Pol J Aviat Med Bioeng Psychol 2020; 26(4): 13-25
DOI: 10.13174/pjambp.17.05.2023.02

ORIGINAL ARTICLE

THE INCIDENCE OF SIMULATOR SICKNESS IN PILOTS AND NON-PILOTS EXPOSED TO SPATIAL DISORIENTATION EVENTS IN THE GYRO-IPT SIMULATOR

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Source of support: This work was supported by the National Science Center (Poland) under Grant (number UMO-2013/09/B/HS6/03266)

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Introduction: A previous study conducted in the Gyro-IPT simulator revealed that applied flight scenarios induced minor severity of simulator sickness symptoms in participants. In this study, however, we did not investigate how the severity of symptoms differs between pilots and non-pilots. Therefore, the presented study aimed to examine whether the symptoms of simulator sickness induced in pilots and non-pilots during spatial disorientation (SD) training are significantly different. We were particularly interested in whether the standard flight scenario used in SD training could be a contributing factor in increasing simulator sickness in novice, inexperienced pilots.

Methods: We used the data from the previous study, where 20 male military pilots (age 31.6 ±8.22) with flight experience (total flight hours 1300 ±1167.4) and 20 non-pilots (age 30.9 ±7.72) were assigned to one of two groups and then exposed to a 1-hour long flight session (12 flight profiles, six involved an SD-conflict) with active control in the Gyro IPT simulator. To measure simulator sickness symptoms, the Simulator Sickness Questionnaire (SSQ) was administered pre and post-simulator exposure. In the presented study, the SSQ scores were analyzed independently for the total SSQ and subscores for nausea, oculomotor, and disorientation, and then were compared between groups.

Results: The score of the total severity and for each subscale of SSQ symptoms in the non-pilots' group were higher than those in the pilots group, however, these differences were not significant. Despite the observed differences, according to the SSQ scoring criteria the simulator sickness symptoms reported by the participants after exposure to the applied flight scenario were negligible.

Figures: 1 • **Tables:** 3 • **References:** 79 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2023 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

Conclusions: The flight scenarios used in SD training did not generate significantly different symptoms of simulator sickness between non-pilots and pilots. The low level of severity of simulator sickness symptoms in these two study groups may indicate difficulty in predicting simulator sickness based on SSQ only.

Keywords: simulator sickness, motion sickness, flight simulator, spatial disorientation, expertise

INTRODUCTION

During and after exposure to different virtual reality environments, such as those created by flight simulators, there is often an adverse phenomenon known as simulator sickness [5,32]. This sickness is referred to when its symptoms result solely from exposure in a simulator and are not present in the real conditions that are reproduced in this device. Simulator sickness can disrupt research measurements [45], negatively influence the effectiveness of training [29], and it may contribute to the interruption of the task performed in the simulator [17,29]. This phenomenon is still an unsolved problem and affects almost every participant in the simulation [20,23,26].

Simulator sickness syndrome

Simulator sickness is a syndrome characterized by a variety of symptoms, many of them motion sickness-like, ranging from malaise, sweating, headaches and dizziness to balance disorders, gastrointestinal disturbances (nausea and vomiting) [36]. Some researchers, however, state that motion sickness tends to be more severe than simulator sickness and that drowsiness does not necessarily indicate simulator sickness [38,74].

Symptoms of simulator sickness and their severity do not only depend on simulator characteristics [21,22,42,43,56,59], but they are also related to scene and scenario design factors [74], user age [40], gender or his/her individual susceptibility to such ailment [6,11] and may increase due to fatigue, alcohol intake [28], as well as anxiety and severe stress [12,32,44].

Simulator sickness in a spatial disorientation simulator

Simulator sickness is a persistent issue in simulator-based training [11,21,32,34], especially in the domain of aviation [10,18,23,46,47,54,55,72,76,77]. It also appears in motion-based simulators as a result of a sensory conflict related to the incongruence of visual and motion cues [34,64].

For many years, a special type of flight simulator has been used in ground-based flight training to demonstrate visual and vestibular in-flight illusions and the loss of spatial orientation phenomenon [51]. This type of simulator, e.g., an Integrated Physiological Trainer (IPT) – the Gyro (Environmental Tectonics Corp., US) uses complex motion and visual stimuli which, under certain conditions, may provoke symptoms of simulator sickness. It has been demonstrated that more than 29% of pilots experience simulator sickness as a result of simulator-based spatial disorientation (SD) training [3]. If simulator sickness occurs, it may reduce the effectiveness of this training, which is an important issue, especially due to the use of SD simulators to teach pilots how to counteract the effects of sensory mismatch during flight. Since the task of the SD simulator is to generate physical stimuli that induce perceptual illusions in pilots, an unpleasant feeling may appear as a side effect of these illusions. Therefore, flight scenarios with motion and visual cues that give the desirable effect (illusion) without any unwanted effects (simulator sickness) should be used in SD simulators.

