AR/VR in Digital Learning: Influence, Opportunities and Risks' Mitigation

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Abstract. The paper discusses AR/VR/MR/XR technologies in learning namely their influence/ opportunity and risks' mitigation. Main aspects are as follows: methodology (factors influencing a student's cybersickness in AR/VR/MR/XR, the improved model of the cognitive activity in synthetic learning environment). It has been developed the technique and ICT to study psychophysiological changes in normal and stressed conditions. The experimentation results demonstrated that decrease in myocardial tension index under cognitive performance conditions in immersive activity over time of observation was more significant and this fact could be accounted in measurement of influence of the synthetic environment on students, as well as the technique to measure AR/VR/MR influence. The technique proposed by the authors is based on modified ICT and used in previous research: to assess influence of AR/VR/MR/XR as changes of short cognitive/perceptual tests (3 minutes before the work and afterwards) with registration of physiological indices informative in our research.

Keywords: ICT, synthetic learning environment, AR/VR/MR, cybersickness.

1 Introduction

Transformational effects created by information and communication technologies (ICT) in various fields of activity attract the attention of researchers because of changes in skills needed [1]. The dynamics of this sector depend on global challenges and broader trends that determine the long-term priorities of science and technology in the 4th Industrial Revolution [2]. One can highlight current trends in (1) *technology*: development of 3D modeling tools for biomedical engineering as a life support technology; creation of effective forms of visualization of information, content and knowledge as technologies of knowledge engineering; (2) *content industry*: the emergence of additional media products in the form of games, virtual realities (VR) and their integration with other media products and social networks through the creation of common stories as a convergence of content delivery models [3]. Note that converging nano, bio-, info- and cognitive technologies create a qualitatively new environment for human life [4]. Thus, due to the development of advanced algorithms and programs for processing, storage and transmission of images of various nature in the near future is expected to increase the efficiency of virtual scene technology and augmented reality (AR), three-dimensional (3D) modeling, in particular for biomedical engineering [5]. As a result of the technological evolution of AR (from VR helmets in the 1970s, AR displays and the first mobile AR applications in the 1990s to "smart" AR glasses today), the preconditions for the use of AR technologies for virtual training of doctors and surgeons have been created [6]. All the necessary information for operations - reference and received in the process of monitoring the condition (from sensors, video cameras) - AR technology will "collect" in a single image, adapted to the rapid perception and learning [7]. That created conditions for a significant improvement in the quality of professional activity for the near future, including mobile [8]. However, the main obstacle predicted by experts will be the lack of specialists, both relevant professional skills, in particular, and relevant digital competencies in general, as well as an appropriate functional state to perform learning as a type of operator work [9]. Another drawback of extended reality technologies is the insufficient understanding of the psychophysiological "cost" of activity in the virtual environment [10] due to insufficient knowledge of the characteristics of human consciousness in a synthetic environment [11] and possible cybersickness [12]. The latter has been researched and characterized in VR for decades, but we don’t know as much about the extent it affects users of AR/VR/MR/XR technologies. Typically, VR users experience more symptoms on the disorientation to nausea end of the scale, whereas AR users are more likely to experience headaches and eyestrain [13]. While these symptoms may not sound debilitating, when AR headsets are used for extended periods of time, these symptoms can have a significant impact and, as indicated by a recent study, be as severe as those associated with VR exposure.

*Purpose***.** To develop the model of risks related to AR/VR/MR/XR technologies in learning, as well as ICT structure and technique to study influence of these technologies at the learner performance and cybersickness.

2 Methodology

The life cycle of technologies, innovative technological products and services will only accelerate. In such conditions it is natural that scientists connect their hopes for creation of the positive integrated reality under conditions of convergence of physical and virtual learning environments. In these conditions, the role of research and development in the field of educational applications of ICT, in particular in general secondary education, remains extremely important. Corporate learning has pioneered such applications, drawing on best practices in VR and AR, artificial intelligence, including the use of chat bots, knowledge bases, including video content creation, micro-learning and mobile learning. These processes push the evolution of tools, forms and methods of teaching in general education as well.

We adhere to the opinion that the potential of the information and educational environment saturated with digital technologies, first of all, should be considered from the standpoint of the development of cognitive activity of learning subjects. If students learn information images, including real natural phenomena and processes, through experimentation with various digital tools and technologies (simulations, computer simulations, virtual and augmented reality, etc.), it will provide creative activity in an integrated (real and virtual) learning environment (including social networks), will affect the cognitive motivation of students, will contribute to the formation of appropriate digital competencies [14].

