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Barbara STEMPIN-MIKA, Marta GALANT-GOŁĘBIEWSKA,
Marta MACIEJEWSKA
Poznań University of Technology (Politechnika Poznańska)

PILOTS' GAZE BEHAVIOR IN SIMULATION RESEARCH

Zachowanie wzrokowe pilotów w badaniach symulacyjnych

Abstract: *Effective processing of information from the sense of sight affects the efficiency and safety of flight operations. Differences in visual behavior between pilots with varying levels of flight experience during basic flight maneuvers were identified as the research problem. Twenty-six pilots participated in the study and were divided in terms of flight experience. The participants' visual behavior was recorded using a Pupil Invisible eye tracker. The test subjects' task was to take off from Poznań-Ławica airport, climbing to 2000ft and making two turns. The results of the study suggest that performing basic maneuvers develops strategies for scanning the cockpit space. It is advisable to conduct further research taking into account the division of experts into groups with varying numbers of flying hours.*

Keywords: aviation experts and novices, basic flight maneuvers, eye tracking, flight simulator, gaze behavior

Streszczenie: *Efektywne przetwarzanie informacji płynących ze zmysłu wzroku wpływa na wydajność oraz bezpieczeństwo operacji lotniczych. Jako problem badawczy określono różnice w zachowaniu wzrokowym pomiędzy pilotami posiadającymi zróżnicowane doświadczenie lotnicze podczas wykonywania podstawowych manewrów lotniczych. W badaniu wzięło udział 26 pilotów, którzy zostali podzielni względem doświadczenia lotniczego. Zachowanie wzrokowe uczestników rejestrowano przy użyciu eye trackera Pupil Invisible. Zadaniem osób badanych był start z lotniska Poznań-Ławica, wznoszenie do 2000ft oraz wykonanie dwóch zakrętów. Wyniki badania sugerują, iż wykonywanie podstawowych manewrów lotniczych wykształca strategie skanowania przestrzeni w kokpicie. Wskazane jest przeprowadzenie dalszych badań uwzględniających podział ekspertów na grupy o zróżnicowanej liczbie godzin nalotu.*

Słowa kluczowe: eye tracking, podstawowe manewry lotnicze, symulator lotu, zachowanie wzrokowe

1. Introduction

As of 2019, the Polish Civil Aviation Administration is issuing about 900 new PPL(A) aviation licenses annually [24]. Thus, an upward trend of new pilots in the sky is observed, which also has its transfer to general aviation safety. Proper pilot training is therefore crucial. Piloting an aircraft poses a huge challenge to the human cognitive system. When flying an aircraft, the pilot must control a number of indicators in the cockpit of the aircraft. Displays indicate to the operator information on the state of the aircraft in flight, and any change in this state must be closely observed by the pilot. Effective processing of information from the sense of sight affects the efficiency and safety of flight operations [8]. In order to understand how the pilot processes information from the organ of sight it is possible to use the eye tracking technique. The application of eye tracking in aviation is used to study workload, situational awareness, or hypoxia phenomenon [29]. In addition, studies show that pilots' visual behavior changes as they gain flight experience [27].

Workload is defined as the difference between the amount of information that must be processed by the cognitive system and the number of cognitive resources that are required to perform a task [13, 17]. When the task is demanding enough and begins to exceed the amount of available cognitive resources the phenomenon of overload occurs and can be observed in the pilot's behavior, for example, lost situational awareness appears [25]. The study proved that the change in the level of workload is reflected in the pilot's visual behavior [6, 18].

Eye tracker is used to measure situational awareness (SA). SA is defined as “the perception of elements in the environment within a volume of time and space [Level 1], the comprehension of their meaning [Level 2] and the projection of their status in the near future [Level 3]” [10]. Li and colleagues' study measured the situational awareness of air force pilots with varying experience. It was shown that those who had situational awareness were characterized by greater fixation time on multifunctional displays than those without situational awareness [18]. Yu, Wang, Li, and Braithwaite (2014) suggested using the eye-tracking technique in situational awareness training on simulator flights [28].

Early recognition of the symptoms of hypoxia is crucial for a pilot performing single-pilot flights. The oxygen-deprived pilot's body may be characterized by increased breathing rate, headache, lightheadedness, dizziness, tingling or warm sensation, sweating, poor coordination, impaired judgment, tunnel vision or euphoria [12]. Di Stasi study showed that pilots who develop symptoms of hypoxia have increased intersaccadic drift velocity [7]. The body's gradual deprivation of oxygen may also be associated with increased blinking frequency [23].