Due to the fact that some symptoms of simulator sickness may not subside until several hours after leaving the simulator, they may pose a potential threat to flight safety during that time [41,55]. For this reason, a recommendation for a temporary flying restrictions due to exogenous factors affecting aircrew efficiency was made [27]. If, as a result of SD training, a pilot is exhibiting symptoms of simulator sickness, actual flight may not be conducted until 12 hours after such symptoms have completely disappeared.

In the case of the Gyro-IPT simulator, which was applied in our previous studies [2,46,48,50,52,53,75], it was found that restitution of the vestibular system after SD training, performed according to STANAG 3114 [70] and AIR STD 61/117/14 [1], varies individually and usually lasts less than 30 minutes [41]. Based on pilots' vestibular system restitution pattern following an exposition in the Gyro-IPT simulator, the researcher [41] evaluated the effects caused by the SD training on the pilots' equilibrium and the impact that it would have on their flight activity and on flight safety. In some pilots, the symptoms of the re-stimulated vestibular system were also observed after the restitution period. However, the researcher [41] did not analyze whether the SD sorties used according to AIR STD 61/117/14 [1] provoke the occurrence of simulator sickness, reducing the effectiveness of training in the Gyro-IPT simulator.

Theories Explaining Simulator/Motion Sickness

There are several theories which have been developed and have even been used to explain why individuals suffer from simulator sickness [74]. These theories relate i.a. to sensory conflicts, postural instability, and the body's response to position. However, none of these theories explain or predict simulator sickness completely. Due to the fact that symptoms of simulator sickness largely overlap with those of motion sickness (motion sickness is a normal physiological response to conflicting sensory stimuli), conflicting cues from the vestibular and visual systems are assumed to have the greatest influence on simulator sickness.

Among the theories that refer to sensory conflicts, the most prevalent in the literature are the 'Sensory Conflict theory' (SC) and 'Subjective Vertical Conflict theory' (SVC). The SC theory was proposed by Reason and Brand [66,67] and then developed by Oman [62,63]. This theory explains motion sickness through a conflict that arises not only between the signals from visual, vestibular and other receptors sensitive to orientation and motion, but also the signals expected by the central nervous system based on previous experience. Therefore, according to this theory, simulator sickness may occur when the received sensory information does not match that which has been retained from immediate past situations.

The SVC theory, used in the second theoretical approach, was described by Bos and Bles [8]. The authors of this theory assumed that all situations that provoke motion sickness are characterized by a state in which the sensed vertical is inconsistent with the subjective vertical, expected based on previous experience [9]. In such a mismatch, a maximum conflict can be assumed in case of a phase difference of 180° between the sensed and expected vertical, and a zero conflict when the detected and expected signals are equal.

Individual differences in susceptibility to simulator sickness and its multisymptomatic nature mean that, despite numerous attempts [14,15,19,24,30,61,73,78], no effective tool has yet been developed to objectively measure the severity of this sickness. Although there are several measures of simulator sickness that can be used in studies where simulator sickness is expected to be a problem, among the most widely used, well-validated measure of simulator sickness is the subjective measurement method involving self-assessment with the Simulator Sickness Questionnaire (SSQ) [7,35,38].

Our previous study

In our previous study [48] we examined pilots and non-pilots for their susceptibility to SD when flying in a flight simulator and we verified whether simulator sickness had negligible effect on the results of that study, as it had insignificant effects as a covariate. However, in the presented study we directly compare the severity of simulator sickness symptoms among pilots and non-pilots. On the one hand, according to Miller and Goodson [57] pilots may be more prone to simulator sickness compared to non-pilots due to possible discrepancies between their response to real aircraft characteristics and expected simulator control characteristics. On the other hand, non-pilots who only occasionally, if ever, passively fly do not have a developed habituation to stimuli occurring during actual flight, which may contribute to their increased susceptibility to motion sickness. It is therefore not possible to clearly indicate which of these two groups of people (pilots and non-pilots) will be more susceptible to simulator sickness when exposed to the same flight scenario in a flight simulator. Such knowledge could be useful in developing a simulator training scenario for both pilot candidates and pilots, who due to their little flight experience and/or insufficient vestibular system habituation to the flight environment may have an increased tendency to develop motion sickness during exposition in a flight simulator. Therefore, in the present study, we wanted to evaluate how non-pilots respond, in terms of simulator sickness symptoms, to visual and motion stimuli generated in a simulator during SD training.

