



Immersive virtual worlds

Multi-sensory virtual environments for
health and safety training

Summary report 2019

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In this document, you'll find a summary of the independent study we commissioned from the University of Nottingham.



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What's the problem?

Traditional health and safety training can fail to motivate and engage employees, and can lack relevance to real-life contexts. Health and safety training also often takes employees away from their primary jobs, reducing productivity.

Virtual environments offer potential solutions by increasing trainees' engagement and understanding by affording them experiential learning in safety-related scenarios. They can also be customised to trainees' own workplaces and could reduce costs by allowing trainees to train locally, and at their convenience, rather than travelling to dedicated training facilities. A particular benefit of virtual environments in a health and safety context is the ability to expose the trainee to a dangerous (virtual) environment with low risk of actual physical harm.

While virtual environments have already been used in a number of training applications, they are typically presented as audio-visual systems, whereas engagement of other senses could increase the immersion in the virtual experience. These other senses play a key role in certain health and safety contexts, for example, heat and the smell of smoke in a fire or the smell of a fuel leak.

The overall aim of this research was to produce evidence-based guidance for the development and use of virtual environments which would provide cost-effective and accessible solutions for health and safety training.

What did our researchers do?

Over several iterations, the research team developed a prototype multi-sensory virtual reality system which included visual, auditory, olfactory and thermal simulation. The system was focused around two business case scenarios identified in collaboration with industry partners. The team conducted a series of studies aimed at testing the ability of the software to simulate smell and heat in accordance with events in a virtual world. The aim was for a system that used only low-cost and easily available components, to reduce barriers to adoption in practice.

The virtual environment was created in the Unity development platform, an engine widely used to create virtual reality games, as well as simulations and other experiences. Automatic triggers were placed in the environment so that as users interacted with it, the heat, smell and sound were activated appropriately by participant movement and interactions, controlled by programming systems that recreate virtual worlds.

The researchers conducted a study to explore how users behaved in the virtual environment in an emergency fire situation, comparing the behaviours they exhibited to those that are demonstrated in the real world, based on literature from incident reports, survivor interviews and other research. The participants were split into two

groups. One group explored a “typical” audio-visual virtual environment with only vision and sound; the other group had a multi-sensory experience in which smell and heat were added to see whether the behaviour differed.

A further empirical study explored the effectiveness of the virtual environment for health and safety training. Virtual environment-based training was compared to traditional PowerPoint training. Multi-sensory feedback was added as an additional variable, so trainees were trained either by PowerPoint or virtual environment, and either with or without multi-sensory feedback. Participants’ knowledge was measured on two health and safety-related subjects (fire safety and safe vehicle disassembly procedure) before and after training, as well as one week after training. The researchers also used questionnaires to capture participants’ attitudes to health and safety, their motivation to train and their engagement, to see if this was affected by the training medium or the inclusion of multi-sensory feedback.

Following completion of the empirical studies, the researchers’ findings and prototype system were presented to stakeholders and industry partners to refine their practical recommendations for implementation.

Figure 1 Examples of traditional PowerPoint training and virtual environment-based training



What did our researchers find out?

The research demonstrated the feasibility of creating a multi-sensory (visual, auditory, thermal and olfactory) virtual environment for health and safety applications. The system used low-cost hardware, with infra-red heaters and a scent diffuser which are commercially available. The researchers developed a customised system, which proved effective in controlling the heat delivery to the user. The scent diffuser

was triggered through an open-source electronics platform controlled script to release a commercially available fragrance. The total hardware costs came to around £2,765, inclusive of a high-specification laptop for running the system.

When considering the validity of behaviours demonstrated in the virtual environment, the results suggested that participants with multi-sensory stimulus felt a greater sense of urgency in response to the fire being triggered than with audio-visual stimulus alone. This was evidenced by their higher ratings of perceived time pressure and greater agreement with the statement “I need to find the exit nearest to me”. It was also reflected in the movement of multi-sensory participants, which indicated adaptive behaviour in response to the perception of a threatening situation. Participants with multi-sensory stimulus were more likely to avoid the fires, or hesitate to approach them, while evidence from the audio-visual condition suggested that participants were treating the experience more like a game.