Researchers are making an attempt to obtain, first and foremost, an answer to the question of how visual scanning of space changes with a pilot's level of knowledge and experience. More experienced pilots seem to make better decisions in terms of speed and accuracy [20]. In addition, they focus attention more strongly on appropriate cues when there are failures on board the aircraft. In a study conducted by Bos and his colleagues (2002), it was shown that flight instructors, unlike their student pilots, directed their gaze to a greater number of onboard instruments. In addition, fixation time on each instrument was shorter. The instructors directed their gaze to elements of the cockpit that, at any given moment of flight, did not provide a valuable source of information. The researchers hypothesized that this strategy allows more experienced pilots to avoid the phenomenon of tunnel vision [4].

Oculographic data is based on two basic eye movements, which are fixations and saccades [2]. Fixations are momentary stabilizations of the eyeball on a selected image element, during which information is extracted from the environment [2, 9]. Saccades are rapid eye movements that occur between fixations. During a saccade, the eyes move at a speed of 300° per second to 500° per second. Due to this high speed, reception of environmental stimuli is not possible during the saccade [1]. The results obtained from the eye tracker can be analyzed qualitatively and quantitatively. Based on quantitative data, researchers can implement appropriate statistical tests showing statistically significant correlations and differences between variables. Dedicated software is used to generate visualizations: heatmaps, gaze scanning paths and areas of interest. Heatmaps allow for qualitative analysis. They use an appropriate color scale: the red color indicates the elements of the image on which the subject's gaze was directed for the longest or most often. Yellow color presents the areas to which the examined person directed his gaze less often. The green color applied to the corresponding parts of the image indicates the negligible exploration of a particular element. The lack of color coding determines that the person was not directing his or her gaze to that area.

Fig. 1. An example of a gaze scanning path [11]

Gaze scanning paths (Fig. 1.), also known as gaze plots or fixations sequences, are graphic representations of perceived elements in the order in which the subject's eyes made each fixation [1]. The sequence of successive fixations is presented in the form of numbered circles, connected by lines. The circles depict fixations – the larger the diameter of the circle, the longer the user directed his or her gaze to the isolated fragment. The lines connecting the circles are saccades. Areas of interest (AOI) are researcher-defined, sub-regions of the analyzed image. Generating areas of interest can be done by selecting an area in the program with the appropriate tool. The creation of areas of interest is primarily used to carry out statistical analysis. Mostly this type of data presentation is expressed as a percentage [11].

Differences in visual behavior between pilots with varying levels of flight experience during basic flight maneuvers were identified as the research problem. The purpose of this article was to determine whether there are differences in visual behavior among aircraft pilots beginning flight training for their license versus pilots who hold a Private Pilot License.

2. Materials and methods

Twenty-six pilots participated in the study. They were divided in terms of flying experience into two groups: thirteen experts and thirteen novices. The expert group consisted of those with PPL(A) aviation licenses. The average flight time in this group was 82 hours. The novice group included people with knowledge and skills in performing basic flight maneuvers, however, without any prior flight experience. Aviation students at Poznan University of Technology were invited to participate in the study. Before taking the survey, they filled out a metric with information including gender, age, aviation licenses held and current airfare. Participants were informed about the purpose and conduct of the study, as well as its anonymous nature. In addition, the subjects were informed that participation in the study was voluntary and that they could withdraw from the study at any time.

The experiments were performed in a CKAS MotionSim5 flight simulator. This device allows to simulate four different types of aircrafts [15]. For the study a very light jet was chosen. Weather conditions were determined to be CAVOK. This acronym indicates clouds and visibility OK, and it means visibility of 10 km or more, no clouds below the 1500m level, no Cumulonimbus clouds, and no rain or thunderstorms [3]. The visualization system consists of three Full HD projectors that project images onto the screen continuously. A wide field of view (200° x 40°) is provided. In the simulator cabin there is a Garmin G1000 type avionics set. It includes two types of displays: primary flight display (PFD) and multifunctional flight display (MFD). The simulator cabin is equipped with two sets of onboard instruments and four seats. On the left side, behind the pilot's seat, there is an instructor's station, which allows simulation within any airport, control of the aircraft's position and atmospheric conditions prevailing during operations [5].

The participants' visual behavior was recorded using a Pupil Invisible eye tracker. The frames of this device contain two cameras that record the movement of the right and left eyes, as well as an infrared transmitting diode that provides adequate illumination of the eyeball. The area to which the subject directs his or her gaze is recorded using a special camera placed on the left side of the glasses via a magnetic connector [21].

