Preliminary Results of the LF/HF Ratio as an Indicator for Estimating Difficulty Level of Flight Tasks

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INTRODUCTION: The main aim of this study was to differentiate the magnitude of a pilot's heart rate variability (HRV) when performing assisted and unassisted flights, as well as simple and complex flight tasks.

METHODS: Cardiac monitoring in flights was carried out using a compact, mobile ECG recorder. A frequency analysis of the heart rate (HR) signal was performed to determine the ratio of low-frequency spectral power (LF) to high-frequency spectral power (HF).

RESULTS: The LF/HF ratio observed in the zone ($M = 1.047$, $SD = 0.059$) was significantly different than the LF/HF calculated preflight ($M = 0.877$, $SD = 0.043$) and postflight ($M = 0.793$, $SD = 0.037$). There was no main effect of the flight type (unassisted zone flight vs. zone flight with an instructor) on the LF/HF parameter. However, greater psychophysiological load of a pilot was observed in the training zone flights when compared to simple circle flights (main effect of the flight type).

CONCLUSIONS: As the LF/HF ratio turned out to be significantly higher in the zone than pre- and postflight, this parameter can be useful for predicting the risk of excessive stress and arousal of pilots during flights. Based on the LF/HF ratio we can also estimate difficulty level of flight tasks, because our research has shown higher values of this parameter in the training zone flights than in simple circle flights.

KEYWORDS: heart rate variability (HRV), pilot's psychophysiological load, spectral analysis, in-flight research.

Skibniewski FW, Dziuda Ł, Baran PM, Krej MK, Guzowski S, Piotrowski MA, Truszczyński OE. *Preliminary results of the LF/HF ratio as an indicator for estimating difficulty level of flight tasks.* Aerosp Med Hum Perform. 2015; 86(6):518–523.

Today, tasks performed on increasingly modern airplanes cause not only an increase in a pilot's physical body burden, but also impose a number of requirements on his or her cognitive and perceptual systems. Therefore, measurement of a pilot's psychophysiological load is taken into consideration when it comes to improving the design of the aircraft's cockpit according to ergonomic principles, in flight planning, as well as in assessing the level of flight task performance. The monitoring of physiological parameters of pilots during their flights has regularly been conducted by the Military Institute of Aviation Medicine, Warsaw, Poland.

The main aim of this research was to assess the level of difficulty of the performed flights on the basis of the low frequency/high frequency (LF/HF) ratio of the heart rate variability (HRV) spectrum. We present the results of the analysis of the LF/HF ratio recorded in 59 cadets of the Air Force Military Academy, Dęblin, Poland, during their training zone flights and zone maneuvers performed under the Basic Aviation Training Program on the PZL-130TC-1/TC-2 "Orlik" plane in the military aeronautical base in Radom, Poland, from 2010-2013.

METHODS

Subjects

The study protocol was approved in advance by the Ethics Committee of the Military Institute of Aviation Medicine. Each subject provided written informed consent before participating.

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This manuscript was received for review in June 2014. It was accepted for publication in March 2015.

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DOI: 10.3357/AMHP.4087.2015

The studies were conducted on a group of 59 second-year cadets (5 women and 54 men) from the Air Force Military Academy from 2010–2013 during their training zone flights, i.e., flights with a higher level of difficulty in which different flight maneuvers are carried out. All the subjects who participated in the research were healthy and had normal body weight. The total number of fully analyzed HRV records was 287.

Procedure

Maneuvers performed during training zone flights included such acrobatics as corkscrews, combat returns, inversions, loops, Immelman turns, and "barrels." The whole training zone flight lasted for an average of 15 min, in which the last 2 min of flight were analyzed. At this time interval, the average value of the LF/HF parameter was determined. The phases of the training zone flight are explained graphically in **Fig. 1**.

Recording the pilots' cardiac activity was carried out during their flights, according to the established flight training program, and in no way affected its course. The data were collected noninvasively during training flight missions and the cadets did not feel that they were involved in an experiment.