An important role in identifying areas for possible transformation of the education system is shared access to new digital technologies. According to world experts, the tools of virtual reality VR, augmented reality AR and augmented virtuality AV, mixed MR and extended reality XR (the latter includes all previous ones as well) are developing at the highest rate. The fourth industrial revolution is accompanied by the transition of production and, consequently, education in a synthetic environment of activity (both production and training). Education reform requires the accelerated implementation of augmented reality tools into the educational process, as well as the preparation of future employees to interact with artificial intelligence systems, as well as robotic systems.

The difference between these terms and means is that they are different combinations of real (RR) and virtual (VR) reality, forming variants of an immersive learning environment in which perception is the result of a synthesis of consciousness and feeling [15, p.16]. The most widespread over time from this spectrum are augmented (AR), virtual (VR), mixed (MR) and extended (XR) realities, for which the following types are distinguished:

- supplemented - market-oriented AR, location-based AR, overlay-based AR, projection-based AR; all these types can be used in the educational process [16];
- virtual - non-immersive VR, full immersive VR, shared VR, web VR;
- mixed - options for combining real, augmented reality, augmented virtuality and virtual reality.

Augmented reality includes the whole spectrum, from "complete real" to "complete virtual" in the concept of the continuum of reality-virtuality, proposed by Paul Milgram.

With the development of technical means of virtualization of reality and means of registration of indicators of human sensory systems and the impact on them there is a specialization and separation of new types of immersive environments. For example, SR (substitutional reality), 360 virtual reality (or 360 VR, which allows to observe the object from any angle), etc. It can be expected that the range of synthetic "realities" will further expand, accounting the possible relationships of human sensory systems, cognitive models of activity and real reality [9].

2.1 Factors influencing a student's cybersickness in AR/VR/MR/XR

It is important that the synthetic environment is not natural for humans, and its impact on his/her mental and physiological processes remains insufficiently studied. Until now, among the factors influencing the synthetic environment with different forms of virtualization on a person and his health, it is proposed to distinguish the following:

1) *personal*: *internal* (inherent in man) - hereditary, gender, age, ethnic; *physiological* - interpupillary distance, flicker fusion frequency threshold, postural stability, strength and mobility of nervous processes, plasticity, cardiovascular system, vestibular apparatus; *mental* - consciousness, cognitive features, spatial operations, thinking; *health* - diseases, disorders of the visual system;

2) *technological*: optical factors; reflection factors; factors related to spatial tracking; sound factors; factors related to the form factor;

3) *operational* – adaptation, the degree of control, head movements, general visual (other sensors, in addition) flow, speed linear and rotational acceleration, speed of self-movement, density and height of the visual scene above the terrain, brightness level, vection (illusion of self-movement), duration, cognitive workload.

The model of influencing factors demonstrates their complex (or even systemic) nature (Fig.1).

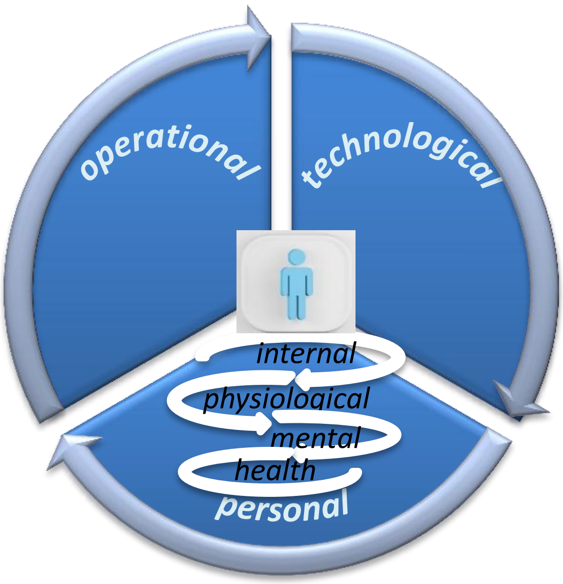

Fig.1. Factors influencing the synthetic environment

For learning, the most significant factors are that relate to the person features/abilities and operational ones.

