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Study of Adverse Factors During Training with Virtual Reality Simulator

Anna MICHALSKA*[1], Mikołaj Marek KONOPACKI[2], Dariusz RODZIK[3]

[1] Polish Airforce University, Dęblin, Poland
[2] 3. Warsaw Air Defense Missile Brigade, Sochaczew, Poland
[3] Military University of Technology, Warsaw, Poland

Abstract

Currently, the dynamic development of information technology contributes to the increasingly widespread application of Virtual Reality (VR) as modern and effective methods and training tools used in the process of self-education and/or training related to understanding the essence of the principles of operation and mastering the tasks of operating even complex systems or technical processes through simulating their actions. A significant argument for the use of virtual reality simulators in training uniformed services is the favorable cost-effect ratio and considerations of trainee safety. However, the use of VR simulators may be accompanied by the possibility of side effects or intensified symptoms of the so-called cybersickness. Bearing this in mind, the purpose of this article is to present the results of preliminary studies of adverse factors occurring during training using a VR simulator. The theoretical foundation for empirical research was provided by the results of a conducted review and analysis of literary content. Among the empirical methods, studies were conducted using a simulator sickness questionnaire and a research trial according to the parallel triangulation strategy scheme, involving the simultaneous use of quantitative and qualitative methods. The results obtained in this way can provide a valuable source of information about factors increasing the risk of adverse symptoms of cybersickness and ways of their mitigation, and can serve for further work on their development and application of VR simulators.

Keywords: simulator, training, cybersickness, Virtual Reality, exercise

* **Corresponding author:** E-mail address: (a.michalska@law.mil.pl) Anna MICHALSKA

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1 Introduction

Since the early 1980s, many intriguing studies have been conducted concerning the applications of Virtual Reality (VR) and its effectiveness in education and training. McLellan carried out comprehensive and in-depth literature reviews in 1996 and 2003 regarding research and application of VR in education and training [23]. Among other things, he described the first use of VR goggles at the United States Air Force Base in Ohio in the 1960s and 1970s. By 1998, Christine Youngblut estimated that VR technology was being used in over twenty schools in the USA [40]. Research involving thousands of students of varying ages using different VR software indicated that there was an overall increase in student attendance and improvement in their grades, and the new technology was a factor increasing students' motivation to learn. Youngblut highlighted that VR technology allows for conducting experiments impossible to achieve in reality (e.g. changing the laws of physics, observing events at the molecular or galactic level, visualizing abstract concepts, or participating in events in which, due to time, distance, or safety, students could not take part).

The studies described in the paper [4] indicate that the implementation of a VR system in education can support the learning and understanding process by providing a connection between knowledge acquired during a lecture and empirical knowledge. Utilizing virtual reality during learning provides an element of practical knowledge, which complements the theoretical knowledge obtained during a lecture. An interesting phenomenon is that the software created for the virtual environment is not as effective a learning tool as when used alone (without support from knowledge obtained during the lecture). The reason for this phenomenon may be the quality of the software and participants' lack of awareness that their knowledge of the material contained in virtual reality will be tested.

In her work, Pantelidis [26] defined the criteria stipulating when virtual reality should or should not be used in the training process (see Table 1).

Table 1. *List of criteria for using VR technology in the training process*

Criteria "for"	Criteria "against"
When training by conventional methods is dangerous, impossible, inconvenient, or difficult.	When it could be harmful to the trained individual, physically or emotionally.
When a simulated environment provides learning and training at the same level as the real one.	When it could distort the trained individual's perception of reality – a simulation so realistic that the trainee cannot distinguish it from the real world.
When training by conventional methods would require disproportionately large financial and logistical resources.	When it is impossible to create a substitute for a real-life situation.
When the training involves manual tasks and physical movement.	When interaction with real people is necessary.
When the use of VR is necessary to make the training more interesting and enjoyable.	When the use of VR technology would be too costly in relation to the achieved effects.
When mistakes made by the person being trained in the real environment could have serious and harmful consequences for the environment, capable of causing unintentional damage to equipment (property) or being costly.	

Source: Authors' own work based on [26]

The criteria listed in Table 1 imply the advisability of employing VR technology in specialized training, including that of soldiers.