Prior to the study, the subjects were briefed on the purpose and the task. The subjects were instructed to take off from Poznań-Ławica airport, climb to 2,000 ft and make two turns, with a 90-degree angle to the right. While performing the basic maneuvers, the subjects wore an eye tracker. The device was calibrated before the test began. The researcher was present in the simulator cabin during the experiment. He was located at the instructor's station, which is positioned behind the pilot-captain's seat. This arrangement avoided interference in the process of recording the test subject's visual behavior.

To analyze the results, statistics generated in iMotions were used for selected areas of interest: the Primary Flight Display (PFD), Multifunctional Flight Display (MFD), analog instruments and the area outside the cockpit. Primary Flight Display (PFD) area which presents the main flight instruments (airspeed indicator, turn coordinator, attitude indicator, heading indicator, altimeter, and vertical speed indicator). The MFD display area is used to depict the aircraft's position on an electronic map. The analog instrument area includes airspeed indicator, attitude indicator, and altimeter. The independent variable in the study was the number of flight hours. The dependent variables in the study were the fixation count, dwell time and revisit count. Fixation count determines the number of fixations detected in a given area. Dwell time specifies how long the respondents fixated at the area of interest and it is expressed in milliseconds. The number of revisits indicates how many times the subject returned to the area with his or her eyes.

3. Results

Novice pilots explored the primary flight display more frequently and for longer time. However, expert pilots revisited this area more often than novice pilots. Aviation experts fixated on the MFD display area 17 times more often than novices. However, the average fixation time had similar values in both groups. In the expert group, only 3 subjects fixated on the analog instrument area. It needs to be noted that a participant with a 100-hour flight time explored this area for 4903 ms, which contributed to the high value of the average score in this group. This result was excluded from further analysis. Experts fixated more frequently, longer, as well as revisited the area outside the cockpit more frequently. Table 1 presents the average values of the variables.

Among aviation novices, the PFD display was the most frequently and longest explored area. In second place, novices explored the area outside the cockpit. Aviation novices most often revisited the PFD display, and less often the area outside the cockpit. The number of revisits in the MFD display area was similar to the number of revisits in the analog instrument area. Among aviation experts, the MFD display was the most frequently explored area. In second place, the experts directed their gaze to the PFD display, then to the outside of the cockpit. Unlike novices, experts fixated the longest on the PFD display area, a little shorter on the area outside the cockpit, followed by the MFD display. Flight experts, like novices, most often revisited the PFD display, and less often the area outside the cockpit.

Table 1

Average values of the distinguished dependent variables

Variables	Aviation experience	PFD	MFD	Analog	Outside
Fixation count	Experts	409.46	1119.77	13.67	228.15
	Novices	485.54	64.69	4.57	168.46
Dwell time [ms]	Experts	58383.85	2706.58	1845.67	39318.35
	Novices	66956.53	2083.83	522.14	30494.88
Revisit count	Experts	43.38	5.25	5.67	33.62
	Novices	36.77	3.75	1.14	25.23

Legend: PFD – Primary Flight Display, MFD – Multifunctional Flight Display, Analog – Analog instruments area, Outside – area outside the window

Fig. 2. Heatmap of aviation expert

Fig. 3. Heatmap of aviation novice

Figures 2 and 3 present the heatmaps of the aviation expert and the novice pilots. The aviation expert's heatmap is characterized by a greater concentration of fixations on particular elements of the cockpit. This pilot fixated his eyes on the PFD display, the MFD display and outside of the cockpit. Within the PFD display, fixations appear on elements such as the attitude indicator and altimeter. The novice's fixations are more dispersed in nature. They occur in the area of the main PFD display and outside the cockpit. Within the PFD display, the pilot explored all indicators. The subject directed his gaze to the area where the control stick is located. The fixations outside the cockpit are visible in the central area of the screen as well as on the right side. In addition, single fixations appear in the area of the PFD display belonging to the co-pilot's seat.

4. Discussion

Experts explored the primary flight display area for a shorter period of time than novices, however, they visually revisited it more often. Presumably, the described visual behavior allows pilots to control basic flight parameters and react quickly enough to changes in their values. This visual behavior of pilots is consistent with other studies in this area. Kramer and his associates showed that expert pilots have shorter fixation durations on cockpit instruments than novices [16]. The increased number of expert revisits to the PFD display area suggests that pilots are already acquiring the right strategies early in their aviation careers that allow them to monitor the most important indicators related to the condition of the aircraft. Similar conclusions were reached by Mumaw and collegues, who stated that areas for which the displayed information changes frequently (e.g., the primary flight display) are likely to receive a larger proportion of the total dwell time [19].