There is increasing interest in determining any risks of using such technology and any aftereffect from exposure. But the duration of the aftereffects from virtual environment (VE) exposure are not well studied to date even after 20-years study [17]. Head-mounted display manufacturers provide general usage guidance, but this is *ad hoc* and there is limited recent evidence comparing early virtual environment studies with experiences from modern head-mounted displays. The primary objective of the study [18] was to explore response activation and inhibition after participants experienced a typical virtual environment in a head-mounted display. The evidence of participant fatigue in the reaction time tests was found. This work confirms safe use of virtual reality experiences in modern head-mounted displays for short duration exposures (15 min) and identifies issues with reaction time testing that are in need of further investigation. Duration of VR activity in many researches are limited by 15-45 minutes. In modern devices (f.e., Oculus Glasses) it is recommended the time of take at least a 10 to 15 minute break every 30 minutes, independently on age, sex, mental health level etc.

But there is only a few studies that aimed to assess the physiological “cost” of cognitive work in VR. The investigation of VR-induced aftereffects on various basic cognitive abilities and its relationship with cybersickness. Previous studies suggest an adverse effect of VR exposure on simple reaction times. Aftereffects on other basic cognitive abilities have rarely been studied. The authors propose a general aftereffect of VR exposure on reaction times that is only slightly related to subjective degrees of cybersickness. Taken together, however, usage of VR systems, even if inducing moderate levels of cybersickness, leads only to minor decrements of cognitive performance [19]. The question aroused in relation to day-to-day stability-instability of cognitive tasks performance: was this characteristic of only selected professionals or our findings had more general nature for people working with digital technologies? Future psychophysiological VR-induced aftereffects needs to be studied in relation to age, experience and prolonged (cumulative) usage of learning/training/work with VR.

As it is known, virtual reality technologies make learning more visual, enable trainees to be activated, and more fully engage them in the learning process. These technologies facilitate and simplify the collaboration of people who are at a distance, who can meet with the help of augmented reality, prepare joint documents, lead projects and perform many other work almost as effectively as with personal contact in the real world. Teachers and students have the opportunity to use virtual laboratories to study the world around them, develop skills, as well as to demonstrate their development and automated assessment [20].

Cognitive activity in VR is the brightest manifestation of the immersive environment for education/training. Virtual Reality glasses, helmets, 360° panoramic cameras and screens, as well as CAVEs give new opportunity for learning, and have some specific features in comparison with more traditional digital devices including computers:

- If in the real world the user interacts with the digital world through a "window“ (computers, tablets and mobile gadgets) observing what is happening "from the outside“, "immersion" is the condition in which the user loses awareness of the facts actually occurring in an artificial world.
- If in the real world the user involves almost only vision (other sensors are not involved or they supply non-observational information), in “immersion”, the user experiences the virtual world with involved his/her senses and is able to interact with the virtual environment.

- Sensory useful (target) load approaches 100% and requires 100% attention and concentration, regardless of the significance of the task. Sensory "hunger" (with monotonous operator activity) can be replaced by sensory exhaustion.

The question is what could be VR/AR/MR consequences for health ? How safe are virtual reality technologies for human health? The long-term consequences of using these technical means are not yet clear. But it is already obvious that they are invading the work of the human body. And we are talking not only about the curvature of the spine due to the prolonged wearing of a heavy device on the head, but also about the impact on the user's eyes. The headset forms a wide field of image; it is a rather complex device that interferes with the normal operation of the visual apparatus. A systematic study of the impact of immersions in virtual reality on human health in general and on his mental health, in particular, is still an open question [21]. Medical and physiological studies over the past quarter century have shown [22] that immersing a person in a specially designed virtual reality can significantly affect his/her mental health. It can help in the treatment of depression, in the elimination of alcohol dependence, in the treatment of anorexia and other mental disorders. However, all these studies are still quite fragmented, and the proposed methods require a qualified psychotherapist to conduct them, which is not applicable in terms of education and training [23].

Further research of the problem should focus on the detailed development of types of threats to participants in the educational process, as well as methods of counteraction. A special point should be the issue of resistance to cyber-hazards, which can use the experience of training operators of the emergent industries, primarily diagnosing the current state of the person and necessary adjustments in order to optimize its activities.

