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LIMITING FACTORS FOR THE USE OF VR TECHNOLOGY IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

Abstract: *This paper presents the current limiting factors in the application of virtual reality (VR) in the training process for safety and health at work. Although VR offers significant advantages in occupational safety and health training, such as the simulation of hazardous situations and the enhancement of interactive learning, several factors may limit its widespread implementation. The main limiting factors include technical barriers and high implementation costs. Additionally, the need for specialized equipment, as well as the psychological effects on workers during training, can pose constraints on its application. Furthermore, various organizational factors, along with the lack of qualified personnel for VR content development, represent additional limitations to its implementation. The paper analyzes these limitations and proposes possible solutions to overcome them, aiming to enable a broader use of VR technology in occupational safety and health training.*

Keywords: virtual reality (VR) technology, limiting factors, training for safety and health work

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INTRODUCTION

The process of training employees for safe and healthy work represents a fundamental step within the occupational health and safety system in every workplace. During this process, workers must become thoroughly familiar with all identified hazards and harmful factors present in the work environment, as well as with the established risk levels and safety rules that have been implemented to manage the recognized risks (Nikolić et al., 2017). In addition to providing information about hazards, the training process also includes education on ergonomic principles, proper use of work equipment and tools, safe movement within the workspace, and correct methods of load handling. The goal of the training process is to equip workers with the necessary knowledge and skills that enable the safe performance of work tasks, while minimizing the risk of injuries and damage (Nikolić et al., 2018). Although complete elimination of errors in the work process is impossible, the likelihood of their occurrence can be significantly reduced through adequate and effective training, that is, by systematically educating workers. Research has shown that effective safety training not only increases employees' ability to recognize hazards but also reduces the frequency of unsafe behaviour, while simultaneously improving the safe handling of work tools and equipment. Therefore, training programs must be specifically tailored to the conditions of each individual workplace, taking into account the specific characteristics of work processes, tools, equipment, and the working environment. Effective training programs for safe and healthy work represent one of the most direct methods for reducing the frequency of human errors, thereby achieving not only an increased level of safety but also significant financial savings through the prevention of accidents and the reduction of treatment costs, compensation claims, and work stoppages (Neville, 1998). A systematic approach to training and the continuous development of employees, combined with the evaluation of acquired knowledge and skills, are key factors in building a lasting culture of occupational safety. The traditional approach to training for safe and healthy work includes both theoretical and practical components. The effectiveness of knowledge acquisition in the theoretical segment largely depends on the expertise, skills, and pedagogical competencies of the instructors. The practical component of training is carried out directly in the workplace, often as an integral part of the preparation for specific work tasks. Hands-on training and demonstrations in real-world conditions have proven to be particularly effective in conveying key safety principles, enhancing hazard awareness, and developing safe work practices. In addition to the traditional approach to training, it is now also possible to incorporate modern technologies into this process. The technology that stands out and demonstrates the best results in training for safe and healthy work is virtual reality (VR). The use of virtual reality technology in occupational safety training offers numerous advantages, such as the simulation of hazardous situations without real risk and increased participant engagement. However, the application of VR also has certain limitations, such as constraints related to the effectiveness of virtual simulations in accurately reproducing all aspects of the real work environment, including complex sensory information such as touch, smell, and the weight of loads. The absence of these elements may reduce the effectiveness of transferring practical skills necessary for the safe performance of work tasks. Additionally, access to VR technology can be limited by the high costs of acquisition, maintenance, and equipment updates, which poses a significant barrier, especially for small and medium-sized enterprises. The technical complexity of using VR systems requires additional resources for training instructors and users, further complicating implementation. Furthermore, some users may experience physiological reactions, such as nausea or fatigue due to prolonged use of virtual devices (a phenomenon known as "cybersickness"), which can negatively impact the quality of learning. According to research, although VR can enhance theoretical knowledge and hazard recognition, there are limitations in transferring acquired skills to the real work environment, especially concerning motor skills and responses in unexpected situations.

This paper aims to provide a detailed overview of the current limitations in the use of VR technology for training in safe and healthy work practices.

APPLICATION OF VR IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

In today's context of widespread use of information technologies, these tools are increasingly being applied across various forms of training, including occupational safety and health. Virtual reality (VR) is being utilized in training processes for safe and healthy work, particularly in high-risk industries such as construction, mining, and energy (Grassini & Laumann, 2020). The application of VR technology enables training participants (Figure 1) to gain practical experience in simulated, yet controlled conditions, without being exposed to real hazards.