It should not be forgotten that the military [20] has made the most significant investments in the development of VR technology and systems. The benefits of using VR technology for soldiers' training were listed by Yamamoto [39]. In his work, he wrote that VR technologies provide the possibility of learning problem-solving, thereby enhancing the training process. Training scenarios can be repeated an infinite number of times, dangerous missions can be simulated without risk, and training costs significantly decrease due to the lack of a need to use real equipment. As early as the 1960s, the DARPA (Defense Advanced Research Projects Agency) invested in the development of the first simulation systems based on VR technology. Technological progress has meant that over time VR technologies have become more accessible and cheaper. Haar [13] wrote that in the 20th century, every kind of force in the United States Department of Defense (Air Force, Navy, Marine Corps, etc.) conducted its development work on VR simulators of various military vehicles (helicopters, aircraft, frigates, submarines, etc.). The implementation of a multiplayer mode in VR technology has allowed for training soldiers' cooperation under simulated battlefield conditions. An example of such a system is the Dismounted Soldiers Training Simulator (DSTS), implemented in 2013, which provides subunits training in a virtual environment, increases soldiers' operational readiness, and reduces the expenditures that would otherwise be incurred on the immense training infrastructure necessary for conducting traditional training.

Although the origins of simulation techniques used in the Polish Army date back to the '90s of the last century, significant interest in battlefield simulation technology was observed in the first decade of this century (including Śnieżnik, PACAST, JTLS, JCATS, Leopard, Jaskier, Life, Aster systems, or simulators used for training airship crews). Col. Czesław Dąbrowski - head of the Tactical Simulation Department of the Military University of Land Forces indicated that "training with the use of simulators increases soldiers' alertness, stimulates their imagination, and leads to greater engagement in activities" [15]. Milewski, Kobierski, Chmieliński [24] describe some of the first sets deployed in the Naval Academy utilizing VR technology for simulating battlefield conditions. Michalski and Radomyski from Polish Air Force University in there article propose new method of evaluating air threat [25]. In 2021, an article appeared presenting a developed simulation environment at the Military University of Technology (MUT), which enabled training for signal officers [38]. The interest in VR technology expressed by the Armament Inspectorate is also suggested by the tender announced for the Tactical Simulator of the Modern Battlefield (STWPW).

The above examples fully justify the development and research conducted on VR technology and simulators, whose advantages and broad possibilities of application can bring significant benefits for soldiers' training or their implementation in autonomous weapon systems [41, 42, 43,44].

However, as a result of using VR simulators, it is necessary to take into account the possibility of side effects or intensified symptoms of the so-called cybersickness. The occurrence of cybersickness is so significant that it was most often mentioned as a phenomenon limiting the possibilities of using VR technology for soldiers' training by participants of a meeting during the NATO assembly in 2001 [3]. Despite the technological development, the problem has not diminished, and over time, the number of publications examining this phenomenon has considerably increased.

Taking the above aspects into consideration, preliminary theoretical and empirical studies were conducted to assess selected factors occurring during training using a VR simulator, which may adversely affect the course of the training itself or the occurrence of undesired psychophysical symptoms among the trainees.

The article presents the selected results of the conducted research.

2 Theoretical research based on a literature review

When designing training, special attention must be paid to the side effects that may arise from using VR technology. Stanney, in his studies [36], distinctly differentiates the concepts of simulator sickness from cybersickness. He pointed out that simulator sickness (acquired by pilots during the use of flight simulators) has different symptoms and they are of a different intensity than cybersickness (obtained as a result of using VR systems). This suggests that these phenomena may be caused by different factors. Understanding the differences between simulator sickness and cybersickness in this case is crucial in minimizing the side effects felt by the user during the use of training software.

In the literature [6], one can also encounter the term symptoms and effects caused by virtual reality (Virtual Reality-Induced Symptoms and Effects, VRISE) which is synonymous with cybersickness, understood as a set of symptoms and effects induced as a result of using virtual reality. In her work, Cobb [6] compiled 35 scientific publications addressing the topic of the side effects of using virtual reality. She pointed out that the negative effects do not disappear immediately but can last for hours after the end of the simulation session. One of the studies, which used real-time physiological data, involved nine experiments using VR. The measurements focused on the symptoms experienced during the study and the effects after the end of the VR session. In total, 148 people used various types of applications and computer systems. Tracking physiological data allowed for a precise understanding of the subjects' experiences.The results of the studies were generalized and diversified, however, they indicated that 80% of the respondents experienced the effects of cybersickness [6].

According to Kennedy et al. [16], the symptoms of cybersickness can be divided into three categories, i.e. disorientation, nausea, and oculomotor symptoms (Table 2).

