A Review of Virtual Reality as a Medium for Safety Related Training in Mining

DR JENNIFER TICHON[1]
DR ROBIN BURGESS-LIMERICK[2]

ABSTRACT

A common problem for high risk industries such as mining is how to provide effective safety related training. Virtual reality simulation offers the opportunity to develop perceptual expertise, perceptuo-motor skills, and cognitive skills such as problem-solving, and decision-making under stress, without exposing trainees or others to unacceptable risks. This review examines the evidence for the effectiveness of virtual reality as a medium for safety related training in mining.

Evidence exists to demonstrate the effectiveness of virtual reality as a medium for safety related training in a range of other industries (e.g. training perceptuo-motor skills of pilots, surgeons, and drivers of a range of vehicles; maintenance inspection tasks; spatial awareness for specific locations; and improved decision making under stress). However, no satisfactory systematic evaluation of performance changes, or transfer of learning, has been undertaken in mining contexts, with almost all previous evaluations restricted to usability of the simulation and subjective trainee responses. Where performance changes as a consequence of training have been assessed, the evaluations have utilised poor evaluation designs, and very small numbers of trainees. A large scale, systematic, evaluation of the outcomes of safety related training via virtual mining environments is required to inform future practice.

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[1]School of Human Movement Studies, The University of Queensland
[2]Minerals Industry Safety and Health Centre, Sustainable Minerals Institute, The University of Queensland

Correspondence:
A/Prof Robin Burgess-Limerick, Minerals Industry Safety and Health Centre, Sustainable Minerals Institute, The University of Queensland, 4072
Email: robin@hms.uq.edu.au

INTRODUCTION

Miners are constantly exposed to a range of hazards which have the potential to cause serious injury or fatality. These hazards include fire, underground explosions, toxic gases, geotechnical hazards, and working in close proximity to mining equipment such as haul trucks, continuous miners, shuttle cars. Equipment related safety hazards include collisions, being caught between moving equipment parts, as well as exposure to energy sources such as electricity and high pressure fluids (Burgess-Limerick & Steiner, 2006).

Effort has been sensibly devoted to eliminating hazards and reducing risks through implementing design controls. However, it has been recognised in mining (Schofield et al, 2001), as in other industries such as aviation (Helmreich & Foushee, 1993) and rail (e.g. McInerney, 2005), that there will always remain the potential for miners to make skill-based or rule-based errors. For example, failure to perceive a hazard is consistently identified as contributing to injuries and fatalities (Kowalski-Trakofler & Barrett, 2003). In addition, another integral aspect of improving mine safety has been an increased focus on ensuring that employees and contractors are competent to perform their duties, and trained in the actions to take if an unplanned event with adverse safety consequences occurs.

A review of traditional training methods used in mining (Churchill & Snowden, 1996, cited by Schofield et al, 2001) suggested a number of potential problems, including:

> "...rote learning of information is the most common technique used by trainers with the same sets of training media being used from year to year. Many teaching methods present too much material, too rapidly, with little or no opportunity for worker involvement.
>
> Trainees frequently fail to attend to the problem at hand, often dividing their attention between what is going on at the front of the classroom and interpersonal interactions with those around them. ...
>
> Skill degradation is an important issue. When the hazards of a mine environment are combined with the issue of skill degradation, the need for realistic training becomes paramount." (p. 154)

Schofield et al (2001) proposed that virtual reality simulation offered the opportunity to improve safety related training in mining, suggesting that "the capacity to remember safety information from a three-dimensional computer world is far greater than the ability to translate information from a printed page" (p. 155).

There is no doubt that virtual reality simulation offers the opportunity to develop both perceptuo-motor skills, and cognitive skills such as problem-solving, decision-making and hazard perception, without exposing trainees or others to unacceptable risks. This strategy has been employed in other hazardous industries such as aviation, rail, health and defence.

For example, Blickensderfer et al. (2005) provide a historical review of the development of simulation in pilot training. Considerable evidence exists to demonstrate the effectiveness of virtual reality in this domain (e.g. Lintern et al, 1990; Biocca & Delaney, 1995; see Hays et al, 1992 for a meta-analysis; and Carretta & Dunlap, 1998 for a review). While flight simulators have been consistently demonstrated to result in skill acquisition by pilots, the effectiveness of the training is strongly influenced by the task to be trained and the amount and type for training provided. Simulators have been found to be more effective for training take-off, approach and landing than for other flying tasks. Landing skills, and instrument flying learned in a simulator, has also been shown to transfer to the real task (Hays et al, 1992; Pfeiffer et al, 1991).

