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Analysis of the application of virtual reality technology for prevention of occupational risks

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The progressive lowering of the hardware resources necessary for the creation of virtual reality environments creates new opportunities for the application of this technology in the field of training in occupational hazards. Equipment like HTC Vive and Oculus Rift allow with a reduced budget to create experiences with an important level of realism, in addition to a very interesting interaction capabilities. The use of this technology allows to face the subjects of training to situations that in real life would have an excessive level of risk to be experienced in person. Therefore, virtual reality can bring an approach to situations of risk that would not be otherwise viable. This is especially relevant, because the emotional imprint that can mean experiencing a first-person danger situation can be used as a reinforcement tool for those critical concepts related to a particular occupational hazard. The present work will analyse the characteristics and potential benefits that the technology of virtual reality can contribute in the field of the prevention of occupational risks.

Keywords: virtual reality; occupational risks; prevention

Análisis de la aplicación de la tecnología de realidad virtual en la formación para la prevención de riesgos laborales

El progresivo abaratamiento de los recursos de hardware necesarios para la creación de entornos de realidad virtual, crea nuevas oportunidades para la aplicación de esta tecnología en el ámbito de la formación en riesgos laborales. Equipos como HTC Vive y Oculus Rift permiten con un presupuesto reducido crear experiencias de un nivel de realismo importante, además de unas capacidades de interacción con el entorno virtual bastante elevadas. La utilización de esta tecnología permite enfrentar a los sujetos objeto de entrenamiento a situaciones que en la vida real tendrían un nivel de riesgo excesivo para ser experimentadas de forma presencial. Por lo tanto, la realidad virtual puede aportar un acercamiento a las situaciones de riesgo que no sería viable de otra forma. Esto es especialmente relevante, porque la impronta emocional que puede significar el experimentar una situación de peligro en primera persona, se puede utilizar como instrumento de refuerzo de aquellos conceptos críticos relacionados con un determinado riesgo ocupacional. El presente trabajo analizará las características y los potenciales beneficios que la tecnología de realidad virtual puede aportar en el ámbito de la prevención de riesgos laborales.

Palabras clave: *realidad virtual; riesgos laborales; prevención*

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1. Introduction

Accidents can generate big financial and social loss with serious, hard and, sometimes, even irreparable consequences for people and companies. According to data provided by the Spanish Ministry of Labour and Immigration in 2015, there were 479.577 occupational accidents in Spain with medical leaves. This report, also shows that every three-and-a-half seconds, an European worker is forced to stay at home for at least three working days due to a labour accident (Estadística de Accidentes de Trabajo y Enfermedades Profesionales, 2015). In line with the magnitude of the problem, any initiative to improve the current situation will be of great interest. In addition, in this way, safety and prevention become an important topic to students, politics, citizens, companies and others.

Risk prevention and safety is aimed to ensure the physical and mental integrity of workers, offering an environment where the risks of an accident are eliminated or controlled, and the work conditions do not produce excessive worker effort. Safety should be thought since the conception and planning of a project, until its operation, providing an ideal working environment.

The first step in the prevention of occupational accidents is the competency to perceive danger. Workers should have qualified for executing job safely. With this aim, the most important tool of risk prevention is the safety training and so it is a mandatory and important theme in any workplace and in any graduate course. However, the current safety education system has limited effectiveness since it is not reaching their target audiences, and in some cases, not conducted at a scale commensurate with their importance. Therefore, it is important to try to upgrade the safety training tools, in order to make it better.

A recent debate also pointed the higher relation of workplace accidents and unsafe work practices of employees than unsafe working conditions (Mullen, 2004; Garavan & O´Brien, 2001). Unsafe behaviour should be viewed as a combination of organisational and social factors, which include both the human and technical aspects involved in the work. Therefore, it is necessary to try to understand the human safety behaviour and try to influence it.