Table 2. *Categorized symptoms of cybersickness*

Disorientation	Nausea	Oculomotor
Dizziness Balance disorders	Stomach discomfort Increased salivation Burping	Eye fatigue Difficulty concentrating Blurred vision Headache

Source: Authors' own work based on [6, 3, 9, 16, 34]

According to Davis, Nesbitt, Nalivaiko [9], the intensity of cybersickness symptoms can be up to three times greater than that of simulator sickness, and the discomfort can be so intense that the VR training scenario may not be fully realized by the participants [5].

The most popular theories regarding the causes of cybersickness are the sensory conflict theory [29], the poisoning theory [37], and the postural instability theory [30]. Each of these theories has its pros and cons, and it is difficult to determine which one is true. Despite their flaws, they have helped identify several factors that increase the risk of cybersickness symptoms occurring [19] (see Table 3).

Table 3. *Factors increasing the risk of developing symptoms of cybersickness*

Technological factors	Human factors
VR goggle tracking error - refers to inaccuracy in tracking the position of VR goggles and any image shake caused by inaccuracy in position processing.	*Gender* - women are more vulnerable because they have a wider field of view than men. A wide field of view increases the probability of flicker problems [17].
Latency – this is the time between the initiation of an action and the reproduction of movement in the virtual environment.	*Age* - the highest vulnerability in individuals occurs between the ages of 2 and 12. It decreases significantly until age 21, and then decreases gradually (around age 50, the risk of cyber disease is low) [29].
Flicker - a phenomenon associated with a low frame rate. It also means a decrease in the number of frames per second.	*Psychophysical condition* - people who are sick, tired, sleep-deprived, stressed, intoxicated, etc. should not use VR simulators [11].
	Position in the simulator - according to the theory of postural instability, sitting posture is preferable to standing posture during training.

Source: Authors' own work based on [19]

Porcino et al. [28] proposed a structure of techniques to mitigate cybersickness by integrating the functions of VR software, the suggested solutions of which are included in Table 4.

Table 4. *Structure of techniques to mitigate cybersickness*

Phenomenon	Cause	Suggested solution
Locomotion	Smooth movement of the user with the analog sticks causes sensory conflict.	Adding a *teleportation function* to the user's desired location (Fig. 1).
Acceleration	Human vision can adjust to the illusion of movement, but not to the change in speed, resulting in sensory conflict [19].	*Implementing haptics* (devices that simulate physical feelings).
Field of view	Dynamic events in the simulation can create an illusory sense of motion causing a sensory conflict.	*Vignetting* - a gradual reduction in the field of view [31] and *tunneling* (Fig. 1).
Depth of image	The problem occurs due to changes in the convergence and focus of the eyes.	*Programmed blurring of the image* based on distance (Fig. 1).
Usage time	Uninterrupted use for long periods of time causes fatigue and increases the probability of symptoms.	Designing the application to allow the trainee to *rest at any time without losing progress.*
Degrees of freedom	3D provides less control over the character, which can result in disorientation.	*Adding 3D hints* in a VR environment.
Delay	Generating high-resolution images requires computer resources, which are limited. Exceeding a certain level causes flicker.	*Asynchronous image loading* [27] - generating an image located only in front of the user (Fig. 1).
Reference point	The lack of a „visual anchor" in VR leads to a reduced sense of comfort.	*Creating a static element* as a reference point (such as the interior of a car in racing games).
Camera rotation	Smooth camera rotation creates a sensory conflict.	*Applying Gaussian blur* to the displayed image on a scale that depends on the acceleration and rotation values of the camera.

Source: Author's own work based on [28]

