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FLIGHTS WITH THE RISK OF SPATIAL DISORIENTATION IN THE MEASUREMENTS OF OCULOMOTOR ACTIVITY OF PILOTS

Rafał LEWKOWICZ [1], Piotr FRANCUZ [2], Bibianna BAŁAJ [3], Paweł AUGUSTYNOWICZ [2]

[1] Military Institute of Aviation Medicine, Aeromedical Training Division, Warsaw, Poland

[2] John Paul II Catholic University of Lublin, Faculty of Social Sciences, Institute of Psychology, Lublin, Poland

[3] Nicolaus Copernicus University in Toruń, Faculty of Humanities, Institute of Philosophy, Toruń, Poland

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Author's address: R. Lewkowicz, Military Institute of Aviation Medicine, Aeromedical Training Division, ul. Krasińskiego 54/56, 01-755 Warsaw, Poland, e-mail: rlewkowicz@wiml.waw.pl

Introduction: To date, research on oculomotor predictors of the correctness of in-flight maneuvers depending on pilot's expertise was never conducted in relation to situations involving the risk of spatial disorientation. This article describes the developed testing method that facilitates the assessment of oculomotor activity upon spatial disorientation caused by visual or vestibular illusions.

Methods: The experiment will include a group of 20 male pilots (expert group) and 20 male non-pilots (novices group). The testing station consists of a Gyro-IPT spatial disorientation simulator and a mobile oculographic device for the measurement and tracking of subject's oculomotor activity.

Results: The study allowed for the development of a set of flight profiles for the Gyro-IPT simulator as well as a verified testing procedure including oculographic device calibration as well as the measurement and tracking of flight parameters and eyeball movements.

Conclusions: Appropriate setup of the testing station and verification of the developed testing procedure will facilitate successful conduct of the planned experiment. Determination of efficient visual field scanning strategies for flights associated with the risk of spatial disorientation will constitute a significant contribution into aviation psychology as well as would possibly contribute to the development of more efficient pilot training programs as well as improvement of flight safety.

Keywords: flight simulator, oculomotor activity, spatial disorientation

Figures: 3 • **Table:** 1 • **References:** 11 • **Full-text PDF:** http://www.pjamp.com • • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

Piloting aircraft involves a number of cognitive processes. On the basis of information collected from their surrounding as well as the pre-acquired knowledge, pilots make quick decisions that often lead to immediate consequences [3]. Incorrect interpretation of visual and sensory stimuli leads to spatial disorientation [8]. The efficacy of pilotage depends on specific aspects of visual attention. Visual fixation times and positions are commonly assumed in the studies as indicators of open visual attention [9]. In pilots, search was also conducted with regard to oculomotor indicators of situational awareness [11] and cognitive burden [3,4]. However, no studies of this type were conducted in the context of in-flight risk of spatial disorientation. Oculomotor activity indicators are often analyzed by means of comparing the behaviors of experts (pilots) and laypersons (novices). This facilitates examination of strategies adopted by both groups as well as the modeling of strategies optimal for individual flight stages [1,5,6].

This article describes the developed methodology of assessments that facilitates the conduct of experiments to assess oculomotor activity in various situations associated with the risk of spatial disorientation (of visual as well as vestibular origin). The presented method includes the characteristics of the instrumentation as well as of the testing procedure being developed.

METHOD

Subjects

The experiment will include a group of 20 male pilots (expert group) and 20 male non-pilots (novices group). All subjects will have no vision defects or have their vision defects appropriately corrected. Subjects qualified for Gyro-IPT simulator testing will have to meet the following criteria:

- night's rest before the test (at least 6 hours of sleep);
- no alcohol consumption within 24h before the test;
- no fasting condition and not immediately after a meal;
- no reported gastrointestinal dysfunction;
- no reported otitis media;
- no upper airway inflammation;
- no other complaints that might affect the tolerance to motor stimuli.

The experiment was designed to be performed at the Military Institute of Aviation Medicine (MIAM) in Warsaw.

Testing equipment

Subjects will be subjected to a series of aircraft piloting tasks using the Gyro-IPT simulator. Mobile oculographic device will be used to track the oculomotor activity of subjects during the test.

Gyro-IPT Simulator

The testing station includes the Gyro-IPT (Integrated Physiological Trainer) spatial disorientation simulator from Environmental Tectonics Corpora-

a.)

b.)

