TESTING HUMAN ERRORS IN VIRTUAL REALITY TRAINING

LUBOS KOTEK[1], ZDENEK TUMA[1], KAMIL SUBRT[3], JIRI KROUPA[4], PETR BLECHA[2], JANA ROZEHNALOVA[2], RADIM BLECHA[3], PETR HEINRICH[5]

[1]Brno University of Technology, Dept. of Production Systems and Virtual Reality, Brno, Czechia

[2]Brno University of Technology, Dept. of Quality, Reliability and Safety, Brno, Czechia

[3]Brno University of Technology, Research Center of Automatic Manipulation, Brno, Czechia

[4]Brno University of Technology, Production Machines and Robotics Division, Brno, Czechia

[5]Kovosvit MAS, Sezimovo Usti, Czechia

DOI: 10.17973/MMSJ.2022_12_2022128

kotek.l@fme.vutbr.cz

The emergency training of industrial process plant operators is one of the most widely used tools to increase the reliability of human factors to handle an emergency situation. However, the preparation and operation of full-fledged simulators and trainers is very expensive and, therefore, virtual environment tools are used. A question that has not yet been answered is: Can virtual reality match the reliability of other methods of operation and is the same training in virtual reality effective? The experiment was carried out in the three-walled virtual CAVE, with virtual reality glasses, with a computer, a tablet, and a real control panel. Visual stimuli were displayed on the screen of the virtual monitor (green, yellow, and red); auditory stimuli were pure tones with frequencies of 250, 1000 and 4000 Hz. The conclusion should explicitly state if the hypothesis defined for the research has been confirmed and there are significant differences in terms of interface type. Training in virtual reality induces lower operator reliability, but in specific conditions (visual stimuli, virtual reality glasses) can match the reliability of other methods of operation and can be effective.

KEYWORDS

VIRTUAL REALITY; HUMAN FACTORS; TRAINING; HUMAN ERRORS; CONTROL PANEL

1 INTRODUCTION

The advantage of training employees in virtual reality is that there is no need to interfere with operations. This comes in handy for factories with non-stop production lines or areas where the movement of untrained people is risky. Virtual reality is also suitable for training in working with very expensive machinery or equipment, which is itself very expensive to run or where a breakdown could easily occur and cause costly damage to the company [Lawson 2015]. Remote training has also been found to be useful during times of pandemics. At times when factories were closed or operated on a limited basis, companies could at least train employees and upgrade their skills remotely. All without the risk of spreading the virus. Virtual reality is also a good solution for employee substitutability.

The importance of the human factor in the manufacturing industry increases due to the growth of the complexity of technological equipment, the quality of its maintenance, and the increasing share of automation with a high degree of safety integrity level [Kotek 2015]. A large amount of control activities of operators in large plants have already been carried out in the control room; the operator remotely controls the technology. Therefore, a design of control panels and desks with respect to operator reliability has become a key aspect of technology design. In addition to the methods of Human Reliability Analysis (HRA), which are due to a high degree of uncertainty limited in use [Yang 2007], there is an increased deployment of direct testing and debugging of design of control panels directly with the staff involved in implementation of these activities. Due to the high costs of full-scale experiments of human reliability, virtual reality systems have recently started to be exploited [Kotek 2015]. Virtual reality not only provides an environment for visualizing a three-dimensional environment, but it also enables the interaction with objects to improve decision making from both quantitative and qualitative aspects.

Another aspect, which relates to the use of virtual reality systems, concerns the training of staff, an inadequate training of staff played a significant role [Shaluf 2008]. This is, even in complex equipment, often done only verbally, without the possibility of trying out the situation in a real environment [Hamilton 2012]. Virtual reality systems allow users to carry out immersion emergency training and networking of rescue teams with emergency control of the plant in the control room. The aim is to improve the reliability and performance of staff and improve their sensory-motor skills, knowledge, and skills in performing tasks using virtual reality.

Currently, many organizations are experimenting with centralized teams of experts that can project expertise to a remote operator through a wearable device. This allows the remote expert to see and hear first-hand what the local operator is dealing with in real time and help [Thompson 2007].