The aim of the study

The study aimed to examine whether pilots and non-pilots exposed to the same flight scenario (visual and motion stimuli) in a specially designed flight simulator (spatial disorientation simulator) manifest significantly different severity of simulator sickness symptoms. More precisely, we were interested in whether the standard flight scenarios used in SD training could be a contributing factor in increasing simulator sickness in novice, inexperienced pilots. This study has been performed as part of a larger research in which we analyzed flight performance and instrument scanning strategy during SD events [2]. Thus, the results presented in this paper are derived from a reanalysis of the data we collected in that earlier study.

The inclusion of the non-pilots' group in this study allowed us to examine how simulator-generated SD cues affect, in term of simulator sickness, people who do not actively fly (do not expect stimuli that occur in a real flight) or fly passively (as a passenger) only occasionally (have a minor habituation to stimuli occurring in real flight). On the other hand, pilots are a group of people who expect simulator control characteristics to be the same as that of a real aircraft. Moreover, some of them are unfamiliar with the stimuli that induce in-flight visual and vestibular illusions and have no experience of exposure to simulator-induced SD events; the latter was an inclusion criterion in our study. For this reason, we expect that they will also be, to some extent, susceptible to the motion sickness caused by illusions related to sensory conflict generated in the simulator.

METHOD

Study design

To compare the severity of simulator sickness symptoms among pilots and non-pilots, the between-group study design consisted of an experiment in which participants performed flying tasks in an SD simulator was used. The experiment consisted of carrying out maneuvers with the maintenance of flight parameters according to the flying instructions given in defined standard flight scenarios. To rule out the influence of exposition in a flight simulator on simulator sickness incidence, the participants completed the Polish version of the Simulator Sickness Questionnaire (SSQ) [7].

Participants

The forty volunteers (20 pilots aged 31.6 ±8.22, and with a flight experience of 1300 ±1167.4 total flight hours; 20 non-pilots aged 30.95 ±7.72) were recruited to perform a flight simulator experiment, conducted according to the SD training program in the Military Institute of Aviation Medicine (WIML) (Warsaw, Poland). The inclusion criteria were healthy, active flying male pilot (fixed-wing aircraft) or non-pilot between the age of 20 to 55, with normal or corrected to normal vision and no history of neurological disorders, especially any negative clinical history of vestibular symptoms e.g., dizziness, vertigo, or disorientation. Moreover, none of the voluntaries reported any history of severe motion sickness or simulator sickness.

All participants were male, Polish military aviators actively flying fixed-wing military aircraft (M-28M, CASA C-295M, MiG-29, F-16, and M-346 Master) with no experience of exposure to simulator-induced SD. All non-pilots had no previous flying experience. All participants reported normal sleep patterns and avoided alcohol 24 hours prior to the study.

The protocol study was approved by the Ethical Committee (Institute of Psychology at the John Paul II Catholic University of Lublin, Poland) and an informed consent form was completed by each participant prior to the experiment. All subjects were paid for their participation.

Stimuli and apparatus

Flight simulator. To demonstrate the SD event the spatial disorientation Gyro-IPT (Integrated Physiological Trainer) simulator (Environmental Tectonics Corporation, Inc., Southampton, US), located at the Military Institute of Aviation Medicine (WIML, Poland) was used. This dynamic motion-based simulator with 3-degrees of freedom (roll ±30°, pitch ±15°, and yaw 360°) has a one-channel, non-collimated out-the-window visual display (with a total field-of-view ~40° horizontally by ~28° vertically). Although the simulator does not represent the aircraft that the pilots normally fly (the motions are generated by the simulation model of the TS-11 Polish jet trainer aircraft), the flight instruments displayed in the cabin represent typical indicators that are applied in the pilots' aircraft.

The Gyro-IPT is particularly recommended for the training of pilots in evoked SD condition [16]. This training follows NATO Standardisation Agreement (STANAG) Number 3114 (Aeromedical Training of Flight Personnel) [70] with general recommendations concerning ground-based demonstration and training (AIR STD 61/117/14) [1].

Stimuli. The set visual, vestibular and auditory cues were included in defined twelve flight scenarios. The flight profiles comprised of general maneuvers in a fixed-wing aircraft. The following six well-known visual and vestibular-origin illusions [16,65] were implemented in the six flight profiles:

- daytime false horizon illusion (caused by a sloping cloud deck) included in the straight and level flight (S&LF) profile;
- constant shape illusion (caused by an up-sloping runway) implemented in a circle-to-land procedure (C-T-LP) at nighttime;
- constant size illusion (caused by a narrower-than-usual runway) included in a straight-in approach (S-IA) profile at nighttime;
- somatogyral illusion (caused by erroneous perception of the strength and direction of actual rotation – the false sensation or lack of rotational motion) induced in a straight and level flight after a left turn (S&LFALT) at daytime, during flight in clouds;
- Coriolis illusion (created by cross-coupled stimulation of semicircular canals when there is a change of head position during rotational motion) induced in a right banked turn (RBT) at daytime;
- leans illusion (caused by the limited sensitivity of vestibular organs) induced in a straight and level flight after a right turn (S&LFART) at nighttime.