Fig. 1. Gyro-IPT Simulator: a) pilot's cockpit, b) operator's console.

tion (ETC) in Southampton, USA (Fig. 1). The simulator is particularly recommended for the training of pilots in evoked spatial disorientation condition [2]. The mobility of the simulator cockpit including three degrees of freedom facilitates the use of subliminal stimuli as well as generation of relatively high angular accelerations.

The available simulation programs include presentation of visual illusions, vestibular illusions, desensitization to motor stimuli (to fight the symptoms of motion sickness) as well as the training of the ability to regain control from atypical positions. Detailed description of the simulator is presented in an article from 2004 [7]. The other element of the simulator system consists in the operator's console (Fig. 1b) comprised of control monitors (from left: view of the subject recorded using an infrared camera; simulation screen accurately reflecting the cockpit monitor and the monitor of the navigating computer). Selected for the tests was a simulation plane model with dynamic properties corresponding to the TS-11 "Iskra" aircraft in standard configuration (without suspended fittings or armament).

The manufacturer of the simulator had predefined several disorientation profiles within the software. Results of studies presented in the doctoral dissertation of Kowalczuk [8] were taken into account in the comparative assessment of profiles including the strength of disorienting stimulus as the main criterion. Selected for the studies were three profiles with visual illusion elements as well as three profiles with vestibular illusion elements. The flight profiles were appropriately extended so as to account for the required 60-second periods after the illusion-inducing stimulus. In addition, to increase the strength of the disorienting stimulus, the target angular velocity of the simulator cockpit was increased by 12°/s.

The following 6 in-flight illusion profiles were selected for the planned experimental studies:

a) visual illusions:
   - daytime false horizon illusion – a profile that demonstrates the predominance of peripheral vision in vision-based spatial orientation;
   - constant shape illusion (landing on an inclined runway) – an illusion associated with the constancy of shapes being expected by the pilot; may be particularly strong when flying over an unknown terrain or approaching an unknown airport;
   - constant size illusion (landing on a runway of atypical dimensions) – an illusion associated with the constancy of sizes being expected by the pilot; may be particularly strong when flying over an unknown terrain or approaching an unknown airport;

b) vestibular illusions:
   - somatogyral illusion – a profile that demonstrates the false sensation of rotational motion (or lack of rotational motion) resulting from erroneous perception of the strength and direction of actual rotation;
   - Coriolis illusion – demonstration of the effect of cross-stimulation of semicircular canals occurring when head is moved during fixed rotational motion;
   - leans illusion – disturbed perception of leaning position due to the limited sensitivity of vestibular organs.

A total of 22 flight parameters will be tracked at 10Hz during the experiments including the kinematics of the simulation model and the simulator cockpit.

Oculographic device

Visual perception of pilots and laymen will be assessed by means of the measurement of eyeball movements using oculographic devices. The testing station is equipped with a mobile oculographic device adapted to work in simulated flight conditions. The analysis of the capabilities of devices available at the market showed that the use of contactless systems did not ensure the expected accuracy of measurements due to the imperfections of the head motion detection algorithms.

SMI EyeTracking Glasses (Fig. 2) were selected as the device to track the activity of eyeballs and vision being directed into the predefined regions of interest. The device has angular resolution of 0.5° and data tracking frequency of 30Hz. In addition, the device is equipped with automatic parallax correction and post-hoc calibration mechanisms. The device is built inside glasses with a total weight of 75g, thus generating no additional stimulus, either in terms of the physical, or cognitive load. Manufacturer-provided software allows for a significant degree of automatization of the

Fig. 2. SMI EyeTracking Glasses [10].

statistical analysis and computations of data recorded during the tests. The most important parameter measured during the test are visual fixations that define the duration of subject's focus on a particular area. Location and duration of fixations are assumed to be the measures of subject;s focus on a particular object.

Procedure

The tests of oculomotor activity during the perceptive tasks being performed while exposed to visual and motor stimuli in a Gyro-IPT flight simulator will include:

- An introductory flight aimed at introducing the pilot to the operational characteristics of the simulator and the used plane simulation model.
- A flight including the elements of illusions leading to spatial disorientation provided as a set of profiles involving pilotage tasks.