This paper deals with the experimental evaluation of the reliability of the staff (operation error rate) operating the panel in the control room in the virtual reality system (using virtual reality glasses and a virtual cave) and using the standard tools used so far (real control panel, computer monitor, and tablet) when testing the design of the control panel. Factors evaluated are the arrangement of buttons on the panel (horizontal / vertical) and the type of stimulus (visual, auditory). Experimental research of the influence of these two factors has already been implemented [Cheng 2008]; our experiment should demonstrate whether virtual reality can match the reliability of other methods of operation and whether the training in virtual reality is effective. This article builds on previous research described in the article [Cheng 2008] and is based on the proposed experiment [Kotek 2015]. An investigation of the effect of each stimulus was carried out on the test rigs described in this paper.

2 METHODS

2.1 Equipment

The experiment was carried out in the three-walled virtual CAVE, with virtual reality glasses, with a computer, a tablet, and a real control panel. The panel always looked exactly the same and was placed at the same height and in the same stable conditions.

General experimental setup

The control buttons are marked with three colors (green, yellow, red). The control panel also has a START button. The distance between the control buttons was always 10 cm.

We proceeded from the standard testing panel arrangement and layout proposed in the article [Cheng 2008].

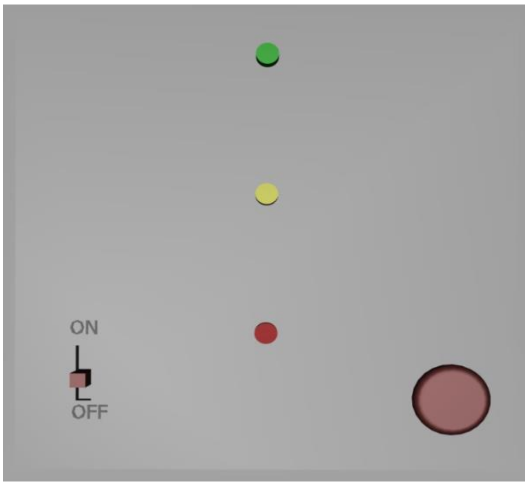

Figure 1. Arrangement chart of buttons on a vertical panel

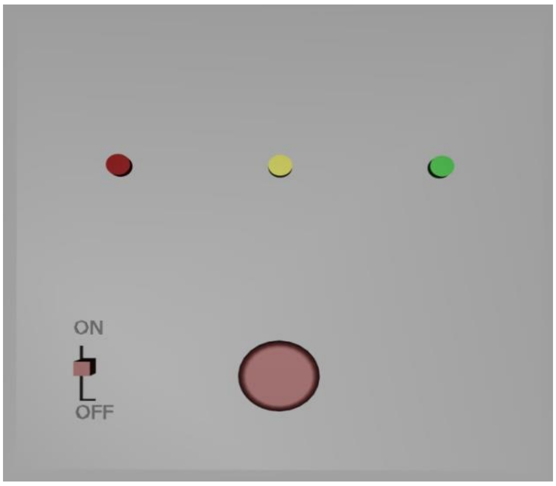

Figure 2. Arrangement chart of buttons on a horizontal panel

Layout of the testing position in the next figure.

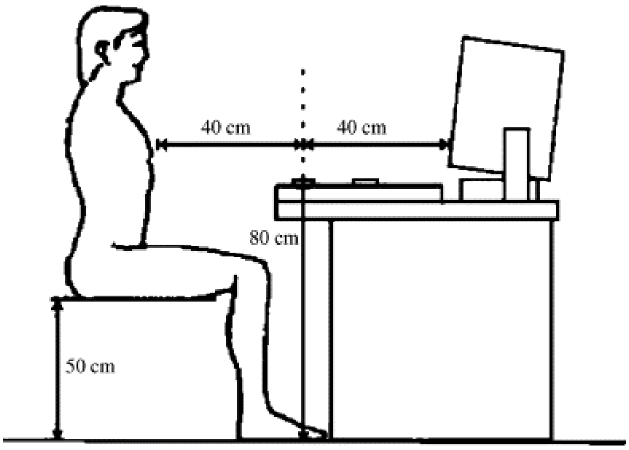

Figure 3. Standard testing layout and the position of the test device related to the participant [Cheng 2008]

Virtual reality cave

The virtual reality cave is a projection-based system that uses a passive stereoscopic rear projection that consists of three vertically oriented projection walls. The system is completed with a fourth projection screen, which is realized by direct projection on the floor. For channel separation, interference filters technology (Infitec) is used. The display of images on all projection screens is ensured by the cluster comprised of eight computing stations GK nVidiaQuadro 5000, each of which is connected to one projector. The function of direct interaction with the virtual prototype and the control of the system in immersion mode is ensured by the ART optical tracking system with six infrared cameras, including the service tracking software. For actual control, the Flystick input device was selected.

