Burgess-Limerick & Associates
Ergonomics & Research Consultants
www.burgess-limerick.com
ABN 84976421949

A Review of Virtual Reality as a Medium for Safety Related Training in the Minerals Industry

Jennifer Tichon PhD
Robin Burgess-Limerick PhD CPE

Burgess-Limerick & Associates
December, 2009

Coal Services Health and Safety Trust

Prepared as part of Coal Services Health and Safety Trust
Grant Number 20578 - "An evaluation of the benefits that
virtual reality brings to industry based vocational training packages - Stage 1"

A Review of Virtual Reality as a Medium for Safety Related Training in the Minerals Industry

Jennifer Tichon PhD
Robin Burgess-Limerick PhD CPE
Burgess-Limerick & Associates

Abstract

A common problem for high risk industries is how to provide efficient and 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 a range of industries, including mining. A range of issues associated with the implementation and evaluation of virtual reality as a training medium are also presented as a means of providing a principled basis for conducting an evaluation of virtual reality as a medium for training safety related competencies in the minerals industry.

While further evaluations of the consequences of training in virtual environments, and particularly regarding the transfer to real world performance, is undoubtedly required; evidence does exist to demonstrate the effectiveness of virtual reality as a medium for training perceptuo-motor skills of pilots, surgeons, and drivers of a range of vehicles including cars, trains, trucks and snow plows. Novice drivers' hazard perception abilities can be improved via training in a virtual reality environment, as can children's road crossing behaviour. Maintenance inspection tasks have been shown to benefit from training in virtual environments, and spatial awareness for specific locations can be similarly trained. Evidence exists to support the use of simulation to improve decision making under stress, and there is evidence to suggest crew resource management training, and team training, may be successfully undertaken in virtual environments.

The following principles for obtaining maximum benefit from the use of virtual reality simulation as a training medium may be derived from current evidence:

✳ The use of simulation should be an integrated part of a training plan (derived from a systematic training needs analysis) which includes clearly stated goals, quantitative performance measures, and trainee feedback.

✳ Trainee feedback should be referenced to operational requirements.

✳ An event-based approach should be used in which trainees are presented with discrete scenario-based training events which allow practice of the specific skills (identified through systematic task analysis) that would be required in real-life situations.

✳ Trainees should be given the opportunity to make, detect, and correct errors without adverse consequences.

✳ Trainees should experience success or a sense of mastery during the training.

✳ Interaction with the simulation is a factor which contributes to high levels of presence/immersion, which in turn supports the transfer of knowledge to the real world. Consequently, simulators should provide an experience in which trainees are active participants rather than passive bystanders

* Skill development requires practice. Trainees should have opportunity for repeated practice under operational conditions similar to the real-world.
* Simulator sickness may cause trainees to disengage from the immersion, and should be avoided as far as possible.
* Effective transfer to high stress operational environments occurs in conjunction with higher levels of perceived affective intensity within the virtual environment, and consequently, the virtual world should aim to recreate the same stress levels.
* Fidelity may be necessary to ensure trainee acceptance, however it is not necessarily always required for effective cognitive skills training.
* Mixed fidelity approaches to the use of simulation in which combinations of different simulation technologies of varying degrees of immersion, coupled with practice in real world environments, may provide the most effective training regime.

Virtual environments of varying kinds are increasingly being employed for safety related training in the mining industry. However, no satisfactory systematic evaluation of performance changes, or transfer of learning, has been undertaken, 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.

Contents

1.0 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 (eg., haul trucks, continuous miners, shuttle cars; eg., Burgess-Limerick & Steiner, 2006). 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.

Historically, both injury rates and fatality rates for Australian coal mines have steadily decreased. Much of this improvement has been driven by changes in technology such as the introduction of roof bolting, although as Mark (2002) illustrates, technological change alone is not sufficient. The introduction of risk based legislative frameworks has also been associated with recent reductions in Australian injury rates (Poplin et al, 2008).

While effort has been sensibly devoted to eliminating hazards; and reducing risks through implementing design controls; it has been recognised in mining (Schofield et al, 2001), as in other industries such as aviation (Helmreich & Foushee, 1993) and rail (eg., 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). Consequently, 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 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 defense.

The potential for improved safety suggested by Schofield et al (2001) and others (eg., Bise, 01997; 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 - in the wider context at least, it is considered that evidence for the effectiveness of simulation is far from conclusive (eg., Bell et al, 2008; Jia et al, 2008; Salas et al, 2009).

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 where the transfer of skills occurs to a hazardous context.

The next sections of this review examine the current evidence for the effectiveness of virtual reality as a medium for safety related training in a range of industries including mining. The final section discusses a range of issues associated with the implementation and evaluation of virtual reality as a training medium. The aim of the review is to provide a principled basis for an evaluation of virtual reality as a medium for training safety related competencies in the minerals industry.

2.0 Evidence for Effectiveness of Virtual Reality as a Medium for Safety Related Training in Industries other than Mining

Virtual environments have been used as a training medium for many years in aviation, medicine (and particularly surgery), defense and a variety of other domains. Traditionally there are four main purposes for training personnel in virtual environments rather than physical environments: (i) Practical difficulties such as cost and time limitations arise in the real world when building realistic hazardous physical environments; (ii) after the time and expense is invested, the resulting training and education facilities are only of limited utility in planning/ training activities, given that there exist a practically endless array of workplace accident scenarios; (iii) using realistic physical facilities to develop the critical thinking and decision-making skills of personnel is potentially dangerous to the participants and others; and (iv) in the virtually rendered world, trainees can see and experience things that are not possible to see or experience in the real world.

However while number of virtual environments for training continues to increase dramatically, less focus has been given to evaluation of the training provided via this technology. This is an critical short-coming. If systematic evaluations of the performance consequences of training using virtual environments, let alone evaluations of transfer to real world situations, are not undertaken, an opportunity to optimise the potential benefits of virtual reality simulation is squandered.

Construction of the hardware and software to support training via virtual environments is a costly investment. Systematic evaluation, at least of performance outcomes, is an essential step in ensuring maximum return on this investment. This section reviews the evidence which exists in industries other than mining regarding the effectiveness of training in virtual environments.

2.1 Pilot training

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).

Flight simulators are typically used to complement flying time rather than substituting for flight time, however there is evidence that simulators reliably produce superior training compared to aircraft-only training (Jacobs et al, 1990). For example, research with naval pilots suggests that simulator training increased performance in subsequent actual carrier landing practice. In this study, increased visual fidelity had no effect on actual performance, and lower fidelity simulator training appeared to be as effective as higher fidelity training (Taylor et al, 1997).

The use of virtual simulators for pilot training is accepted and regulated by aviation authorities. The US Federal Aviation Administration, for example, maintains a National Simulator Program[1] which has the dual roles of applying regulations and seeking improvements in flight simulation, and the use of simulation has more recently been extended to the training of pilots of unmanned aircraft (Guido & Montrucchio, 2006).

2.2 Surgical skills

Strong evidence exists to demonstrate that learning of surgical skills may be achieved in virtual environments (eg., Grantcharov et al, 2004; see Issenberg et al, 2005; Gurusamy et al, 2008 for reviews). For example, both Seymour et al (2002) and Cosman et al (2007) describe blinded randomised controlled trials in which laprascopic surgical trainees who received simulator training were found to have superior performance during their first real world performance of a laprascopic task. The use of simulators for surgical training is becoming a standard feature of medical education with the introduction of facilities such as the Queensland Health Skills Development Centre[2], and indeed the use of simulators for medical training has been highlighted as an "ethical imperative" (Ziv et al, 2006). Considerable research, and significant evaluation work, is ongoing, however, to determine to provide an evidence base for the optimal use of simulators for specific procedures such as colonoscopy (eg., Karamatic et al, 2009; Hill et al, 2009).

2.3 Driving

Similarly, evidence 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; Turpin & Welles, 2006; Uhr, 2004), trucks (Parkes & Reed, 2006; Strayer & Drews, 2003) snow plows (Kihl & Wolf, 2007; Strayer et al, 2005; Masciocchi et al, 2007), and emergency vehicles (Lindsey, 2005) in terms of both safety related behaviour, and fuel efficiency.

There is also evidence that simulator driving behaviour is closely related to real world behaviour (Tornos, 1998; Santos et al, 2005; Winter et al, 2009), and driving simulators are frequently used to investigate applied research questions relating to improved safety (eg., Bullough & Rea, 2001, Enriquez et al, 2001). Driving simulators have also been widely used to investigate fundamental processes of human attention and visual perception while driving (Readinger et al, 2002) and the effects of visual and cognitive demand on driving performance. Simulation has been used to assess attentional differences (as measured by eye-movement recording) between expert and less-experienced drivers (Dorn & Barker, 2005), to assess changes in driving behaviour which occur with fatigue (Ting et al, 2008) and the effects of distraction while driving (Greenberg et al, 2003).

These applications (flying, surgery and driving) have in common, a large perceptuo-motor skills component. Laboratory based examinations have also demonstrates that perceptuo-motor tasks can be learned in virtual environments (Hamblin, 2005; Rose et al., 2000).

It is also known, however, that driving skill is a poor predictor of crash risk (Horswill & McKenna, 2004), and hazard perception ability and risk-taking propensity are better predictors. 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).

2.4 Train Driving

Technology changes in rail have increased the complexity of the train driver's role. Increased train speeds, for example, have increased the temporal demands on a driver's decision making (Li et al., 2006). This, combined with a number of high profile incidents in which human errors were found to play a causal role, has directed the industry's attention to the use of virtual environments for train driver training (Eichinger & Geraghty, 2005).

1 http://www.faa.gov/about/initiatives/nsp/
2 www.sdc.qld.edu.au

Indeed a 3.7M Euro project is nearing completion ("2TRAIN - *TRAINing of TRAIN Drivers in safety relevant issues with validated and integrated computer-based technology*")[3] which "aims at developing European standards for the training of train driver competencies providing best-practice guidelines for an efficient, safety enhancing and cost-effective use of the latest computer-based training technologies".

A report on the project titled "Transfer-of-Training Effects" (Schmitz & Maag, 2009) provided subjective data from drivers regarding the simulations, but did not provide any evaluation of performance. The report noted that the lack of evaluation of simulation training in rail is a "central research gap".

A range of hazards are addressed in train driver training in virtual environments including signal recognition and fatigue (Roach et al., 2001; Li et al., 2006). Immersive wide-screen reality centers and in-cab simulators provide the opportunity for train drivers to repeatedly practice the identification of, and response to, a range of pre-emergency situations; including environmental conditions such as fog, rain, wind, and dazzling sun; and specific difficult operating conditions such as heavy traffic, accidents, faulty signs and people on the track (Simmons-Boardmann Publishing Corporation, 2004).

The 1999 Glenbrook train disaster and subsequent Commission of Enquiry led to an expansion of virtual reality training in the New South Wales rail sector. Curved screen reality centres have been used to immerse employees in rail specific disaster and work place accident scenes. The training was designed to support both construction of knowledge and cognitive learning. This was a consequence of the Safety Management System, which required a shift from the historical culture of having a rule for every event, to new requirements that rules are built on a foundation of risk management. To assess a critical incident as it unfolded, staff were trained in critical thinking and decision-making under stress (Tichon, 2007b).

A recent study evaluated the effectiveness of the NSW rail virtual reality scenarios to enhance decision-making under stress. The decision-making skills necessary to successfully complete the scenarios were first identified through cognitive task analysis of experienced train driver responses to the difficult driving conditions encountered in the scenarios. A skills assessment tool was developed on the basis of the cognitive task analysis, and was subsequently completed by trainers observing drivers undertaking their training in virtual reality (Tichon, 2007b).

Participant's results were collated to gain baseline data on the decision-making skills trainees displayed during their first exposure to the virtual reality scenario. The same group of drivers repeated the same training scenario twice in the following year. Their results were compared to the baseline data gathered in the previous year, and performance did improve in that fewer errors were made, and when errors were made, a significantly higher number were self-corrected by the drivers (Tichon & Wallis, 2009).

Interestingly, however, these improved skill levels were not maintained during the break between annual training sessions. It has become an important and pressing focus of virtual reality research to determine how often training should be undertaken to maintain effective training levels (Gerbaud et al, 2008), and this topic is addressed in more detail in section 4 of this review.

2.5 Road crossing

Thompson et al (2005) provided road crossing training for children in a virtual environment and reported improved performance (fewer missed safe crossing opportunities) in the simulation following training. Congiu et al (2008) confirmed this finding in an experiment utilising a a control group, and reported that the differences remained after a one month follow up. Whether this altered behaviour transfers to a real world environment is unknown.

3 http://ec.europa.eu/research/transport/projects/article_4971_en.html

2.6 Maintenance inspection

Evidence is also 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). These findings suggest that perceptual expertise may be developed through a virtual environment of sufficient fidelity. More recently investigations have included the use of virtual reconstructions of a large-bodied aircraft cargo bay, and varied interaction modalities ranging from fully immersive (using a head-mounted display and 6 degrees-of-freedom mouse) to semi-immersive (using a spatially-tracked suspended, touch-sensitive window display) to non-immersive (using a basic desktop computer and mouse); and 3D virtual environments of turbine engine blades where nondestructive inspection methods could be practiced (Washburn et al, 2007; Sadasivan et al, 2007).

2.7 Spatial awareness

The performance of naval firefighters in navigating 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. This finding is consistent with a finding that virtual reality training in underground cave structures resulted in task performance which was two to three times faster (Bowman & Schuchardt, 2007). A submarine virtual environment has also been developed as a means of improving spatial awareness of submariners (Stone & Caird-Daley, 2009; Stone et al, 2009), however no evaluation of subsequent performance has been reported to date.

2.8 Crew resource management

Desktop virtual reality simulation has also been employed to train crew resource management in aviation. Whether such training increases the safety cannot be evaluated using accident rates because the overall accident rate is so low. In the absence of a direct measure, the two criteria which have most often investigated are behavior on the flight deck and attitudes showing acceptance or rejection of crew resource management concepts.

Data from audits where crews are observed under non-jeopardy conditions has demonstrated that crew resource management training does produce desired changes in behavior. The attitudes that have been measured to assess the impact of crew resource management were ones identified as playing a role in air accidents and incidents. Data from a number of organizations show that attitudes about flight deck management also change in a positive direction (Helmreich et al, 1999).

The US Air Force used a desktop simulation designed to elicit the communication and crew coordination behaviors associated with instrument and visual airdrop missions. For these two targeted skill areas simulator-trained student navigators required on average, 10.2 sorties to achieve proficiency, compared to 11.8 sorties for their control group counterparts, a reduction of 13.6 percent (Nullmeyer et al, 2006). Similar training has been provided in a simulated operating theatre (Aggarwal et al, 2004; Nishisaki et al, 2007) although no evaluation has been reported.