Equipment

The research under flight conditions was carried out using a compact, mobile ECG recorder, usually located in a pocket of a pilot's flight suit, and a 1-lead electrocardiogram (CM5) was acquired. The CE-certified recorder and the analyzing software were designed at the Military Institute of Aviation Medicine[16] and allowed the simultaneous acquisition of ECG signals and some environmental data such as acceleration signals in the three axes and ambient temperature.

Statistical Analysis

In order to determine the HRV parameters, a frequency analysis specifying the ratio of the LF spectral power (frequency range: 0.04 Hz – 0.15 Hz) to the HF spectral power (frequency range: 0.15 Hz – 0.40 Hz) was used. This method involved determining the estimation of power spectral density (PSD) for the signal of time intervals between successive heartbeats, e.g., interbeat intervals, which is called a tachogram. The tachogram was a discrete time function, sampled irregularly, and it was first preprocessed by removing the ectopic beats.[7] In the next step, this function was interpolated by the spline function and sampled regularly at a frequency of 4 Hz. The PSD estimation using a nonparametric method, i.e., periodogram with a hamming window, was utilized. The analysis was based on a comparison of the LF/HF ratio calculated for 2-min time intervals including training zone flights, with 2-min segments of reference states, including the time before departure (the last 2 min before the start) and the time after returning from the flight (the first 2 min after landing). The LF/HF ratio describes the interdependence of both branches of the autonomic nervous system (ANS), and, above all, the activity of the sympathetic nervous system, whose importance increases in situations of high levels of stress and arousal, even though there is no visible change in heart rate (HR). The module of calculation applied was verified in accordance with the IEC 60601-2-47:2001 norm.[27]

In order to verify whether the phase of the flight (i.e., 2-min phase preflight, 2-min phase in the zone, and 2-min phase postflight) and the type of flight (assisted vs. unassisted zone flight, zone flight vs. circle flight) influence LF/HF values, a one-factor repeated measures analysis of variance (ANOVA) and a two-factor repeated measures ANOVA were used. Mean values of the LF/HF parameter for each flight phase and for each flight type in the studied group were calculated. For analysis of the results, Statistica 9.0 software package for Windows by StatSoft was used.

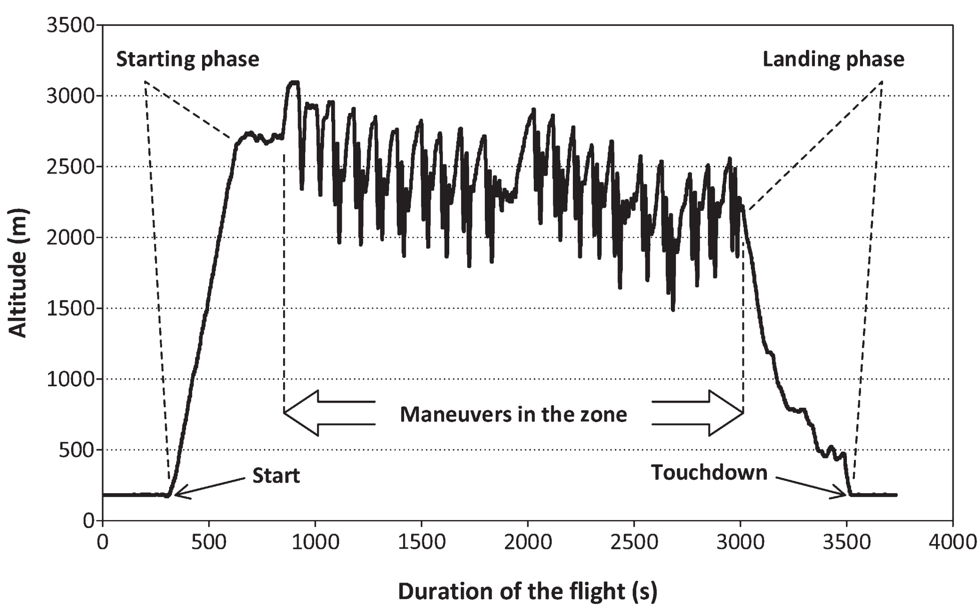

Fig. 1. The main phases of the zone flight.