In virtual reality, two test panels were created with a set of three control buttons and a start button (vertical and horizontal arrangement - Figures 1-2). The experimental facility was created in virtual reality using IC.IDO Visual Decision Platform software (IC.IDO VDP), which is a software package designed both for the operation and control of the immersion systems presented above and also for the creation, management, and projection of virtual scenes.

Virtual reality glasses

These are standard Oculus rift CV1 glasses with controllers, but without any haptic device. The screen displays two images adjacent to each other, one for the left eye and one image for the right eye. The combination of lenses is placed above screen, enabling the zoom-in-out and re-shaping the picture for both the eye, thereby creating a stereoscopic 3D image. Rift devices monitor the wearer's head motions by the embedded sensor and accordingly adjust the image. The latest version of the Oculus Rift is bolstered by an external positional tracking accessory that helps track head movements more accurately.

The glasses were accompanied by a glove that recorded the movement of the hand.

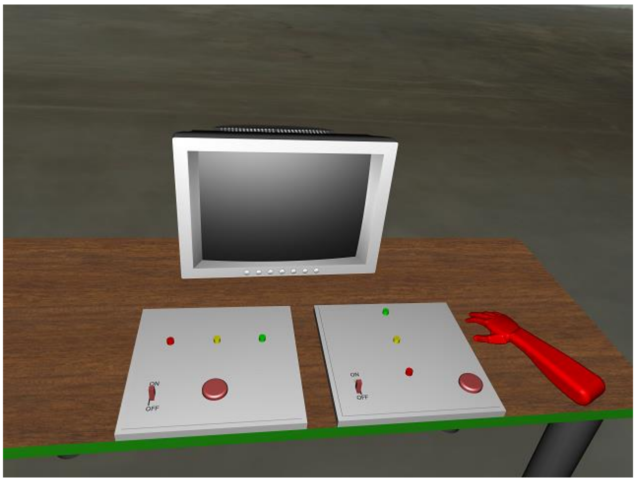

Figure 4: Experimental workplace in virtual reality

Computer and tablet

It was a standard office PC with 24-inch LCD display, where the control was done with a laser mouse. For the tablet (HP EliteBook 2760p), the interface was operated through a 12.1-inch touchscreen display.

Real panel

This was a standard panel with buttons that was operated via a Labview interface from a PC, recording operator intervention and time.

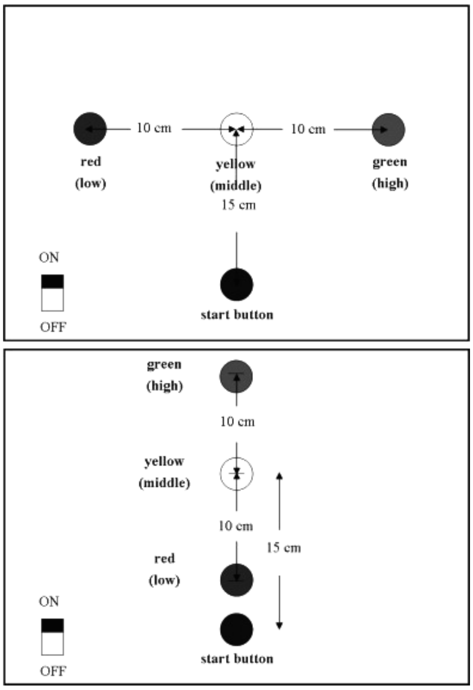

Figure 5: Real panel with horizontal and vertical arrangement

2.2 *Description of task*

Visual stimuli were displayed on the screen of the virtual monitor (green, yellow, and red); auditory stimuli were pure tones with frequencies of 250, 1000 and 4000 Hz.