2.8 Decision making under stress

An key factor in safety related training is training people to cope with ill-defined problems resulting from insufficient or unreliable information, in the face of hazardous environments and threat of physical injury (Salas et al, 2002). Enhancing such emergency response skills is important for a number of industries. Of particular interest are those cognitive skills known to degrade under stress such as critical thinking and decision-making.

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).

Such training focuses on developing those cognitive skills required to maintain effective performance under degraded work conditions. The aim is to incite the same emotional reaction and stems from research demonstrating that for some tasks normal training procedures did not improve task performance when the task was later performed under stress conditions (Zakay & Wooler, 1984; Tichon & Wallis, 2009).

Negative, affective states such as stress can impair decision-making by causing overestimation of risks which results in unprofessional or unsafe choices based on perceived levels of danger to self and others - errors which Peters et al (2006) termed "avoidant choices". Sub-goals of stress training include gaining specific knowledge of, and familiarity with, the operational environment to assist trainees to form accurate expectations. This will improve trainee's ability to predict outcomes and avoid errors, as well as to decrease their propensity to be distracted by novel sensations (Driskell & Johnston, 1998). The overall goal of cognitive training via virtual reality is to build confidence in trainees in their ability to perform under adverse conditions.

While it has been suggested that Stress Exposure Training must necessarily be conducted under the same stressful operating conditions that will be encountered in the real work environment (Breazeal, 1999), there is little research on the factors that contribute to effective learning in high affect simulated environments (Wilfred 2004). Prior research does indicate the most effective learning in disaster response simulated training occurs in conjunction with higher levels of perceived affective intensity (Hall et al, 2004).

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 Defense. For example, Stansfield et al (1998) describe a virtual reality simulation (BioSimMER) aimed at training personnel who might be called upon to provide emergency triage at the scene of an act of terrorism involving both an explosion and the release of a biological warfare biotoxin with the goal of training rapid situational assessment and decision-making under highly stressful conditions. A similar application was described by Kizakevich et al (2007) for mass casualty triage for medical personnel stationed in Iraq, although no objective evaluation was reported.

2.9 Team training

Cross training via simulation has been found to be effective in improving team performance (Volpe, 1996). Cross-training is a method of strengthening a team's shared mental model. When all team members consistently share a common awareness and understanding of the situation, the correct tasks are accomplished in a timely manner. In terms of team communication, cross-trained teams volunteered significantly more information than the teams without cross-training (Cannon-Bowers et al, 1998). Significant improvements in team performance and teamwork skills were obtained for navy teams who received team adaption and co-ordination training in a simulation-based experiment (Serfaty et al, 1998).

High fidelity simulation based team training has also been reported to improve clinical team performance when simulation was added to an existing team training curriculum. Emergency department staff who had recently received training in an "Emergency Team Coordination Course" also received an 8 hour intensive experience in an emergency department simulator in which three scenarios of graduated difficulty were encountered. A comparison group was assigned to work together in the emergency department for a eight hour shift. Experimental and comparison teams were observed in the emergency department before and after the intervention. The experimental team showed a trend towards improvement in the quality of team behavior, while the comparison group showed no significant change in team behavior during the two observation periods (Spillane, 2003). Progress towards developing a CAVE based immersive virtual environment for medical team training funded by the US Army was also reported by Lee et al (2007).

Lessons learned in a simulator team training project undertaken by TADMUS indicate the key areas to target in assisting teams to be more adaptive in high stress operational conditions are:

- The extent to which team members can anticipate one another's needs
- The confidence team members have in one another
- The extent to which team members believe they should monitor other team members
- The extent to which team members believe they should readjust to changes in stress/workload

(Kozlowski, 1998)

2.10 Other applications

Many other applications of virtual reality as a training medium exist in a variety of industries. While there are publications which describe the applications, and many provide an evaluation of the usability and/or trainees subjective impressions of the virtual environment, there is generally little objective assessment of the performance outcomes of the training in comparison to other training media, and even fewer evaluations of transfer to real environments.

For example: Ki (2009) describes a simulator for training operators to use an aerial working platform; Li et al (2005) describe an emergency rescue simulation; Stansfield et al (2000) describe a simulation for medical first responders which aims to train training of multiple users for tasks in which situation awareness and critical thinking are the primary determinants of success (see also Holcomb et al, 2002; Lai et al, 2007); Ellis et al (2002) describe the use of simulation for training military medical personnel to manage casualties, and Smith and Ericson (2009) describe the use of an immersive game-based virtual environment to teach children fire safety skill. None provide evaluations of performance relative to other training methods, or transfer to novel situations.

3.0 Evidence for Effectiveness of Virtual Reality as a Medium for Safety Related Training in Mining

Virtual reality has been identified as a potential avenue for safety related training in the mining industry for some time (Bise, 1997; Filigenzi, et al, 2000; Wilkes 2001), and this application of virtual reality was identified as desirable research focus by the US National Research Council (Committee on Technologies for the Mining Industry, 2002). However, while there are a number of reports of safety related training being conducted in virtual minerals industry environments, there is very little evaluation reported other than usability or subjective trainee responses. This section examines the evidence which exists.

3.1 Evaluations of safety related training using virtual reality in mining

3.1.1 Mining equipment operation. A range of equipment simulators including dozers, dragline, haul truck, shovel, continuous miner, longwall and roof bolter are available from commercial vendors [4] with others under development. While reports of their use are available (eg., 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 LHD operation (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.

3.1.2 Mining equipment safety. A virtual conveyor belt safety training program has also been described (Lucas, 2008; Lucas et a., 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.

4 eg., www.mining.5dt.net/; www.immersivetechnologies.com

McMahon et al (in press) will report an evaluation of twelve trainees assigned to either desktop or immersive versions of the conveyer belt safety training program using a "knowledge assessment test". No significant difference in the average increase in knowledge was found between desktop and immersive versions of the training, however the number of trainees, and hence the power of the comparison, was extremely low.

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 (in press) will also report 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 the conclusion drawn (that the the methods were equally effective) is very likely erroneous.

3.1.3 Mining hazard identification. The ability to detect and identify hazards has been another target for training in virtual environments (eg., 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 preferring 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 (eg., Ruff, 2001). 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 immersive tendency and presence, however no evaluation of the understanding gained was reported.

3.1.4 Desktop virtual reality applications in mining. 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 focussed 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 Defense to run defense 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 apply 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).

3.2 Other uses of virtual reality in mining

There is no doubt that virtual reality simulations have other potential roles in the minerals industry beyond safety related training. Other uses include data visualisation, accident reconstruction, and improving equipment design through the exploration of virtual equipment models to assess safety related design issues such as visibility (eg., Delabbio et al, 2003, Gilles et al, 2005; Kaiser et al, 2005; Kizil, 2003; Qizhong et al, 2008; Schofield et al, 2001).

For example, virtual reality has been used from mining equipment concept development through to 3D Visualisation for numerous project hazard reviews and analyses. Work being undertaken at Laurentian University addresses the need to improve operator visibility when driving mobile equipment in underground environments. A fully interactive underground model combining CAD LHD models or haulage trucks in different mine designs layouts is being constructed with the aim of helping to improve operator visibility. The model is being investigated for use in design review and emergency response, for example mining rescue operations (Delabbio et al., 2003).

Simulation is also being used to gain a better understanding of how spontaneous combustion initiated fires can interact with the complex ventilation behaviour underground during a substantial fire (Gillies et al 2005). Hazard assessment in burst-prone mines has been enhanced through the use of virtual reality for seismic data interpretation. Using a double-curved screen, a team of twenty people were fully immersed in the data allowing the team to develop procedures and tools to effectively interpret seismicity and its impact on workplace conditions including identification of hazardous areas in space and time(Kaiser et al., 2005).

3.3 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.

4.0 Issues Associated with Implementing and Evaluating the use of Virtual Reality as a Medium for Safety Related Training in the Minerals Industry

The final sections of this review discuss a range of issues and concepts associated with the implementation and evaluation of virtual reality as a training medium. While not directly speaking to the question of the effectiveness of virtual environments as a medium for safety related training, these concepts are relevant to both the design and evaluation of training, and an improved understanding will assist in providing a principled basis for a subsequent evaluation of virtual reality as a medium for training safety related competencies in the minerals industry.

4.1 Instructional Design

Conducting effective training in virtual environments requires effective instruction design. This may be achieved in a variety of ways, however Instructional System Design models (eg., Gordon, 1994) exemplify the application of human factors principles to training. Such models involve Front End analysis steps (analysis of the situation, task, trainees, training needs, and resources) which result in the definition of functional specifications of training, followed by Design and Development steps (training concept generation, training system development and prototyping, usability testing) and System Evaluation steps (determining training evaluation criteria, collection and analysis of these data, and subsequent modification of the training if indicated).

The front end analysis (or training needs analysis) step in training design is critical. In particular, a comprehensive analysis of the tasks performed, and decisions required of trainees in the real environments is required before the training needs and associated functional specifications can be determined. The aim of the task analysis is to describe the knowledge, skills and behaviours required for successful task performance, and identify the potential sources and consequences of human error.

This task analysis would typically involve interviews with experts, reviews of written operating and maintenance procedures and observation. It should include consideration of the information required by miners and how this information is obtained, the decision making and problem solving steps involved, the action sequences, and attentional requirements of the situations which are the subject of training. The task analysis should be conducted systematically, and well documented, to provide a solid foundation for the design of training and to provide a template for future training needs analyses.

An extension of the task analysis to include a cognitive task analysis may be justified for more complex situations. Cognitive task analysis seeks to understand the cognitive processing and requirements of task performance, typically through use of verbal protocols and structured interviews with experts. The outcomes of a cognitive task analysis include identification of the information used during complex decision making, as well as the nature of the decision making. The cognitive task analysis can also reveal information which will underpin the design of training and assessment.

The results of the task analysis are also used in the second phase of training design to define actual the contents of the training program, as well as the instructional strategy required. Regardless of the content of the training (the competencies required) or the methods employed (eg., simulation), most effective instructional strategies embody four basic principles:

- the presentation of the concepts to be learned;
- demonstration of the knowledge, skills and behaviours required;
- opportunities to practice; and
- feedback during and after practice

(Salas & Cannon-Bowers, 2001).

An initial training design concept is typically refined iteratively through usability evaluation of prototype training models, until a fully functional final prototype is considered ready for full scale development. Issues to be considered include the introduction of variation and the nature and scheduling of feedback.

A compelling case has been presented (Schmidt & Bjork, 1992) to suggest that variation in the way tasks are ordered and in the versions of the tasks to be practiced is important, and that less frequent feedback should be provided. While immediate performance may be reduced, retention and generalisation are enhanced as a consequence of the deeper information processing required during practice. For example, Swadling & Dudley (2001) describe the use of a virtual simulation to train operators prior to the introduction of remotely controlled LHD in an underground mine. Research would suggest that such training should ideally include increasing variability (including both normal operation, and abnormal situations such as virtual equipment malfunction), and periods of practice in which knowledge of performance feedback was withheld.

Task analysis aids in determining the appropriate performance measures to be used in evaluation (or indeed in the assessment of competency). A valid training evaluation requires careful selection of evaluation criteria and measures (closely connected to the task analysis results), and systematic collection and analysis of data.

4.2 Characteristics of expertise

Expertise is not easily acquired. Attaining expert performance across a variety of domains has been estimated to typically require about 10 years, 10,000 hours, or millions of trials (Ericsson et al., 1993). Studying the differences between experts and novices, and the development of expertise, has also been proposed as a means of deriving principles for training design (eg., Abernethy, 2001).

Comparing the behaviours of novices and experts can assist in identifying the factors which limit the performance of novices. Identification of the factors which do, and which do not, discriminate the performance of experts and novices provides guidance towards the aspects of the task towards which attention should particularly be directed during training. Comparison of the information sources used by novices and experts, for example, can help determine what information must be learned by to become an expert in a given task.

4.2.1 Sensation & Perception differences. Across a range of skills and domains, there are some consistent findings relevant to the design of training which emerge from the study of expert-novice differences, expertise and skill development. For example, it is unsurprising to note that persons with poor sensory reception may have difficulty performing tasks which require the acquisition of information via the sense in which they have a specific deficit. People with visual defects perform poorly on inspection tasks requiring high visual resolution, for example, and this suggests an obvious need for occupational screening. Any screening must be very specific to the perceptual abilities required during the task, however. For example, assessment of static visual acuity is inappropriate for tasks that require assimilation of dynamic visual information, such as driving a vehicle.

While poor perceptual ability may limit performance, the corollary is not true - there is no evidence that experts are characterised by above average sensory abilities. Attempts to alter performance through training to enhance perceptual abilities is misguided. Where experts and novices do differ in sensory terms is in the ability to make sense of the sensory information, that is, in perception. Tasks specific measures of perception across a range of domains indicate that experts are superior at discriminating perceptual events such as flaws (Blignaut, 1979), are better able to recognise patterns, and better able to predict future events based on current sensory information. In mining this is particularly relevant to the ability to perceive the probability of hazards, such as roof fall, on the basis of vision of the roof and rib conditions. Expert equipment operators might similarly be expected to make use of engine, or other noises, as indications of the state of the equipment, or the likelihood of future events such as a stall.

Some evidence exists to suggest that acquisition of these perceptual skills can be accelerated through training (Starkes & Lindley, 1994; Williams & Grant, 1999), and this is a particular opportunity for virtual environments.

4.2.2 Decision making differences. Another area in which experts and novices differ is in decision making. Experts are typically faster at problem solving; have better short and long term memory of relevant states or events; and have more knowledge of relevant facts and procedures. Experts are also more likely to see and represent problems (such as fault diagnosis) at a deeper, more principled level, and spend greater time analysing problems before arriving at a diagnosis of solution (Gilhooley & Green, 1988; Glaser & Chi, 1988; Ye & Salvendy, 1996).

While it is attractive to try to facilitate the acquisition of such cognitive skills by providing novices with access to experts' procedural knowledge structures, evidence for success in this is scant. Experts and novices also differ greatly in their decision making under stress, and this is an opportunity for training in virtual environments.

4.2.3 Action differences. Differences between experts and novices in reaction and movement times are evident for tasks which require rapid responses, although these differences may reflect greater perceptual skill leading to more rapid assessment of the response required. No differences in are found in simple reaction times, and experts are constrained in the same way as novices when multiple successive responses are required. In terms of movement production, both the movements and forces produced by experts are less variable than novices, and experts harness the complex intersegmental dynamics of the body and produce more efficient, and less effortful body movements.