Figure 1. *Trainee undergoing occupational safety and health training using VR technology (source: author's own)*

In this way, hazard awareness is enhanced, safe behaviour skills are developed, and preparedness for emergency response is improved (Hendrix & Johannsen, 2008). The most common models of VR application in training include desktop simulations, game-based training, and integration with Building Information Modelling (BIM) software. Desktop solutions enable the visualization of work environments (Pedro et al., 2020), while VR-based games help simplify complex tasks and strengthen user interactivity (Wang et al., 2018). BIM-integrated systems offer additional capabilities for simulating construction processes and improving decision-making with the aim of reducing risks on construction sites (Chen et al., 2022; Park et al., 2013). VR has also proven to be extremely useful in the mining industry, where training based on virtual simulations improves miners' preparedness for various scenarios and emergency situations (Grabowski & Jankowski, 2015; Duarte et al., 2019). In addition to enhancing safety, VR contributes to better visualization of complex information and ergonomic challenges, as well as to the optimization of equipment design (Foster & Burton, 2004). Flexibility, repeatability of training, mobility, and relatively lower operational costs make VR technology an attractive option for enhancing occupational safety and health training systems.

LIMITATIONS IN THE APPLICATION OF VR TECHNOLOGY IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

Despite its numerous advantages, challenges remain – particularly regarding the high costs of content development and the need for continuous software updates. Although hardware advancements in VR technology are progressing, software development aimed at safety training still lags behind, which poses a limitation to the broader application of this technology. Creating high-quality and relevant training content requires significant resources and the involvement of competent educators. Technical difficulties, physical discomforts such as fatigue, nausea, and disorientation, psychosocial factors such as anxiety or feelings of isolation, as well as legal ambiguities regarding liability and regulation, represent key barriers that can limit the effective use of this technology. Additionally, there is a risk that inadequately designed VR scenarios may generate new forms of hazards for users, which necessitates careful planning, standardization, and continuous improvement of VR training programs. Upon analysis of previous research on the limitations of virtual technology usage, all limitations can be classified into two groups (Figure 2): limitations arising from the direct impact of virtual technology on humans and technical-administrative limitations in the application of VR technology.

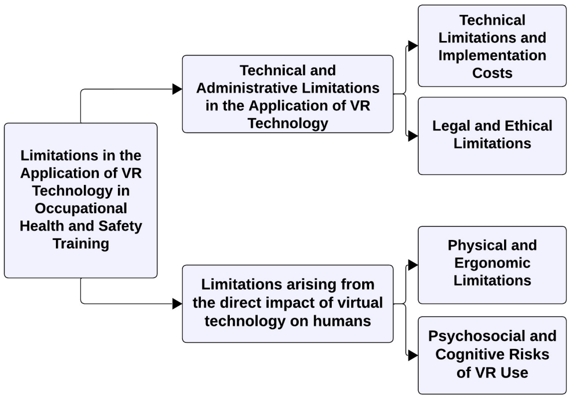

Figure 2. *Limitations in the application of VR technology in occupational health and safety training*

Technical Limitations and Implementation Costs

The application of virtual reality (VR) technology in training processes requires significant initial investments in both hardware and software infrastructure. High-quality head-mounted display (HMD) devices demand high-performance graphics processors, precise motion-tracking sensors, as well as adequate network infrastructure capable of supporting real-time processing and transmission of large volumes of data (Bérastégui, 2024). The costs of acquiring high-end equipment, along with additional expenses for regular maintenance and software updates, often exceed the financial capabilities of small and medium-sized organizations. In addition to the high cost of basic equipment, issues of technical compatibility between different VR platforms and devices also arise, making it difficult to standardize and scale VR training programs. Software packages developed for specific industrial applications typically require expensive licenses, while the need for content localization and customization generates additional costs. Technical characteristics, such as image transmission latency, limited display resolution, and the need for physical space sufficient for safe user movement, further complicate implementation – especially in facilities not designed for the use of such technologies, which require additional adaptation. Additionally, technical maintenance of VR systems poses an ongoing challenge, as hardware failures can directly cause interruptions in training and reduce its overall quality. Due to all these factors, VR solutions are currently significantly more accessible to organizations with substantial investment capacity, while remaining less accessible to a broader range of users.

Within the scope of technical limitations, the quality of VR presentation content must also be mentioned. This necessitates the involvement of qualified educators who will be engaged in creating appropriate content. VR presentation materials should comprehensively familiarize trainees with all aspects of the workplace required for safe work performance. This primarily refers to familiarizing trainees with all existing hazards and harmful factors, the prescribed measures for their avoidance and mitigation, as well as the procedures for responding to the occurrence of risky situations.