2.2 Model of the cognitive activity in synthetic learning environment

As it was stated [24], VR/AR/MR/XR are the brightest manifestation of the immersive environment for education/training, and have some specific features in comparison with more traditional networks/devices, and the object of activity (mental) is not external in relation to the human, but internal one. The model of the cognitive work (P. Anokhin’s model of the activity functional system that has been developed by authors for cognitive activity) can be specified for the case of VR/AR, where activation of the sensory (affector) inputs (Fig.2) happen not so from the outer environment, as from the *Virtual Act Program* without activating the *Act Program* mechanism (as in physical activity). In other words, the chain “*Act acceptor – Act program – Act – Object – Result*” in traditional activity transforms into the chain “*Act acceptor – Virtual act program – Cognitive object – Cognitive result*”.

The most important feature of such a process is that *all* system elements and their interactions are part of the human organism, i.e., its internal environment, in contrast with physical (or miksted) activity, where its object is located outside the organism and activity takes place in whole or in part of the external environment. We believe, that this model can explain, why such regulation can deplete and imbalance the body:

Act Program works in coordination with the *Act Acceptor* and *Substratum* needed for the normal life and activity. But lack of the signals from the *Act Program* cannot activate the general feedback from activity, only simulating it at the neurological level [24, p.352].

Another difference is influence of the *Virtual act program* on the *Decision making* block, because both blocks and the *Cognitive objects* are parts of the same cognititve process. Besides, the *Virtual act program* can influence on the *Afferent inputs* activating sensors participated in the particular cognitive activity according to the work task.

As a result, all neurophysiological subsystems (blocks in the schema) are more active the more immersive is the task performance. That is why the control of operational parameters in AR/VR/MR/XR is so important to mitigate cybersickness, especially in learning process that can take hours of a human activity, in general [25].

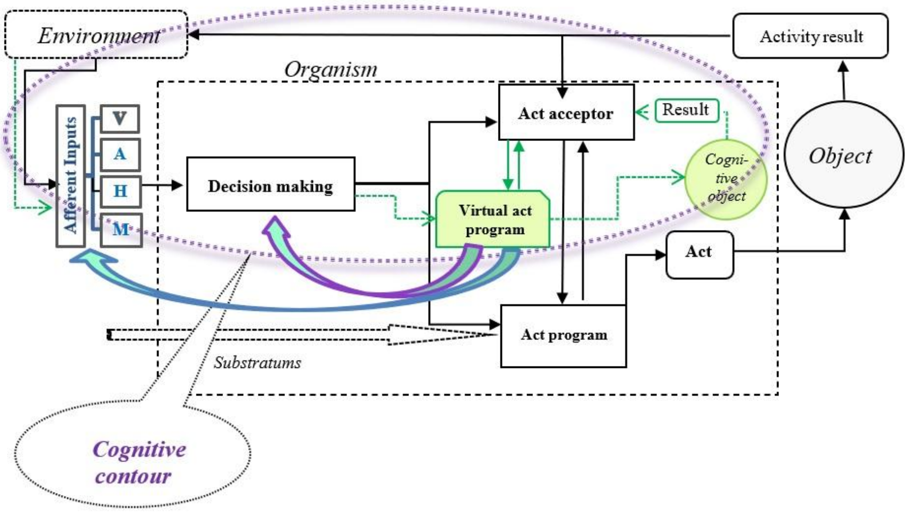

Fig.2. Theoretical scheme of the functional system of learning activity in VR/AR/MR/XR, where the cognitive contour is associated with the "internal" activity (modified from [25]). Note: "Afferent Inputs" are: V -visual, A - audial, H – haptic, M – motion.

3 Results and Discussion

To date, it was confirmed that changes in efficiency of immersive cognitive activity with digital units had strongly individual nature in day-to-day performance of the same complexity that could be explained by the internal (physiological) and external influences on a human.This notion has been confirmed by the high relationship between indicators of test performance (rate and reliability of problem solving) and physiological indices. Only the simultaneous activation of both paths (energy and information) provides higher level of optimization of educational/training capacity - quality education [9]. An unbalanced path and thus the strain of regulatory mechanisms of adaptation may be the cause of functional impairment and eventually the case of violations of students' health. It has been found that:

- Work with computer in "classroom" can blur attention because of low workload of non-active sensors and their ability to be affected by unplanned external signals.
- Higher workload of all or many sensors can be accompanied by more significant increase of adverse changes in physiological support of activity.
- Because involvement of a user into VR activity is very high (motivation, sensors workload), information environment coincides with cognitive one, but the latter is significantly *individual*.