Prior to actual exposure to spatial disorientation elements, each subject will participate in an introductory flight aimed at introducing the pilot to the operational characteristics of the Gyro-IPT simulator and the used plane simulation model. The introductory flight profile includes the basic elements of pilotage including the approach-to-landing maneuver.

Proper performance of the introductory flight, i.e. performing all the maneuvers within the predefined deviation limits (course ±5º; altitude ±100 ft; tilt ±10º; speed ±20 knots; rate of climb/descent ±500 ft/min) is the prerequisite for participation in the main part of the study.

The main part of the study will be carried out in two sessions. Session 1 will include flight profiles without preprogrammed motor disorientation stimuli. Profile randomization will be used for each subject with regard to the sequence of exposures (6 profiles without preprogrammed motor disorientation stimuli and 3 profiles including visual illusions). The total of 40 subjects will be subjected to a total of 360 simulator exposures. Session 2 will include 3 profiles with preprogrammed motor disorientation stimuli. Taking into account the profile randomization, the total of 40 subjects will be subjected to a total of 120 simulator exposures. Overall, the experiment will involve 480 exposures.

SMI EyeTracking Glasses will be calibrated using the three-point method before each flight profile.

RESULTS

Studies on the adaptation of Gyro-IPT stimulator for the planned experiments and verification of the developed procedure afforded the following flight profiles with basic parameters listed in Tab. 1.

The daytime false illusion profile is started during the flight at the speed of 200 knots, altitude of 15000 feet and course of 360 degrees. Overcast (8/8), cloud base 14500 feet, cloud top 19000 feet. Pilot receives a command to turn right to follow the course of 060 and climb to the altitude of 20000 feet at the rate of 3000 feet/min. After the course of 060 degrees and the altitude of 20000 feet are achieves, the artificial horizon is blacked out (by the instructor) and the pilot regains horizontal flight using the visual reference to the cloud cover. The program simulates a 10° rightward tilt of the cloud cover. The artificial horizon is displayed back on the simulator screen the instructor 30 seconds after it has been blacked out. Then, the pilot may observe the potential discrepancy between the artificial horizon and the maintained angular

Tab. 1. List of basic flight profile parameters.

Profile name	Duration [s]	Duration of stimulus [s]	Acceleration Stimulus [°/s²]	Condition for generation of illusion	Control condition	Artificial horizon blackout time [s]
Daytime false horizon illusion	190	60	none	Altitude of 20,000 ft and course 060 achieved	No tilt of the cloud cover	130-190
Constant shape illusion	166 or runway level achieved	60	none	regain course 360	no runway inclination	none
Constant size illusion	90 or runway level achieved	90	none	take-off	runway size 150x5000 ft	none
Somatogyral illusion	290	60	+0.4 to the velocity of 76°/s -15 to the velocity of 0°/s	regain horizontal flight	no programmed acceleration stimulus	none
Coriolis illusion	210	60	+0.5 to the velocity of 70°/s -2 to the velocity of 0°/s	head movement on command	no programmed acceleration stimulus	none
Lean illusion	150	66	+0.5 to the velocity of 60°/s -4 to the velocity of 0°/s	regain horizontal flight	no programmed acceleration stimulus	92-105

position of the plane. The profile ends after 190 s with simultaneous discontinuation of the illusion-generating stimulus. The control condition for the false horizon illusion differs from the testing condition only by the course of 150 for which no cloud cover tilt is observed.

The constant shape illusion profile is started during nighttime flight at the speed of 150 knots, course of 060 degrees, and with terrain visibility at the altitude of 800 feet. Pilot receives a command to turn left to follow the course of 360 at 30º lean and begin the approach-to-landing procedure on runway 36. The runway incline is 10º. The illusion is displayed after the course of 360 is achieved. The disorienting stimulus is turned off and the test is finished when the runway level is achieved. The control profile used in the testing of the constant shape illusion is characterized by runway incline of 0º.

The constant size illusion profile is started during nighttime flight at the speed of 90 knots, course of 360 degrees, with terrain visibility at the altitude of 800 feet and at the distance of 9000 feet from the runway threshold. The pilot receives the commend to start the approach-to-landing procedure on the runway displayed (runway 36, landing gear and flaps down). The disorienting stimulus consists in non-standard dimensions of the runway which is 300 feet wide and 5000 feet long. The illusion starts once the profile is activated and ends when the runway level is achieved. The control condition used in the testing of the constant size illusion is characterized by non-manipulated dimensions of the runway which is 150 feet wide and 5000 feet long.