RESULTS

One of the elements of the HRV analysis in the examined group of the cadets was to determine average values of the LF/HF parameter at three time intervals connected with zone flights: the last 2 min preflight, the last 2 min in the zone and the first 2 min postflight. One value of the LF/HF parameter of HRV was calculated for each subject for every time interval of the flight.

One-factor repeated measures ANOVA revealed a significant main effect of the flight phase, $F(2, 572) = 36.19$, $P < 0.001$, $\eta^2 = 0.112$, separately for every year of the cadets' training, and collectively in the years 2010–2013. Bonferroni's post hoc analysis showed that the LF/HF ratio observed in the zone (M = 1.047, SD = 0.059) was significantly different than the LF/HF calculated preflight (M = 0.877, SD = 0.043) and postflight (M = 0.793, SD = 0.037) ($P < 0.05$). There were also significant differences between the LF/HF ratio observed 2 min preflight and 2 min postflight ($P < 0.05$). The average values of the LF/HF ratio in three designated time intervals in the performed flights in the years 2010–2013 in a group of 59 cadets are presented in **Fig. 2**.

As shown in Fig. 2, the average value of the LF/HF parameter in the zone was the highest when compared to both 2-min time intervals before and after the flight. The analysis of changes in the LF/HF ratio showed a significant increase in the LF/HF value in the zone compared to the other two selected moments in time (Fig. 2), i.e., an increase of more than 16% compared to the moment before the start and an increase of over 24% in comparison to the moment after landing. Postflight, the LF/HF value was reduced, even below the level recorded preflight (decrease of over 9%).

Analysis of changes in the LF/HF ratio was also conducted in relation to the flight type (assisted vs. unassisted zone flights), and thus to the level of difficulty of the performed flights. In order to check whether the flight phase and the flight type differentiated the LF/HF parameter, a two-factor repeated measures ANOVA was used. In this case, the same subjects initially performed zone flights with an instructor and afterwards without. The ANOVA revealed a significant strong main effect of the flight phase, $F(2, 74) = 16.71$, $P < 0.001$, $\eta^2 = 0.311$. Bonferroni's post hoc analysis showed that the LF/HF ratio observed in the zone was significantly different than the LF/HF calculated pre- and postflight ($P < 0.05$), regardless of the flight type. The average values of the LF/HF ratio set at three time intervals, i.e., the last 2 min preflight, the last 2 min during the zone flight and the first 2 min postflight, for the training flights with and without an instructor in the same group of cadets are shown in **Fig. 3**.

As seen in Fig. 3, the LF/HF parameter was higher in the zone when compared to the other selected flight time intervals. This result is consistent with the results depicted in Fig. 2.

Although an increase in the HRV parameters is expected when the level of difficulty of the flight increases and the average values of the HRV parameters, determined in the zone, were higher for the training flights without an instructor (M = 1.159, SD = 0.237) compared to those with an instructor (M = 0.995, SD = 0.096) in the examined group (Fig. 3), the ANOVA did not reveal a significant main effect of the flight type, $F(1, 37) = 2.61$, $P > 0.05$, $\eta^2 = 0.066$. Moreover, there was also no interaction effect of the flight phase and the flight type with regard to the LF/HF parameter, $F(2, 74) = 0.82$, $P > 0.05$, $\eta^2 = 0.022$.

Additionally, in the framework of the ongoing analysis, a two-factor repeated measures ANOVA was used to check whether the phase of the flight and the type of the flight, i.e., unassisted zone flight vs. unassisted circle flight (flight in which the cadets performed circles), influenced the LF/HF parameter. In this case the same subjects performed both types of flights. The ANOVA revealed a significant strong main effect of the flight type, $F(1, 47) = 20.37$, $P < 0.001$, $\eta^2 = 0.302$, which means that irrespective of the flight phase, performing zone maneuvers or performing flight circles affected the LF/HF parameter. The average values of the LF/HF parameter set at three time intervals, i.e., the last 2 min preflight, the last 2 min in the zone flight and in the circle flight, and the first 2 min postflight, for the unassisted zone flights and the unassisted circle flights in the same group of cadets are shown in **Fig. 4**.