It should be noted that the psychological/ psychophysiological aspects of cybersecurity, inherent in the human factor in human-machine systems, can be significantly enhanced in the synthetic environment [26], which is currently an unexplored area in general and in education in particular [27]. On the other hand, the use of models for predicting the effectiveness of learning (included in adaptive systems) allows to assess and predict the effectiveness of augmented and virtual reality for synthetic learning environment [28] and human integration in general [29], expecially accounting modern trends in the ICT evolution [30]. To realize such an approach, it is necessary to apply appropriate ICT that provides methodical maintenance of cybersickness risks' measurement and assessment, test generation and control, data storing, data analysis and necessary service for researchers.

3.1 Method

In our previous research the cybersickness has been modeling in experimental study of cognitive activity with measuring of its psychophysiological response to a human focused (with high motivation and without external disturbances) cognitive test performance with and without time pressure [24]. In addition, the technique included measurement of electropuncture diagnostics' indices by Nakatani (24 regular points and 3 stress' points), as well measurement of lipid metabolism using sweat collection before and after the test session for each subject. Subjects included 28 males of 18-40 year old.

The experiments differed by the test (permutation of random non-repeating digits from 0 to 9 in ascending order) workload: training E1 (60 min); E5 - free rate ("«auto-pace"), and E6 - fixed rate calculated as average by results of the appropriate test performance in E1. The E6 could be evaluated as the model of immersive cognitive test performance (high motivation and time "pressure", because according to our previous study the individually "average" rate of task exposure was more difficult than twice as slow or as fast). Duration of the test performance session was 3-hours long.

As indices of physiological "cost" of activity and the human state we registered a heart rate HR and blood pressure (systolic BPs, diastolic BPd) by means of the cardiomonitor "Solveig". The indices HR, BPs and BPd we registered during 10 min prior to the tests beginning (index "0") and 10 min after finishing (relaxation), as well as every 5 min during the test activity [24, p.352]. Clear changes appeared in physiological response: increase of the level of low density lipids, energy balance (Electropuncture), heart rate (myocardial tension index after R. Baevsky) and blood pressure. The data received have demonstrated quite individual nature of changes in time.

To study that phenomenon, we carried out the similar experiments, but with another analysis of data stored. The method of computer data processing was aimed to analyse physiological changes at different phases of test performance that would correspond phases of a human performance after Egorov&Zagriadskii. Because diastolic blood pressure has been revealed as the most informative (sensitive to the cognitive workload) physiological index, BPd was averaged for consequent 20-minutes intervals and was represented at the "phase plane" (vector diagram where one point corresponded to one 20-minutes interval). Vizualization of the physiological changes on the phase plane (Fig.3) has confirmed that first 20…40 minutes of tests performance are accompanied by the higher systolic pressure and/or at the end of the performance (this corresponds the phase of the "end gust effect" after Egorov&Zagriadskii). But the first phase could have individual features from viewpoint of time structure, if to analyze it in more detailed way (f.e., minut-by-minut or in 5-minute intervals) that could be significant accounting that VR/AR activity longer 40 minutes were not studied, and "normal" academic hour is 45 minutes.

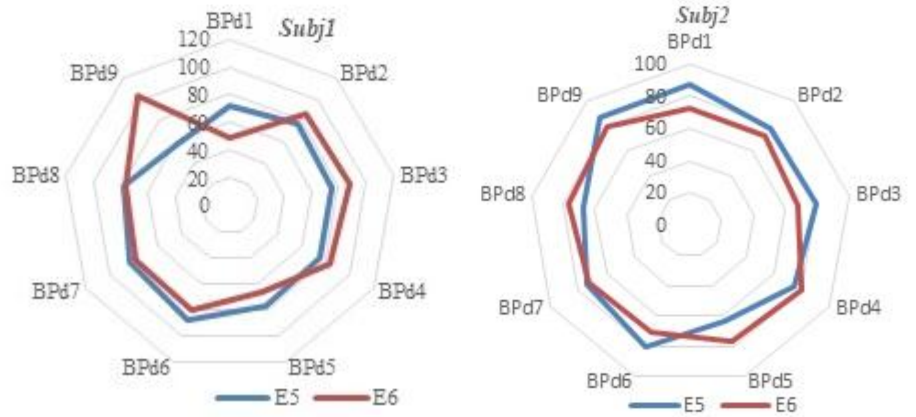

Fig.3. Physiological (blood pressure) changes on the phase plane in two subjects.