Each flight profile was presented in two conditions, the disorientation condition (conflict flight), in which visual or vestibular disorientation cues were present, and the control condition (non-conflict flight), in which these specific disorientation cues were absent. The remaining parts of the flight profiles were kept the same for the control and disorientation conditions. All the participants flew the same profiles (a total of 12 flight profiles)

List of basic flight profile parameters is given in Table 1, whereas detailed description of the applied flight profiles, including the specifications of stimuli and flight instrument manipulation is presented in our earlier papers [49].

Simulator Sickness Questionnaire. Although the results of some studies [19,31,58,60,73,79], which are based on the measurement of specific physiological parameters seem promising for evaluating simulator sickness, they are still an auxiliary method for questionnaires such as SSQ. Therefore, to examine whether motion sickness during flights in the SD trainer had occurred, a Polish version of the Simulator Sickness Questionnaire (SSQ) [7] was administered.

The SSQ is widely used in studies on the SD to rule out the influence of simulator sickness on flight and cognitive performance. This questionnaire consists of 16 symptoms regarding motion sickness that can be caused in a flight simulator, which are rated in terms of severity (0 – none, 1 – slight, 2 – moderate, 3 – severe) and then are summed to yield three subscale scores (a nausea score, an oculomotor score, a disorientation score), and a total score.

Procedure

The course of study in a flight simulator included familiarizing and training flight (for pilots and non-pilots, respectively) and the main exposition consisted of 12 flight profiles (six conflict flights and six non-conflict flights). Participants were randomly assigned to compose a study group. They

Tab. 1. List of parameters of the flight profiles.

Flight profile	Duration of profile [s]	Disorientation condition	Control condition	Flight instrument manipulation
The Circle-To-Land Procedure (C-T-LP)	166 [a]	Nighttime runway up-sloped 10°	No up-sloped runway	None
Straight-and-Level Flight (S&LF)	190	Slope of cloud deck tilted 10° rightward from 19,000 ft to 21,000 ft	No tilt of the cloud deck	From 130 s to 160 s blackout of attitude director indicator
Straight-In Approach (S-IA)	90 [a]	Nighttime runway narrowed in width from 300 ft to 150 ft	Runway 300 ft wide	None
Straight-and-Level Flight After Left Turn (S&LFALT)	290	$76°\cdot s^{-1}$ of sustained yaw (at $0.4°\cdot s^{-2}$) stop yaw rotation in 217 s of flight (at $-15°\cdot s^{-2}$)	No programmed acceleration stimulus	None
Right Banked Turn (RBT)	210	$70°\cdot s^{-1}$ of sustained yaw (at $0.5°\cdot s^{-2}$) stop yaw rotation in 173 s of flight (at $-2°\cdot s^{-2}$)	No programmed acceleration stimulus	None
Straight-and-Level Flight After Right Turn (S&LFART)	150	$68°\cdot s^{-1}$ of sustained yaw (at $1°\cdot s^{-2}$) stop yaw rotation in 84 s of flight (at $-4°\cdot s^{-2}$)	No programmed acceleration stimulus	From 92 s to 105 s blackout of attitude director indicator

Note. [a] or runway level achieved

Tab. 2. The subscale scores of SSQ symptoms.

Nausea SSQ-N	Oculomotor SSQ-O	Disorientation SSQ-D
General discomfort	General discomfort	Difficulty focusing
Increased salivation	Fatigue	Nausea
Sweating	Headache	Fullness of head
Nausea	Eye strain	Blurred vision
Fullness of head	Difficulty focusing	Dizzy (eyes closed)
Stomach awareness	Difficulty concentrating	Dizzy (eyes opened)
Burping	Blurred vision	Vertigo

were only briefed with all relevant flight related requirements, but were not introduced to the flight scenario and purpose of research.

The participants were in full control of simulator flying. The non-pilots were trained in the procedures for maintaining straight-and-level flight, turning with 30 deg bank angle, changing attitude and approach-to-landing maneuver. This training was to ensure that all non-pilots could demonstrate a basic level of eye-hand coordination proficiency in flying the simulator. The minimum proficiency required is detailed in the paper [49]. The training flight lasted for approximately 30 minutes. Only participants who achieved the required level of proficiency could participate in the study (the main exposition consisted of 12 flight profiles).

To get acquainted with operational characteristics of the simulator all pilots were given 5-10 minutes of "free-flight." This familiarization flight profile included the basic elements of pilotage with the approach-to-landing maneuver. If a pilot reached a given target attitude, heading, vertical speed, bank (within the same acceptable deviations as for non-pilots), he could participate in the study.