Overall, behaviours shown in the virtual environment were often consistent with those shown in real life. There were a few notable exceptions such as the fact that participants in the virtual environment did not delay action as much as we would expect in the real world. Behaviours shown when the multi-sensory feedback was added were more consistent still with real-world behaviour.

Considering the training study, virtual environment training had several benefits over PowerPoint-based training. Self-reported levels of engagement, attitude to occupational safety and health, and the extent to which participants would want to undertake training in the future were all significantly higher for the virtual environment than for PowerPoint. These attitudinal factors could play an important role in improving general health and safety culture in the workplace.

If employees indicate negative attitudes towards health and safety training, virtual environment-based training could encourage engagement and, more generally, improve motivation. While participants trained through PowerPoint had a greater increase in knowledge test scores (immediately after training), their decrease in knowledge scores was significantly larger when retested one week later. This demonstrated that knowledge retention was better with the virtual environment.

The researchers suggest that the format of the PowerPoint training aligned more closely with the testing method (traditional fact-based verbal Q&A), and that it had the benefit of simplified delivery of direct messages. In the shorter term it was comparatively easy for participants to recall the answer, but the limited mental processing means that the knowledge, despite being superficially well-learned for immediate recall in a similar form to which it was delivered, is not well retained.

The research team speculates that increased cognitive engagement of learning in the virtual environment, combined with the experiential benefits of virtual environment training, creates more established and comprehensive mental models.

This warrants further exploration, but in any case presents a clear implication that testing an employee's knowledge immediately following health and safety training may not be an effective means of gauging long-term knowledge of health and safety.

Despite the evidence to support virtual environment-based training, the results of the second study provided weak evidence for the use of multi-sensory simulation for health and safety training, and would not justify the investment required to add the additional feedback modalities. This outcome was surprising, given the theoretical importance of multi-sensory feedback for virtual experiences which are comparable to the real world.

The results were also unexpected, given the differences in experiences between multi-sensory and audiovisual conditions identified in the first study of this research. The findings in the second study may be due to the specific implementation of the hardware, training programme, scenarios and experimental design, and should be explored further.

The overall conclusion from industry stakeholder work in relation to the study findings is that with the current state-of-the-art in technologies, virtual environments would be more effective for general inductions and for teaching personal safety, rather than for in-depth, detailed procedures, processes and navigation.

Despite the results from the second study, the data from the study of behavioural validity and feedback from industrial partners suggest that training in a multi-sensory virtual environment can contribute to improved health and safety outcomes. This benefit lies in the different experience afforded by the multisensory virtual environment, which is closer to a real emergency. Thus, while the second study did not find evidence for knowledge uptake, as tested in a question-and-answer type quiz, it may be that the more realistic experience of the multi-sensory virtual environment better prepares people for an emergency.

What does the research mean?

Based on the input from the research team's industrial partners, study outcomes and prior research, the researchers present the following list of benefits to business of virtual environment training in health and safety over traditional approaches:

1. Increased engagement with occupational safety and health (OSH) training.
2. Improvement in attitudes towards OSH training.
3. Greater motivation to participate in future OSH training.
4. Better retention of OSH knowledge.

5. Opportunity to conduct OSH induction sessions remotely, reducing the costs associated with on-site training and with delays while waiting for new starts to be trained.
6. Opportunity to train populations who would not receive the training benefits of drills (for example, workers who were absent at the time of the primary drill).
7. Opportunity to conduct training at a time that is convenient to the trainee.
8. Ability to customise the training to the needs of the trainee. In this way, the trainee only needs to spend the time needed to achieve competence, reducing their time away from other work activities.

The following benefits to business are suggested for the use of multi-sensory virtual environments specifically:

1. The ability to train employees to respond to a cue (e.g. smell of smoke) during the early stages of an emergency. In this way, employees' actions could be more likely to lead to containment of the emergency and/or lead to greater safety of themselves and others.
2. Predicting human behaviour in emergencies. Valid predictions of behaviour can be important when designing buildings, training or response procedures. This research showed that multi-sensory virtual environments revealed behaviours which were close to those seen in the real world than behaviours from audio-visual virtual environments. However, the limits of behavioural prediction must be considered in this scenario, including the fact that even the multisensory virtual environments revealed behaviours which would not be expected in real-life.

Don't forget...

It's important to bear in mind that evaluating behaviour and training in safety-critical contexts always poses ethical challenges of using real world scenarios for validation. This constrains the extent to which it can be concluded that skills learned and behaviours exhibited in the virtual environment would transfer to the real world.