4.2.4 Attention differences. One of the characteristics of skill development is increasing automaticity. The consequence is a freeing up of attentional capacity to deal with additional information. For example, the novice driver's attentional capacity is all but exhausted by the management of the essential vehicle controls (brake, gears, accelerator) and the primary goal of maintaining course through the environment, and little or no attentional capacity remains for watching ahead for potentially hazardous situations. Conversely, with practice, these essential vehicle control functions become automatic, and experts are able to attend to the road ahead, identifying hazards, and taking necessary actions well before arriving at the hazard.

Attentional differences between experts and novices have been revealed through eye movement recording (Crundell & Underwood, 1998). When cognitive load increases (such having to drive on busier roads in more populated areas) experienced drivers increase their spread of search. This strategy could be expected to be effective for anticipating potential hazards from peripheral locations. Novice drivers showed little difference in search variation.

A study was undertaken to test whether it was possible to train novice drivers to use more appropriate strategies, or if proper scanning while driving is a skill that can only be learned through experience. The training intervention involved tracking participants' eye movements as they drove on real roads and while they watched video clips of hazardous situations after training in adaptive scanning patterns (Chapman et al, 2002). Novice drivers were found to retain knowledge of adaptive scanning, and eye movements did change, however it was not demonstrated that the drivers transferred their new knowledge to the real world.

4.3 Decision-making

Decision making is a key skill which improves with expertise, and is a common target of training, with good reason. Decision errors were associated with 33% of accident/incident cases analysed in a 2008 Queensland mining study (Patterson, 2008). These errors occurred when miners found themselves in a situation where they could not rely on standard procedures to complete a task. Instead, the people concerned had to resort to using procedures for what they believed were similar tasks, or they were forced to create novel responses. The errors occurred when the action decided on proved to be inadequate, or contra-indicated. Problematic decision-making was also highlighted during emergency response exercises of the Queensland Mines Rescue Service conducted in underground coal mines (Cliff & Moreby, 2005).

The quality of decision making is known to decrease under stress and, as noted earlier, the use of virtual environments for training decision-making under stress has a strong empirical basis. The US Office of Naval Research project on decision-making under stress (TADMUS) revealed that characteristics present in high stress operational environments included the necessity to cope with multiple information sources, adverse physical conditions, or actual physical threat, and pressures from insufficient time and work overload (Cannon-Bowers & Salas, 1998).

Investigations of decision-making strategies in stressful operational environments reveal that personnel often do not have sufficient time to make a structured decision. Early models of analytic decision-making described the process as one in which the decision maker was able to undertake a "systematic, organized information search, considers all available alternatives, generates a large option set, compares options and successfully refines alternative courses of action to select an optimal outcome" (Driskell & Johnston, 1998, p.191). In safety critical situations, however, it is highly unlikely that personnel will have the time to compile a mental picture of each alternative action and then analytically evaluate each in turn.

While increased time pressure may result in a reduced use of analytic strategies to make decisions, this does not necessarily need to impact on the quality of decision-making. The Recognition-Primed Decision model was developed in an attempt to understand decision making in naturalistic settings characterized by high-demand and time-pressured conditions (Klein et al, 1989). Without the time to generate a large set of response options, personnel instead fall back on a simple comparison between a favored option and a comparison option (Lipshitz et al, 2000). The Recognition-Primed Decision conceptualization of decision-making takes a serial evaluation approach in which an option is generated, tested for feasibility, and then either implemented or rejected. It also assumes that an acceptable course of action may be chosen without conscious generation of alternatives (Klein et al, 1989). The Recognition-Primed Decision model has been used to investigate decision-making processes across a range of professional groups including emergency ambulance dispatchers (Wong, 2005), fireground commanders (Klein et al, 1989) and military ground navigators (Peterson et al, 2004).

The generation of an option is pivotal to the Recognition-Primed Decision model; however, generating an option requires retrieval of information from long-term memory, such as prior experience with similar conditions. Prior experience may not be available for novice miners to rely on. Simulated real-world experiences can be used to train decision-making skills through assisting learners to generate in their long-term memory their own version of an expert decision response.

As noted earlier, one characteristic which distinguishes experts and novices is the ability of experts to perceive meaningful patterns that less-experienced personnel may miss altogether. This enables experts to quickly construct an understanding of the whole situation, to think about how many different elements fit together and affect each other. Novices can be trained to recognize all relevant cues located within a hazardous situation and thereby increase the likelihood of being able to head off a problem before it develops. Experts only develop their expertise through experience and over time. For novices, virtual reality training provides an opportunity to add experiences to their long term memory which can later be called upon when a decision is required. Presenting real world problems in virtual reality provides a way for trainees to formulate effective mental schema (Andrews & Bell, 2000).

Elicitation of expert knowledge through tools such as cognitive task analysis can support virtual reality training design and evaluation by identifying appropriate behavioral and cognitive markers of an 'ideal' strategy for decision-making in target situations. While cognitive task analysis has been widely used to this end, and specifically in virtual reality training for degraded and critical workplace conditions across aviation and defense contexts (Fowlkes et al, 2000) its similar application in the mining sector is limited (although see Marling & Horberry, 2009 for an example).

The importance of the identification and incorporation of decision points into training scenes lies in the nature of simulation training, which lends itself more readily to event-based training. In event-based training it is the scenario which provides the basis of curriculum, through crafting required responses from the training exercise in line with desired decision-making training objectives.

The job of virtual reality training is to develop a mental schema within trainees' long term memory which they can call upon when needed. Delineating decision points, and providing information on how to cue trainees that a decision is required, ensures that the cues used are the same as those found in the real world environment. Virtual reality achieves this by presenting all relevant cues a trainee must be able to recognize as an emergency response is taught. Presenting real world problems in virtual reality provides a way for trainees to formulate effective mental schema (Andrews & Bell, 2000).

4.4 Situation awareness and hazard perception

Situation awareness refers to a person's ongoing awareness understanding of the dynamic environment within which they are operating. Situation awareness includes a person's perception of elements in the environment, comprehension of that information, and the ability to project future events based on this understanding. This awareness and comprehension is critical in making correct decisions that ultimately lead to correct actions (Wright et al, 2004). Situation awareness therefore is a significant adaptive cognitive response because it precedes decision making, and is an important support to dynamic decision making. Situation awareness is an individual-level cognitive component of performance, although an individual team member's situation awareness clearly can influence the rest of the team when an individual passes along something he or she is aware of to other team members (Smith-Jentsch et al, 2004).

Situation awareness is very strongly linked to performance. The more relevant information a worker has about a situation, the more adaptive their responses will be. Conversely, limitations in a person's situation awareness skills, such as incorrectly interpreting information, are likely to increase the risk of errors (Klein et al, 1989; Wright et al, 2004).

Measures of situation awareness correlate with performance across diverse groups such as air traffic controllers, pilots, power plant operators, army personnel and medical practitioners. The Situation Awareness Global Assessment Technique (SAGAT) is one method used in virtual environments, and is proposed to be as a direct measure of situation awareness.

The use of SAGAT requires a detailed analysis of the task, similar to cognitive task analysis, to be undertaken to identify situation requirements, and in turn, develop appropriate situation awareness queries. In a study evaluating a new avionics system, pilot's perception, comprehension and projection of a operational situation as it unfolded was assessed using SAGAT during simulation freezes (Endsley, 1988). Though a common method, the measurement technique has been criticised because of the perceived intrusiveness of freezes in a simulation to collect SAGAT data, and the potential degree to which it reflects memory rather than situation awareness (Sarter, 1991).

Hazard perception may be considered to be a particular form of situation awareness (Horswill & McKenna, 2004). Hazard perception has been extensively studied in driving research and is increasingly being adopted in other domains. It is being applied as a tool of safety training evaluation in construction (Sokas et al, 2009) and has been of interest to a number of safety projects within the mining sector. Training utilizing slides illustrating degraded images of hazards such as dangerous roof and rib conditions has been implemented with miners in the classroom and reported improvement in perceptual skills. A longitudinal follow-up study analyzing lost-time injuries the following year revealed incident rates dropped significantly, however there was some confounding of the results making it impossible to determine how much of the drop was directly attributable to the slide-based hazard training. (Kowalski-Trakofler & Barrett, 2003).

Ideally, studies of hazard perception ability involve development of a task in which trainees must identify potentially hazardous cues (cues that could indicate that an accident may occur), while carrying out a range of normal operational tasks. Initial investigations of the construct with drivers required participants to imagine they were driving while watching a series of film clips of traffic situations. Participants would press a response button whenever they detected a potentially dangerous situation (Horswill & Helman, 2003).

This progressed to a series of research projects developing hazard perception testing using filmed road scenes in which drivers are required to detect potential dangers which might result in an accident or a near accident. The hazard perception video test developed by McKenna et al (2006) involves participants viewing roadway scenes on video and pressing the response button whenever they perceive a hazard. Reaction times to each of the hazards are recorded, also referred to as detection time, and averaged across a number of scenarios to obtain a hazard perception metric.

The hazard perception test had been found to discriminate among novice drivers, experienced drivers and expert drivers (McKenna & Crick, 1994) and can predict accident involvement (McKenna & Horswill, 1999). Hazard perception improves with experience, and can be trained in drivers (Mckenna & Crick, 1994; Sexton, 2000; McKenna et al., 2006).

Experienced drivers have been found to have faster reaction times to hazards than novice drivers. Wallis & Horswill (2007) also found novice drivers require a higher threshold of danger to be present before they notice a situation is hazardous, or before they are willing to classify a situation as hazardous. They suggested that individual differences between expert and novice hazard perception scores could reflect both sensitivity (drivers' ability to discriminate between hazardous and non-hazardous situations) and response bias (the threshold of perceived hazardousness above which drivers respond (Wallis & Horswill, 2007).

Training novices to anticipate environmental cues for potential hazards improved performance on the hazard perception test (Wallis & Horswill, 2007). Since hazard perception ability is related to crash risk, these findings imply that novice training methods should focus on recognizing anticipatory cues, and encouraging anticipatory rather than delayed avoidance responding. As a consequence of the success of these techniques, driving hazard perception tests are now being used as part of driver licensing process[5], and use of virtual environments offers great potential to train hazard perception without exposing trainees to hazards.

4.5 Eye tracking as a measure of cognition

Training for disaster response and rescue operations where events are entirely unpredictable is different to training in some other high stress environments such as aviation where event progression can often be more easily modeled. Different techniques are required for obtaining objective measures of trainees' performances.

The use of retrospective self-reports may hinder rather than support such a process. The overuse of subjective evaluation methods for complex cognitions continues to be problematic in human-machine system design and development (Stephane & Boy, 2005). Real-time collection and interpretation of performance data is required to support the training process (Cannon-Bowers & Salas, 1998). In attempts to move from outcome to process measurement approaches, eye tracking and cognitive modeling have been used to evaluate user-interfaces and to evaluate visual displays to support tactical decision making (Morrison et al, 1997). More recently, eye tracking has moved beyond defense contexts. An example is its use in the design of radiologists' workstations (Atkins et al, 2006) and it has also been used very successfully in ascertaining the effect of training and experience on driving performance.

Initially, technological limitations made it less appealing for use in dynamic training environments. However, eye-tracking technology has developed to the point where it can now be inserted into virtual reality training environments without dramatically impacting the operator's ability to perform required tasks. Usability studies that involve investigations relating eye-tracking data to cognitive activity are leading to greater inclusion of eye tracking in evaluating user-interfaces (Jacob & Karn, 2005).

The investigation of eye movement patterns has practical application in the evaluation of virtual reality training. It also assists to inform basic knowledge of critical aspects of cognitive skill acquisition during training in high stress tasks. Current research being undertaken with the United States Air Force aims to further determine the association between cognitive processes and visual patterns to significantly extend current approaches to virtual reality-based cognitive training evaluation (Tichon, 2009).

5 eg., http://www.transport.qld.gov.au/Home/Licensing/Driver_licence/Getting_a_licence/Car/Provisional_licence/Hazard_perception_test/

Current performance measures provide information about the end result of training, such as the number of correct actions and response times. They say relatively little about the refinement of advanced cognitive tasks such as situation awareness, problem-solving and decision-making. It is difficult to measure complex cognitive skill development without strong performance measures relating to improved higher-order cognitive skills and ability to transfer newly acquired skills to the real world.

Eye-tracking allows trainee cognitive behaviour to be tracked and categorized in meaningful ways in order to examine trainee responses during different stages of virtual reality scenarios. To achieve this, a method is developed that associates eye-tracking measurements of gaze paths and cognitive models developed from experts for the specific tasks being evaluated. This tool is used as a guide to better understand elicited visual patterns for evaluation purposes. Some initial research into eye tracking has occurred based on what is known about skill learning, that people can learn to distinguish between task-relevant information and task-irrelevant information (Sohn et al, 2000). Interface usability studies that have incorporated eye tracking have reported differences between novice and more experienced participants (Jacob & Karn, 2005) suggesting it would be useful to investigate the process by which people evolve from novice to experts – the goal of providing practice in a simulated environment – via visual patterns.

In terms of the analysis, learning should be reflected in the pattern of attention distribution or eye fixation. That is, people should learn to pay more attention to on-task regions relative to off-task regions with practice (Sohn et al, 2000). A measure of the success of training is whether time spent looking at irrelevant regions falls, and conversely, time looking at relevant ones increases. An applied example of this from the mining sector: when a shuttle car operator detects a presence in the path of the shuttle car, perhaps just a glimmer of reflected light, their eye-movements should next reveal more attention on the cue attempting to discern it's nature through shape, size or movements (Kowalski-Trakofler & Barrett, 2003).

To gain these measures, eye movements are tracked throughout virtual reality training scenario runs. Data is generally collected for both left and right eyes using a head-mounted eye tracker to capture visual patterns (sequences of eye points of gaze). The metrics that have been tested most frequently eye tracking research to date include:

- Number of fixations overall. This is thought to be negatively correlated with search efficiency.
- Gaze percent on each area of interest. The proportion of time looking at a particular scene element could reflect the importance of information located there.
- Fixation duration mean, overall. Longer fixations (or gazes) are generally believed to be an indication of a participant's difficulty extracting information from a display.
- Number of fixations on each area of interest. Used to study the number of fixations across tasks of differing overall duration. More important display elements should be fixated more.
- Gaze duration mean, on each area of interest – gaze will be longer if user has difficulty interpreting information.
- Scan path (sequence of fixations) – may be used to indicate efficiency of the arrangement of information in the training scene.
- Number of gazes on each cue.
- Percent of users fixating on an area.
- Time to 1st fixation on target area of interest – is useful when a specific search target exists.

Eye-movement patterns reveal the degree of interest paid to different parts of the virtual reality training scene. Instances requiring problem-solving/decision-making will be correlated with eye movements to ensure that the highest levels of mental effort are occurring at the points in the scenario requiring high level cognitive skills to negotiate. Eye-movement pattern analysis should reveal visual patterns that reflect recognition and use of the key cues inserted into the scene as part of the learning design. Comparisons against the benchmark of expert visual patterns for the same scene can indicate improvements.