According to the data shown in Fig. 4, the LF/HF ratio was higher in the zone (M = 1.149, SD = 0.238) than in the circle (M = 0.706, SD = 0.120) for the studied group. However, the ANOVA did not reveal in this case a significant main effect of the flight phase, $F(2, 94) = 2.70$, $P > 0.05$, $\eta^2 = 0.054$. There was also no interaction effect of the flight phase and the flight type on the LF/HF ratio, $F(2, 94) = 0.42$, $P > 0.05$, $\eta^2 = 0.009$.

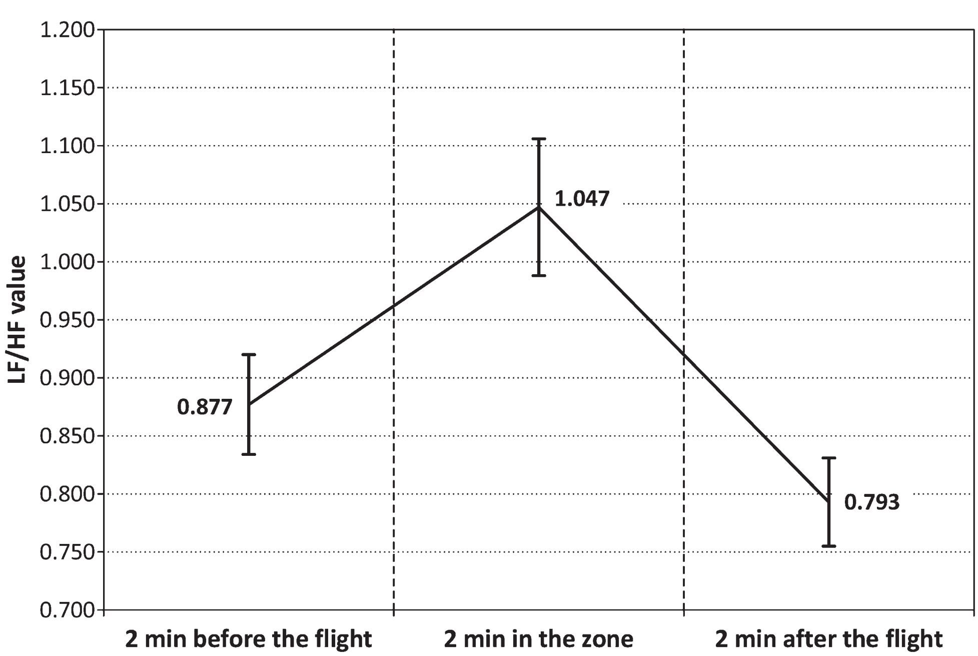

Fig. 2. The average values of the LF/HF ratio 2 min preflight, 2 min in the zone, and 2 min postfight in the same group of cadets (main effect of the flight phase, $F(2, 572) = 36.19$, $P < 0.05$).

DISCUSSION

Evaluation of a psychophysiological state can be carried out in order to predict the occurrence of any incapacitation of a pilot