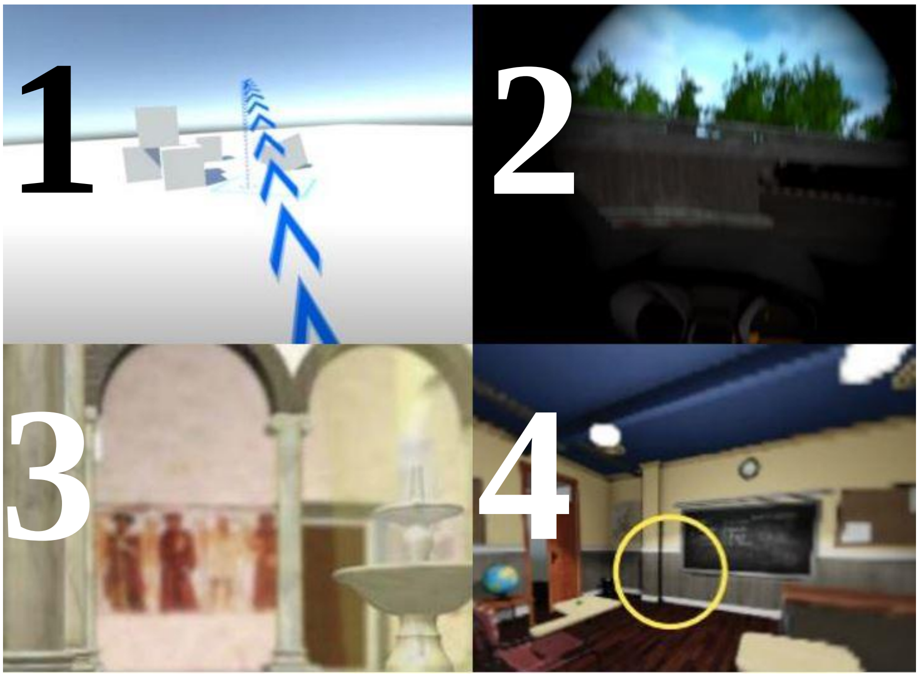

Fig. 1. *Techniques to mitigate cybersickness: 1 – teleportation, 2 – tunneling, 3 – image blurring, 4 – asynchronous image loading*

Source: Authors' own work based on [11]

High hopes are brought by the solution proposed by LaViola [19]. His idea is similar to adding a moving platform, but involves the use of a device that would stimulate the eighth cranial nerve (CN VIII) through electrical signals. In this way, the vestibular system could be tricked into sensing linear or angular acceleration. The use of such a device could likely completely eliminate the occurrence of symptoms of cybersickness [19].

In 2022, Galvanic Vestibular Stimulation (GVS) was used to suppress the effects of cybersickness (Fig. 2). Groth, Castillo, Tauscher [12] emphasise that the use of the device led to a twofold reduction in perceptible symptoms of cybersickness, and the comfort of using virtual reality significantly increased. However, these studies could be flawed as they did not consider the placebo effect. While designing their studies, Sra, Jan, and Maes [33] took into account the transfer and habituation effect, the placebo effect, and the novelty effect. The results indicate that, in addition to improving comfort due to the reduction of cybersickness symptoms, the level of immersion also increased, and 85% of the subjects preferred virtual reality with the GVS device.

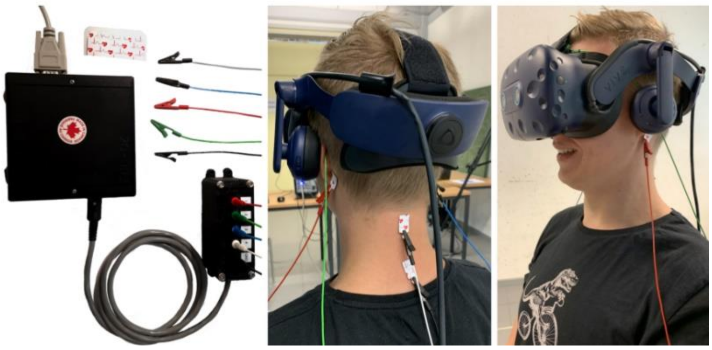

Fig. 2. *GVS device* [33]

3 Preliminary empirical studies using the VR simulator

3.1 Subject and conditions of the study

The subject of the research was a VR simulator of the SA-6 Gainful missile launcher system developed at MUT [18]. The task for those undergoing training using the VR simulator was to independently master both theoretical and practical aspects of performing one of the checks of the functioning of the missile launcher component of the SA-6 Gainful system. The degree of knowledge and practical skills mastery by the trainees was verified by the examiner during the exam on the actual weapons equipment.

Firstly, suitable training conditions were organized for the trainees, i.e., all participants could use the VR software while sitting in an ergonomic chair, in an air-conditioned room with appropriate lighting. Initially, a preliminary guide on 'How to effectively use the VR simulator' was conducted, and during the main training, technical support was provided to the trainees.

To correctly use the aforementioned VR simulator, the following minimum hardware requirements of the station must be met: a GTX 1060 / RX 580 graphics card – 6GB VRAM, Core i5-7500 / Ryzen 5 1600 processor, RAM - 12GB, and the VR set Oculus Rift S. The system software of the station is at least Windows 10 x64, and it is recommended to have Internet access during the first launch of the VR simulator, which allowed updating of the necessary drivers and installation of the Microsoft Visual C++ 2015-2022 Redistributable (x86) package.