4.6 Skills acquisition

Investigation of the impact of virtual reality training on operational skills acquisition, both in the short and long term, has been employed to assess virtual reality training scenarios since their first inception. Although criticised more recently for focusing on end of task rather than intermediate processing, these tests can provide data comparing virtual reality training to traditional training techniques and provide insight into the impact of training back in real world workplaces across a number of outcome variables related to operational skills. While not able to measure the processing of cognitive skills such as hazard awareness directly, they can indirectly investigate variables associated with the outcome of decisions-made and actions taken as a result of prior training and are therefore briefly mentioned here.

The aim of research designed to measure operational skills, as with cognitive skills, are also often designed to assess virtual reality training scenarios based on their targeted influence of the key factors that best reveal novice/expert differences in performance. This is most often done via a comparative analysis of control and experimental group behavioural skills testing both immediately post training and longitudinally after both groups of trainees are back at work.

Short term analysis of outcome variables related to operational skills such as adherence to safe operating procedures immediately post training can provide data on the effectiveness of virtual reality versus traditional training techniques. Long term measures provide an opportunity to explore whether virtual reality training has transferred successfully to the real world. Longitudinal studies in driving analyze long term accident statistics. Maintenance data can also be considered, with evidence that fuel efficiency and maintenance costs related to the operation of heavy machinery can all be improved through simulator training (Strayer et al, 2004).

A comparison of annual mines accident/incident rates from personnel who accessed virtual reality training versus those who accessed traditional training methods could provide an indication as to whether the performance outcomes achieved in virtual reality training transfer to the real world. In their assessment of hazard perception training for miners using degraded slide-based illustrations, Kowalski-Trakofler & Barrett (2003) used a three-year design in which lost-time injuries in the year prior to training, the year of training and the year post-training were compared. Similarly, to investigate the overall effectiveness of virtual reality training, the annual incident rates for the year before training and the year after training for a company's personnel who have undergone the training could be examined for positive impact.

4.7 Affect

In the past decade, the topic of 'affective computing' is an area of computer and information science receiving increasing attention. Affective computing is computing that relates to, arises from, or deliberately influences emotions (Picard, 2000). Affective state is a key variable for investigation in the development and evaluation of virtual reality training.

Emotions play an essential role in decision-making (Norman, 2004). Negative, affective states such as stress can negatively affect decision-making and learning abilities. Little emotion can also impair decision-making. Both experienced, and perceived, affect has been shown to influence higher-order mental abilities such as situation assessment and decision-making. It can cause undue anxiety or fear, overestimation of risks and poor decision making as a consequence. It can also be a distraction when it provides information or motivation to attend to or act on emotional information, at the expense of more important content (Peters et al., 2006).

Consequently, the impact of high affect requires consideration when training complex cognitive skills. However, while the causes and manifesting features of various user affective states have been extensively investigated in psychology, computer vision, physiology, behavioral science, ergonomics and human factors engineering for the purposes of developing intelligent user affect recognition and assistance systems (Breazeal, 1999; Liao et al, 2006), user affective states has rarely been applied to investigations of factors which mediate the effectiveness or failure of virtual reality training.

While virtual reality has been demonstrated to enhance the development of quality decision making skills, particularly under the stress imposed by time limitations (Romano & Brna, 2001), there remains a general lack of knowledge as to what factors are most important for learning, and how these are mediated by important variables such as the learner and information representations used in virtual reality (Wilfred et al, 2004).

Affective considerations are critical to situations of first response where there is the potential to reduce human error by considering user affective states during design of the virtual reality training scenarios. Ensuring the virtual reality experience replicates emotional reactions within users similar to what they will experience in the real world and then using the virtual reality scene to assist trainees to develop the cognitive skills to mitigate their effects is critical to successful training outcomes i.e., successful completion of a task, achieving optimal performance, and for improving learning and decision-making capability.

Additionally, when decision options are unfamiliar to the decision maker/trainee, providing them with appropriate 'affective cues' in training may help provide meaning to the information presented (Peters et al, 2006). In complex disaster response scenes the psychological and emotional reactions to simulated events will impact on both performance and ability to recognize task requirements. Clearly immersive virtual environments have potential advantages over traditional classroom training techniques in replicating emotional responses.

Research identifying the psychological impact of virtual reality training environments has enabled a shift from an emphasis on quality of image or graphic perfection to investigations of the emotional experience/ level of engagement of the user. Measurement of user affect during simulation-based training is limited and has relied heavily on subjective self-reports and psychological surveys (Stetz, 2007; Wilfred et al, 2004). Real-time classification of evoked emotions using facial feature tracking is a very recent field of endeavor (Bailenson et al., 2008) but with potential to value-add significantly to virtual reality training evaluation.

Recent work undertaken by Liao and colleagues (2006) to develop an intelligent user affect recognition and assistance system focuses on recognizing human affect from external symptoms using feature extraction via computer vision techniques. Commencing with eye detection and tracking Liao and his associates developed a set of non-invasive computer vision techniques for monitoring eyelid movement, eye gaze, head movement and facial expression from which visual features that can characterize a person's affective states were extracted.

4.8 Immersion and presence

Another psychological concept which has been at the centre of virtual reality training evaluations for more than a decade is that of 'presence'. Presence has been described 'as the subjective experience of being in one place or environment, even when one is physically situated in another' (Witmer & Singer, 1998).

Psychologically, a successful virtual experience is described as one in which the user becomes involved in the virtual training environment to the point where he or she experiences a sense of presence in the virtual world or of 'really being there' (Juang & Alessi, 2000). The ability of virtual reality to develop critical thinking and decision-making skills in users rests in its ability to make an individual feel they are present or immersed in the virtual environment (Romano & Brna, 2001).

A major source of knowledge on which trainees will ultimately rely, is their own experiences of dealing with different situations within the virtual environment. A strong sense of presence is consequently essential to ensure the quality of the training, so that their experience in the virtual environment produces recallable knowledge in the real world.

Presence is reported as one of the major features needed to ensure the transfer of knowledge from the virtual to the real world (Romano & Brna, 2001). Riva and Gamberini (2000) have gone as far as to claim that the effectiveness of virtual reality applications in education are more strongly dependent on the sense of presence felt by the trainee, than image quality in the virtual reality.

Sense of presence has therefore been widely researched as a key construct facilitating the effectiveness of virtual reality and educational training and the two do seem to be inextricably tied (Lombard & Ditton, 1997; Witmer & Singer, 1998). It is well established that meaningfulness and coherence of a stimulus set promotes learning (Underwood & Schulz, 1960) and in virtual reality presence has been identified as a key requirement in achieving this (Witmer & Singer, 1998). As with learning, presence is enhanced through attention, and eroded by distraction. Learning has been shown to be aided by requiring responses that are natural for the learner in a given situation (Seligman, 1970). Presence is enhanced by a virtual environment in which interactions and responses feel natural.

Considerable research has been devoted to discovering what other variables might contribute to an enhanced sense of presence (Sheridan, 1992; Slater & Usoh, 1993; Banos et al, 2004). A large number of presence measures use a causal factorial experimental approach to measurement (Lessiter et al, 2001; Schubert et al, 2001; Witmer et al, 2005). An alternative approach is to ask users to retrospectively introspect on their experiences in the virtual environment (Schubert et al, 2001).

The Presence Questionnaire (PQ) developed by Witmer and Singer (1998; Witmar et al 2005) within the U.S. Army Research Institute for the Behavioral and Social Sciences, Simulator Systems Research Unit, is one survey that has gained a significant level of acceptance and has been tested across a number of studies (Stanney et al, 2002; Jung et al, 2008; Eastin & Griffiths, 2009; Fiore et al, 2009).

The PQ measures participant's perception of display system features across four factors:

- Involvement occurs if the virtual environment is successful in causing the user to focus their mental energy and attention on a coherent set of stimuli or meaningfully related events. Involvement increases when the interface feels natural and facilitates the user's ability to control activities in the virtual environment.
- Sensory Fidelity can influence the user's energy and attention. It is proposed that poor sensory fidelity would distract the user's attention away from the required task. The more the sensory information is engaging and makes sense to the user the more likely they will be able to ignore external distractions to their experience of presence.
- Adaptation/Immersion is related to the user's ability to adapt to the virtual environment. Participants who adjust quickly and readily to the virtual environment and its interfaces are more likely to feel immersed in the virtual environment. Within this factor the user's perceived proficiency of interacting with and operating in the virtual environment will impact how quickly they adjust to the virtual environment.
- Interface Quality should influence presence; for example a poor interface would be likely to increase the time it takes to adapt, translating into performance deficits. This factor hypothesizes that the increased degree of ability to search, survey or examine objects in the virtual environment will correlate to increased presence.

As alternatives to causal factorial approaches to presence measurement, another approach is to ask users to retrospectively introspect on their experiences in the Virtual Environment. The main criticisms of introspection are related to the need for subjectivity in responses. Slater (1993) claims self-report is not appropriate for measuring presence because the measurement becomes inexplicably tied to personal aspects of the user.

Nisbett & Wilson (1977) similarly argue that introspective reports do not function as memories of mental process, but rather they are a process of the subject constructing an explanation of their behavior based on personal theories of behavior. Even if virtual environment participants have same experience, therefore, it is unlikely they would report the identical experience (Slater & Usoh, 1993). However, the measurements of causal factors of Presence also rely on self report. In utilizing any self-report measure of Presence it must be considered that results can be tied to the personal aspects of the user.

Physiological measures for presence can be recorded fairly unobtrusively as the subject is participating in the virtual environment, potentially allowing for a real-time response to the subject's level of presence. Possible physiological measures for presence include posture, muscle tension, and cardiovascular, respiration rate, skin conductance/temperature and bio-chemical measures including salivary amylase and cortisol levels (Lombard & Ditton, 1997; Stetz, 2007; Witmer & Singer, 1998).

4.9 Immersive tendency

Although less research has been conducted on the question of the impact of individual characteristics, it has been acknowledged by some that characteristics of users/trainees are important determinants of presence. Two variables important in this regard are highlighted by Lombard & Ditton (1997) as the virtual reality user's willingness to suspend disbelief and her/his knowledge of and prior experience with the medium. It has been suggested that individuals who have a tendency to become more involved in other tasks in their lives will also have greater immersive tendencies in a virtual environment (Witmer & Singer, 1998).

The Immersive Tendencies Questionnaire (ITQ) was developed to measure differences in the tendencies of individuals to experience presence (Witmer & Singer, 1998). The ITQ measures involvement in common activities and correlation data support it as a measure of the tendency to experience presence. High ITQ scores should correlate to an individual reporting a higher experience of presence in virtual reality.

Previous studies report mixed results on this (Witmer & Singer, 1998). It has been suggested this may be because the measure has not always been individualized for the experimental group. Using the ITQ, the immersive tendencies of first responders being trained in higher-order mental abilities in virtual reality scenarios replicating terrorist chemical weapons attacks were found to have a strong impact on presence (Wilfred et al, 2004). It does seem clear that to some extent individual characteristics may influence the degree to which trainees are engaged by a virtual reality training scene.

4.10 Simulator sickness

Simulator sickness is a concern because people who experience simulator sickness may not be able to maintain concentration, either interfering with immersion levels, or resulting in withdrawal from training. While up to 95% of people can experience some degree of simulator sickness (Stanney & Salvendy, 1998) typically only around 20% to 30% of individuals experience sickness to the extent that they cannot continue to operate a vehicle simulator (Masciocchi et al, 2007).

Some individuals, such as older people, may be at increased risk for simulator sickness (Arns & Cerney, 2005). Effects can last for hours potentially affecting the trainee when he or she leaves the training facility. Longer immersions were found to progressively induce more sickness, however symptoms tend to be less severe after a few repeated immersions (Kennedy et al, 2000)

There are several theories regarding the cause of simulator sickness. The most popular is the view that simulator sickness is a form of motion sickness induced by discrepancies between visual and vestibular information. There are also several contributing factors that can be manipulated to reduce discomfort (Masciocchi et al, 2007). Several researchers have suggested that providing individuals with rest frames may reduce simulator sickness (Duh et al, 2004). A rest frame is any object that an individual perceives to be stationary and that can aid people in determining which other objects in the environment are stationary and which are in motion. People who have difficulty identifying a rest frame in a virtual environment are more likely to experience simulator sickness.

It may be of benefit to training providers to determine the extent to which simulator sickness is interfering in the learning experience of their individual virtual reality programs. The simulator sickness questionnaire (SSQ) which was developed by Kennedy et al (1993) has been used to measure participant's reported level of simulator sickness after completing virtual reality training. The SSQ contains 16 questions regarding potential symptoms of simulator sickness investigated via three subscales: nausea, oculomotor discomfort, and disorientation. Participants are instructed to report via Likert scale the extent to which they experience each of an assortment of symptoms. Use of this questionnaire post-training for snowplow operators found that participants' simulator sickness ratings were relatively low, indicating that simulator sickness was not an obstacle to the use of immersive training for that user group (Masciocchi et al, 2007). Modern high-fidelity simulators tend to cause less simulator sickness than older models due to improvements in screen refresh rates.

4.11 Fidelity

Fidelity is a controversial subject and continues to be widely researched as a key factor in the effectiveness of virtual reality training. There is no simple direct relationship between fidelity and learning outcome, and questions remain over the level of fidelity required for successful training outcomes (Hoffman et al, 2001).

However, it is recognized that the similarity of the training environment to the actual conditions under which the trainee will perform in the real world is an important factor in virtual reality training design. While realistic rendered scenarios do not always translate directly to training effectiveness, good outcomes have been reported when virtual environments have reproduced realistic tasks and afforded trainees an engrossing experience they can relate to their real world (Baker et al, 2005).

It has also been determined that while absolute fidelity in training for stressful workplace situations is not critical for skills to be transferable, the virtual environment does need to replicate conditions similar to those that will be encountered in the real-world when the aim of training is to develop cognitive skills such as hazard perception and decision-making (Driskell & Johnston, 1998; Cannon-Bowers & Salas, 1998).

To investigate fidelity at the training level a number of categorizations of fidelity have been examined. They include physical fidelity, functional fidelity, psychological fidelity and task fidelity (Hays & Singer, 1989; Macfarlane, 1997). Task fidelity stresses the importance of creating operationally realistic simulations; it is frequently equated to aspects of physical and functional fidelity of the simulation.

Kemeny and Panerai (2003) reviewed the literature on perception within driving simulators to determine which factors most strongly contributed to high fidelity in this context. They found the primary feature of driving simulators that accounted for a user equating them to real vehicles was the quality of immersive optic flow information gained from viewing the movement of objects in the virtual reality scene. This related to all objects in the scene, including those in the periphery that were not the immediate focus of attention. A wide field of view provides a sense of optic flow that is important for visual fidelity.