An important point is to highlight that current technological developments such as Internet, “smart” environments, virtual reality (VR) and others affect not only the work, they bring new challenges to the safety of workers and opportunities to improve safety training. It is important to evaluate and try to improve the tools used for training, adapting these technologies and trying to use all of their possibilities, for example developing realistic training environments, reducing costs, showing the impact of a decision during the training, enabling warnings appropriately tailored to the situation and users’ characteristics. For instance, VR can fulfill many of these improvements; however, if VR environments and interactions are not designed and implemented properly, users have the risk of feeling frustrated and or even sick. For obtaining good results is critical, provide a human–centred design, considering previously studies and tests by the end-users. Immersive virtual reality also offers a learning environment without distractors and the possibility of personalizing the learning experience. In this context, we conceive safety as a promising domain for virtual reality applications because it is able to develop engaging learning experiences without exposing trainees to risky situations. VR technology can be used to enhance learning processes, being able to activate human senses, feelings, and emotions and to improve memory performance.

This paper analyses how virtual reality technology can be applied to prevention of occupational risks. Section 2 describes the main issues related to safety at work; at section 3, we describe technological advances related to virtual reality; then, at section 4, we identify how virtual reality could be used in safety training; finally, the last section presents conclusions and provides an outline of future works.

2. Safety at work

Wallace (2016) defined occupational health and safety in organisations as actions, behaviours and outcomes that employees deal with in almost all jobs to promote health and safety on co-workers, customers and the environment.

Classic occupational safety and accident prevention theories have traditionally blamed the human errors for most of occupational accidents and injuries. This old view of occupational safety opposes to the new vision where human errors are considered as a symptom and not a cause. So as mentioned by Wallace (2016) human error, just like the accident, demand an explanation. Recently, researchers have been debating that the workplace accidents used to be attributed more to unsafe practices of employees than to unsafe working condition. In this way, we want to highlight the importance of changing the focus to unsafe behaviours for improving safety performance.

The behaviour of a person is determined by the context in which he/she develops an activity. So, when thinking about behaviour and performance is necessary to consider the interaction between the person and her working environment. In order to investigate the human behaviour and its relation to accidents and human errors is important to observe individuals working during critical situations, taking account of performance, emotional and physiological levels. Besides analysing human behaviour in a critical situation, it is important to fill the gaps of safety knowledge, avoiding the “cognitive paralysis” in front of critical, stressed situation. This is possible through safety education.

Safety performance, i.e. employees’ behaviors that are intended to promote individual, organizational, environmental or societal well-being has four main components (Burke et. al, 2002) : (a) properly utilizing personal protective equipment; (b) engaging in work practices that reduce risk, including adherence to safety practices and procedures; (c) communicating health and safety information and (d) exercising employee rights and responsibilities. Lectures have been the most common and at the same time the least engaging methods of safety training, aiming to be predictive on safety performances and outcomes. It is already proved that these methods do not transfer to the workplace, do not last long term (Wallace, 2016) and are easily distractible.

A key to making safety training more engaging is to require participants to plan activity actions as opposite to a passive role. This learning-by-doing paradigm is considered the most efficient model for learning (Amokrane, Lourdeaux, & Burkhardt, 2008). This affirmation and model are totally aligned with the constructivism theory, which values the active presence of the learner for constructing the learning process.

Over the past decades, there has been a movement in the industry to improve work safety practices based on previous experiences. This happens based on the premise that personal experiences and memories strongly influence the perception of risk. A challenge faced today is to transfer the knowledge gained from past experience to citizens who may not have witnessed serious works incidents and as a result may fail to recognise the potential injury associated with the job.

In addition to well-designed procedures and well-trained staff wearing individual protection equipment, a number of human factors are crucial for safety behaviour. Risk perception (identification of hazards, subjective assessment of accident happening, associated risks and how concerned we are with the consequences), for example, can influence behaviour and vice versa. A distorted perception of risk may lead the worker to erroneously conclude that the likelihood of occurrence of an event is negligible when it is possible or likely, or the potential severity or injury is minor when the consequences could be fatal.