Each participant in the experiment was sitting on a chair of 50 cm high in front of a virtual panel, with 3D glasses placed on his/her eyes, holding a tracking controller Flystick in his/her hand. Using this controller, the participant's task was, after pressing the START button, to press the right control button (in the case of visual stimulus to press the control button of the same color; in the case of auditory stimulus to press the green button at the tone with a frequency of 250 Hz, the yellow button at the tone with a frequency of 1000 Hz and the red button at the tone with a frequency of 4000 Hz). The sounds were reproduced by an external Genius active portable speaker system with adjustable volume. The equivalent sound pressure level at the operator's location was set to 50 dB.

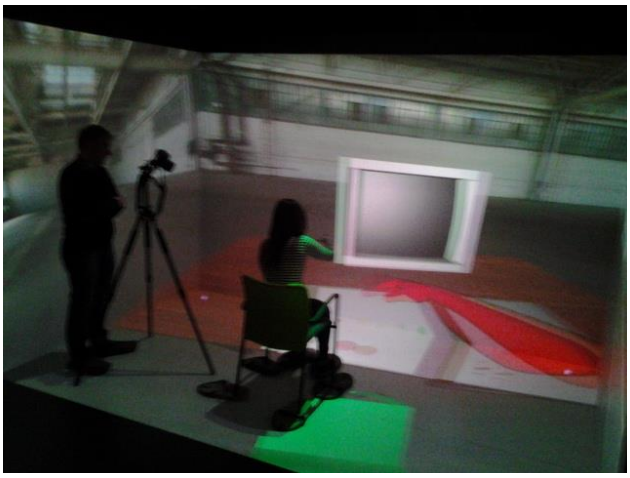

Figure 6: Experimental workplace – photo

2.3 *Design of an experiment*

The purpose of this study was to empirically examine the impact that an arrangement of control buttons could have on the response to auditory and visual stimuli in terms of operator reliability in different environments. Evaluation was carried out using the variable HEP (human error probability).

Conceptually HEP are the number of failures divided by the number of response opportunities (equation 1) [Chang 2014].

$$HEP = \frac{Number\ of\ Failures}{Number\ of\ Response\ Opportunities} \qquad (1)$$

Forty university students and academics from Brno University of Technology participated in the experiment as volunteers. First, each of the participants took part in the training session (15 randomly ordered stimuli for every environment, totally 75 stimuli), then in five sets of experiments, each of them with 15 stimuli in a random order (two for different arrangements, two for different stimuli) in all five environments. In total, each of the participants responded to 300 stimuli. The order of stimuli was modified for each environment.

3 RESULTS

The main results of ANOVA are shown in the following table. This table presents both the HEP values for different types of stimuli (sti – color, sound), different arrangements of control buttons (loc - horizontal, vertical) and interface (Tablet, PC, Real Panel, Virtual Cave, Oculus).

The ANOVA test examines the variation and tests whether the between group variance is greater than the within group variance. The larger the F ratio (the larger the variation between the groups), the greater the probability (the lower p value) of rejecting a multiple group, the situations being the same. A one-way ANOVA (p<0.05) is used to determine if there is a difference between the groups. Repeated measures within-subjects design compared the arrangement of control buttons (two levels: horizontal and vertical arrangements), the type of stimuli (two levels: auditory and visual stimuli), and the type of interface (two levels: Tablet, PC, Real Panel, Virtual Cave, Oculus) in a choice reaction.

Source of variation	F-value	p-value
orientation	16	<0.001
stimulus	1810	<0.001
interface	1396	<0.001
orientation*stimulus	21	<0.001
stimulus*interface	400	<0.001
location*interface	1	0.558
location*interface*stimulus	1	0.220

Table 1. ANOVA results of HEP for the experiment

From the results, it is evident that combinations of the factors location*interface and location*interface*stimulus are not statistically significant.

The arrangement (orientation) of control buttons is a significant quantity; HEP in vertically arranged buttons is 0.191, while in horizontally arranged buttons it is 0.212. The F value is 16.2424, p value <0.001.