The participants (pilots and non-pilots) performed maneuvers with the maintenance of flight parameters according to the flying instructions given (recorded commands). The order of flight profiles (six conflict flights and six non-conflict flights) was fixed at random. Participants did not know the order of profiles and which of them were conflict flights.

To rule out the influence of exposition in the simulator on simulator sickness incidence and ensure that participants did not feel sick before the main part of experiment (12 flight profiles), they completed the form concerning their health condition (i.a. physical fitness, previous motion sickness episodes, taking medicines or alcohol during the last 24 hrs). Immediately following the main exposition in the simulator (12 flight profiles), the SSQ [7] was administered to obtain simulator sickness ratings. After completing the questionnaire, all participants were debriefed and paid. Finally, prior to the participant leaving the study, the researcher ensured that any simulator-induced sickness symptoms had subsided.

The duration of a single experiment did not exceed 60 minutes (not including training or familiarization flight). All participants completed the study at the same time of day (between 10:00 and 16:00).

Measurements

SSQ data were rated regarding severity and then were summed to yield three subscale scores: nausea score (SSQ-N), oculomotor disturbances score (SSQ-O), disorientation score (SSQ-D), and total severity score (SSQ-TS). The SSQ symptoms included in each subscale score are given in Table 2.

Mean SSQ scores that were obtained after completing all flight profiles were determined based on pre-defined factor weightings suggested by Kennedy et al. [38]. These factors are obtained by adding up the results of all relevant items (each factor consists of 7 items) and multiplying this sum by the specified weight; for nausea factor by 9.54 (scores ranging from 0 to 200.34), for oculomotor factor by 7.58 (with scores ranging from 0 to 159.18), and for disorientation factor by 13.92 (scores ranging from 0 to 292.32) [21]. Finally, the scoring criteria of SSQ that reflect the severity of simulator sickness symptoms was applied [71].

Statistical Analysis

To compare the effect of the between factors that are represented by the group type (pilots' and non-pilots' groups) a t-student test was used. The t-test was run on the recorded mean scores of SSQ, and was performed for each subscale of SSQ symptoms (nausea SSQ-N, oculomotor SSQ-O, and disorientation SSQ-D) separately. A significance level of $p = 0.05$ was considered statistically significant and was set for all analyses. For all statistical analysis IBM SPSS version 17.0 (IBM Corporation, US) was used.

Tab. 3. The t-test results and the mean scores of SSQ symptoms for each subscales and experimental conditions.

Subscale of SSQ symptoms	Group type		Statistical results			
	Pilots	Non-Pilots	*t*	*df*	*p*	*Cohen's d*
Nausea SSQ-N	1.46 (2.51)	1.79 (1.88)	-0.478	36	0.635	0.12
Oculomotor SSQ-O	3.41 (2.12)	4.33 (2.76)	-0.969	36	0.339	0.32
Disorientation SSQ-D	1.90 (1.63)	2.31 (1.21)	-0.609	37	0.546	0.22
Total SSQ-TS	2.25 (1.52)	2.81 (1.95)	-1.537	37	0.133	0.27

Note. values represent mean and standard deviation

RESULTS

Overall, in our study, the occurrence of simulator sickness symptoms (measured by SSQ) was reported by approx. 30 % of participants. All of the reported symptoms remained in a low severity and no discomfort was reported both in pilots and non-pilots [71]. There were no differences between pilots and non-pilots in total scores of SSQ (SSQ-TS t(37) = -1.537, p = 0.133). The commonly reported symptoms were general discomfort, difficulty focusing, dizziness with eyes opened, and fullness of head. The mean scores of SSQ symptoms for each analyzed subscales of SSQ symptoms and study groups are shown in Table 3.

The t-test performed separately for each subscale of SSQ symptoms (SSQ-N, SSQ-O, and SSQ-D), and for the total score of SSQ symptoms showed no significant differences between the symptoms reported by the study groups (pilots and non-pilots). The results of the t-test are shown in Table 3.

The mean scores of SSQ symptoms for each subscales and study groups are given in Fig. 1.

DISCUSSION

Our study revealed that according to the SSQ scoring criteria [71], the symptoms of simulator sickness reported by pilots and non-pilots after exposure to the standard flight scenario were negligible. It also implies that the Gyro-IPT simulator did not produce symptoms of simulator sickness which would raise concern for post-simulator exposure activities.