The ability to perceive risks varies among individuals and is a social and cultural construct affected by their beliefs, motivations, history and relations with other people. Usually, people

react according to their mental models of a potentially risky situation rather than to the real risk itself (Nedel et al., 2016). When a person thinks about the probability of an event to occur, they often rely on personal experience to draw conclusions. Also, they tend to underestimate risk associated with everyday activities and familiar situations. On the other hand, events that bring to mind a vivid emotional impact are often overestimated (Haluik, 2016)

3. Virtual Reality

The first attempt to adding depth to visual perception using a hardware device came around 1838 from Sir Charles Wheastone that designed a mirror stereoscope (Jerald, 2016). Since these first hardware developments, virtual reality technology has evolved to become almost a mainstream product avoiding high costs and solving cyber-sickness issues.

Users can be immersed in virtual environments by different technologies but the most affordable immersive technology is based on the head-mounted display concept (HMD), a visual display that is more or less rigidly attached to the head. In 1985, according to Jerald (2016), Scott Fisher developed the VIVED. It was the first commercially viable HMD and was built adding two displays coming from a pocket TV to a scuba diver's facemask. It showed that this type of visualization device could be produced at a relatively accessible price. The same project developed a new kind of glove that could be used in a simulation. In this way, the VR industry was born.

The potential of VR for training and education were quickly identified by some companies which started to use it for simulators with lower operational costs and safer than real trainers (military aviation) (Gigante, 1993). Modern HMD devices provide high-resolution displays, room-scale user tracking capabilities and object/hands tracking: HTC Vive or Oculus Rift are good examples of it. Its commercial availability since 2016 is opening the opportunity of their application in safety training (Chittaro & Buttussi, 2015). These type of HMDs require to be connect to a powerful PC equipped with a high-end graphic card. This can be a limitation, if a low cost of implementation is the critical issue for its adoption.

Alternatively, mobile virtual reality (mVR) platforms such a Google Daydream or Samsung Gear VR provide an entry-level experience of immersive VR, without the tracking and interaction capabilities of HMDs connected to personal computers. This solution combine a last generation smartphone and a low-cost headset that has opened the door to cheap implementations of immersive mobile learning experiences. Current fast pace in development of mobile processors and their graphic coprocessors means that in a near term smartphone-based HDMs will be able to offer high graphic quality and improved interaction functionality.

4. VR for safety

Learners require the experience of failure to learn. Persons who have already suffered an occupational accident or were present when occurred one, usually respect and pay more attention to safety signs and standards than others (Cavalcanti & Soares, 2012). In real-life, taking into account safety training, applying the wrong tool or even acting slowly could result in death. This is why in the majority of cases, safety education is not delivered under real world conditions. Considering this, VR emerges as a potential instrument for safety training, allowing users to learn without risks (Amokrane, Lourdeaux, & Burkhardt, 2008). Virtual reality permits trainees to employ similar cognitive processes and behaviours as they would do in the real-world context, generating experiences in a way that users can acquire safety concepts efficiently. This happens because VR can represent the work environment with a high-fidelity level, allowing to analyse human behaviour in certain situations.

VR flexibility provides students with a wider variety of learning experiences. This is especially important to consider that students learn best when a variety of teaching methods are used and that different students respond best to different methods (Bell & Fogler, 1995). This fact is not different considering safety education. Virtual reality stands poised to add a variety of educational delivery mechanisms in different ways and through multiple sensory channels. One example is the narrative device which provides opportunities for reflection, evaluation, illustration, exemplification and inquiry (Dickey, 2005). Also, VR promotes dynamic learning built over users' actions (learning-by-doing).

Kalawsky (2000) classified the virtual environment as a fully immersive system (when the display presents a full 360° information space), semi-immersive system (if the display is less than 360°) and no-immersive system for desktop VR system (using a regular flat monitor). A fully immersive system can isolate the user from all distractions, increasing his feeling of presence (a stronger feeling of being in a virtual environment than being in a lab or in a classroom) submerging him in a new, desired reality (Winn et al., 2002).