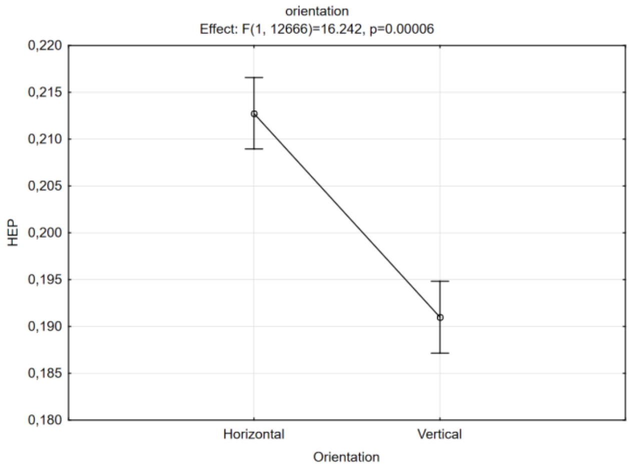

Figure 7: Evaluation of the experiment for button orientation (Statistica)

The type of stimulus is a significant quantity; the HEP for the auditory stimulus (0.321) was higher than the visual stimulus (0.091). The F value is 1810.4, p value <0.001.

The result of the test is the finding that the vertical layout is preferable in terms of human factor reliability because it resembles the traffic light, which also has a vertical layout.

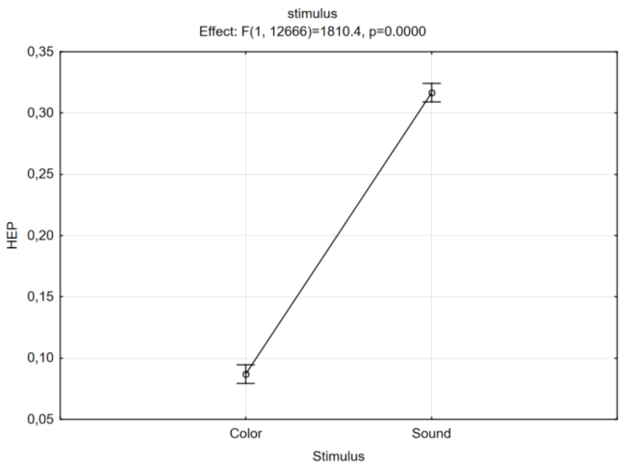

Figure 8: Evaluation of the experiment for the type of stimulus (Statistica)

The type of interface is a significant quantity, HEP for Tablet is 0.065, for PC is 0.040, for Real Panel is 0.033, for Virtual Cave is 0.541 and for Oculus is 0.006. The F value is 12666, p value <0.001.

The result of the test is the finding that the pitch-only signal is less reliable because a portion of the population has difficulty distinguishing pitch and cannot distinguish these tones.

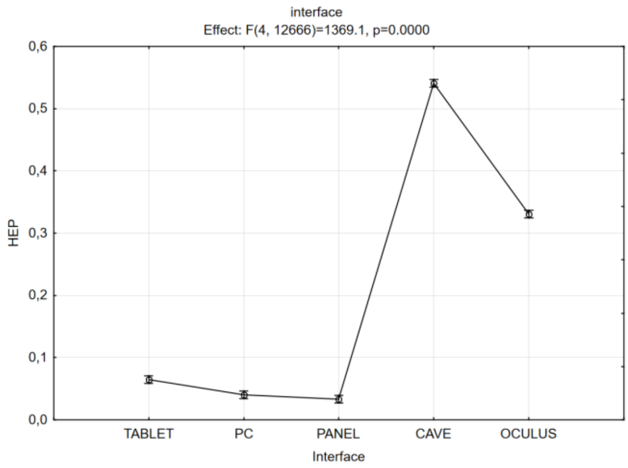

Figure 9: Evaluation of the experiment for the type of interface (Statistica)

From this test, it was found that the most reliable way to operate the device is with a real control panel, followed by a PC and a tablet. Virtual control methods have significantly higher HEP.

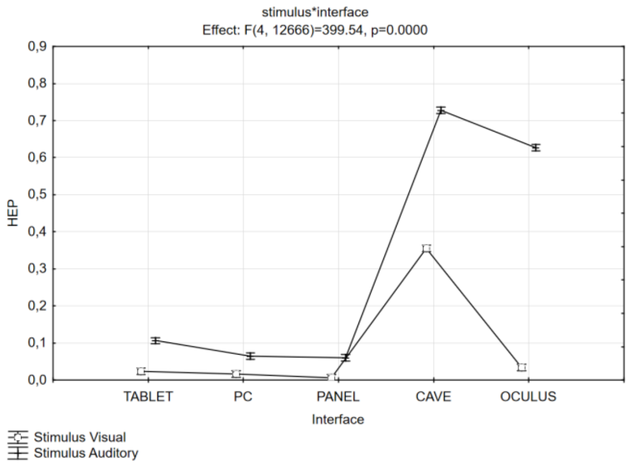

Figure 10: Evaluation of the experiment for combination of stimulus factors and type of interface (Statistica)