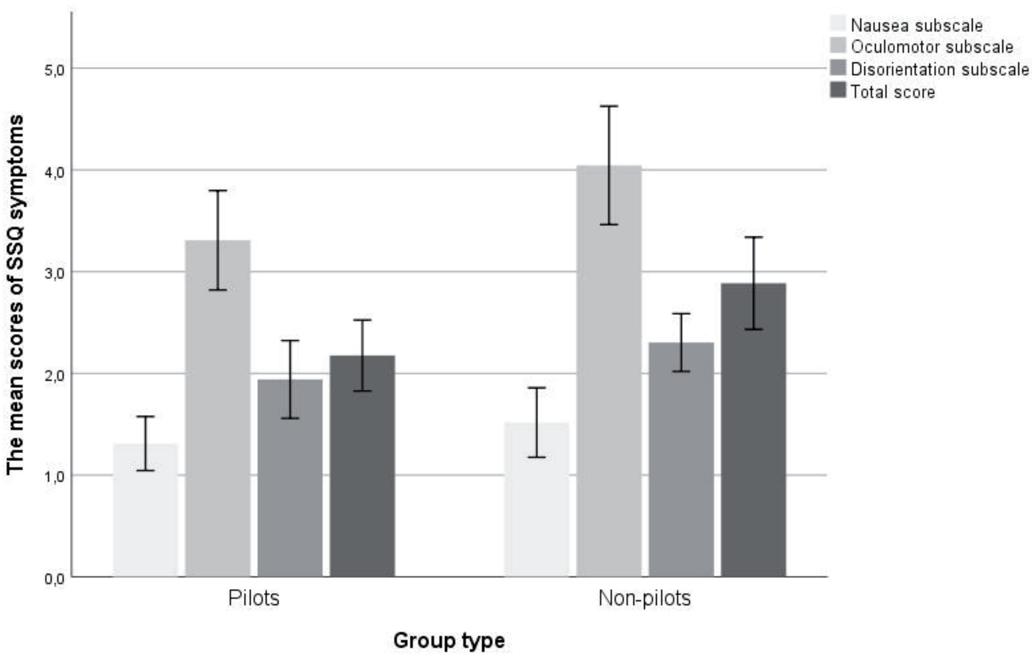

Fig. 1. The mean scores of SSQ symptoms in three subscales (nausea, oculomotor, and disorientation) and total scores by study group type. Error bars represent the standard error of the mean.

Differences in severity of simulator sickness symptoms

The incidence of simulator sickness between the pilots' and non-pilots' group does not significantly differ at total severity score (SSQ-TS) and for each subscale of SSQ symptoms (Tab. 3, Fig. 1). The non-pilots' group reported a higher severity of simulator sickness symptoms (MSSQ-TS=2.81) compared to the group of pilots (MSSQ-TS=2.25) performing the same task, under the same conditions. Although, this outcome – symptoms of simulator sickness – is negligible [71], the higher severity of the symptoms in the non-pilots' group is not surprising. The non-pilots' group consisted of people who do not fly or only occasionally fly passively . Pilots, on the other hand, actively fly, which may result in habituation of their vestibular system to motion stimuli generated in the Gyro-IPT simulator [4]. Such habituation may decrease the simulator sickness symptoms' severity. Additionally, it is worth noting that the lack of statistical significant difference between the group of pilots and non-pilots may also indicate that pilots who participate in SD training after extended break in flying or minor flight activity will not be at risk of simulator sickness.

The eye movement disturbances, which refer to the oculomotor subscale, are more common symptoms in the non-pilots' group (MSSQ-O=4.33) than in the pilots' group (MSSQ-O=3.41). This result can be explained by the fact that the non-pilots' group does not hold the appropriate aviation authority-issued medical certificate, which all pilots hold. It mainly concerns the test of the vestibular system, which is important in the regulation of the vestibular-ocular reflex. Vestibular system impairments may manifest themselves in nystagmus, which can be induced by a kinetic stimulus (e.g. motion generated by the simulator cabin). The difficulty with focusing eyesight increased from 20% to 67%, and the general discomfort of pilots increased from 27% to 45% [77]. It is also confirmed by our results of oculomotor activity (MSSQ-O=3.41) which have the highest value among the other analyzed subscales of SSQ symptoms.

Another explanation for the lack of differences between the group of pilots and non-pilots may be explained by the fact that stimuli (visual and motion) applied in the flight scenarios might not be strong enough to show differences in susceptibility to simulator sickness between these study groups.

Finally, it should be noted that due to the small effect size (Cohen's d, Tab. 3) and sample size, the above-discussed results of the study may not be representative. This observation is also confirmed by the low statistical power (not exceeding 0.25) which means that there is a high probability of an erroneous conclusion that there is no effect (no statistically significant difference between the groups) when one may actually exist. To increase the power of the study, a larger sample size and/or interventions to increase the effect size would need to be considered.