4.12 Spacing

The ideal interval between virtual reality training sessions is a question of key concern across all sectors relying on virtual reality and simulator training programs. Investigations of this question have largely been limited to the medical sector. Initial indications in that field are that without further practice, skills gained from initial simulator training deteriorated after three months (Lammers et al, 2008).

Investigation of spacing repetitions is likely to become of increasingly key interest to new virtual reality training providers however findings cannot be transferred across industries. No two sectors are alike in their learning demands, and skills that vary in degree of difficulty may have to be repeated at different intervals.

Key questions virtual reality training providers, working without the benefit of an established human factors research program such as aviation, may need to consider include:

- How many virtual reality training sessions are necessary for the skills to be considered as learned (retained in Long Term Memory)?
- After the initial virtual reality training session what is the ideal interval before the second repetition?
- What is the longest period of time that can be allowed to elapse between virtual reality training sessions before memory of learned skills begins to degrade?

Clearly some of the skills tested in high affect virtual reality involve circumstances which personnel would rarely if ever experience in the real world, and this lack of repeated exposure is likely to result in some of the skills degrading over time. The role of spaced repetitions in learning theory would suggest that altering the virtual reality training program would assist to address this problem.

There has been a great deal of research on how different spacing of repetitions in time affects the strength of memory and how this effect can be applied in the practice of effective learning (Wozniak, 1995). The spacing effect indicates key aspects of memory to consider in terms of virtual reality training frequency and retention. Firstly that repetitive learning over a long period of time (spaced presentation) is more effective than repetitive learning in a short period of time (massed presentation).

This effect can be explained by the study-phase retrieval theory in which it is proposed that the first presentation is retrieved at the time of the second leading to an elaboration of the first memory trace. As long as a training session is repeated before the memory is forgotten it can regain its initial value while its stability in long term memory increases. For virtual reality training across new industries it is important to determine the longest inter-repetition interval that avoids retrieval failures. This would provide an indication as to the ideal frequency of accessing repeat training (Tichon & Wallis, 2009).

4.13 Mixed fidelity training

In many applications, exposure of trainees to virtual reality training occurs at long intervals. For example, New South Wales train drivers travel to a central training facility to access high-fidelity, immersive simulator training once every 2 years. In medical and aviation contexts, this use of high-fidelity simulation training sessions has also been described as 'sporadic forays' (Thomas, 2004). Most simulation systems are reported as monolithic, ad hoc and non-reusable (Su et al, 2005). A key feature of successful training is allowing students to repeat the activities for as long as it takes to master the concepts, principles and skills (Barfield & Furness, 1995). Infrequent, *ad hoc* usage alone is unlikely to achieve high levels of learning.

Preliminary research in aviation and medicine indicates that a higher transfer of training can be achieved through expanding the simulation curriculum beyond the initial complete immersion in stressful scenarios via high fidelity interfaces. While the experiential nature of simulation-based training is an obvious benefit to learning, it is suggested that its potential could be maximized with a greater emphasis placed on the essential events of instruction which occur pre-and post the simulator events. Integrated curriculum structures that wrap low-fidelity desktop scenarios around high-fidelity simulation have been proposed both in commercial aviation and anesthesia crisis resource management (Thomas, 2004).

Such an approach to simulator training may to assist to overcome the logistical barriers faced when attempting to deliver regular immersive virtual reality training to large numbers of distributed personnel. The ability of desktop computers to support the high-affect experiential component of virtual reality training rests on targeting its use to specific areas of the curricula.

There may be benefits of delivering some sections of the curriculum, such as pre-simulation briefing and opportunity for subsequent reflection on actions and practice, via a desktop simulation. The question has been raised regarding whether the high-fidelity simulation provides only the experiential component for a learning process, that actually begins prior to the simulation and that, in fact, the majority of the learning actually takes place during the post-simulation debrief and subsequent reflection on actions (Thomas, 2004).

A mix of low and high fidelity interfaces to deliver simulator training may achieve more effective learning outcomes than relying solely on a high-fidelity simulator in a standalone curriculum design. An appropriate mix of simulation technologies must be chosen that is best suited to the task. The US military has reported that hybrid solutions have been shown to be ideal in many cases (Orlansky et al, 1997), and there is evidence that some industries outside the military have begun to explore the hybrid desktop approach. In the power plant operation area, the implementation of the desktop simulation training as a complement to a full-scope training simulator program has been found to shorten training time and decrease time away from the plant to undertake training (CTI Simulation International Corp., 2006).

5.0 Conclusions

Virtual reality has been demonstrated to be an effective medium for training perceptuo-motor skills of pilots, surgeons, and drivers of a range of vehicles including cars, trains, trucks and snow plows. Novice drivers' hazard perception abilities can be improved via training in a virtual reality environment, as can children's road crossing behaviour. Maintenance inspection tasks have been shown to benefit from training in virtual environments, and spatial awareness for specific locations can be similarly trained. Evidence exists to support the use of simulation to improve decision making under stress, and there is evidence to suggest crew resource management training, and team training, may be successfully undertaken in virtual environments.

The following principles for obtaining maximum benefit from the use of virtual reality simulation as a training medium may be derived from current evidence:

- The use of simulation should be an integrated part of a training plan (derived from a systematic training needs analysis) which includes clearly stated goals, quantitative performance measures, and trainee feedback.
- Trainee feedback should be referenced to operational requirements.
- An event-based approach should be used in which trainees are presented with discrete scenario-based training events which allow practice of the specific skills (identified through systematic task analysis) that would be required in real-life situations.
- Trainees should be given the opportunity to make, detect, and correct errors without adverse consequences.
- Trainees should experience success or a sense of mastery during the training.
- Interaction with the simulation is a factor which contributes to high levels of presence/ immersion, which in turn supports the transfer of knowledge to the real world. Consequently, simulators should provide an experience in which trainees are active participants rather than passive bystanders
- Skill development requires practice. Trainees should have opportunity for repeated practice under operational conditions similar to the real-world.
- Simulator sickness may cause trainees to disengage from the immersion, and should be avoided as far as possible.
- Effective transfer to high stress operational environments occurs in conjunction with higher levels of perceived affective intensity within the virtual environment, and consequently, the virtual world should aims to recreate the same stress levels.
- Fidelity may be necessary to ensure trainee acceptance, however it is not necessarily always required for effective cognitive skills training.
- Mixed fidelity approaches to the use of simulation in which combinations of different simulation technologies of varying degrees of immersion, coupled with practice in real world environments, may provide the most effective training regime.

The use of virtual reality as medium for training in the mining sector is currently largely still at prototype stage, and rigorous and systematic evaluations have not been undertaken. However, the industry is in strong position to benefit from the research and development undertaken by other industries, and there are considerable potential benefits of virtual reality as a training medium for the mining sector. Virtual reality offers a means of enabling staff to familiarise themselves with hazardous situations without the risk of injury. Immersive training in degraded or emergency conditions targeting cognitive skills such as problem-solving, decision-making and hazard perception has the potential to greatly reduce the impact of such events.

This literature review provides a foundation for an accompanying proposal for the evaluation of virtual reality training programs for safety related training provided by Coal Services Mines Rescue. The proposed evaluation will provide a principled basis for future training practice by Coal Services Mines Rescue. It will also be one of the most comprehensive evaluations of virtual reality training undertaken in any industry, and will place Coal Services Mines Rescue at the forefront of virtual reality training evaluation research internationally.

6.0 References

Abernethy, B. (2001) Learning from experts: How the study of expertise might help design more effective training. In Stevenson, M. & Talbot, J. (Eds). *Proceedings of the 37th Annual Conference of the Ergonomics Society of Australia*. (pp. 3-12). Canberra: ESA.

Aggarwal, R, Undre, S, Moorthy, K, Vincent, C, & Darzi, A. (2004) The simulated operating theatre: comprehensive training for surgical teams. *Quality and Safety in Health Care, 13*, i27-i32.

Andews, DH, & Bell, HH. (2000) Simulation-based training. In S. Tobias & JD Fletcher (Eds.), *Training and retraining: A handbook for business, industry, government, and the military* (pp. 357–384). New York, NY: Macmillan.

Arns LL and Cerney, MM. (2005) The relationship between age and incidence of cybersickness among immersive environment users. *Proceedings of the 2005 IEEE Conference on Virtual Reality*, 267-268.

Atkins, MS, Moise, A. & Rohling, R. (2006) An application of eye gaze tracking for designing radiologists' workstations. *ACM Transactions on Applied Perception, 3(2)*, 136-151.

Bailenson, JN Pontikakis ED, Mauss IB, Gross JJ, Jabon, ME Hutcherson CAC, Nass C, Oliver J. (2008) Real-time classification of evoked emotions using facial feature tracking and physiological responses. *International Journal of Human-Computer Studies, 66,* 303-317.

Baker, DP, Gustafson, S, Beaubien, J, Salas E, & Barach, P. (2005) Medical teamwork and patient safety: the evidence- based relation. AHRQ Publication No. 05-0053. Rockville, MD: Agency for Healthcare Research & Quality.

Banos RM, Botella C, Alcaniz M, Liano BA, Guerrero B, Rey B. (2004) Immersion and emotion: Their impact on the sense of presence. *Cyberpsychology & Behavior, 7*, 734-740.

Barfield W, & Furness TA. (1995) *Virtual Environments and Advanced Interface Design*. New York: Oxford Press.

Barnett, B, Helbing, K, Hancock, G, Heininger, R, & Perrin, B. (2000) An evaluation of the training effectiveness of virtual environments. *Proceedings of the Interservice/Industry Training, Simulation and education conference (I/ITSEC 2000)*. Orlando FL

Bell, B, Kanar, A, & Kozlowski, S. (2008) Current issues and future directions in simulation-based training in North America, The International *Journal of Human Resource Management, 19,* 1416 - 1434.

Biocca, F., & Delaney, B. (1995) Immersive virtual reality technology. In: Biocca, F., Levy, M.R., (eds.) *Communication in the Age of Virtual Reality.* Hillsdale NJ: Lawrence Erlbaum Associates, 57-124.

Bise, CJ, (1997) Virtual Reality: Emerging Technology for Training of Miners. *Mining Engineering, 49(1)*, 37-41.

Blickensderfer, B, Liu, D, & Hernandez, A, (2005) Simulation-Based Training: Applying lessons learned in aviation to surface transportation modes. http://catss.ucf.edu/projects/documents/reports/pdf/ProjectFR_AviationSurface.pdf.

Blignaut, CJH. (1979) The perception of hazard. II. The contribution of signal detection to hazard perception. *Ergonomics, 22*, 1177-1185.

Bossard, C, Kermearrec, G, Buche, C, & Tisseau, J. (2008) Transfer of learning in virtual environments: a new challenge? *Virtual Reality, 12*, 151-161.

Bowman DA & Schuchardt P. (2007) The benefits of immersion for spatial understanding of complex underground cave systems. *Proceedings of the ACM Symposium on Virtual Reality Software and technology,* 121-124.

Bowman DA, & McMahan RP. (2007) Virtual Reality: How much immersion is enough? *Computer 40*, 36-43.

Breazeal, C. (1999) Robot in society: Friend or appliance? *Workshop on Emotion-based Agent Architectures*,18-26.i

Bullough JD, & Rea MS. (2001) Forward vehicular lighting and inclement weather conditions. *In Proceedings of PAL 2001 Symposium, Darmstadt University of Technology*: 79-89. http://www.utzverlag.de/buecher/31971dbl.pdf

Burgess-Limerick, R & Steiner, L. (2006) Injuries Associated with Continuous Miners, Shuttle Cars, Load-Haul-Dump, and Personnel Transport in New South Wales Underground Coal Mines. *Mining Technology (TIMM A) 115*, 160-168.

Cannon-Bowers J.A. and Salas E. (1998) *Making Decisions Under Stress: Implications for Individual and Team Training.* Washington DC: APA Press.

Cannon-Bowers JA, Salas, E, Blickensderfer EL & Bowers CA. (1998) The impact of cross-training and workload on team functioning: A replication and extension of initial findings. *Human Factors, 40*, 92-101.

Caretta, TR, & Dunlap, RD. (1998) *Transfer of effectiveness in flight simulation: 1986 to 1997*. US Airforce Research Laboratories: NTIS.

Chapman, P, Underwood, G, & Roberts, K. (2002) Visual search patterns in trained and untrained novice drivers. *Transportation Research Part F, 5*, 157-167.

Cliff D & Moreby R. (2005) The demonstration of electronic systems to assist in the management of a significant incident. In *Proceedings of Coal2005 Conference*, Brisbane 26-28 April, 291-298.

Committee on Technologies for the Mining Industry, National Research Council. (2002) *Evolutionary and revolutionary technologies for mining.* Washington: National Academy Press.

Congiu, M, Whelan, M, Oxley, J, Charlton, J, & Muir, C. (2008) *Child Pedestrians: Factors associated with ability to cross roads safely and development of a training package.* Monash University Accident Research Centre - Report #283. http://www.monash.edu.au/muarc/reports/muarc283.html

Cosman, PH, Hugh, TJ, Shearer, CJ, Merrett, ND, Biankin, AV, & Cartmill, JA. (2008) Skills acquired on a virtual reality laprascopic simulators transfer in the operating room in a blinded randomised controlled trial. In Westwood, JD, Haluck, RS, Hoffman, HM, Mogel, GT, Phillips, R, Robb, RA, & Vosburgh, KG. (eds). *Medicine meets virtual reality 15*. Amsterdam: IOS Press. (pp. 76-81).

Crundall DE & Underwood G. (1998) Effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics 41*: 448-458.

CTI Simulation International Corp. (2006) *Desktop simulator training as complement to full-scope simulator training*. Available http://www.cti-simulation.com/ctisimulation/Simulation_articles.htm

Delabbio FC, Dunn PG, Iturregui L,Hitchcock S. (2003) The application of 3D CAD visualization and virtual reality in the mining and mineral processing industry. *CAMI*, Sept 2003, Calgary.

Denby, B, Schofield, D, McClarnon, DJ, Williams, M & Walsha, T. (1998) Hazard awareness training for mining situations using virtual reality. *APCOM '98 27th International Symposium on Computer Applications in the Minerals Industries*, London, 695-705.

Dezelic, V. Apel, DB, Denney, DB, Schneider, AJ, Hilgers, MG, Grayson, LR. (2005) "Training for new underground rockbolters using virtual reality", *The Sixth International Conference on Computer Applications in the Minerals Industries (CAMI)*, September 2005, Banff, Canada.

Dorn L & Barker D. (2005) The effects of driver training on simulated driving performance. *Accident and Analysis and Prevention, 37*, 63-69.

