our measurements were based on normal state without any workload (called like reference state), and secondly we made measurements with additional influence factors and consequently, we compared the results of these both states [2].

MEASURING EQUIPMENT – SUUNTO TEAM POD

For all our measurements we used the sport equipment, called Suunto Team Pod (*Figure 3*) – a peripheral observation device that shows the heart beat frequency, caloric expenditure, etc. – that is used for increase the effectiveness of group fitness training.

The system consists of a receiver antenna with a USB cable and consequently, the software is installed in the computer to make subsequent analysis of all the results that were obtained.

This system enables to receive the real-time current heart rate with the help of wireless transmission directly to the computer screen from a distance of up to 330 feet. In addition, data sent from the chest belts are directly transmitted to digital receivers and consequently connected to the computer.

Data on all monitored heart rate are displayed on the screen either as a beat per minute or as percentage of their maximum heart rate. The cooperation between Suunto Team Pod and Suunto Monitor is based on the activity where Team Pod receives data in real time from the chest belts and consequently Suunto Monitor displays and records the data from Suunto Team Pod [3], [4].

Figure 3. Illustration of Suunto System [Suunto official website]

3.1 Research outcomes

For our research we cooperated with 7 pilots; each of them made 25 ILS approaches (final approaches). Also, each pilot had to solve his flight tasks during about 6 flight hours in flight training simulation devices.

The obtained data were compared to the reference values that cover the activity without any unfavourable impact on pilot concentration.

We made an analysis of the obtained results related to the precision of piloting under the influence of various factors, for each pilot.

The reference column illustrated in Figs.4-10 shows the average heart beats per minute during the whole measurement cycle without any effect of unfavorable conditions for the flight. From all obtained data we also count : the total average number of deviations from the specified speed and glide path and localizer deviations by more than one dot on the Horizontal Situation Indicator during ILS approach; the deviations from flight altitude by more than 100 feet in the outbound segment of initial approach after crossing NDB (non-directional radio beacon ZLA) to the final approach point; the deviations from the specified speed (by more than 10 knots, the assigned speed for this segment was 200 knots and measurements were carried out in 10-second intervals).

Consequently, we used an additional variable, namely the difference between the average and the maximum average values.

As can be seen in *Figure 4*, the pink graph covers the average heart beats per minute related to Pilot 1. Pilot 1 has about 300 flight hours and it is visible that during the Heat factor applying the highest values of the heart beats per minute were registered during both flight phases – the intermediate and the final approach. In addition, we can see that the smallest impact on heart beats was caused by the noise factor. Also, it was confirmed that the final approach represents one of the hardest flight phases where the biggest values of the heart beat measurement were registered.

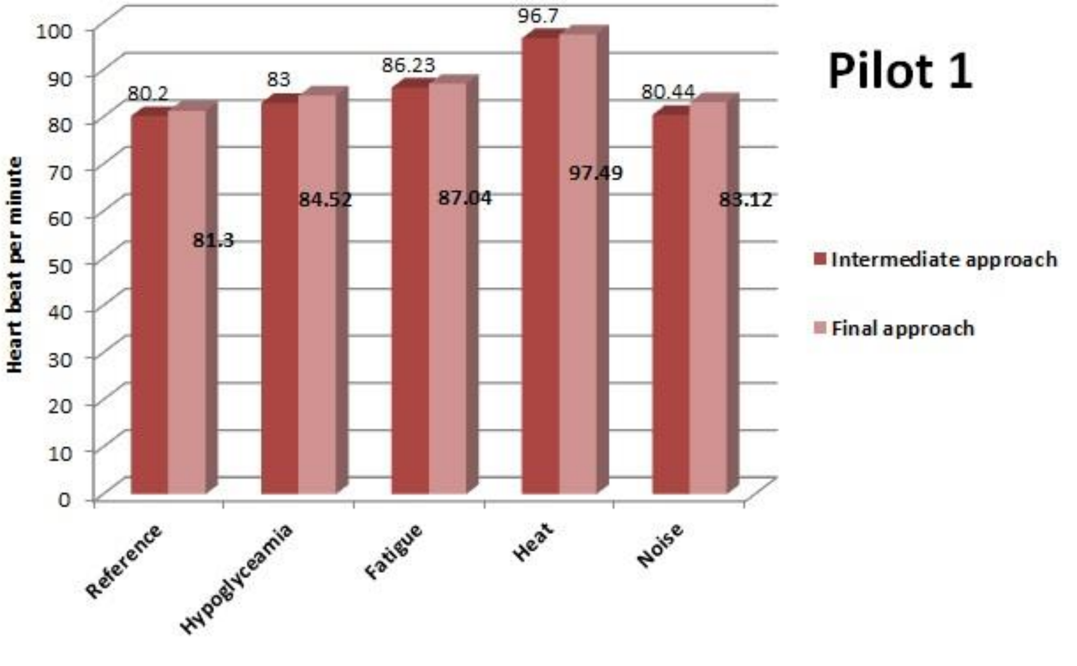

Figure 4. Heart beat measurement related to Pilot 1 [compiled by authors]

As can be seen in *Figure 5* below Pilot 2 (about 50 flight hours) had the highest values of heart beats related to the heat factor during the Final approach phase, but heat and noise factor caused the increase of his heart beating during the intermediate approach phase.