While the behaviour study showed good evidence of increased validity in some respects when multisensory feedback was added to a fire simulation, there were a number of factors not explored, particularly in relation to social cues which are known to be of critical significance in emergencies. Caution must be urged in interpreting behavioural predictions from virtual environment training without further work to explore this. Moreover, it is important to understand the limits of any behavioural prediction. For example, behaviours were observed in both multi-sensory and audio-visual virtual environments which would not be expected in real life.

This project had limited scope for exploring the simulation of different configurations of sensory feedback modalities individually and combined. Further investigation could lead to more effective solutions. The prototype used in testing may not be the optimal solution for all scenarios, and there would be value in exploring alternatives. The resulting outcomes from alternative solutions could differ from those arising from this project.

Appendix

Guidelines for use of virtual environments and implementation of multi-sensory feedback in occupational safety and health (OSH) applications.

1.	Virtual environments (VEs) can be used to facilitate prediction of human behaviour in emergency scenarios.
2.	Caution should be taken on interpreting human behaviour in VE, particularly around pre-evacuation delays, time to evacuate and where discrepancies arise from the VE interface e.g. overshooting errors resulting from use of the controls.
3.	Multi-sensory simulation including heat, smell, audio and visuals should be used where viable to increase the validity of behaviour predictions, particularly in relation to risky behaviours and where emotional or psychological response is salient.
4.	VEs are recommended to deliver OSH training for improved retention.
5.	Investment in multi-sensory systems for OSH training is not recommended without further exploration of appropriate implementation, or further advancement of affordable technologies.
6.	Head-mounted displays may improve immersion and block external influences, but pose practical and sickness issues, therefore decisions should be taken on a case-by-case basis as to the most appropriate display technology for the specific application.
7.	Use established techniques to reduce risks of simulator sickness, and screen potential users for increased susceptibility to adverse effects.
8.	Limit potential distress for trainees in VEs, particularly where realism is high, and screen for previous traumatic experience.
9.	Use infra-red heaters to provide an appropriate simulation of radiant heat from a fire.
10.	More than one heat source should be used for thermal simulation, positioned symmetrically around the user. The absolute position of the heaters is not important for this purpose, provided that they are symmetrical.
11.	A minimum of two 2kW infra-red heaters provides safe heat simulation and is reliably perceived by users, but using three or more heaters improves the experience and increases realism.
12.	Control thermal feedback by blocking the heating element with movable heat-deflective panels, rather than by turning the infra-red heater on and off.
13.	For olfactory simulation, position a diffuser approximately one metre in front of the user, with a fan immediately behind it to direct the fragrance particles.
14.	Use fragrances approved by IFRA for olfactory simulation.
15.	Conduct COSHH assessment on fragrances and establish safe limits for diffusion.
16.	Use appropriate extraction equipment to prevent build-up of fragrance.
17.	Use the olfactory system in a well-ventilated area.
18.	Ensure an odour-free environment for olfactory simulation, removing or covering soft furnishings and odour-absorbing materials.
19.	Test fragrances with users to establish the lowest usable concentration that is consistently perceived and recognised.
20.	Screen users for asthma, odour intolerances, allergies and respiratory conditions prior to exposure to olfactory simulation.
21.	Current off-the-shelf low-cost scanning technologies are unlikely to be suitable for creating interactive training environments, and scans will require significant post-processing by an experienced technician to adapt them for use.
22.	Adapt pre-made VEs or create models from existing building plans in a suitable VE development tool such as Unity, rather than investing in expensive scanning technologies.
23.	Without dedicated instructional design, customised training scenarios may not be effective.
24.	In many cases, the cost of creating bespoke VE-based training may outweigh potential benefits, therefore where suitable off-the-shelf software and training modules are available, they should be used.
25.	Employees should be tested on their knowledge after an interval, rather than immediately following training, in order to evaluate their health and safety knowledge.
26.	Traditional testing is appropriate for traditional training, but may not be a valid indicator of success for VE-based training, and does not address transfer of training to the real-world.

Our summary gives you all the major findings of the independent study by the University of Nottingham. If you want to read about the study in more depth, you can download the full report at [iosh.com/research](https://www.iosh.com/research).

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