Driskell JE & Johnston JH. (1998) Stress exposure training, in JA Cannon-Bowers & E Salas (eds.), *Making decisions under stress: Implications for individual and team training*, Washington, DC: American Psychological Association, 191-217.

Driskell, JE, Johnston, JH, Salas, E. (2001) Does Stress Training Generalize to Novel Settings? *Human Factors, 43*, 99-110.

Duh, HBL, Parker, DE, Furness, TA. (2004) An independent visual background reduced simulator sickness in a driving simulator. *Presence, 13*, 578-588.

Eastin, MS & Griffiths, RP. (2009) Beyond the shooter game: Examining presence and hostile outcomes among male game players. *Communication Research, 33 (6),* 448-466.

Eichinger, MJ & Geraghty, B. (2005) Multi-purpose Reconfigurable Simulations for Rail Operations Research and Operator Training - A Case Study of the Challenges of the Introduction of Simulation into the Sugar Industry. *SimTect 2005.* www.siaa.asn.au/get/2411853334.pdf

Ellis, AM, Morris, RW & Hendrickse, AD. (2002) Simulation and training for military resuscitation teams. *Australian Military Medicine, 11*, 12-18.

Endsley, MR (1988) Situation Awareness global assessment technique (SAGAT). *Proceedings of the National Aerospace and Electronics Conference (NAECON)* New York: IEEE, 789-95.

Enriquez M, Afonin O, Yager B, Maclean K (2001) A pneumatic tactile alerting system for the driving environment. *In Proceedings of the 2001 Workshop on Perceptive User Interfaces*: 1-7.

Ericsson, KA Krampe, RT & Tesch-Romer, C. (1993) The role of deliberate practice in the acquisition of expert performance, *Psychological Review, 100*, 363-406.

Filigenzi MT, Orr TJ, Ruff TM. (2000) Virtual Reality for Mine Safety Training. *Applied Occupational and Environmental Hygiene. 15(6),* 465-469.

Fiore, SM. Harrison, GW, Hughes, C. & Rutstrom, E. (2009) Virtual experiments and environmental policy. *Journal of Environmental Economics and Management, 57,* 65-86.

Fisher, DL, Pollatsek, AP, Pradhan, A. (2006) Can novice drivers be trained to scan for information that will reduce their likelihood of a crash? *Injury Prevention, 12(Suppl.1)*, i25-i29.

Fisher, NE, Laurie, R, Glaser, K, Connerney, A Pollatsek, SA & Duffy, JB. (2002) Use of a Fixed-Base Driving Simulator to Evaluate the Effects of Experience and PC-Based Risk Awareness Training on Drivers' Decisions. *Human Factors, 44*, 287-302.

Fowlkes, JE, Salas, E, Baker, DP, Cannon-Bowers, JA, & Stout, RE. (2000) The Utility of Event-Based Knowledge Elicitation. *Human Factors, 42*, 24.

Gerbaud, S, Mollet N, Ganier F, Arnaldi B, Tisseau, J. (2008) GVT: a platform to create virtual environments for procedural training. *Proceedings of IEEE Virtual Reality*, 8-12 March, Reno, Nevada, 225-232.

Gilhooley, KJ & Green, AJK. (1988) The use of memory by experts and novices. In A.M. Colley & J.R. Beech (Eds). *Cognition and action in skilled behavior.* Amsterdam: North-Holland. pp 379-395.

Gillies ADS, Wu HW, Humphreys D. (2005) Spontaneous Combustion and Simulation of Mine Fires and their effects on mine ventilation systems. *Proceedings of Coal2005 Conference*, 225-236.

Glaser, R & Chi, MTH. (1988) Overview. In M.T.H. Chi, R. Glaser and M.J. Farr (Eds). *The nature of expertise.* Hillsdale, NJ: Erlbaum. pp. xv-xxvii.

Gordon, S.E. (1994) *Systematic training program design: Maximising effectiveness and minimizing liability*. Englewood Cliffs, NJ: Prentice Hall.

Grantcharov, TP, Kristiansen, VB, Bendix, J, Bardram, L, Rosenberg, J, & Funch-Jensen, P. (2004) Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *British Journal of Surgery, 91(2)*, 146-150.

Greenberg J, Tijerina L, Curry R, Artz B, Cathey L, Grant P, Kochhar D, Kozak K & Blommer M (2003) Evaluation of driver distraction using an event detection paradigm. *Journal of Transportation Research Board, 1843*, 1-9.

Guido, M, Montrucchio, C. (2006) Modelling & Simulation for Experimentation, Test & Evaluation and Training: Alenia Aeronautica Experiences and Perspectives. In *Transforming Training and Experimentation through Modelling and Simulation* (pp. 5-1 – 5-16). Meeting Proceedings RTO-MP-MSG-045, Paper 5. Neuilly-sur-Seine, France: RTO. Available at http://ftp.rta.nato.int/public//PubFullText/RTO/MP/RTO-MP-MSG-045///MP-MSG-045-05.pdf

Gurusamy, K, Aggarwal, R, Palanivelu, L & Davidson, BR. (2008) Systematic review of randomized controlled trials on the effectiveness of virtual reality training for laparoscopic surgery. *British Journal of Surgery, 95(9)* 1088-1097.

Hall, R.H., Wilfred, L.M., Hilgers, M.G., Leu, M.C., Walker C.P. & Hortenstine, J.M. (2004) Virtual Terrorist Attack on the Computer Science Building: Design and Evaluation of a Research Methodology, Presence-Connect, 4(4) http://lite.mst.edu/documents/vr_affect_presence_connect_2004.pdf

Hall, RH, Nutakor, D, Ape, D, Grayson, L, Hilgers, MG, & Warmbolt, J. (2008) Evaluation of a virtual reality simulator developed for training miners to install rock bolts using a Jackleg drill. *Proceedings of the Annual Conference of the Society for Mining Engineers.*

Hamblin, CJ. (2005) *Transfer of training from virtual reality environments*. PhD thesis, Wichita State University. Available at http://soar.wichita.edu/dspace/bitstream/10057/635/1/d05006

Hays RT, Jacobs JW, Prince C & Salas E (1992) Flight simulator effectiveness: A meta-analysis. *Military Psychology, 4(2)*, 63-74.

Hays RT, & Singer MJ. (1989) *Simulator fidelity in training systems design: bridging the gap between reality and training.* Springer-Verlag: New York.

Helmreich RL, & Foushee HC. (1993) Why crew resource management? Empirical and theoretical bases of human factors training in aviation. In E.L. Wiener, B.G. Kanki, and R.L. Helmreich, *Cockpit Resource Management*, San Diego, CA: Academic Press.

Helmreich RL, Merritt AC, & Wilhelm, JA. (1999) The evolution of Crew Resource Management training in commercial aviation. *International Journal of Aviation Psychology, 9(1)*, 19-32

Hilgers MG, Hall RH, Leu M, Reddy M, Lambert T, Agarwal S, Warmbrodt J, & Nebel K. (2005) *The First Responder Simulation and Training Environment (FiRSTE) Project: Development and Evaluation*, Laboratory for Information Technology Evaluation Technical Report, University of Missouri-Rola. Available at http://lite.mst.edu/tech_reports.html

Hill A, Karamatic R, Horswill MS, Watson MO, Basit T, Plooy AM, Zupanc C, Riek SP, Wallis GM, Burgess-Limerick R, Hewett DG. (2009) A Systematic Comparison Of The Realism Of Four Colonoscopy Simulators. *Australian Gastroenterology Week*, Sydney, Australia, 2009.

Hoffman H, Garcia-Palacios A, Thomas A, and Schmidt A. (2001) Virtual Reality Monitoring: Phenomenal Characteristics of Real, Virtual and False Memories, *Cyberpsychology & Behaviour, 4 (5)*, 565-572.

Hoffman, RR, Crandall, B, & Shadbolt, N. (1998) Use of the critical decision method to elicit expert knowledge: a case study in the methodology of cognitive task analysis. *Human Factors, 40*, 254-277

Holcomb, JB, Dumire, RD, Crommett, JW, Stamateris, C, Fagert, MA, Cleveland, JA, Dorlac, GR, Dorlac, WC, Bonar, JP, Hira, K, Aoki, N, & Mattox, K. (2002) Evaluation of trauma team performance using an advanced human patient simulator for resuscitation training, *The Journal of Trauma: Injury, Infection, and Critical Care, 52*, 1078-1086.

Horswill MS, & Helman S. (2003) A behavioral comparison between motorcyclists and a matched group of non-motorcycling car drivers: Factors influencing accident risk. *Accident Analysis and prevention, 35,* 589-597.

Horswill MS, & McKenna FP. (2004) Driver's hazard perception ability: situation awareness on the road. In S. Banbury & S. Tremblay (Eds.) *A Cognitive Approach to Situation Awareness* (pp. 155-175). Aldershot, UK: Ashgate.

Issenberg B, Mcgaghie W, Petrusa E, Lee G, & Scalese, R. (2005). Features and uses of high-fidelity medical simulations that lead to effective learning: A BEME systematic review. *Medical Teacher, 27*, 10-28.

Jacob RJK, & Karn KS. (2005) *Commentary on Section 4. Eye tracking in human-computer interaction and usability research: Ready to deliver the promises.* http://www.cs.tufts.edu/~jacob/papers/ecem.pdf

Jacobs JW, Prince C, Hays RT, & Salas E (1990) *A meta-analysis of the flight simulator training research*. Human Factors division, Naval Training Systems Center. NAVTRASYSCEN TR-89-006.

Jia D, Bhatti A, & Nahavandi, S. (2008) Computer-Simulated Environment for Training: Challenge of Efficacy Evaluation, *Simtect 2008*. Available at www.siaa.asn.au/get/2451314006.pdf

Juang M, & Alessi NE. (2000) An introduction to virtual reality in psychiatry. *Canadian Psychiatric Association Bulletin, 32*, 1-3.

Jung, D, Jo, S. & Myung, R. (2008) A study of relationships between situation awareness and presence that affect performance on a handheld game console. *Advances in Computer Entertainment Technology*, 240-243.

Kaiser PK, Vasak P, Suorineni FT. (2005) Hazard assessment in burst prone mines. *Eurock 2005: Impact of Human Activity on the geological Environment. Proceedings of the International Symposium of the International Society for Rock Mechanics.* Leiden: New York. 239-247.

Karamatic R, Basit T, Hill A, Horswill MS, Watson MO, Plooy AM, Zupanc C, Riek SP, Wallis GM, Burgess-Limerick R, Hewett DG. (2009) Colonoscopy looping management: does explicit instruction help? *Australian Gastroenterology Week*, Sydney, Australia.

Kemeny A, & Panerai F. (2003) Evaluating perception in driving simulation experiments. *Trends in Cognitive Sciences, 7(1)*:31-376

Kennedy RS, Lane NE, Berbaum KS & Liliethal MG. (1993) A simulator sickness questionnaire (SSQ): A new method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*: 203-220.

Kennedy R, Stanney S, Dunlap W. (2000) Duration and exposure to virtual environments: Sickness curves during and across sessions. *Presence 9(5)*, 463-472.

Ki, J. (2009) Interactive training simulator for aerial working platform in a virtual environment. *Computer Applications in Engineering Education*, DOI 10.1002/cae.20358

Kihl, M, & Wolf, PJ. (2007) Using Driving Simulators to Train Snowplow Operators: The Arizona Experience. *Proceedings of the 2007 Mid-Continent Transportation Research Symposium*. Ames, Iowa, August 16–17, 2007. www.intrans.iastate.edu/pubs/midcon2007/KihlSnowplow.pdf

Kizakevich PN, Culwell A, Furgerg R, Gemeinhardt D, Grantlin S, Hubal R, Stafford, A & Dombroski RT. (2007) Virtual simulation-enhanced triage training for Iraqi medical personnel. In Westwood, JD, Haluck, RS, Hoffman, HM, Mogel, GT, Phillips, R, Robb, RA, & Vosburgh, KG. (eds). *Medicine Meets Virtual Reality 15*. Amsterdam: IOS Press. (pp. 223-228).

Kizil, M. (2003) Virtual reality applications in the Australian minerals industry. *Application of Computers and Operations Research in the Minerals Industries, South African Institute of Mining and Metallurgy, 2003*. http://espace.library.uq.edu.au/eserv/UQ:99728/Kizil_2003_Apcom_South_Africa.pdf

Kizil, M, & Joy, J. (2001) 'What can virtual reality for safety?'In *Proceedings of Queensland Mining Industry health and safety Conference: Managing Safety to have a future,* 173-181.

Klein, GA, Calderwood, R, & MacGregor, D. (1989) Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man and Cybernetics, 19*, 462-472.

Knerr, BW, Breaux, R, Goldberg, SL. & Thurman, RA, (2002) National Defense. In K.M. Stanney (Ed.), *Handbook of Virtual Environments: Design, Implementation and Applications*, Erlbaum, Mahwah, NJ, 857-872.

Kowalski-Trakofler, KM, & Barrett, EA. (2003) The concept of degraded images applied to hazard recognition training in mining for reduction of lost-time injuries. *Journal of Safety Research, 34*, 515-525.

Kozlowski SWJ. (1998) Training and developing team: Theory, principles and research. In JA Cannon-Bowers & E Salas (eds.), *Making decisions under stress: Implications for individual and team training,* Washington, DC: American Psychological Association, 115-154.

Lai, F, Entin, EB, Brunye, T, Sidman, J, & Entin, EE. (2007) Evaluation of a simulation-based program for medic cognitive skills training. In Westwood, JD, Haluck, RS, Hoffman, HM, Mogel, GT, Phillips, R, Robb, RA, & Vosburgh, KG. (eds). *Medicine meets virtual reality 15*. Amsterdam: IOS Press. (pp. 259-261).

Lammers RL, Davenport, M, Korley F, Griswold-Theodorson S, Fitch MT, Narang AT, Evans LV, Gross A, Rodriguez E, Dodge KL, Hamann CJ, Robey WC, (2008) Teaching and assessing procedural skills using simulation: metrics and methodology. *Academic Emergency Medicine, 15(11)*, 1079-1087.

Lathan, CE, Tracey, MR, Sebrechts, MM, Clawson, DM, & Higgins, GA, (2002) Using virtual environments as training simulators: Measuring transfer. In K.M. Stanney (Ed.), *Handbook of Virtual Environments: Design, Implementation and Applications*, Erlbaum, Mahwah, NJ, 403-414.

Lee, CH, Liu, A, Del Castillo, S, Bowyer, M, Alverson, D, Muniz, G, & Caudell, TP (2007) Towards an immersive virtual environment for medical team training. In Westwood, JD, Haluck, RS, Hoffman, HM, Mogel, GT, Phillips, R, Robb, RA, & Vosburgh, KG. (eds). *Medicine meets virtual reality 15*. Amsterdam: IOS Press. (pp. 274-279).