The environmental dimension is manifested in the use of manipulating colour and lighting, the shape, size and placement of objects. It is visual but also outlines the cultural context. Uses of muted colour and distorted objects could invoke a disturbing environment simulating an accident moment. The possibility of using auditory cues (such as explosions and yell sounds), in addition, strongly contributes to the realism of the overall experience. Also, immersive VR offer a first-person experience, an important feature that increases users' immersion and engagement along their learning process. The formal education as the regular teaching practice promotes symbolic third-person learning experiences. Therefore, virtual environments can help to solve the gap between experiential learning and information representation.

A possible tool to make better safety training is using games. Games are designed to involve players. Electronic games require active engagement with environments, which supports discovery, observation, trial and error, and problem-solving. Computer games are graphical environments that require players to read the visual environment and interpret symbol, actions that are becoming an increasingly important skill to foster learning. Virtual reality games offer all of this in an immersive way as the person lives the experience with body and mind. Increasing challenge, fantasy, curiosity, clear goals and reinforcing feedback are efficient mechanisms to be incorporated into educational learning experiences.

Rolling and Adams (2003), pointed that a game setting can be defined by emotional and ethical issues. According to them, the degree of emotion generated by an experience increases memory retention. Knowledge retention becomes stronger and more efficient when students´ experiences emerge from emotional activities. Educators know that there is an indissoluble relationship between body (learning by doing and interaction with the environment) and emotions to promote learning (Butler-Kisber, 2011). The EMMA project (Alcañiz et al., 2003) demonstrated that virtual environments are capable of generating emotions in their use. Chittaro and Buttussi (2015), brought out the efficiency of negative emotions for increase memory retention. VR offers a sophisticated tool to integrate emotions into the learning experience.

In terms of Human Factors, a number of individuals' characteristics have been shown to be predictive of safety performance and outcomes: safety knowledge, safety motivation, locus of control, risk taking and neuroticism. Virtual reality simulators have been used to continuously assess the capability for safety and risk behaviour (the decision-making behaviour of individuals in a risk context) among workers (Nedel et al., 2016). These systems could become a tool for the periodical evaluation of workers' capability to perceive risks in different scenarios or to help recruiters assess the psychological profile of job candidates. Also, they could be used to assess the human behaviour in a critical situation, without exposure to real physical consequences of risks.

5. Conclusions

The possibility of designing first-person fully immersive experiences with high-quality visualisations, the advanced interactive capabilities, connectivity and flexibility offered by current available HMDs open the opportunity of a great improvement in safety education.

Nowadays technology advances at an amazing speed, providing better performance with lower cost in each commercial iteration. This fact permits breaking one of the most important barriers to the massive use of virtual reality: high deployment costs. According to the available budget, smartphone-based headsets or PC-based HMDs are feasible options. Each alternative offers some advantages and issues. Mobile VR solutions currently offer worse interaction and graphical capabilities than those HMDs tethered to a powerful PC. However, they support learning in any place that can be a very interesting question in a safety education context. One key benefit of both options for safety training is that make it more engaging, requiring participants to play an active role in the training, as opposed to a passive role, and so make it more efficient.

Also, as previously mentioned, the ability to perceive risk changes from one individual to another, due to their beliefs, motivations, and relations with other people. User characteristics as age, cultural variables, gender and others, are variables that need more research. Garcia (2003) considers, for example, culture as primarily social mediation for incorporating significant action schemes, and we totally agree with him. The flexibility of virtual reality environments makes them easily adaptable to different characteristics of users.

Finally, we would like to emphasize the great potential of immersive virtual reality to move safety education to a higher level. The chance of an immersive learning, contextualised content, living a more realistic experience, a better content apprehension without risks, its flexibility, and a current affordable cost if compared to recreate those situations in the real life, make VR the technology to put the focus on in the next years.

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