Physical and Ergonomic Limitations

Prolonged use of virtual reality devices, especially head-mounted display (HMD) systems, is associated with various physical and ergonomic risks. The weight of the device itself, combined with often inadequately designed ergonomics, can cause pain in the neck, shoulders, and upper back, as well as contribute to the development of musculoskeletal disorders in users (Souchet et al., 2023). Additionally, due to the close proximity of the screen to the eyes, users often experience visual fatigue, difficulty focusing, blurred vision, and, according to some studies, a potential increased risk of developing myopia (Turnbull & Phillips, 2017; Németh et al., 2021). One of the most serious challenges related to the physical health of users is the occurrence of the so-called cybersickness, a phenomenon that includes symptoms such as nausea, dizziness, disorientation, headaches, and general discomfort (Stanney et al., 2020; Bérastégui, 2024). Research (Vajkić et al., 2025) shows that older people are more prone to the effects of cybernetic illness when using VR technology. Cybersickness occurs due to a mismatch between the visual information received through the VR system and the proprioceptive and vestibular information coming from the body's internal sensors, leading to confusion in sensory perception processing. According to available research, it is estimated that between 30% and even 90% of users may experience some form of cybersickness, depending on the characteristics of the VR simulation, the duration of exposure, and the technical specifications of the equipment used (Caserman et al., 2021; Kim et al., 2021). Prolonged exposure to VR environments can lead not only to immediate symptoms but also to longer-lasting effects, such as disturbances in spatial perception, reduced stability, and a sense of insecurity, which may persist for several days after using the VR system (Bérastégui, 2024).

Psychosocial and Cognitive Risks Associated with the Use of VR

The application of virtual reality (VR) technology in the work environment and training processes may generate significant psychosocial and cognitive risks that can negatively impact workers' well-being and overall performance. One of the frequently reported issues is the sensation of isolation experienced by users during or following VR sessions. The limited opportunity for physical interaction with colleagues and the reduction in direct social communication may contribute to elevated stress levels, feelings of loneliness, emotional exhaustion, and a decline in motivation (Biener et al., 2022). In addition to psychosocial challenges, VR environments often require users to process a large volume of visual and auditory information within a short period of time. This increased cognitive load can result in reduced attention, accelerated mental fatigue, and a heightened risk of errors or accidents occurring in real-world environments following the completion of training (Filho et al., 2018; Zielasko et al., 2019). A particular challenge is the phenomenon of technostress, which arises as a result of rapid technological development and the need for constant adaptation to new systems and software. Technostress is increasingly being identified among workers exposed to VR technologies and may manifest through symptoms such as anxiety, frustration, a sense of insecurity regarding one's own abilities, and resistance to technological innovations (Bondanini et al., 2020). Another significant risk is the potential development of addiction to VR technology. Excessive use of VR environments, particularly in contexts characterized by a high level of immersion and user engagement, may lead to compulsive behaviour and difficulties in controlling usage. According to available studies, between 2% and 20% of users have shown signs of addiction to VR content, which further underscores the need for responsible planning and monitoring of VR technology usage (Barreda-Ángeles & Hartmann, 2022).

Legal and Ethical Challenges

One of the key challenges to the wider adoption of virtual reality (VR) technology is the lack of clear and comprehensive legal regulation that would address issues of privacy, data security, and liability in case of incidents. Although existing regulations, such as the General Data Protection Regulation (GDPR) in the European Union, provide a certain framework for the protection of personal information, they largely fail to cover the specificities arising from the use of VR technology, particularly with regard to the processing of biometric data collected through HMD devices (EU-OSHA, 2023). During the use of VR systems, sensitive information is collected, including users' kinematic fingerprints such as eye, head, and body movement patterns. Although technical in nature, these data can enable highly precise individual identification, thereby increasing the risk of privacy breaches and compromising workers' security (Spiegel, 2017). In addition to data protection concerns, VR environments raise new ethical challenges, including risks of cyberbullying, identity theft, and digital harassment. Virtual interactions through avatars, which are often inadequately regulated, may become venues for various forms of abuse and violations of users' dignity (Porta et al., 2024). Additionally, the issue of legal liability for injuries that may occur during VR sessions remains undefined. Traditional occupational health and safety laws are not fully adapted to the specificities of virtual work environments. It is often unclear who bears responsibility in cases of injuries caused by technical malfunctions, design flaws in VR programs, or inadequate simulation settings, highlighting the need for the development of new legal standards and guidelines to keep pace with the expansion of this technology.