When evaluating the stimulus and interface type, the high unreliability of the audio signals appears interesting when controlling in the CAVE and in virtual reality. This may be due to the fact that in the case of the virtual CAVE the apparatus is placed in a large echo chamber where the ability to discriminate sounds is lower.

The generally lower HEP when using virtual resources may be due to limited feedback (visual only).

4 DISCUSSION

From the results obtained, it is evident that when tested in virtual reality, the HEP is higher than in conventional tests, especially for the auditory stimulus.

Auditory signals can improve human presence within a VR experience [Morosi 2021]. They increase the hippocampal response by engaging with cognitive processes related to memory. Appropriate sounds help the user to better recognize the environmental conditions and react promptly when needed. Due to the high human capacity to detect sounds and their localization, it is extremely important that audio sources are correctly calibrated in terms of both placement and intensity [Adreano 2009].

The differences are probably caused by uncertainties when the tasks are performed in virtual reality.

Nevertheless, it is possible to state that from an operational perspective it is possible to use virtual reality to improve the reliability and performance of staff, to develop their sensory-motor skills, knowledge and skills in performing the tasks. Using virtual reality is also beneficial for the reasons of saving financial and time resources [Dado 2013].

In this paper, human error probability (HEP) is the likelihood of failure to perform a task. Since human performance in diagnosing emergency situations is strongly dependent on the available time to perform the requested actions correctly, the tests were performed for different cases, corresponding to different capacities of the process plant to cope over a specified time interval [Nespoli 2010].

From the results of the experiment it seems that the most important use of virtual reality can be for:

- Quick validation of design - using visualization in virtual reality, current data are available, and there is no need to wait for the production of costly prototype.
- Control of design – allows for a quick and effective change of colors, textures, enlightenment of scenes, etc.
- Simulation and control of situations difficult to replicate – it is possible to replicate the same situation (e.g., emergency) many times without security risks.
- Verification of design ergonomics - virtual prototypes can be combined with the real models that can be quickly adjusted so that the user "touches" both the real and virtual space simultaneously. Thus, for example, it is possible to quickly verify the intuitiveness of control in the control room, to perform a variety of ergonomic analyses of the product use, etc. The participant of the experiment may have sensors on different parts of the body to capture his/her motions in real time (motion capture); these can then be analyzed.
- Verification of workplace ergonomics - if 3D models of workplace components are available, it is possible, using CAVE, to verify ergonomics of physically non-existing workplace.
- Virtual training - in CAVE (or HMD) it is possible to train new employees without the risk of losing expensive equipment or material.

5 CONCLUSIONS

This article presents an experimental study of the reliability of the operators in the control room. The ability to quickly acquire data to increase the reliability and performance of control room operators is crucial for improving safety. Human factor issues understood as human interaction (characterized by human conduct) with the working environment or with impacts of environmental factors are being increasingly viewed as an important area of impacts on operational safety of equipment and technologies. However, a strict assessment of the impacts of physical factors on human reliability is no longer considered sufficient. Not only does the increasing sophistication of technologies bring an ever-greater burden for human operators, and this pressure is reflected in particular in the performance of their mental and sensory functions [Russ 2014].

The purpose of this study was to empirically examine the impact that an arrangement of control buttons could have on the response to auditory and visual stimuli in relation to the reliability of the operator in different types of interfaces.

Training in virtual reality induces lower operator reliability, but under specific conditions (visual stimuli, virtual reality glasses) it can match the reliability of other methods of operation. The results show worse HEP values in VR, but even with this weakness, VR can be used to simulate hazardous areas, simulate non-existent environments, etc.

A limitation was the large number of repetitions in a short time frame that had the potential to reduce participants' attention to the task. We should redesign the experiment with at least 15 minutes break between the sessions (testing stations for different interfaces [McLaren 2022].

The response time was also recorded during the experiment. Evaluation of this time will be the subject of further research.