Also, in comparison with Pilot 1 we can see considerable differences of the heart beating activity for Pilot 2 with lesser amount of flight hours which reflected in higher values of heart beat measurement during all tested physiological factors.

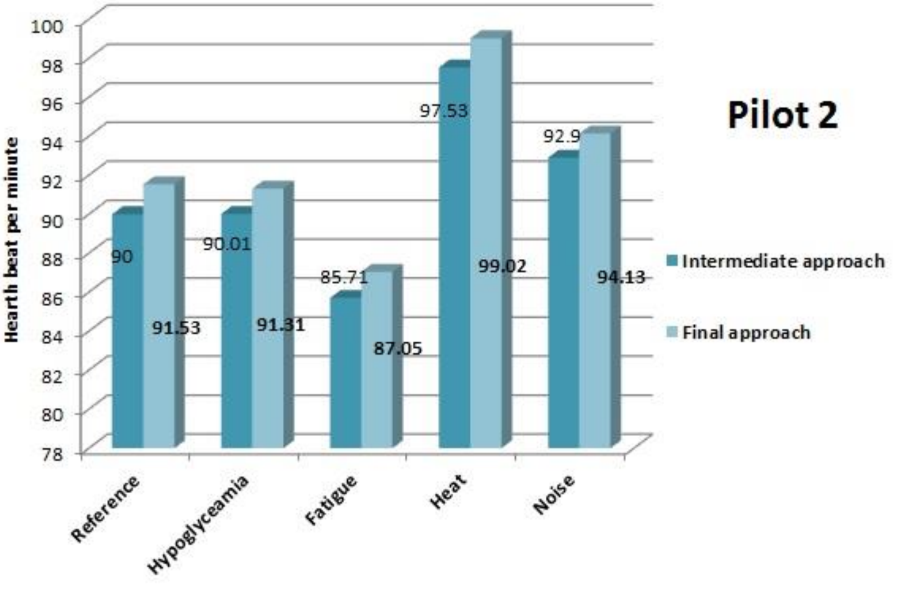

Figure 5. Heart-beat measurement related to Pilot 2 [compiled by authors]

According to *Figure 6* we can see that the worse physiological factor that had impact on the pilot concentration was heat not just during intermediate but also during the flight approach phase while the smallest impact was caused by the fatigue factor. An Interesting fact is that Pilot 3 had about 150 flight hours and despite this his heart beat was higher than in the case of Pilot 2 with lesser amount of flight hours.

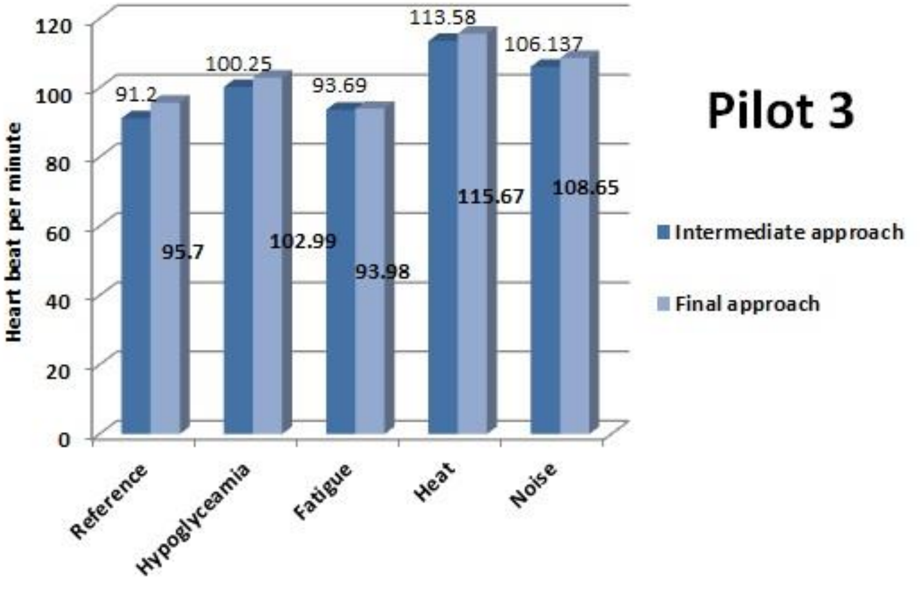

Figure 6. Heart beat measurement related to Pilot 3[compiled by authors]