The next step of analysis was carried out to study myocardial tension index's variation (after R. Baevsky) at the 1st 45-minutes interval of test performance (that could be considered as equivalent of the academic hour) with 5-minut consequent phases. We compared physiological workload in experiments E5 and E6 again. If in previous analysis with 20-minutes phases some individual differences were registered, it has been revealed a clear trend in subjects' myocardial tension between experiments E5 and E6: the higher level of tension under "harder" conditions (experiment with time "pressure") during first 20 minutes (four phases) of test performance (Fig.4).

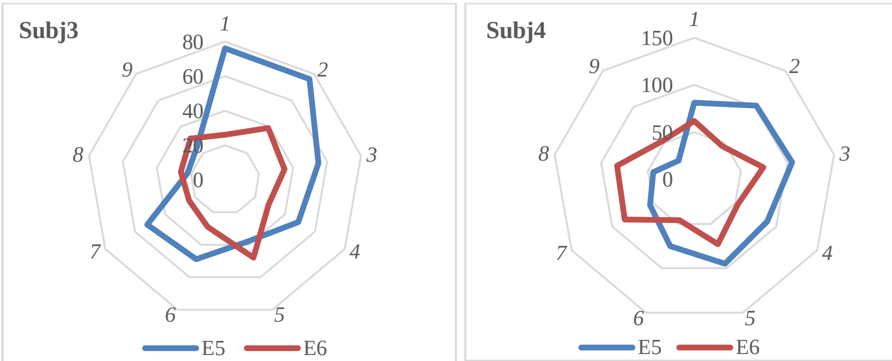

Fig.4. Physiological (myocardial tension index) changes on the 45-minut phase plane in two subjects.

In other words, decrease in myocardial tension index under cognitive performance conditions in immersive activity over time of observation was more significant and this fact could be accounted in measurement of influence of the synthetic environment on students.

3.2 The technique to measure AR/VR/MR influence

The main difficulty in measuring influence of AR/VR/MR/XR on a human cognitive performance is to differentiate psychophysiological effects of usual cognitive workload and synthetic "realities", especially in the education process. This is a general problem of assessment of Associations Between Digital Technology Engagement and Mental Health/Efficiency Problems. Even more, according to the study [31], there is no evidence that associations between adolescents' digital technology engagement and mental health problems have increased over. These results are based on observation of 430,561 participants (adolescents) over period 1991-2019 in the United States and United Kingdom. But that study did not take into account that everyday environment of todays' young people is digital with related specifics. That is why measurement of possible influence of the synthetic environment should be provided by means the same or similar digital tools.

The technique proposed by the article authors is based on modified ICT described above and used in our research. But we plan to assess influence of AR/VR/MR/XR as changes of short cognitive/perceptual tests (3 minutes before the work and afterwords) with registration of physiological indices informative in our research.

Thest performance is controlled by appropriate ICT in on-line or off-line modes.

4 Concluding Remarks and Future Work

Augmented (AR), virtual (VR), mixed (MR) and extended (XR) realities become the part of a human everyday life in all areas of life and activity. It is important that the synthetic environment is not natural for humans, and its impact on his/her mental and physiological processes remains insufficiently studied. Factors influencing a student's cybersickness in AR/VR/MR/XR can be considered as: *personal* (internal, inherent in human; physiological; mental; health); *technological* (technical means, ergonomic); *operational* (adaptation, the degree of control, head movements, general visual flow, linear and rotational acceleration, speed of self-movement, brightness level, vection (illusion of self-movement, duration, cognitive workload).

It has been developed the theoretical scheme of the functional system (TFS) of learning activity as a further development of the TFS model for learning. It was highlighted that all neurophysiological subsystems are more active the more immersive is the task performance. That was why the control of operational parameters in AR/VR/MR/XR was so important to mitigate cybersickness, especially in learning process that could take hours of a human activity, in general.

Decrease in physiological indices (myocardial tension index and blood pressure) under cognitive performance conditions has been revealed in immersive activity over time of observation, and it was more significant than in "normal" conditions. Those results were confirmed by use of the technique "phase plane" proposed by authors.

That fact could be accounted in measurement of influence of the synthetic environment on students. Application of developed ICT provides methodical maintenance of cybersickness risks' measurement and assessment, test generation and control, data storing, data analysis and necessary service for researchers. Respectively, it was developed the technique to assess influence of AR/VR/MR/XR as changes of short cognitive/perceptual tests (3 minutes before the work and afterwords) with registration of informative physiological indices. Future work is planned to provide evidence of such a technique efficiency for learning.

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