In the developed simulator, much attention was devoted to minimizing risks associated with the potential occurrence of symptoms of cybersickness among trainees. During the software design, particular attention was focused on the following elements of the application, i.e.:

- *Character rotation* – a incremental rotation of the character by 30° as a result of the deflection of the analog stick is better perceived by the user than a smooth rotation dependent on the angle of stick deflection;
- *Character movement* – it was decided to implement a system of smooth movement instead of a teleportation system. This results in intuitive control, unfortunately, at the cost of a higher likelihood of the occurrence of symptoms of cybersickness;
- *Frame rate* – the aim was to achieve a stable display speed at 60 fps. For this purpose, processes burdening the computer's operating system were disabled, and the texture resolution was either dynamically decreased or increased depending on the degree of object visibility;

Progress saving – the trainee can create his individual profile, where current progress in training is saved automatically. This allows for breaks in exercise without the need to start the whole training from the beginning.

3.2 Objective of the study

The main objective of the study was to preliminarily assess the possibility of utilizing the developed VR simulator in the process of training soldiers and to obtain answers to the following questions:

Q1) Are the mitigation measures for symptoms of cybersickness, applied during the development of the VR simulator, sufficient?

Q2) How burdensome were the technical problems for the trainees while using the VR simulator?

Q3) Are the user interface and navigation through the application intuitive enough for the trainees?

Finding answers to these questions would allow for a preliminary assessment of the capabilities of the developed VR simulator in terms of:

1. **Occurrence of symptoms of cybersickness** – assessed based on quantitative data (*Pretest*) and information obtained through open interviews and supplemental notes (*Posttest*).
2. **Technical condition of the VR simulator**– qualitative assessment based on information obtained through full observation of the training, subjective experience surveys of the study subjects, and open, unstructured interviews with study participants (*Posttest*).

3. **Intuitiveness of the user interface** – qualitative assessment based on information obtained during the observation of the training course, surveys of subjective feelings of the study subjects, and open, unstructured interviews with study participants

3.3 Adopted methodology

In the study, it was assumed that a preliminary assessment of the possibilities of using the VR simulator in the process of training soldiers would be conducted, in accordance with the assumed procedure scheme (Fig. 3) based on the analysis of data:

– **quantitative** – by comparing the results obtained from the exam of soldiers trained using the VR simulator and analyzing the results of their subjective feeling surveys at the same time;

– **qualitative** – by comparing data from individual interviews and examiner's notes made during the exam.