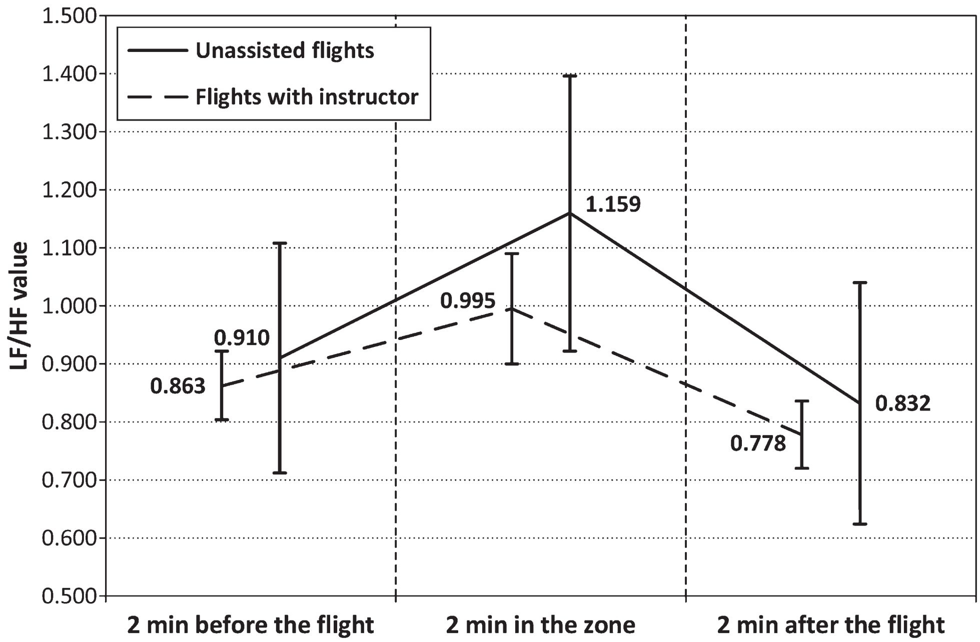

Fig. 3. The average values of the LF/HF ratio 2 min preflight, 2 min in the zone, and 2 min postflight in the unassisted zone flights and the zone flights with an instructor in the same group of cadets (main effect of the flight phase, $F(2, 74) = 16.71$, $P < 0.05$).

methods of measurement, as well as the lack of interference of the subjects in the results obtained. The most frequently recorded psychophysiological variables during flights include: HR, eye movements, breathing activity, the level of cortisol in saliva, and trends of brain waves.[8] It should be noted, however, that the information derived from psychophysiological measurements should also be supported by other data, for example, related to the quality of the flight task performance.[2]

The ANS influences the structures of the human body which control the cardiovascular system, with its components acting in an antagonistic manner: the parasympathetic part of the system suppresses while the sympathetic part stimulates heart activity. The results of several studies, such as those of Brooke and Long[5] and van Doornen,[20] conducted in conditions that were similar to natural ones, clearly showed that the stress factor activates the sympathetic part of the ANS and consequently leads to a significant acceleration of HR and the subjective experience of strong anxiety. In psychophysiology, cardiovascular reactions are treated as an indicator sensitive to any changes in magnitude of the load included in a task, e.g., cognitive load, and HR belongs to the most commonly used indicators.

during the flight, such as spatial disorientation and a lack of situational awareness due to hypoxia, and even loss of consciousness as a result of significant accelerations. In addition to high predictive power, psychophysiological parameters have diagnostic value for determining the magnitude of mental and physical loads of a pilot during the flight. Their benefits include conducting ongoing and continuous recording without the need to operate the system by the operator, nondestructive