Reasons for the low severity of simulator sickness symptoms

Due to the severity of simulator sickness symptoms being positively correlated with the duration of simulator exposure [33,39], slightly stronger symptoms of this sickness could be expected in our study. Such relation of simulator sickness and the time spent in a simulator is explained by researchers [64] by the visuo-vestibular mismatch. In our study, the participants were given a single simulator exposure for a period not exceeding 60 minutes, while Cobb et al. [17] indicated that simulator sickness symptoms' severity steadily increases for up to one hour during simulator exposure exceeding 30 minutes. Similarly, Wojciechowski and Błaszczyk [77] point out that when training lasted longer than 60 minutes, as many as 85% of respondents felt more tired, while in sessions lasting less than 1 hour only 33% of the respondents complained about such ailment. In our study, therefore, the duration of simulator exposure (up to 60 minutes) might have not been the reason for occurrence of severe symptoms of simulator sickness. On the other hand, the results of a recent study [68], indicate that the duration of exposure in a more advanced SD simulator (AirFox Disorientation Simulator; AMST-Systemtechnik GmbH, Austria) lasting 45 minutes might have been the reason for occurrence of simulator sickness.

Field of view (FOV) is another factor which may have influenced the severity of simulator sickness symptoms in our study. Several studies [37,42] have revealed that using a wide FOV in a simulator display system makes individuals more prone to simulator sickness. It has been found [55,64], that a FOV of >60° induces a large optical flow and is conducive to simulator sickness. In the present study, the Gyro-IPT simulator has a narrow FOV (a total field of view of ~40° horizontally by ~28° vertically) that may explain the low score of simulator sickness symptoms.

Moreover, in some flight scenarios, to induce some SD illusions a degraded visual environment, e.g., by clouds in the flight profile with somatogyral illusion (S&LFALT), or by nighttime in the flight profile with leans illusion (S&LFART), was administrated. Thus, by weakening the impact of visual cues on the pilot's ability to maintain spatial orientation, in line with the sensory conflict theory of motion sickness, we expected the occurrence of more severe symptoms of motion sickness than those observed. Probably the lack of visual cues, displayed outside the virtual cockpit may not have been enought to trigger a more severe sensory (visual-vestibular) conflict.

When analysing other factors influencing simulator sickness, several relevant individual factors should be mentioned, such as age, gender, health status and flight experience. Some of them e.g., sex, were considered in the criteria for exclusion from our study. Kolasinski [42] and Johnson [33] found that medication and alcohol intake also predispose simulator users to become simulator sick. In our study, the participants were healthy and avoided alcohol 24 hours prior to the study thereby reducing the risk of simulator sickness.

The studies [40,69] on simulator sickness in younger and older adults revealed that the latter experienced significantly more simulator sickness than younger adults. Moreover, prolonged experiences of sickness were observed to a greater extent in older adults than younger adults. Renjhen (2018) also found that the older experienced pilots have more severe symptoms of simulator sickness than the younger pilots. The group of pilots and non-pilots in our study consisted of both older (above 39 years old) and younger adults participants (less than 26 yerrs old), therefore, the differences in simulator sickness scores due to the participant's age are not assessable.

Another reason for the low severity of motion sickness symptoms in our study may be that the applied flight scenery was simple [74]. When the scene presented during the simulation is too complex, this may cause an increase in the severity of symptoms [37]. Moreover, there were also no freeze or reset commands and no flying backwards scenarios in our study, which according to Johnson [33] are conducive to simulator sickness.

Finally, a pilot is also particularly susceptible to simulator sickness when there are discrepancies between his/her expected simulator control characteristics and the response to real aircraft characteristics [57]. It is worth mentioning that the SD simulator used in our study does not replicate characteristics of the aircraft that the pilots normally fly (in this simulator the stimuli are generated by the simulation model of the TS-11 Polish jet trainer aircraft). Wherefore, the pilots, who were actively controlling the flight simulator, may have been more prone to simulator sickness than non-pilots, who due to the lack of flight experience, could not demonstrate specific sensory expectations.

Study limitation and further considerations

In this study, the participants were exposed to both motion and visual stimuli simultaneously during one flight sortie. While motion stimuli predominate in vestibular illusions (flight profiles at night or in clouds without visibility of the natural horizon, where stimuli are limited to the indications of flight instruments), visual stimuli are mainly involved in profiles with visual illusion (false horizon illusion, size illusion, and shape illusion). Therefore, we were unable to evaluate which of these stimuli (visual or motion) had a greater impact on the reported incidence and severity of simulator sickness.

Moreover, the study involved non-pilots who had not been previously tested for vestibular dysfunction and susceptibility to motion sickness. They also do not hold the appropriate aviation authority-issued medical certificate, which confirms i.a. the health condition of the pilot's vestibular system. Although they had not any history of prior episodes of motion or simulator sickness prior to the study (inclusion criteria), we cannot be completely assured that individuals in this group were not susceptible to motion sickness. Johnson [33] indicated that people who have such a history of sickness are more likely to experience simulator sickness. For screening non-pilots' susceptibility to motion sickness and to ensure that they did not differ from groups of pilots with respect to their susceptibility to motion sickness, the Motion Sickness Susceptibility Questionnaire [25] should be used.