The MFD display begins to play an important role in the process of acquiring flight information as flight experience increases. Novices directed their gaze significantly less often to the MFD display, however, the average exploration time of this area was very similar to the average exploration time of experts. Presumably, novices were less likely to explore the navigational cues displayed on the MFD, as this information may have placed an additional burden on their cognitive system, and at the same time, it was not required to correctly perform the imposed task. Research indicates that fixation durations depend partly on cognitive processing of the fixated material [14]. It is worth noting, however, that the data extracted from the eye tracker makes it possible to determine where a person directed his or her gaze, while it does not provide an answer as to whether the information extracted from the environment has been properly processed. With similar average fixation times among experts and novices, it is therefore difficult to determine the efficiency of processing information from the MFD display. Further research should be based on determining how much information was extracted from the MFD display by novice and expert pilots. In part, this is possible at least by analyzing their performance while executing certain tasks.

Analog instruments in the cockpit of civil aviation aircraft have been replaced by glass cockpits, or electronic flight instrument systems in the late 1990s. By 2003 they were starting to appear in general aviation airplanes [22]. In analog cockpits pilots must scan six different instruments, contrary in glass cockpits relevant information is displayed on one screen. Round dials can be difficult to read, so it can be observed that pilots used digital displays rather than analog displays during this study.

Experts directed their gaze outside the cockpit more often than novices. Previous research indicates that how much time experts or novices explore the area outside the cockpit depends on the nature of the task they are performing [20]. Presumably, the results of this study indicate the experience that the pilots examined have. The experts held PPL(A) licenses, meaning that most of them perform visual flights rules (VFR) flying. These flights require scanning the space outside the cockpit to, among other things, determine the position of the aircraft in space.

Heatmap analysis led to the conclusion that lack of flight experience results in higher entropy of fixation on individual cockpit elements. The conclusions of van Dijik (2011) and van de Merwe (2012) allow us to suggest that performing a takeoff and right turn was a more demanding task for novices compared to the expert group. Researchers found that entropy had increased after the failure of instruments in the cockpit, which is assumed to involve an increased workload [25, 26].

Among the limitations of the study, the deliberate sampling and low sample size should be noted. This contributed to the decision not to use significance of difference tests to compare the results of variables between pilot novices and experts. Conclusions from such quantitative analysis could not be transferred to pilot populations. In addition, the study included people who have no experience in flying an airplane. It is likely that their visual behavior was intuitive, and they themselves did not know which elements to direct their gaze to. The number of variables analyzed is also a limitation of the study. A larger number of oculographic parameters would allow a more accurate characterization of the differences in visual behavior between pilots with varying flight experience.

5. Conclusions

The results obtained in the study suggest that already at the initial stages of flight training, pilots develop specific strategies for scanning the cockpit space, thus differentiating from those with no flight experience. In order to verify this hypothesis, a suggested action would be to analyze visual scanning paths that allow graphical representation of perceived elements in the order in which the subject's eyes performed each fixation. In addition, it is advisable to carry out further research taking into account the division of experts into groups with different numbers of flying hours, as well as increasing the sample size. It would be suggested that in future studies the novice pilots should be people who already have several flying hours. Moreover, a suggestion would be to subject a larger number of oculographic parameters to statistical analysis, such as: average amplitude of all saccades detected inside the AOI or average peek velocity of all saccades detected inside the AOI. Gaze behavior analysis is a valuable tool for determining a pilot's level of experience.

The eye tracking technique can also be used in pilot training to assess progress in flight training, as well as to modify training plans according to the needs of student pilots. The use of eye tracking allows for the detection of problems with scanning instruments in the cockpit and allows for the improvement of techniques for future flights. Such tests can be carried out in simulator conditions, where the pilot's visual behavior is recorded and analyzed by the instructor in real-time or after the training session. At the same time, after completing the task, the instructor would provide feedback to the pilot. The information that could be given in feedback should be based on quantitative eye movement measures such as fixation count, dwell time, amplitude of saccades, peak velocity, blinks as well as pupil diameter. A very important aspect is the analysis of the pilot's performance based on flight parameters, among which can be distinguished altitude, airspeed, rate of climb, attitude, and bank angle. Only by combining these variables together with the data obtained from the eye tracker will it be possible to infer the effectiveness of flight training.

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