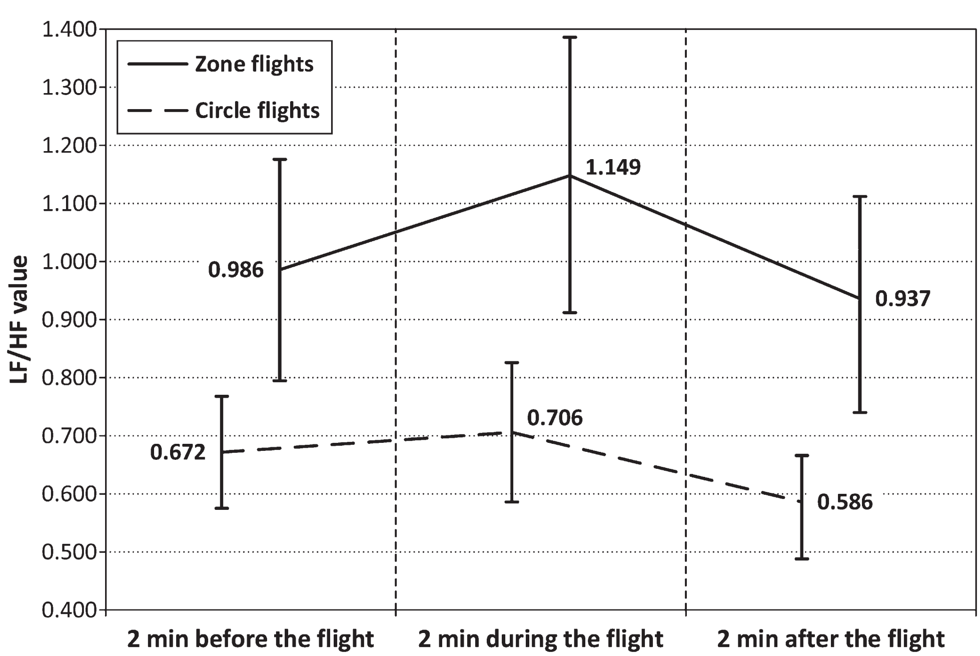

Fig. 4. The average values of the LF/HF ratio 2 min preflight, 2 min in the flight, and 2 min postflight in the unassisted zone flights and the unassisted circle flights in the same group of cadets (main effect of the flight type, $F(1, 47) = 20.37$, $P < 0.05$).

The HR parameter is sensitive to changes in a pilot's mental workload, which depend on a variety of flight aspects. A significant increase in HR was reported during the most difficult elements of the performed flights, i.e., containing the greatest information load and thus being the most mentally aggravating, which were the starting phase, the approaching phase, and the landing phase.[11,24,25] Moreover, higher values of HR were also observed during flights with loaded weapons. Therefore, it can be said that in certain stages or types of flights, pilots obtain contrasting results in HR to those in straight line flights, both in real and simulated conditions.[12,22] As the flight itself is a heavy psychophysiological burden for a pilot, it may also cause a high level of adrenaline in military pilots before and after aerobatic and combat flight maneuvers.[14]

In addition, compared to other members of the crew, a significantly faster HR was reported in a group of pilots when taking control of the wheel, interpreted as taking responsibility for the flight.[9,13] Also, higher values of HR have been shown in cases where the plane is manually flown rather than using autopilot.[15]

In turn, Zimmer et al.[26] observed that, in tasks with a high level of difficulty, there was a specifically greater decrease in HR after the initial increase. The authors explained this using the strategy of resignation, which often accompanies the tasks requiring too much cognitive effort. The impact of task difficulty on cardiovascular changes has also been considered in studies by Allen et al.[1] and Turner et al.,[19] showing that the greatest changes in cardiovascular parameters appeared during tasks with high cognitive demand, which are dealt with by the individual. In conclusion, it can be said that there is typically an increase in HR as an individual's mental load increases, e.g., as a consequence of performing complex air tasks.[23,24]

Important cardiovascular indicators which have been taken into account in different studies on the effects of task difficulty include not only HR parameters, but also cardiac arrhythmia parameters, known as the HRV indices. In most studies that have analyzed the HRV indices,[17,18] an increase in cognitive load induced by a specific task contributed to a decrease in HRV, even if the HR itself was subject to minor changes. In general, it appears that the growth of the HR parameter is accompanied by a decrease in HRV amplitudes of oscillation as a result of performing a cognitive loading task.[6]

On the other hand, some studies have shown that the HRV parameters were significantly less susceptible to variations due to different flight demands in comparison with other peripheral nervous system indicators, such as HR variables.[21,24] In addition, it was also noted that HRV, determined as the ratio of the LF and HF spectrum of heart beat interval signals, could be considerably influenced by some factors, e.g., low values of respiration rates.[21] In this case, it is crucial to control breathing processes in order to interpret HRV data accurately. Furthermore, the LF/HF ratio has also been criticized for its susceptibility to applied mathematical calculations as well as the complexity that it does not reflect simple linear interactions between sympathetic and parasympathetic parts of the ANS.[4] Nevertheless, on the basis of the majority of research carried out thus far, it is assumed that the analysis of HRV provides valuable information about the health condition of the individual, including the degree of his/her physical and mental load.[3,10]