Similarly, strong evidence exists to demonstrate that learning of surgical skills may be achieved in virtual environments (e.g. Issenberg et al, 2005; Gurusamy et al, 2008), and evidence also exists which demonstrates that virtual reality simulations is effective as a means of training drivers of cars (Fisher et al, 2002; Roenker et al, 2003; Uhr, 2004), trucks (Parkes & Reed, 2006; Strayer et al., 2004) snow plows (Kihl & Wolf, 2007; Masciocchi et al, 2007), and emergency vehicles (Lindsey, 2005) in terms of both safety related behaviour, and fuel efficiency. Evidence also exists to suggest that virtual environments can be used to improve the hazard awareness of novice drivers (Fisher et al, 2006; Pollatsek et al, 2006) and motorcyclists (Liu et al, 2009).

Evidence is available to suggest that an immersive virtual environment is an effective training medium for aircraft maintenance inspections (Barnett et al, 2000; Vora et al, 2002). The performance of naval fire-fighters in wayfinding around a ship during a subsequent exercise was found to be improved (fewer wrong turns) by rehearsal in a virtual environment (Tate et al, 1997), suggesting that spatial awareness for specific locations may be learned in a corresponding virtual environment.

The development and evaluation of virtual environments for training in decision-making under stress has a strong empirical basis provided by the military. In 1998 the US Office of Naval Research completed a seven-year research project focusing on decision-making under stress (TADMUS) (Cannon-Bowers & Salas 1998). Rather than focussing on skills development, the focus here is on ensuring that performance does not deteriorate under stressful conditions, hence - Stress Exposure Training (SET) (Driskell & Johnston, 1998). Stress Exposure Training has been demonstrated to transfer to performance in novel environments (Driskell et al, 2001), and has been adopted as a standard training tool in Defence.

THE USE OF VIRTUAL ENVIRONMENTS FOR SAFETY RELATED TRAINING IN MINING

The potential for improved safety suggested by Schofield et al (2001) and others (e.g. Bise, 1997; Filigenzi, et al, 2000; Wilkes, 2001) has been embraced by the mining industry, and virtual reality simulation is beginning to be adopted. Kizil (2003), for example, suggests that "There is no doubt that the use of VR based training will reduce these injuries and fatality numbers" (p. 569). This conclusion may be premature.

The general difficulty with evaluating the effectiveness of training in a virtual environment is that it is first necessary to measure performance of the skills being trained, before and after, training. An initial evaluation question would be: how does final performance compare to baseline measures? That is, did performance improve following exposure to the training? A second evaluation question might be: how does performance after exposure to training in the virtual environment compare to performance following conventional training methods, or real world practice?

These are important questions, however, the true test of the effectiveness of training, whether in a virtual or physical environment, is whether the skills learned transfer to different contexts and situations (Bossard et al, 2008). This is a difficult topic to address empirically in many contexts, and this is especially so for safety-related training because of the hazardous nature of the contexts.

A range of equipment simulators including dozers, draglines, haul trucks, shovels, continuous miners, longwall and roof bolters are available from commercial vendors with others under development. While reports of their use are available (e.g. Williams et al, 1998; Wilkes, 2001), no systematic performance evaluations could be located. One exception was a conference paper by Swadling & Dudley (2001) in which operators' performance while driving a virtual simulation of a remote Load-Haul-Dump LHD vehicle (VRLoader) was compared with the operators' subsequent performance during driving the remote LHD. The simulation was found to be an effective training tool, and performance on the simulation was predictive of subsequent performance while driving the remote LHD.

A jackleg drill simulation (MinerSIM) aimed at training new operators (Dezelic et al, 2005; Hall et al, 2008; Nutakor, 2008) has been constructed. MinerSIM consists of a web tutorial, and a virtual reality simulation which allows trainees to install rock bolts in a virtual environment. The simulation provides exposure to both normal, and abnormal situations. The only evaluation results available to date are preliminary results of a usability assessment of the web tutorial component.

Based on the results of evaluations of equipment operation in other domains, it is likely that equipment simulators will be effective in assisting trainees develop the perceptuo-motor expertise required to operate the equipment, and that this will reduce the real world practice necessary to achieve competent operation. This has potential safety benefits for both the trainee, and others located in the vicinity of the equipment.

A virtual conveyor belt safety training program has also been described (Lucas, 2008; Lucas et al., 2007, 2008; Lucas & Thabet, 2007, 2008). The simulation consists of an instructional module, and a task-based training module in which the trainee completes assigned tasks. Both desktop, and immersive versions, have been described. The development of the simulation, and a usability evaluation has been reported.