Furthermore, to replicate an in-flight illusion, the flight profile applied in this study requires much higher angular velocities and accelerations in the SD simulator than those that occur in the actual flight scenario. Despite this, the symptoms of simulator sickness appeared to be negligible and the differences between these symptoms reported by the pilots and non-pilots were statistically insignificant. It might be anticipated that with a stronger stimulus and/or a longer exposure time, the effect of higher angular velocities and accelerations would have become evident.

We also observed that the participant perceives the symptoms of the simulation sickness if they are strong enough. The development of the simulator sickness symptoms is initially not noticeable by the participant, which means that the effect of a motion sickness triggering stimulus on participant performance starts before the participant realizes that he/she is affected by this sickness. By using objective methods of measuring simulator sickness, e.g. by measuring psychophysiological responses, it would be possible to observe the changes that usually occur before the participant is aware of any of them.

The last major limitation of our study is the small sample size, which was beyond our control. This was due to the fact that the data reanalysed in the presented study were collected previously in another research [2]. This problem would not exist if the effect size was larger (Tab. 3). It would then be possible to draw conclusions about detected differences between groups with greater certainty.

CONCLUSION

The present study considered whether pilots and non-pilots exposed to the same stimuli during piloting the Gyro-IPT simulator manifest different severity of simulator sickness symptoms. The non-pilots group consisted of people who, due to lack of flight experience, could not expect, during exposure in the simulator, the stimuli that occur in a real flight and have not had the opportunity to become habituated to such stimuli. We conducted this study because we were interested in whether the standard flight scenarios used in SD training could be a contributing factor in increasing simulator sickness in novice, inexperienced pilots.

We found that among 30% of participants who reported symptoms of simulator sickness, the severity of these symptoms was negligible. It can therefore be concluded that simulator sickness did not have a negative impact on the SD demonstration during the training performed according to STANAG 3114 [70] and AIR STD 61/117/14 [1].

By investigating the role of flying experience in simulator sickness episodes we found, that simulator sickness symptoms reported by pilots and non-pilots after SD training, were not significantly different. Nevertheless, our findings (although not statistically significant and with low statistical power) suggest that pilots are less prone to motion sickness than non-pilots.

On the other hand, such a low level of severity of simulator sickness symptoms in these two study groups (pilots and non-pilots) may indicate the difficulty in predicting simulator sickness based on the SSQ only. Therefore, the use of objective indicators based on the measurement of physiological parameters should be considered in the assessment of the severity of simulator sickness, as studied by other researchers [58,74,79].

Finally, although our study results did not show influences of the standard flight scenarios used in SD training on the occurrence of simulator sickness, it is worth recalling a few preventive measures, which should be used when possible to help reduce this sickness. These measures may include monitoring and screening participants, controlling environmental conditions, and adjusting the scenarios and protocol. Based on the findings of previous studies [13,36,39] and their summaries [74,77], we would like to remind the readers of a few more important principles for reducing the incidnce of simulator sickness:

- individuals who have not previously had contact with the simulator or who had a long break from the last simulator exposure are at risk of simulator sickness,
- training / exposure in the simulator should not exceed 1 hour in one session, breaks should be planned,
- the simulator session should be the shorter the more intense it is,
- the simulator cabin should be kept cool and well-ventilated,
- participants should be screened to exclude those who are particularly susceptible to simulator sickness, such as those who have recently taken drugs or alcohol, or report fatigue, lack of sleep, cold or infection (e.g., ear or an upper respiratory infection).

AUTHORS' DECLARATION:

Conceptualization: Rafał Lewkowicz, Bibianna Bałaj. **Methodology:** Rafał Lewkowicz, Bibianna Bałaj. **Data collection:** Rafał Lewkowicz, Bibianna Bałaj. **Writing-original draft preparation:** Rafał Lewkowicz, Bibianna Bałaj, Piotr Francuz. **Writing-review and editing:** Rafał Lewkowicz, Bibianna Bałaj. **Supervision:** Piotr Francuz. **Project administration:** Piotr Francuz. **Funding acquisition:** Piotr Francuz. The Authors declare that there is no conflict of interest.

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Cite this article as: Lewkowicz R, Bałaj B, Francuz P. The Incidence of Simulator Sickness in Pilots And Non-pilots Exposed to Spatial Disorientation Events in The Gyro-IPT Simulator. Pol J Aviat Med Bioeng Psychol 2020; 26(4): 13-25. DOI: 10.13174/pjambp.17.05.2023.02