On the basis of the analyzed records of HRV in our examined group of cadets, it can be concluded that the LF/HF ratio may be a good indicator of a pilot's psychophysiological load in real flight conditions, which is dependent on the nature of the flight and the level of difficulty of the performed tasks. Specific moments in flight and the type of maneuvers performed in flight differentiated the magnitude of the LF/HF ratio. The data presented in Fig. 2 showed that the LF/HF ratio in the zone was significantly higher than pre- and postflight. This result was associated with a higher level of difficulty of the task carried out in the zone, which stimulated physiological arousal of the body and evoked a larger physical and mental workload. This, in turn, was reflected in higher indicators of a pilot's cardiovascular system. There was, however, a significant decrease in the LF/HF ratio in the first 2 min after finishing the flight in comparison to its value just before the flight (decrease of over 9%) and during the flight, which may result from a drop in a pilot's psychophysiological load and tension postflight. It can be concluded that due to the fact that the LF/HF ratio turned out to be significantly higher in the zone than pre- and postflight, this parameter can be useful for predicting the risk of excessive stress and arousal of pilots in flights.

Furthermore, the conducted analyses demonstrated that the presence or lack of an instructor when performing zone flights did not significantly affect the magnitude of the LF/HF ratio (Fig. 3). In other words, responsibility for the flight, i.e., a pilot's awareness that he/she is not supported by an instructor during the flight and the success of the flight depends on him/her, was not so aggravating as to be visible in cardiovascular parameters. It can also be assumed that a pilot during the flight mainly relies on his/her own abilities and as a consequence the presence or lack of other people on a plane's board does not significantly influence his/her psychophysiological state, at least when nothing dangerous or unexpected happens in flight.

Moreover, on the basis of Fig. 4, it can be observed that performing zone flights caused a much greater psychophysiological load in a pilot than the circle flight, which was associated with a high level of difficulty regarding zone maneuvers, such as corkscrews, combat returns, inversions, loops, Immelman turns, and "barrels." It seems that such aerial acrobatics caused an increase in tension and stress in a pilot, whereas flights in which a pilot performed relatively simple circles did not result in a large psychophysiological load. The two-factor repeated measures ANOVA confirmed a significant strong main effect of the flight type on the LF/HF parameter. Therefore, on these grounds, it is possible to anticipate the potential risk of some hazards appearing in flights due to high levels of stress and tension in a pilot. What is more, as the LF/HF parameter turned out to be significantly higher in the training zone flights than in simple circle flights, it can also be treated as a good indicator for estimating the difficulty level of flight tasks.

It is worth mentioning, however, that collecting physiological data during real flights is still a huge challenge for the researchers. The main difficulty is the need to ensure such conditions in which conducting the measurement in no way endangers flight safety or affects a pilot's flight task performance.[8] Hence, assessing the level of difficulty of the performed flights on the basis of a pilot's cardiovascular parameters requires the appropriate recording device. Another limitation of this kind of research is that it is difficult to determine which kind of load influences a pilot's HR and HRV parameters the most in flight, i.e., cognitive load, physical load, or emotional state.[25]

In conclusion, the monitoring of a pilot's cardiovascular parameters, such as HR and HRV, during the flight can be a source of valuable information about his/her actual psychophysical condition, and thus may be crucial for maintaining flight safety. Although opinions on how to interpret these parameters are divided, the results of various studies on the cardiovascular changes which arise as a result of performing the tasks of varying difficulty confirm the validity and meaningfulness of this kind of research. Our own studies presented in this paper also revealed that the HRV LF/HF may be a good indicator of a pilot's physical and mental load, depending on the phase and the level of difficulty of the performed flight tasks.

For this reason, monitoring psychophysiological parameters during real flights should be carried out despite its complexity and different limitations and difficulties in the organization of this type of research. Therefore, this kind of research has become a part of various programs and experimental studies which have been running for many years by scientists around the world, and are still being appreciated and of particular interest in different environments related to aviation.

ACKNOWLEDGMENTS

This article includes the results of work carried out within the framework of Project No. 03/WNiI/2007/IWSZ, "Improvement of examinations in real flight conditions of physiological and psychological parameters in cadets and pilots retrained on new types of aircraft for the assessment of environment and training progress," financed by the resources of the Ministry of National Defence, Republic of Poland.

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