Leitao JM, Moreira, A, Santos, JA, Sousa, A Ferriera FN, (1999) Evaluation of driving education methods in a driving simulator. *In proceedings of GVE 1999*, 159-164.

Lessiter J, Freeman J, Keogh E, & Davidoff J. (2001) A cross-media presence questionnaire: The ITC sense of presence inventory. *Presence: Teleoperators and Virtual Environments, 10*: 282-297.

Li G, Hamilton I, Morrisroe G, Clarke T. (2006) Driver detection and recognition of line side signals and signs at different approach speeds. *Cognition, Technology & Work 8*, 30-40.

Li QZ, Zhang LC, Wang ZL, & Zhang YB. (2008) Application of VR in Coal Mining Safety and its achieving method. *Progress in Safety Science and Technology, 7*, 1291-1294.

Li, L, Zhang, M, Xu, F, & Liu, S. (2005) *ERT-VR: an immersive virtual reality system for emergency rescue training.* Virtual Reality, 8, 194-197.

Liao, W, Zhang, W, Zhu, Z, Ji, Q, & Gray, WD. (2006) Toward a decision-theoretic framework for affect recognition and user assistance. *International Journal of Human-Computer Studies, 64 (9)*, 847-873.

Lindsey, JT. (2005) The perceptions of emergency vehicle drivers using simulation in driver training. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, 27-30 June, Rockport, Maine. http://ppc.uiowa.edu/driving-assessment/2005/final/papers/10_Lindseyformat.pdf

Lintern, G, Roscoe, SN, Koonce, JM, & Segal, LD, (1990) Transfer of landing skills in beginning flight training. *Human Factors, 32*, 319-327.

Lipshitz, R, Klein, G, Orasanu, J, & Salas, E. (2000) Taking stock of naturalistic decision making. *Journal of Behavioral Decision Making, 14*, 331-352.

Liu CC, Hosking SG, Lenne MG (2009) Hazard perception abilities of experienced and novice motorcyclists: An interactive simulator experiment. *Transportation Research Part F, 12*, 325-334.

Lombard M, & Ditton T. (1997) At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication, 3*, 1-3.

Lucas, J (2008). *Improving conveyer belt safety through the use of virtual reality.* MSc in Building Construction Management thesis. Virginia Polytechnic Institute and State University. http://scholar.lib.vt.edu/theses/available/etd-12212008-182830/unrestricted/Lucas_Thesis_Complete01-21-09.pdf

Lucas J. & Thabet W. (2008) Implementation and evaluation of a VR task-based training tool for conveyor belt safety training. *Journal of Information Technology in Construction, 13,* 637-659.

Lucas J, Thabet W, & Worlikar P. (2008) A VR-Based training program for conveyor belt safety. *Journal of Information Technology in Construction, 13,* 381-407.

Lucas, J, & Thabet, W. (2007) Benchmarking user performance by using virtual reality for task-based training. *7th International Conference on Construction Applications of Virtual Reality*, 70-79.

Lucas, J, Thabet, W, & Worlikar, P. (2007) Using Virtual Reality (VR) to Improve Conveyor Belt Safety in Surface Mining. In: *24th W78 Conference Maribor 2007 & 5th ITCEDU Workshop & 14th EG-ICE Workshop: Bringing ITC knowledge to work.* Maribor, Slovenia, 431-438.

Luke, T, Brook-Crater, N, Pares, AM, Grimes, E, & Mills, A. (2006) An investigation of train driver visual strategies. *Cognition Technology & Work, 8*, 15-29.

Macfarlane, R. (1997) Simulations as an instructional procedure, in GJF Hunt (ed) *Designing instruction for human factors training in aviation*. Ashgate: Aldershot, UK, 59-93.

MacPherson, C, & Keppell, M. (1998) Virtual reality: What is the state of play in education? *Australian Journal of Educational technology, 14 (1)*, 60-74.

Mallett L, & Orr TJ. (2008) Working in the Classroom – A vision of miner training in the 21st century. *First International Future Mining Conference*, Sydney NSW 19-21 Nov, 83-89.

Mark, C. (2002) The introduction of roof-bolting to U.S. underground coal mines (1948-1960): A cautionary tale. In Peng, S.S., Mark, C., Khair, A.W., Heasley, K. (eds.) *21st International Conference on Ground Control in Mining*. Morgantown, WV: West Virginia University, 150-160.

Marling, GJ, & Horberry, T. (2009) Operator Decision Making Before Starting and While Doing an Activity/Task: Development and Evaluation of Integrated Front-end Priming and Heuristic Risk Management Tools for Operators. *Proceedings of NDM9, the 9th International Conference on Naturalistic Decision Making London*, UK, June 2009. 362-369. http://www.bcs.org/upload/pdf/ewic_ndm09_s4paper6.pdf

Masciocchi C, Dark V, & Parkhurst D. (2007) Evaluation of Virtual Reality Snowplow Simulator Training. Iowa Dept of Transportation Technical Report, http://www.ctre.iastate.edu/reports/snowplow_simulator_final.pdf

Masciocchi, CM, Dark, VJ, & Parkhurst, DJ. (2007) Evaluation of Virtual Reality Snowplow Simulator Training. *Proceedings of the 2007 Mid-Continent Transportation Research Symposium*, Ames, Iowa, August 2007. www.intrans.iastate.edu/pubs/midcon2007/MasciocchiVirtual.pdf

McInerney, PA. (2005) *Special Commission of Inquiry into the Waterfall Rail Accident: Final Report.* Office of the Governor, New South Wales State Government.

McKenna FP, & Crick JL. (1994) *Hazard perception in driving: A methodology for testing and training* (TRL Report 313). Crowthorne, United Kingdom: Transport Research Laboratory.

McKenna FP & Horswill MS (1999) Hazard perception and its relevance for driver licensing, *Journal of the International Association of Traffic & Safety Science, 23(1)*, 26-41.

McKenna FP, Horswill, MS & Alexander, JL (2006) Does anticipation training affect driver's risk taking? *Journal of experimental psychology: Applied, 12 (1)*, 1-10.

McMahan RP, Bowman DA, Schafrik S, & Karmis M. (2008) Virtual Environment Training for Preshift Inspections of haul Trucks to improve mining safety, *First International Future Mining Conference,* Sydney, NSW, 19-21 Nov, 167-173.

McMahan, RP, Schafrik, S, Bowman, DA, & Karmis, M. (in press) Virtual Environments for Surface Mining Powered Haulage Training. *100 Years of Mining Research Symposium, 2010 SME Annual Meeting*.

MISC (2009) Project Canary: Translating Risk Knowledge to Safe Behaviour. http://www.projectcanary.com/

Morrison JG, Marshall, SP, Kelly, RT, & Moore, RA. (1997) Eye Tracking in Tactical Decision Making Environments: Implications for decision support evaluation, *Third International Command and Control research and technology symposium*, National Defense University, June 17-20.

Nichols, S, & Patel, H. (2002) Health and safety implications of virtual reality: a review of empirical evidence. *Applied Ergonomics, 33*, 251-271.

NIOSH (2009) *Underground Coal Mine Map Reading Training*. http://www.cdc.gov/niosh/mining/products/product165.htm

Nisbett RE, & Wilson TD (1977) Telling More Than We Know: Verbal Reports on Mental Processes, *Psychological Review, 84*, 231-259.

Nishisaki, A, Keren, R, & Nadkarni, V. (2007) Does Simulation Improve Patient Safety?: Self-Efficacy, Competence, Operational Performance, and Patient Safety. *Anaesthesiology Clinics, 25,* 225-236.

Norman, DA. (2004) *Emotional design: Why we love or hate everyday things.* New York: Basic books

Nullmeyer, RT, Spiker, VA, Golas, KC, Logan, RC, & Clemons, L. (2006) The effectiveness of a PC-based C-130 crew resource management aircrew training device. *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2006 Conference Proceedings*. http://www.iitsec.org/documents/Trng_2807.pdf

Nutakor, D. (2008) *Design and evaluation of a virtual reality training system for new underground rockbolters*. PhD thesis, Missouri University of Science and Technology. http://scholarsmine.mst.edu/thesis/pdf/Nutakor_09007dcc80672480.pdf

Orlansky J, Taylor HL, Levine DB, & Honig JG. (1997). Cost and Effectiveness of the Multi-Service Distributed Training Testbed (MDT2) for Training Close Air Support. Institute for Defense Analysis paper P-3284, NTIS ADA 327227.

Orr, TJ, Filigenzi, MT, & Ruff, TM. (1999). Hazard recognition computer based simulation. In Jenkins, F.M., Langton, J., McCarter, M.K. & Rowe, B. (Eds). *Proceedings of the Thirtieth Annual Institute on Mining Health, Safety and Research 1999,* 21-28.

Parkes, AM. & Reed, N. (2006) Transfer of fuel-efficient driving technique from the simulator to the road: steps towards a cost-benefit model for synthetic training. In D. de Waard, K.A. Brookhuis, and A. Toffetti (Eds.), *Developments in Human Factors in Transportation, Design, and Evaluation.* Maastricht: Shaker Publishing, 163-176.

Patterson, J (2008) The development of an accident/incident investigation system for the mining industry based on the human factors analysis and classification system (HFACS) framework. *Proceedings of the Queensland Mining Industry health and safety conference,* Townsville. http://www.qrc.org.au/conference/01_cms/details.asp?ID=84

Peters, E, Lipkus, I, & Diefenbach, MA. (2006) The functions of affect in health communications and in the construction of health preferences. *Journal of Communication, 56(s1)*, s140-s150.

Peterson, B, Stine, JL, & Darken, RP. (2004) Eliciting knowledge from military ground navigators. In H. Montgomery, R. Lipshitz and B. Brehmer (Eds.) *How Professionals Make Decisions*. Mahwah, NJ: Lawrence Erlbaum Associates.

Pfeiffer MG, Horey JD, Butrimas SK, (1991) Transfer of simulated instrument training to instrument and contact flight. *The International Journal of Aviation Psychology, 1,* 219-229.

Picard, RW. (2000). *Affective computing*. Boston: MIT Press.

Pollatsek A, Narayanaan V, Pradhan A., & Fisher, D. (2006) Using eye movements to evaluate a PC-based risk awareness and perception training program on a driving simulator. *Human Factors. 48*, 447-464.

Poplin, GS, Miller, HB, Ranger-Moore, J, Bofinger, CM, Kurzius-Spencer, M, Harris, RB, & Burgess, JF. (2008) International comparison of injury rates in coal mining: A comparison of risk and compliance-based regulatory approaches. *Safety Science, 46,* 1196-1204.

Qizhong, L, Zhang L, Wang, Z, & Zhang, Y. (2008) Application of VR in coal mine safety and its achieving method. *2008 International Symposium on Safety Science and Technology,* 1291-1294.

Readinger, WO, Chatziastros, OA, Cunningham, W, Bulthoff H, Cutting JE. (2002) Gaze-eccentricity effects on road position and steering. *Journal of Experimental Psychology: Applied, 8*, 247-258

Riva, G, & Gamberini, L. (2000) Virtual Reality in telemedicine. *Cyberpsychology & Behaviour, 5(3)*, 219-224.

Roach, GD, Dorrian, J, Fletcher, A, & Dawson, D. (2001) Comparing the effects of fatigue and alcohol consumption on locomotive engineer's performance in a rail simulator. *Journal of Human Ergology, 30*, 125-130.

Roenker, DL, Cissell, GM, Ball, KK, Wadley, VG, & Edwards, JD. (2003) Speed-of-Processing and Driving Simulator Training Result in Improved Driving Performance, *Human Factors, 45,* 218-233.

Romano DM, & Brna, P. (2001) Presence and reflection in training: Support for learning to improve quality decision-making skills under time limitations. *Cyberpsychology and Behavior, 4*, 265-277

Rose, FD, Attress, EA, Brooks, BM, Parslow, DM, Penn, PR, & Ambihaipahan, N. (2000) Training in virtual environments: transfer to real world tasks and equivalence to real world training. *Ergonomics, 43*, 494-511.

Rubio, J, Rubio, B, Vaquero, C, Galarza, N, Pelaz, A, Ipina, JL, Sagasti, D, and Jorda, L. (2009) Application of virtual reality technologies to improve occupational and industrial safety. *Safety, Reliability and Risk Analysis: Theory, Methods and Applications, Vol. 1-4*, 727-731.

Ruff TM. (2001) *Miner training simulator: User's Guide and Scripting language/documentation*. NIOSH. US Department of Health and Human Services. Pittsburg, PA, DHHS Publication No 2001-136.

Sadasivan, S, Vembar, D, Washburn, C, & Gramopadhye, A. (2007) Evaluation of Interaction Devices for Projector Based Virtual Reality Aircraft Inspection Training Environments. R. Shumaker (Ed.): *Virtual Reality, HCII 2007*, LNCS 4563, Springer-Verlag Berlin Heidelberg, 553-542.

Salas, E., Cannon-Bowers, J. (2001) The Science of training: A decade of progress. *Annual Reviews of Psychology, 52*: 471-499.

Salas, E, Oser, RL, Cannon-Bowers, JA., & Daskarolis-Kring, E. (2002) Team training in virtual environments: An event-based approach. In K.M. Stanney (Ed.), *Handbook of Virtual Environments: Design, Implementation and Ap plications*, Erlbaum, Mahwah, NJ, 873-892.

Salas, E, Rosen, M, Held, JT, & Weissmuller, J. (2009) Performance Measurement in Simulation-Base Training: A Review and Best Practices, *Simulation & Gaming, 40*, 328 - 76.

Santos, J, Merat, N, Mouta, S, Brookhuis, K, Waard, D (2005) The interaction between driving and in-vehicle information systems: Comparison of results from laboratory, simulator and real-world studies. *Transportation Research Part F: Traffic Psychology and behavior 8*,135-146.

Sarter, NB & Woods, DD. (1991) Situation awareness: a critical but ill-defined phenomenon. *International Journal of Aviation Psychology, 1,* 45-57.

Satava, RM, & Jones, SB. (2002) Medical applications of virtual environments. In K.M. Stanney (Ed.), *Handbook of Virtual Environme nts: Design, Implementation and Applications*, Erlbaum : Mahwah, NJ, 937-957.

Satish, U, & Streufert, S. (2002) Value of a cognitive simulation in medicine: towards optimizing decision making performance of healthcare personnel. *Quality and Safety in Health Care, 11*,163-168.

Schafrik, SJ, Karmis, M, & Agioutantis, Z. (2003) Methodology of incident recreation using virtual reality. *2003 SME Annual Meeting.* Feb 24-26, Cincinnati, Ohio.

Schmidt, R.A. & Bjork, R.A. (1992) New conceptualizations of practice: Common principles in three paradigms suggest new concepts for training. *Psychological Science, 3*, 207-217.