According to *Figure 7* that illustrates the performance of Pilot 4 with about 160 flight hours, we can observe that his performance was mostly influenced by the heat and hypoglycaemia effect (Pilot 4 received the level of 4.8 mmol/l sugar in his blood). However his heart beat measurement was not very different during the intermediate and final approach as it was in previous cases of Pilot 1, Pilot 2 and Pilot 3. As can be seen in *Figure 8* Pilot 5 had about 160 flight hours and his worst results were linked with highest number of heart beat that was represented by fatigue and hypoglycaemia effect. Also, during the impact of all physiological factors we observed the highest number of heart rate during the final approach phase. The smallest impact was caused by the heat factor while in the case of Pilot 1, 2, 3 and 4 it was the most significant factor related to their performance.

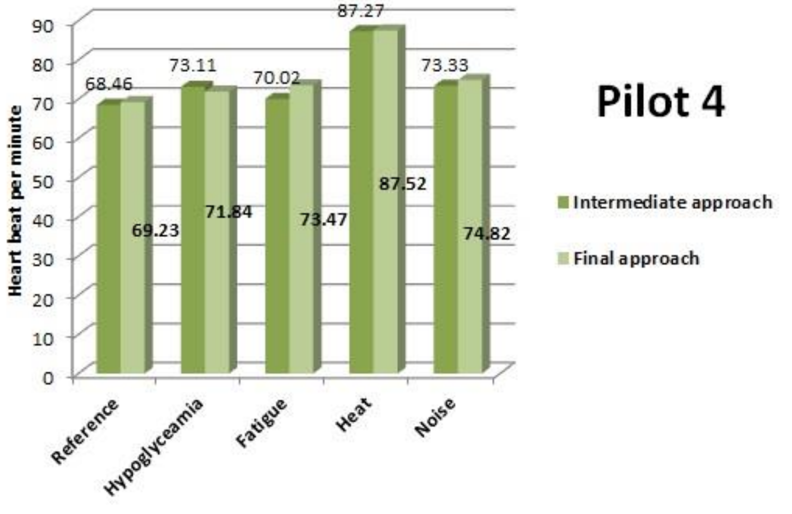

Figure 7. Heart beat data related to Pilot 4 [compiled by author]

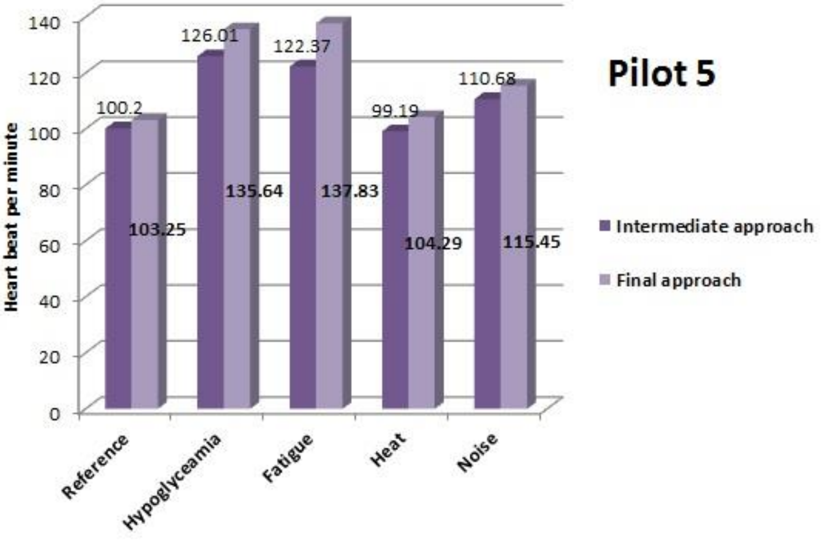

Figure 8. Heart beat data related to Pilot 5 [compiled by author]

According Figure 9 below, we can see that Pilot 6 had the highest heart rate during the final approach that was mainly caused by the fatigue and heat factor. The smallest effect was caused by the noise factor and the highest one was caused by the heat factor during intermediate approach. In the case of Pilot 6 we can see the biggest deviation between the intermediate and the final approach phase.