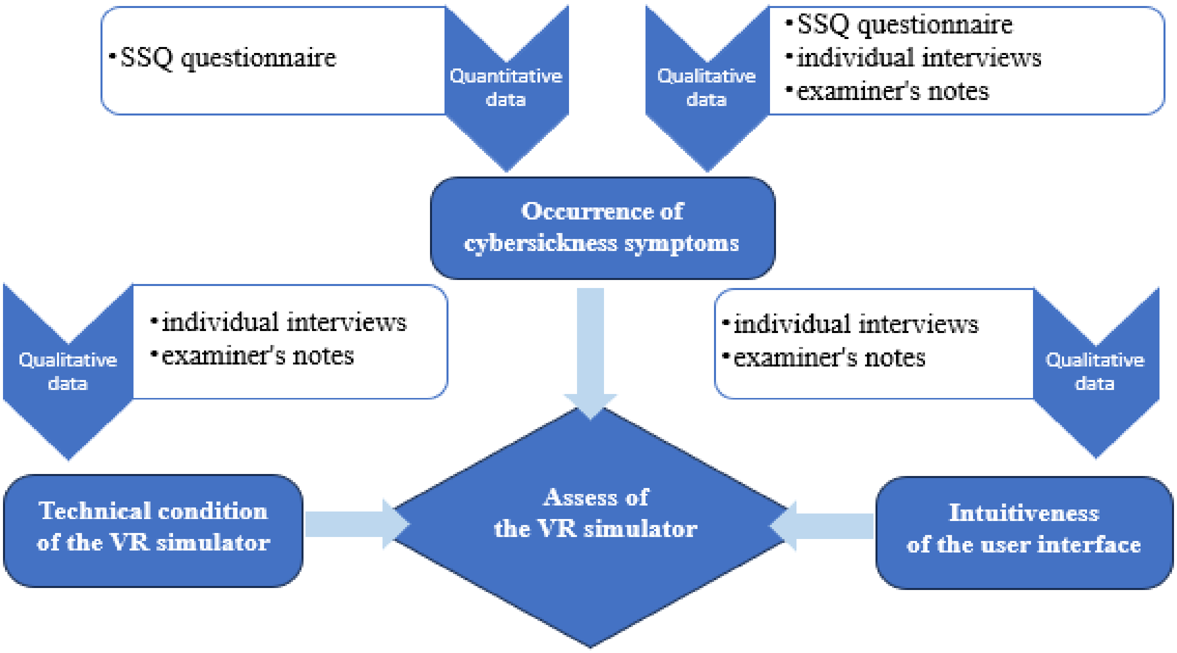

Fig. 3. *Diagram of data analysis for the adopted research methodology*

Data from both information sources underwent validation through a detailed description of each study's process and its review after the conclusion of the exam, in accordance with the methodology specified in the work [36]. Subsequently, the results of qualitative studies were subjected to quantification by calculating the value of the indicator according to the procedure described in work [8], allowing their comparison with quantitative results.

The answer to question **Q1)** was obtained through the analysis of quantitative data collected using the *simulator sickness questionnaire* (SSQ), detailed in the work [16]. The qualitative data, obtained through full observation and interviews, enabled the formulation of answers to questions **Q2)** and **Q3)**.

4 Results of empirical studies

4.1 Assessment of the occurrence of cybersickness symptoms

Before starting the training using the VR simulator, participants completed the first part of the SSQ questionnaire, the so-called Pretest SSQ, in which they determined their psychophysical state before starting the study. The questionnaire also contains quantitative data on the occurrence of the following categories of symptoms:

1. Nausea (N) – drooling, sweating, nausea, stomach discomfort, and belching;

2. Oculomotor disturbances (O) – fatigue, headache, eye strain, and difficulty concentrating;
3. Disorientation (D) – dizziness, feeling of intoxication, and blurred vision [1].

Moreover, it includes qualitative data enabling the acquisition of additional information about the participants such as their general well-being, diseases suffered recently, medicines taken, and previous experience with VR technology. This information was particularly useful in verifying the quantitative results of the studies.

The study participants were trained in measures that can counteract the occurrence of symptoms of cybersickness such as how to move in the simulator, interact with elements, and control training time and break lengths. During the training, observations were conducted on the trainees, who were reminded of the possibility of saving their training progress and returning to it after a break.

After the training was conducted, participants filled out the second part of the SSQ questionnaire – *Posttest SSQ*, which, in addition to the above-mentioned quantitative data, contained qualitative questions concerning atypical events that could occur while working with the VR simulator (i.e., drop in frame rate, unintended teleportation, feeling of falling, etc.). This information was complemented through an open, unstructured interview.

The results of the individual participants, converted to points according to the methodology described in study [8], are presented in Table 5.

Table 5. *Test results by symptom groups*

Participant code	Pretest SSQ				Posttest SSQ			
	N	O	D	OS	N	O	D	OS
A1.	9,54	9,54	13,92	18,70	9,54	22,74	13,92	18,70
B1.	0	7,58	0	3,74	0	37,90	0	18,70
C1.	0	15,16	0	7,48	0	15,16	41,76	18,70
D1.	0	7,58	0	3,74	19,08	15,16	0	14,96
E1.	0	0	0	0	0	0	0	0
F1.	0	7,58	0	3,74	9,54	30,32	0	18,70
Mean	1,59	7,91	2,32	6,23	6,36	20,21	9,28	14,96
Std. dev.	3,895	4,860	5,683	6,5495	7,7894	13,2740	16,8580	7,4800

Symbols: N – Nausea, O – Oculomotor, D – Disorientation, OS – Overall Score

Even though every study participant had the option to interrupt the study at any time and return to it after a short break, only one participant (code D1) chose to take a break.

Another participant (code F1) concluded the training process after 60 minutes but stated that the fatigue he felt in his eyes did not influence this decision.

In one instance, a study participant (code B1) began experiencing a headache an hour after finishing work on the VR simulator. He described the headache as "moderate" and it lasted about two hours. This was noted in the quantitative section of the SSQ questionnaire.

A participant (code A1) underwent the training despite feeling unwell. After completing the training, he reported that he did not experience a worsening of his condition, rather he even felt an improvement. According to the results of the study [2], this improvement in well-being was attributed to the passage of time and was not ascribed to the VR simulator.