Schmitz, M. & Maag, C. (2009) *Report on transfer-of-training effects*. http://www.2train.eu/fileadmin/user_upload/D5.4.1_Report_on_transfer-of-training_effects.pdf

Schofield, D. (2008) Do you learn more when your life is in danger? How to successfully utilize virtual simulators in the minerals industries. *First International Future Mining Conference, Sydney* 19-21 Nov, 2008, 183-188.

Schofield, D, Hollands, R, & Denby, B. (2001) Mine safety in the Twenty-First century: The application of computer graphics and virtual reality. In Karmis M (Ed). *Mine Health and Safety Management.* Colorado: Society for Mining, Metallurgy, and Exploration. (pp 153-174).

Schubert T, Friedmann F, & Regenbrecht H. (2001) The experience of presence: Factor analytic insights. *Presence: Teleoperators & Virtual Environments, 10*, 266-282.

Seligman, MEP. (1970) On the generality of the law of learning. *Psychological Review, 77*, 406-418.

Serfaty, D, Entin, EE & Johnston, JH. (1998) Team Coordination Training. In JA Cannon-Bowers & E Salas (eds.), *Making decisions under stress: Implications for individual and team training*, Washington, DC: American Psychological Association, 221-246.

Sexton B. (2000) Development of hazard perception testing, in *Proceedings of the DETR Novice Drivers Conference*, Bristol. http://www.dft.gov.uk

Seymour, NE, Gallagher AG, Roman SA, O'Brien MK, Bansal MD, Andersen DK, & Satava RM (2002). Virtual reality improves operating room perfromance. Results of a randomised, double-blinded study. *Annals of Surgery, 236*, 458-464.

Sheridan TB. (1992) Musings on telepresence and virtual presence. *Presence: Teleoperators and Virtual Environments, 1*, 120-126.

Simmons-Boardman Publishing Corporation (2004) Simulating can be stimulating: Virtual reality is the next best thing to putting a trainee train driver on the track. *International Railway Journal, 44,* 41-43.

Slater M, & Usoh M. (1993) Representation systems, perceptual positions, and presence in immersive virtual environments. *Presence: Teleoperators and Virtual Environments, 2,* 221-233.

Slater, M. (1999) Measuring presence: a response to the Witmer and Singer presence questionnaire. *Presence: Teleoperators & Virtual Environments, 8*, 560-565.

Smith, S., & Ericson, E. (2009) Using immersive game-based virtual reality to teach fire-safety skills to children. *Virtual Reality, 13*, 87-99.

Smith-Jentsch, KA, Johnston, JH, Payne, SC. (2004) Measuring Team-Related Expertise in Complex Environments. In Cannon-Bowers J.A. and Salas E. (1998). *Making Decisions Under Stress: Implications for Individual and team Training.* Washington DC: APA Press, 61-88.

Snowndararajan, A, Wang, R, & Bowman, DA. (2008) Quantifying the benefits of immersion for procedural training. *Proceedings of the 2008 workshop on Immersive projection technologies/Emerging display technologies.* http://doi.acm.org/10.1145/1394669.1394672

Sohn, MH, Douglass, SA, Chen, MC, & Anderson, J R. (2000) Eye-movements during unit-task execution in a complex problem-solving situation. In *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomics Society*, 378-381.

Sokas, RK, Jorgensen, E, Nickels, L, Gao, WH, & Gittleman, JK. (2009) An intervention effectiveness study of hazard awareness training in the construction building trades. *Public Health Reports, 124*, 161-168.

Spillane, L (2003) The Evidence-Base for Using Simulation in Medical Education: Selected Readings and Executive Summary. Executive summary for SAEM Simulator Task Force. Available http://www.saem.org/SAEMDNN/Portals/0/SAEM%20Obj_3a_Summary.pdf

Squelch, AP. (1997) *Virtual reality simulators for rock engineering related training.* SIMRAC project GAP 420 final report.

Squelch, AP. (2001) Virtual Reality for Mine Safety Training in South Africa, *The Journal of the South African Institute of Mining and Metallurgy, July*, 209 - 216.

Stanney, KM. (2002) *Handbook of virtual environments: Design, implementation and applications*, Lawrence Erlbaum, Mahwah.

Stanney, KM, & Salvendy, G. (1998) Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda. *International Journal of Human-Computer Interaction, 10*, 135-187.

Stanney, KM, Kingdon, KS, Graeber, D, Kennedy, RS. (2002) Human performance in immersive virtual environments: Effects of exposure duration, user control, and scene complexity. *Human Performance, 15*, 339-366.

Stanney, KM, Mourant, RR, & Kennedy, RS. (1998) Human factors issues in virtual environments: A review of the literature. *Presence, 7*, 327-351.

Stansfield, S, Shawyer, S, Sobel, A, Prasad, M, & Tapia, L. (2000) Design and implementation of a virtual reality system and it application to training medical first responders. *Presence, 9*, 524-556.

Stansfield, SA, Shawver, DM, & Sobel, AL. (1998) *BIOSIMMER: A virtual reality simulator for training first responders in a BW scenario*. Sandia National Laboratories. http://www.osti.gov/bridge/servlets/purl/1920-oMiZzC/webviewable/1920.pdf

Starkes, JL, & Lindley, S. (1994) Can we hasten expertise by video simulations? *Quest, 46*, 211-222.

Stephane, L. & Boy, G. (2005) A Cross-Fertilized Evaluation Method based on visual patterns and cognitive functions modeling, *Proceedings of HCI International* Las Vegas.

Stetz, M. (2007) Virtual reality stress inoculation training for combat medical personnel. *Paper presented at the 12th Annual Cybertherapy 2007 Conference: Transforming healthcare through technology*, Washington, DC. http://www.interactivemediainstitute.com/PPT/Training/stetz.pdf

Stone, R, & Caird-Daley, A. (2009) Submarine Safety and Spatial Awareness: The Subsafe Games-Based Training System. In *Contemporary Ergonomics 2009*, Edited by P. D. Bust. Taylor & Francis, London, 320 - 331.

Stone, R, Caird-Daley, A, & Bessell (2009) SubSafe: a games-based training system for submarine safety and spatial awareness (Part 1). *Virtual Reality, 13*, 3-12.

Stothard PM, Galvin JM, & Fowler JCW. (2004) Development, demonstration, and implementation of a virtual reality simulation capability for coal mining operations. *Proceedings ICCR Conference*, Beijing, China.

Stothard, P, Mitra, R, & Kovalev, A. (2008) Assessing levels of immersive tendency and presence experienced by mine workers n interactive training simulators developed for the coal mining industry. *SimTect 2008*.

Strayer, DL, Drews, FA, Burns, S. (2004) *The development and evaluation of a high-fidelity simulator training program for snowplow operators.* Utah Department of Transportation Report UT-04.17

Strayer, D. & Drews, F. (2003) Simulator training improves driver efficiency: transfer from the simulator to the real world. *Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* Park City, Utah. http://ppc.uiowa.edu/driving-assessment/2003/Summaries/Downloads/Final_Papers/PDF/43_Strayerformat.pdf

Strayer, D., Drews, F. & Burns, S. (2005) The development and evaluation of a high- fidelity simulator training program for snowplow operators. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design* (pp. 464-470). Rockport, Maine. http://ppc.uiowa.edu/driving-assessment/2003/Summaries/Downloads/Final_Papers/PDF/43_Strayerformat.pdf

Su, S, Lee, G, & Lampotang, S. (2005) Learning object and dynamic e-learning service technologies for simulation-based medical instruction, Web Information Systems Engineering – WISE 2005 Workshops, *Proceedings Lecture Notes in Computer Science 3807*: 162-171.

Swadling, P, & Dudley, J. (2001) VRLoader - a virtual reality training system for a mining application. *SimTecT 2001*.

Tate, DL, Sibert, L, & King, T. (1997) Using virtual environments to train firefighters. *IEEE Computer Graphics and Applications*, *17*, 23-29.

Taylor HL, Lintern G, Hulin CL, Talleur D, Emanuel T, & Philips S. (1997) *Transfer of training effectiveness of personal computer-based aviation training devices*. US. Department of Transportation, NTIS ADA 325887.

Thomas, MJW. (2003) Operational Fidelity in Simulation-Based Training: The Use of Data from Threat and Error Management Analysis in Instructional Systems Design. In *Proceedings of SimTecT2003* (pp. 91-95). Adelaide, Australia: Simulation Industry Association of Australia.

Thomas, MJW. (2004) Integrating Low-Fidelity Desktop Scenarios into the High-Fidelity Simulation Curriculum in Medicine and Aviation. In *Proceedings of SimTecT2004 Medical Symposium.* Canberra, Australia: Simulation Industry Association of Australia.

Thomson, JA, Tolmie, AK, Foot, HC, Whelan, KM, Sarvary, P, & Morrison, S. (2005) Influence of virtual reality training on the roadside crossing judgements of child pedestrians. *Journal of Experimental Psychology: Applied, 11*, 175-186.

Tichon, J. (2009) *Investigation of affective intensity and its effect on facial features, perceptual processes, physiological responses and electromyographic activity in the training and objective evaluation of complex cognitive skills.* Report for US Air Force Project Number AOARD-09-4095.

Tichon, J. (2007a) Using Presence to Improve a Virtual Training Environment. *Cyberpsychology & Behavior, 10* (6), 781-788.

Tichon, J. (2007b) The use of expert knowledge in the development of simulations for train driver training. *Cognition, Technology & Work, 9(4)*, 177 - 187.

Tichon, J, & Wallis, G. (2009) Virtual Reality Stress Training and Simulator Complexity: Why sometimes more is less. *Behaviour and Information Technology*, 1-8.

Ting, P-H, Hwang, J-R, Doong, J-L, & Jeng, M-C. (2008) Driver fatigue and highway driving: A simulator study. *Physiology & Behavior, 94*, 448-453.

Tornos, J. (1998) Driving behavior in a real and a simulated road tunnel: a validation study. *Accident Analysis and Prevention, 30*, 497-503.

Turpin, D. & Welles, R. (2006) *Simulator-based training effectiveness through objective driver performance measurement*. Paper presented at the DSC Asia/ Pacific Tsukuba: Japan. May/June 2006. http://www.teenresearchcenter.org/research%20articles/Simulator%20Based%20Training%20Effectiveness.pdf.

Uhr, M. (2004) *Transfer of training from simulation to reality: Investigations in the field of driving simulators*. PhD thesis. Aachen: Shaker. http://e-collection.ethbib.ethz.ch/view/eth:27530

Underwood, BJ, & Schulz, RW. (1960) *Meaningfulness and Verbal Learning.* New York: Lippincott

van Wyk, E. (2006) Improving mine safety training using interactive simulators. In Pearson, E., & Bohman, P. (Eds). *World conference on educational multimedia, hypermedia and telecommunications (EDMEDIA) 2006*.

van Wyk, E, & de Villiers, R. (2009) Virtual reality training applications for the mining industry. *Proceedings of the 6th international conference on computer graphics, virtual reality, visualisation and interaction in Africa*.

Victor, TW, Harbluk, JL, Engstrom, JA. (2005) Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: Traffic Psychology and Behavior 8*,167-190.

Volpe, CD, Cannon-Bowers, JA, Salas, E & Spector, P. (1996) The impact of cross training to team functioning. *Human Factors, 28*, 87-100.

Vora, J, Nair, S, Gramopadhye, AK, Duchowski, AT, Melloy, BJ, & Kanki, B. (2002) Using virtual reality technology for aircraft inspection training: presence and comparison studies. *Applied Ergonomics, 33*, 559-570.

Wallis TSA, & Horswill MS. (2007) Using fuzzy signal detection theory to determine why experienced and trained drivers respond faster than novices in a hazard perception test. *Accident Analysis and Prevention, 39,* 1177-1185.

Wallis, G, Tichon, J, & Mildred, T. (2007) Speed Perception as an Objective Measure of Presence in Virtual Environments, *Proceedings of Simtect*, Brisbane, pp.527-531.

Washburn, C, Stringfellow, P, & Gramopadhye, A, (2007) Using Multimodal Technologies to Enhance Aviation Maintenance Inspection Training. V.G. Duffy (Ed.): *Digital Human Modeling, HCII 2007*, LNCS 4561, pp. 1018–1026, 2007. Springer-Verlag Berlin Heidelberg.

Wilfred, LM. (2004) *Learning in Affectively Intense Virtual Environments*, Thesis Masters of Science in Information Science and Technology, University of Missouri-Rola.

Wilfred, LM, Hall, RH, Hilgers, MG, Leu, MC, Hortenstine, JM, Walker, CP, & Reddy, M. (2004) Training in affectively intense virtual environments. *Proceedings of the AACE E-Learn Conference*, 2233 - 2240. http://lite.mst.edu/documents/elearn_wilfred_2004.pdf

Wilkes, JT. (2001) Caterpillar simulation training. In Jenkins, F.M., Langton, J., McCarter, M.K. & Rowe, B. (Eds). *Proceedings of the Thirty-Second Annual Institute on Mining Health, Safety and Research*, 65-67.

Williams, AM, & Grant, A. (1999) Training perceptual skill in sport. *International Journal of Sport Psychology, 30,* 194-220.

Williams, M, Scholfield, D, & Denby, B. (1998). The development of an intelligent haulage truck simulator for improving the safety of operation in surface mines. In Heudin, J.-C. (Ed). *Virtual Worlds 98*, 337-344.

Winter JCF., de Groot, S, Mulder, M, Wieringa, PA, Dankelman, J, & Mulder, JA. (2009) Relationships between driving simulator performance and driving test results. *Ergonomics, 52,* 137-153.

Witmer, BG, Jerome, CJ, Singer, MJ. (2005) The factor structure of the presence questionnaire. *Presence: Teleoperators & Virtual Environments, 14*, 298-312.

Witmer, BG, & Singer, MJ. (1998) Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*, 225-240.

Wong, W. (2005) The integrated decision model in emergency dispatch management and its implications for design. *Australian Journal of Information Systems, 2*, 95-107.

Wozniak, PA, (1995) *Economics of learning*. Doctoral Dissertation. University of Economics. Wroclaw.

Wright, MC, Taekman, JM, & Endsley, MR. (2004) Objective measures of situation awareness in a simulated medical environment. *Quality and Safety in Health Care, 13(Supp)*, 65-71.

Ye, N. & Salvendy, G. (1996) Expert-novice knowledge of computer programming at different levels of abstraction. *Ergonomics 39*, 61-481.

Zakay D. & Wooler S. (1984) Time pressure, training and decision effectiveness. *Ergonomics, 27*, 273-284.

Ziv, A, Wolpe, PR, Small, SD, & Glick, S. (2008) Simulation-Based Medical Education: An Ethical Imperative. *Simulation In Healthcare, 1*, 252-256.