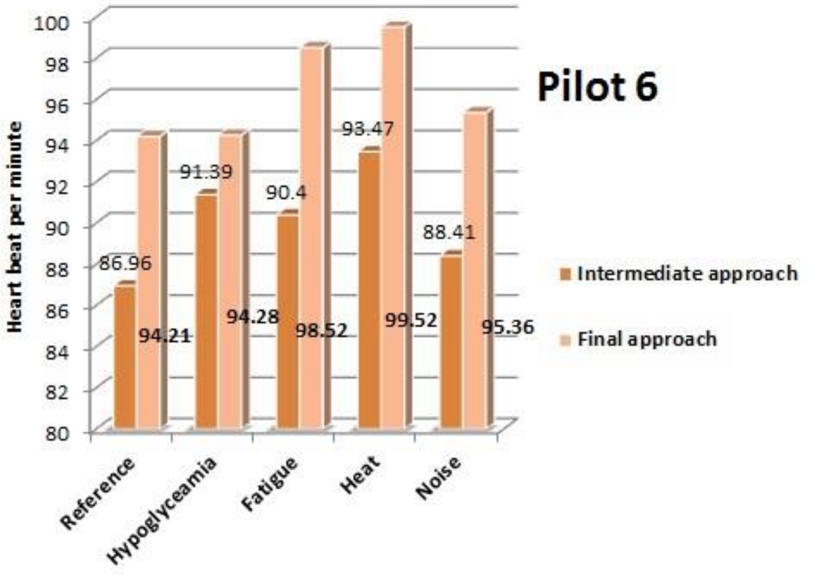

Figure 9. Heart beat data related to Pilot 6 [compiled by authors)

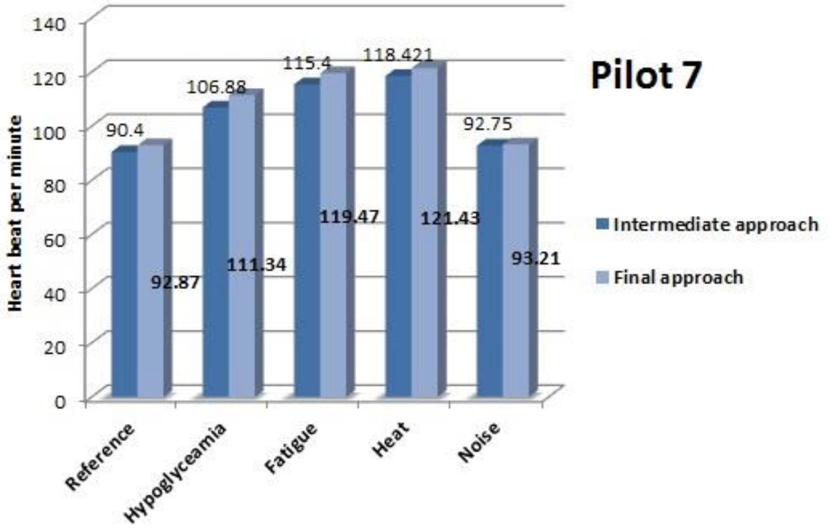

Figure 10. Heart beat data related to Pilot 7 [compiled by authors]

As we can see in Figure 10 above, we can see that Pilot 7 with about 50 flight hours had the highest heart beats due to the fatigue and heat factors. Also, in this case the influence of the highest pressure on pilot performance during the final approach phase was confirmed. The smallest effect was caused by noise that was closely similar to reference.

4. RESULTANT CONCLUSIONS

As could be seen in Figures from the previous chapter, the most significant factor that has an impact on pilot performance was the heat inside the cockpit flight training simulation device. Another fact that we observed was that even Pilot 3 has a bigger amount of flight hours he was under stress because his heart rate measurement was visible higher than in the case of Pilot 2 with smaller amount of flight hours.

In the case of Pilot 4 we observed that his heart beats was similar during the intermediate and final approach. Pilot 4 was concentrated during the flight tasks that reflected in his not very high pulse and small amount of errors made during unfavourable flight conditions. Performance of Pilot 5 was mostly influenced by fatigue and hypoglycaemia effect. Also his results showed the worse performance from all tested pilots. Fatigue and blood sugar (4.4 mmol/l) had the same impact on pilot performance and caused that his number of errors was three times higher as compared to reference.

Pilot 6 had about 150 flight hours and his performance showed the biggest deviations in his performance during the intermediate and final approach phase. In the case of Pilot 7 the most significant effect was caused by the heat and fatigue factors that caused the highest heart beats. Briefly, the highest impact on pilot performance was caused by the heat factor (the temperature inside the flight training simulation device was about 47°C. During the effect of this factor pilots felt dizzy and had significant problems with concentration on flight tasks. The smallest impact on pilots' performance was represented by the noise factor and also it was confirmed that in general pilots had the biggest problems with concentration during the final approach where they had to arrange more flight tasks in the same time.

As pilots were selected according to different amount of flying hours, our research does not confirm that the number of the pilots' errors is proportional to the number of their flying hours, but their performance depend on their physical and mental conditions.

In brief, as for the practical contribution of this research we could say that it offers another possibility to extend the group of studied physiologic and psychological factors, such as heart rate, mental fatigue or drowsiness in order to improve the safety of the flight operations.

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