Figure 4 presents the averaged results of the studies.

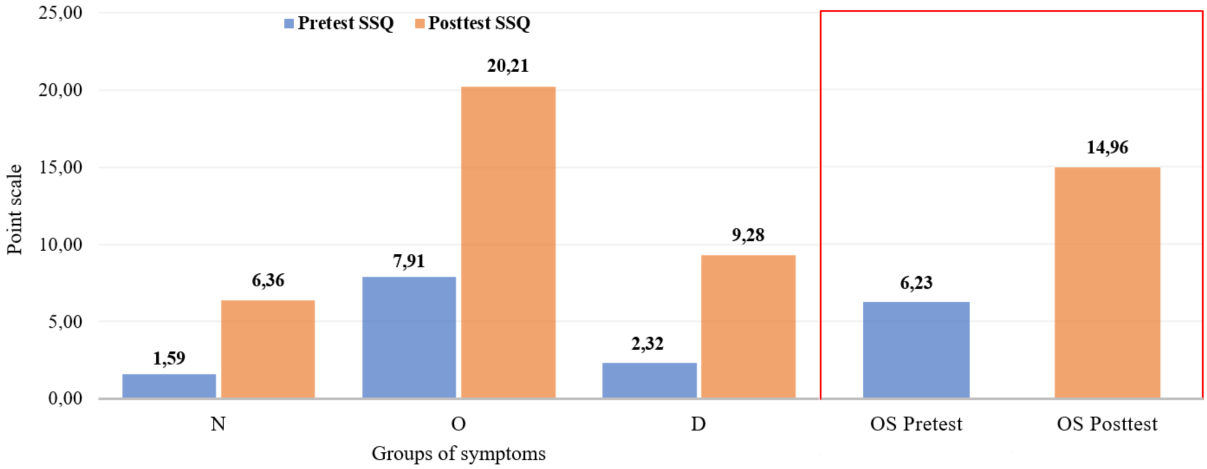

Fig. 4. *Test results by symptom groups*

Having analysed the distribution of the occurrence of symptoms of cybersickness, divided into symptom groups (Figure 4), it should be indicated that some of the trainees experienced similar symptoms to those defined in individual groups in different situations even before the training, and the use of the VR simulator caused their recurrence and an increase in the overall indicator to a value of OS = 14.96. The dominant group of symptoms turned out to be oculomotor symptoms such as eye fatigue, concentration problems, or headaches. According to Stanney's scale, if the overall score of the OS index exceeds 20 points, the assessed simulator is of low quality. In his article, the author [35] included a scale that allows the categorization of the overall level of symptoms caused by the use of the VR simulator (Table 6).

Table 6. Simulator category based on overall score

OS index [points]	Category
0	No symptoms
<5	Negligible symptoms
5-10	Minimal symptoms
10-15	Non-obstructive symptoms
15-20	Symptoms that are a noticeable problem
>20	Symptoms that pose a significant problem

Source: Authors' own work based on [35]

4.2 Evaluation of the technical condition of the VR simulator

Qualitative data were collected through observation during the training and individual interviews with study participants.

In the first stage of the study, the course of the training was observed, focusing on the reactions of the trainees while experiencing situations involving technical problems. During the training, the application's algorithm interpreted a correctly performed activity as an error for two individuals, which negatively affected their overall impression, slightly demotivating and delaying the training, as it was necessary to wait a moment until the virtual instructor finished playing the instruction of the correct performance of the activity and reverted the simulation to the last correctly performed activity.

Additionally, the commitment of errors by two other trainees at the level of mastering activities inside the launcher caused delays, as they had to redo the stages they had already gone through. After finishing the Learning stage, one person had the left controller in the simulator stop working, which required software resetting.

It was observed that during the study, the generation of the virtual image was stable at all training levels, maintaining a value of 59 ±1 [fps], with one exception for outside launcher scenes in the Learning stage, where the image generation speed decreased to a value of 50 ±2 [fps].

After the training was completed, open unstructured interviews were conducted with each of the training participants, asking about their impressions related to technical problems. Two trained individuals reported technical problems. However, they did not observe that these problems were serious enough to affect their ability to concentrate on the training and learning new skills.

Based on the obtained information, it was concluded that the inconvenience of technical problems that occurred during the use of the VR simulator is at a moderate level. Most of the problems could be solved by returning to the previous (last) save of the training progress.