ACKNOWLEDGEMENT

The authors would like to acknowledge the funding support from the Czech Ministry of Education, Youth and Sports under the project "CZ.02.1.01/0.0/0.0/16 026/0008404\ Manufacturing engineering and precision Engineering" financed by OP RDE (ERDF). The project is also co-financed by the European Union.

REFERENCES

[Andreano 2009] Andreano J, Liang K, Kong L, Hubbard D, Wiederhold BK, Wiederhold MD. Auditory cues increase the hippocampal response to unimodal virtual reality. Cyberpsychol Behav. 2009, 12, 3, 309–313. https://doi.org/10.1089/cpb.2009.0104

[Chang 2014] Chang J., Y., Bley, D., Criscione, L. et al. The SACADA database for human reliability and human performance. Reliability Engineering and System Safety, 2014, 125, 117-133. https://doi.org/10.1016/j.ress.2013.07.014

[Cheng 2008] Cheng SY, Hsu HT, Shu CM. Effects of control button arrangements on human response to auditory and visual signals. Journal of Loss Prevention in the Process Industries. 2008, 21, 3. https://doi.org/10.1016/j.jlp.2007.03.002

[Dado 2013] Dado M, Hnilica R, Schwarz M. Development of virtual laboratory for evaluation and control of workplace hazards. Engineering for Rural Development Conference 2013. Latvia University of Agriculture.

[Hamilton 2012] Hamilton I. TCE: Human factors: Human error: In the loop. TCE The Chemical Engineer. 2012, 854, 39-41

[Kotek 2015] Kotek L, Tuma Z, Blecha P, et al. Evaluation of human error of response to auditory and visual signals in the virtual reality. Safety and Reliability of Complex Engineered Systems - Proceedings of the 25th European Safety and Reliability Conference, ESREL 2015: CRC Press/Balkema. https://doi.org/10.1201/b19094-395

[Lawson 2015] Lawson, G, Herriotts, P, Malcolm, L, et al. The use of virtual reality and physical tools in the development and validation of ease of entry and exit in passenger vehicles. Applied Ergonomics, 2015, 48, 240-251. https://doi.org/10.1016/j.apergo.2014.12.007

[McLaren 2022] McLaren, R, Chaudhary, S, Rashid, U, et al. Reliability of the triangle completion test in the real-world and in virtual reality. Frontiers in Human Neuroscience, 2022. 16. https://doi.org/10.3389/fnhum.2022.945953

[Morosi 2021] Morosi F, Caruso G. Configuring a VR simulator for the evaluation of advanced human–machine interfaces for hydraulic excavators. Virtual Reality. 2022, 26, 3, 801 – 816. https://doi.org/10.1007/s10055-021-00598-z

[Nespoli 2010] Nespoli C, Ditali S. Human error probability estimation for process risk assessment with emphasis on control room operations. Chemical Engineering Transactions, 2010, 19, 219-224. https://doi.org/10.3303/CET1019036

[Russ 2014] Russ AL, Zillich AJ, Melton BL, et al. Applying human factors principles to alert design increases efficiency and reduces prescribing errors in a scenario-based simulation. Journal of the American Medical Informatics Association: JAMIA. 2014, 21, e2, 287-296. https://doi.org/10.1136/amiajnl-2013-002045

[Shaluff 2008] Shaluf IM. Technological disaster stages and management. Disaster Prevention and Management: An International Journal. 2008, 17, 1, 114-126. https://doi.org/10.1108/09653560810855928

[Thompson 2020] Thompson M, Falco J. Leveraging technology to minimize operational error and hazards—Rise of the operator 2.0. Process Safety Progress. 2020, 39, 1. https://doi.org/10.1002/prs.12078

[Yang 2007] Yang CW, Lin CJ, Jou YT, et al. A review of current human reliability assessment methods utilized in high hazard human-system interface design. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Springer Verlag; 2007, 4562 LNAI, 212-221. https://doi.org/10.1007/978-3-540-73331-7_23

CONTACTS:

Ing. Lubos Kotek, Ph.D.
Brno University of Technology,
Dept. of Production Systems and Virtual Reality,
Antoninska 548/1, Brno, 601 90, Czechia
+420 54114 2391, kotek.l@fme.vutbr.cz, https://www.vut.cz/en/