The xantogranuloma illusion profile is started during daytime flight at the speed of 200 knots, altitude of 5000 feet, and course of 310 degrees. Overcast (8/8), cloud base 6000 feet, cloud top 9000 feet. Eighteen seconds into the flight, the pilot receives a command to turn left to the course of 180 degrees and climb to the altitude of 7000 feet. Fifteen seconds after simulation starts, the simulator cockpit starts rotating counter-clockwise around its vertical axis at subliminal angular acceleration of 0.4°/s^2 (not perceived by the subject) to reach the constant rotational speed of 76°/s after 205 seconds of flight. One hundred and eighty seconds into the flight, the pilot receives a command to turn left to the course of 030 degrees and maintain the altitude of 7000 feet. At 212 seconds, the subject receives the command to regain horizontal flight while maintaining the steady course. At 217 s, cockpit rotation is slowed down at deceleration of 15°/s^2 (perceived by the subject). This is a disorienting stimulus. The test duration is 290 seconds. The control condition used in the testing of the xantogranuloma illusion is characterized by the lack of counter-clockwise rotation at subliminal acceleration of 0.4°/s^2 and deceleration of this rotation starting from the rotational speed of 76°/s.

The Coriolis illusion profile is started during daytime flight at the speed of 200 knots, altitude of 5000 feet, and course of 090 degrees in normal atmospheric conditions. Five seconds after simulation starts, the simulator cockpit starts rotating clockwise around its vertical axis at subliminal angular acceleration of 0.5°/s^2 (not perceived by the subject). At 14 seconds, the pilot receives a command to turn rightwards to the course of 240 and climb to the altitude of 7000 feet. At 131 seconds, the subject receives a command to turn rightwards to the course of 360. At 145 seconds, when constant rotational speed of 70°/s is achieved, the subject receives a command to enter settings using the transponder. Due to the fact that the transponder keypad is located to the left of the pilot's chair in the simulator cockpit, the pilot must perform a leftward-downward turn on his head in order to enter the setting. This results in the Coriolis illusion and is considered the onset of the disorienting stimulus. At 173 seconds of simulation, the rotational speed is decelerated at the rate of -2.0°/s^2 (perceived by the subject) until the cockpit stops completely. The test duration is 210 seconds. The control condition used in the testing of the Coriolis illusion is characterized by the lack of clockwise rotation at subliminal acceleration of 0.5°/s^2 and deceleration of this rotation starting from the rotational speed of 70°/s.

The lean illusion profile is started during nighttime flight with no terrain visibility at the altitude of 7000 feet and course of 010. Five seconds into the flight, the cockpit starts rotating clockwise with angular acceleration of 0.5°/s^2. Twelve seconds into the flight, the pilot receives a command to turn right while leaning the plane by 30°. Simultaneously, the simulator cabin starts rotating clockwise within the lean plane with angular acceleration of 1.0°/s^2 do as to reach the final angular speed of 68°/s. After several second, additional rotation of cockpit is started within the right-lean plane (at 17 seconds) and backward-lean plane (at 21 seconds) with angular acceleration of 0.5°/s^2 to reach rotational speeds of 3° and 2°/s, respectively. At 82 seconds, the pilot receives the command to regain horizontal flight and continue the previous course. The disorienting stimulus is applied at 84 seconds when the cockpit returns to the horizontal position with acceleration of 1.0°/s^2 within the lean and inclination planes and stops rotating with deceleration of 4.0°/s^2. Simultaneously, at 92 seconds, artificial horizon display is blacked out for 13 seconds and the pilot received a command to continue horizontal flight. The test duration is 150 seconds. The control condition used in the testing of lean illusion lacks the stimulus consisting of pre-programmed rightward lean and forward inclination of the cockpit combined with clockwise rotation of the cockpit.

Fig. 3. presents an image recorded by the scene camera of the SMI EyeTracking Glasses oculographic device during the tests of the training station. Along with the in-flight scenery, the flight and navigation instruments, and plane engine indicators, the figure features the orange ring indicating the momentary visual fixation area.