4.3 Evaluating intuitiveness of user interface

During the conducted study, special attention was paid to those training stages when where the intervention of the instructor was most often necessary. Two training participants got stuck already at the Tutorial stage, while learning to use virtual knobs and levers in the VR simulator. All the trainees most often paused at the Learning stage during the setting of the address connector and while moving to perform the practical part of the topic. During the open interview, after completing the training, participants were keen to point out elements that require improvement and proposed changes concerning the VR application interface.

The conditions of the study allowed the instructor to establish and maintain individual contact with the trainees and to provide them with immediate assistance, which ensured that trainees did not lose time searching for interactive elements needed to perform the next exercises. As a result, progress in training was faster than if they had worked independently.

Having analysed the responses given by the trainees, it was concluded that if classes using the VR simulator could be conducted with a larger number of trainees at the same time, the time allocated for training the entire group would be significantly reduced.

5 Summary

The effectiveness of applied solutions intended to mitigate the risk of cybersickness symptoms affects the level of trainees' satisfaction with using the VR simulator. The occurrence of psychophysical side effects during or after the training may be a reason for reduced engagement in using new teaching techniques. Therefore, assessing the effectiveness of applied mitigation measures is essential to determine the validity of using a VR simulator for a given training.

Considering the conducted empirical studies, it is evident that the overall rating indicator set according to Stanney's scale at OS = 14.96 suggests that the VR simulator used during the study may cause symptoms of cybersickness, defined as non-bothersome. However, using the above scale to assess the simulator used in our studies might not be entirely appropriate for two main reasons: 1) the study sample to develop Stanney's scale were military pilots – individuals selected based on their heightened resistance to unnatural sensory stimuli and 2) it did not consider the time spent working with the simulator, while other similar studies [21-22, 32, 34] show a strong correlation between the occurrence of cybersickness symptoms and the time spent in VR simulators, regardless of the content provided by the software. Given this these limitations, future quantitative assessments of the occurrence of cybersickness symptoms are planned to be conducted based on expanded studies using different computer programs employing virtual reality and other assessment indicators. For instance, Hirzle et al. [14] reviewed 309 literature items, based on which they calculated the average OS = 25 points. From their conducted survey studies (N = 352), they obtained an average result at OS = 53 for the average time spent in a virtual environment T = 53 minutes.

Comparing our study results, it can be pointed out that the cybersickness mitigation measures used in the developed VR simulator were sufficient, as the OS indicator of the developed simulator is 40% better than the average value given in the study [23]. Therefore, there is no need to apply other remedial measures.

Continuing, another important factor of the conducted study on the use of the VR simulator was the assessment of the impact of technical problems occurring during the simulator training. The technical condition of the used training application can indeed affect the result of the training and can also cause the symptoms of cybersickness.

The level of intuitiveness of the user interface directly affects the progress of trainees during the performance of training tasks. The lack of progress can lead to an increase in their frustration, which in turn translates into a decrease in the effectiveness of using VR software. The amount of instructor intervention to explain unclear commands related to the operation of the VR simulator depends on the level of intuitiveness of the user interface. A user interface is considered well-designed if the instructor does not have to intervene during the training to explain what actions should be taken at a given moment. Therefore, the level of intuitiveness of the user interface affects the maximum number of people who can train simultaneously under the supervision of one instructor.

From the above considerations, it follows that the research results presented in the article, although interesting and allowing a general assessment of the quality of the developed VR simulator, should not be treated as final due to the small scale used (N = 6) and the significantly limited thematic scope of the training, but rather as preliminary (pilot) studies determining the directions of further actions.

The best-conducted studies of a similar nature, but on a much larger scale, can be considered the results of the evaluation of the effectiveness of training using a VR simulator during helicopter pilot training conducted at West Point [8]. In the aforementioned study, the null hypothesis that "*pilots trained with the VR simulator will be trained at a similar level as those trained on actual equipment*" was adopted. The assessment of trainees' qualifications was also similar - by means of a practical test (using a real helicopter) conducted by the Federal Aviation Administration for pilot certification. The control group (N=145) consisted of historical data of practical test results. The conducted T-Student test indicated that the level of knowledge and skills of the control and studied group at the initial stage was similar (95%). The studied group (N = 116) were pilots trained using the VR simulator. The hypothesis was confirmed. However, the authors point out that further monitoring and analysis of data related to the training program are necessary to draw significant conclusions regarding the effectiveness of using VR simulators in aviation schools.

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