A similar application was described by McMahan et al (2008) in which training in pre-shift inspection for haul trucks was provided in both desktop and immersive virtual environments. The training included a "virtual tour" which introduced the information necessary to conduct a pre-shift inspection (parts to be inspected and explaining defects). The trainees then completed a virtual inspection, and were shown a simulation of the potential consequences of overlooking defects.

McMahan et al (2010) reported an evaluation of the effectiveness of this training in terms of the retention of information after using the virtual reality simulation, by administering a knowledge assessment test before and after using the simulation. While a significant improvement in knowledge was found following the training, the evaluation design was flawed and an order effect cannot be excluded because all participants performed the knowledge assessment test twice. A comparison of the effectiveness of the desktop version to the CAVE version, and to conventional "powerpoint" presentation was also reported (n=9, 10 & 10 respectively). Again, although no significant differences in knowledge retention were found, the statistical power of the comparisons was very low, and the conclusion drawn (that the methods were equally effective) is very likely erroneous.

The ability to detect and identify hazards has been another target for training in virtual environments (e.g. Filigenzi et al, 2000; Orr et al, 1999). Squelch (1997; 2001) provided hazard awareness training via desktop virtual reality. A comparison with traditional training methods was attempted for two groups of 30 miners. While the trainees reported that they preferred the virtual reality training, no quantitative comparison between two training media was possible.

Denby et al (1998) similarly trained mine operators in hazard identification and hazard avoidance using a desktop virtual haul truck, processing plant walkthrough, and underground fire and explosion, however no evaluation was reported other than trainee reactions. Schafrik et al (2003) provided reconstructions of accidents using desktop virtual reality to "emphasise the significance of unsafe acts" as a method for influencing safety culture, although no evaluation was undertaken.

Training in hazard identification has also been extended to include procedural information. For example, van Wyk (2006, van Wyk & Villiers, 2009) trained underground mine workers in hazard recognition and correct safety procedures using desktop virtual reality and reported "positive results in South African context" although no results were provided. Stothard et al, (2008) similarly aimed to improve understanding of hazards, procedures and processes. A survey of 51 trainees was undertaken to assess psychological characteristics of the trainees and their reaction to the simulation (immersive tendency and presence), however no evaluation of the understanding gained was reported.

Desktop virtual reality training for miners has been of interest for some years, with one of the earlier desktop applications being to educate mine workers on the hazards of mining, and in safe evacuation routes and evacuation procedures discussed in the previous section (Orr et al, 1999). More recently, the use of gaming technology is gaining popularity with a number of training alternatives based on this technology appearing in the area of mines safety training. NIOSH offers desktop virtual reality based training in underground coal mine map reading.

The program "Mine Navigation

Challenge" was built using a first person shooter computer game engine and is designed for new miners. Trainees can practice using skills trained while navigating through a simulated mine. To successfully complete the tasks, trainees count cross-cuts, go through man doors and find belt crossovers. It is reported that the game was tested in new miner classes at three training locations as it was being developed. This field testing, however, conducted in 2007 appears to be limited to a qualitative survey provided to trainees and instructors. Questions gauged the degree to which trainees liked or enjoyed the session, what parts of the course they liked best and if they would like computer-based sessions in future training (NIOSH, 2009).

The Queensland-based Mining Industry Skills centre (MISC) has also focused on serious-games with project CANARY (MISC, 2009). It is described on the MISC website as 'an industry first serious-game based training tool.' This project offers a suite of PC-based training scenarios which have been built using the game engine Virtual Battle Space 2, an engine previously used by the Australian military to run defence-specific scenarios for Australian and international forces pre-deployment. The hazard awareness scenario is designed to be used in a facilitator-led classroom and depicts a mine site workshop in which a clean-up needs to be performed while identifying key hazards and applying tagging and isolation processes. No underground scenarios are available. No evaluation of its use in the mining sector could be located.

Very limited research exists regarding the effectiveness of serious games for training miners. Private companies developing serious games either do not evaluate their product in applied settings or do not release publicly in-house evaluations of their products (Mallet & Orr, 2008). The military, both in Australia and overseas, but most notably in the United States, are investing significantly in what is still to a large degree an experimental use of this technology. There may be value in such applications, however much military research is not accessible to researchers working in civilian industries. Clearly those developing computer-based scenarios for training miners should be devising associated evaluations (Mallet & Orr, 2008).

CONCLUSION

There are promising results derived from other domains which indicate that virtual environments can be effectively used for safety related training, at least in some situations. These results suggest that there is potential for virtual environments to be effective in the minerals industry. However, other than evaluations of usability, or the subjective impressions of trainees, there has been little systematic evaluation of the effectiveness of virtual environments as a training medium in the minerals industry. Where evaluations have been undertaken, the designs were poor, and the sample sizes very small. A large scale, systematic, evaluation is warranted.

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