Fig. 3. Illustration of flying instruments located on the screen within the simulator cockpit.

CONCLUSIONS

The objective of the study was to prepare the Gyro-IPT flight simulator for tests conducted as part of the research project titled "Oculomotor, electroecephalographic and behavioral activity during performance of perceptive and cognitive tasks". The planned tests will facilitate the assessment of oculomotor predictors of the correctness of in-flight maneuvers in various situations involving the risk of spatial disorientation depending on pilot's expertise. Comparison of oculomotor behaviors of experts and novice pilots will facilitate the development of an explanatory model of visual scanning processes in pilots. Tracking the trajectories of ocular movements performed by expert pilots will allow to identify the effective visual scanning strategies. Determination of efficient visual field scanning strategies for flights associated with the risk of spatial disorientation will constitute a significant contribution into aviation psychology as well as would possibly contribute to the development of more efficient pilot training programs as well as improvement of flight safety.

AUTHORS' DECLARATION:

Study Design: Rafał Lewkowicz, Piotr Francuz, Bibianna Bałaj, Paweł Augustynowicz; **Data Collection:** Rafał Lewkowicz, Piotr Francuz, Bibianna Bałaj, Paweł Augustynowicz; **Statistical Analysis**: Rafał Lewkowicz, Piotr Francuz, Bibianna Bałaj, Paweł Augustynowicz; **Manuscript Preparation:** Rafał Lewkowicz, Piotr Francuz, Bibianna Bałaj, Paweł Augustynowicz; **Funds Collection:** Rafał Lewkowicz, Piotr Francuz, Bibianna Bałaj, Paweł Augustynowicz. The Authors declare that there is no conflict of interest.

REFERENCES

1. Adamczak M, Sęk H. Znaczenie jakości życia w nowoczesnej opiece psychologicznej pacjentów onkologicznych. In Meyza J, Bellenkes AH, Wickens CD, Kramer AF. Visual scanning and pilot expertise: The role of attentional flexibility and mental model development. Aviation, Space and Environmental Medicine 1997; 68:569-579.
2. Cheung B, Wong WT. Recommendation to implement Gyro-IPT for disorientation training at CFSAT. Report Number: DCIEM-98-TM-59. Defence and Civil Inst of Environmental Medicine, Downsview ONT (CAN) 1998. 15.
3. Di Nocera F, Camilli M, Terenzi M. A random glance to the flight deck: pilot's scanning strategies and the real-time assessment of mental workload. Journal of Cognitive Engineering and Decision Making 2007; 1(3):271-285.
4. Di Nocera F, Terenzi M, Camilli M. Another look at scanpath: distance to nearest neighbour as a measure of mental workload. In de Waard D, Brookhuis KA, Toffetti A. eds, Developments in Human Factors in Transportation, Design and Evaluation. Maastricht, the Netherlands: Shaker Publishing; 2006:295-303.

5. Huemer V, Hayashi M, Renema F, Elkins S, McCandless J, McCann R. Characterizing scan patterns in a spacecraft cockpit simulator: expert vs. novice performance. Paper presented at the Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting; 2005:83-87.
6. Kasarskis P, Stehwien J, Hickox J, Aretz A, Wickens CD. Comparison of expert and novice scan behaviors during VFR flight. In Proceedings of the 11th International Symposium on Aviation Psychology, Columbus The Ohio State University; 2001.
7. Kowalczuk K. Wartość diagnostyczna parametrów fizjologicznych podczas wywoływanej dezorientacji przestrzennej. Polski Przegląd Medycyny Lotniczej 2004; 10(1):7-22.
8. Kowalczuk K. Wartość diagnostyczna parametrów fizjologicznych podczas wywoływanej dezorientacji przestrzennej. Rozprawa na stopień doktora nauk medycznych. Wojskowy Instytut Medycyny Lotniczej; 2003.
9. Rayner K. Eye movements in reading and information processing: 20 years of research. Psychological Bulletin 1998; 124:372-422.
10. SMI Eye Tracking Glasses @ONLINE. Retrieved 18 February 2015 from http://www.smivision.com/en.html
11. van de Merwe K, van Dijk H, Zon R. Eye movements as an indicator of situation awareness in a flight simulator experiment. International Journal of Aviation Psychology 2012; 22(1):78-95.

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