RECOMMENDATIONS FOR OVERCOMING THE LIMITATIONS OF VR TECHNOLOGY APPLICATION IN OCCUPATIONAL SAFETY AND HEALTH TRAINING

Although the identified limitations in the application of virtual reality (VR) in occupational safety and health training present significant challenges, they are not insurmountable. Contemporary technological advancements, combined with appropriate strategic planning and institutional support, create opportunities for their substantial mitigation. Effective implementation of VR technology requires a multidisciplinary approach that involves coordinated activities at technical, organizational, educational, and regulatory levels. Based on the previously analyzed limitations, it is possible to identify a range of specific measures and recommendations that can contribute to reducing their impact and, in some cases, even completely eliminating them.

Recommendations for Overcoming Technical and Economic Limitations

To mitigate the high initial costs of implementing VR technology, the establishment of public-private partnerships is recommended, along with the adoption of shared ownership models for equipment among multiple organizations. The development of open-source software and modular VR systems can significantly reduce dependence on expensive, closed platforms. Furthermore, improving technical interoperability between different devices and systems would reduce integration costs and facilitate content standardization. Recommendations for enhancing the quality of VR content include additional training for educators responsible for developing VR training materials, as well as the involvement of multidisciplinary teams. The creation of such content should involve multidisciplinary experts, including specialists in occupational safety and health, as well as experts in andragogy. Occupational safety experts should be engaged in the analysis of the specific work environment to identify all hazards and harmful factors associated with the particular workplace, while andragogues should provide appropriate models for the presentation and transfer of information to the targeted users.

Measures to Reduce Physical and Ergonomic Risks

To mitigate physical discomfort such as fatigue and cybersickness, it is recommended to limit the duration of VR sessions and introduce regular breaks. The use of lighter and ergonomically designed HMD devices, as well as adaptation of simulations to the physical capabilities of users, can contribute to greater comfort and safety. Additionally, improving software algorithms to reduce latency and optimize display performance may alleviate symptoms of discomfort and disorientation.

Psychosocial Support and Cognitive Adaptation

To reduce psychosocial and cognitive risks, it is recommended to develop VR programs with a moderate intensity of information and the possibility of personalizing content complexity. Incorporating elements of social interaction and team collaboration within the VR environment can help alleviate feelings of isolation. Furthermore, it is important to provide psychological support to employees during the adaptation to VR technologies and to offer training for the development of digital competencies, thereby preventing technostress.

Guidelines for Overcoming Legal and Ethical Limitations

It is essential to develop specific legal frameworks and ethical guidelines concerning the use of VR in the workplace. This includes regulating the collection and processing of biometric data, defining liability in cases of injuries during VR training, and ensuring mechanisms for protecting users from digital harassment. Institutions and employers should collaborate with regulatory bodies and ethics experts to establish standards that safeguard the rights and safety of users.

CONCLUSION

The foundation for overcoming and mitigating the limitations of applying VR technology in occupational safety and health training lies in continuous monitoring and evaluation. This process enables the timely identification and resolution of potential issues, ensuring not only the improvement of the technical and functional aspects of VR systems but also the optimization of the training programs themselves. Through ongoing analysis of feedback from users, as well as experts in safety, ergonomics, and adult education, it is possible to detect and correct deficiencies in simulations, reduce the risk of physical discomfort or psychosocial issues, and enhance the overall training experience. Continuous monitoring allows for the detection of even the smallest technical errors or irregularities that could affect the quality of training, enabling their prompt and efficient correction, thereby ensuring optimal outcomes. Moreover, this approach contributes to the ongoing alignment of VR training programs with new standards, technologies, and labour market demands, making VR training increasingly relevant and beneficial for all stakeholders involved. Following the pace of technological advancement and the continuous need to improve occupational health and safety training, the potential offered by new technologies such as virtual reality (VR) should not be overlooked. The overarching goal of any occupational safety training is to reduce the likelihood of risk realization in the workplace, thereby decreasing the number of injuries and enhancing workers' well-being. To achieve this in occupational safety, it is essential to provide adequate training to all workers within the workplace. In any case, the possibility of improving training through the application of new technologies should not be disregarded, especially in work environments where employees face elevated levels of risk. Moreover, during the training process itself, it is crucial to avoid exposing workers to risks unless absolutely necessary. Furthermore, other advantages of VR-based training, such as flexibility, mobility, and easy reproducibility and repeatability, should also be utilized. The general conclusion is that the occupational safety specialist is the person responsible for selecting the appropriate training model, carefully considering both the advantages and disadvantages of traditional occupational safety training methods, as well as the benefits and limitations of new technologies.

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