Immersive Virtual Reality for Fire Safety Behavioural Skills Training via Gesture-based Technology

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Abstract. The fire safety can be one of the biggest problems in metropolitan area. To reduce injuries in a fire, the virtual reality based behavioural skills training (BST) has been used to train people to survive in emergency circumstance. VR-based BST training has been demonstrated to effectively help people of different ages to acquire safe escape skills in a virtual environment. However, most of people have encountered difficulty to train in a right gesture or poor body performance, such as running at unsuitable body position. Gesture-based technology can effectively help people to learn the correct gestures in order to enhance training efficiency. Thus, this paper proposes a theoretical framework of "VR-Gesture BST", which is expected to improve behavioural skills training more effectively for fire safety training. It adopts motion capture device obtaining user’s body data to evaluate the body performance during the BST training. The outcomes of the study provide guideline and suggestions for VR based design in practice of the behavioural skills training adopted gesture-based technology.

1. Introduction

Fire hazard in high buildings is determined by the structure, size of building, and the complexity of domestic electric power etc. One of the effective ways to reduce damages from a fire is to adopt behavioural skills training to improve the people’s fire emergency management and escape ability [1]. Research has demonstrated that behavioural skills training (BST) can be effective for developing a range of safety skills, by employing instruction, modelling, rehearsal, praise and corrective feedback [2]. BST program is also applied “for teaching personal safety skills to individuals from various age groups and skill levels for abduction, firearm safety, sexual harassment, wild animal injuries, and fire safety” [3-5]. However, some studies argue that the skills developed through behavioural skills training cannot be used effectively in hazardous situations [6]. Other studies suggest more innovative approaches are required to teach behavioural skills for safety [6].

BST training requires as close to the real environment as possible during the process of training and VR can create a "real" environment for behavioural skills training. The "real" environment enables situational learning. Situated learning theory emphasizes the interaction between knowledge and situation, and it suggests that learners are actively construct knowledge within a real environment [7]. For example, VR technology has been used as an innovative way to create an effective learning environment for behavioural skills training for teaching children the fire safety skills [8-9].

The learning environment created by VR technology can be used as a “real” learning environment, which "contains rich and colourful learning resources and presents more interactive activities" [7]. Compared to the traditional training methods, the virtual reality learning environment is more likely to highly attract the attention of the trainees and provides them positive feedback in real time [10]. It
effectively enhances the motivation of the trainees as they continue to learn, in particular in family situation [11].

However, fire safety training faces some problems to obtain effective and satisfying training, such as incorrect body gesture or poor body performance during the behavioural skills training. The training may take more time to complete and it also lacks an effective method to evaluate the body performance. Therefore, it is critically important to improve body correct gesture during fire safety skills training.

2. Virtual reality Based Fire Safety Training

Traditional fire safety training can be dangerous and a high cost. The advantage of VR is to simulate the fire scene, so that the trainees can immerse themselves into virtual environment. The trainees can actively interact with the learning environment through exploring the virtual environment, which makes easier for the trainees to construct knowledge [12]. The “reality” of VR allows for immersion, interaction and imagination, which in turn facilitate trainees’ active construction of knowledge [13]. The knowledge construction supports the obtaining of knowledge and its transformation to solving practical problems.

The learning environment provided by virtual reality has been used to train professionals to work in complex environments, such as fire safety in mines [14-15]. Smith and Ericson [16] suggest that VR technology was not only used to simulate “real” fire scenes, but also to help the trainees learn about knowledge of fire safety. Interactive design has been used to encourage trainees to explore the virtual world. However, there are few studies on fire safety skills training for evaluate body performance in a virtual environment. Therefore, this study applies gesture based technology along with virtual reality technology to fire safety training and also applies behavioural skills training to improve the trainee fire safety ability and correct performance.

2.1. Behavioral Skills Training

Behavioural skills training are considered as an effective way to correct behavioural response. It consists of four steps: instruction; modelling; rehearsal; and feedback (Figure 1). The instruction involves trainers demonstrating the correct behaviour to the learner. Modelling provides targeted description of specific activities. Rehearsal has learners practice the correct behaviour after the instruction and modelling have been completed. This should be carried out as far as possible in a real situation or in a real simulated environment, to promote the behaviour being generalised. Feedback is provided to the learner on the outcome of rehearsal, which should include praise and corrective enhancements, including corrections to the errors if it is necessary. Further instruction on how to improve is provided.

![Behavioral skills training model](image)

**Figure 1.** The behavioural skill training model

Behavioural skills training emphasizes the repeatability of training and requires continuous instruction, modelling, rehearsal and feedback processes until the correct behaviour is able to be demonstrated consistently.
2.2 VR-BST Fire Safety Training
Çakıroğlu and Gökoglu [17] propose a behaviour skills training (VR-BST) model based on virtual reality technology to teach children basic behavioural skills for fire safety. The four steps formed the basis of design; VR is a technical means to provide children with the perception of real experience and opportunities for self-learning, using In situ training (IST) and In situ assessment (ISA). The study adopted design-based research methods including analysis, design and evaluation [17]. The results showed that the fire safety training of virtual reality technology developed within the framework of VR-BST method, could demonstrably improve the behaviour skills of children, and that this positive effect was enhanced when VR-BST was combined with IST. Most children were able transfer the skills they acquired in VR-BST training to the real world [18].

Although the VR-BST model may effectively improve fire safety behaviour skills for children, it lacks a method to evaluate trainee body performance, such as correct gesture, speed, reaction and ability to handle fire equipment. Therefore, this paper proposes to add gesture based technology to VR based behavioural skills training to train fire safety skills.

3. Virtual reality and gesture-based technology
Gesture-based technology with VR is associated with entertainment, education, immersion, interaction and imagination (Figure 2). Gesture-based technology has the advantage of facilitating and enhancing interactivity and immersion, in particular in manipulating with body gesture. It can enhance the learning experience through highly immersive human-computer interaction with a simulated "real" environment. Additionally, gesture-based technology enables trainee manipulating the avatar with their body movement, which is considered as natural movement. It also can be correct the trainee’s body gesture and position, which are required from the professional fire safety training. The correct body performance in behavioural skills training improves the effective of the training. Therefore, this training method, which combines VR technology with gesture-based technology, has advantage over traditional training methods. This VR-Gesture framework needs to design the behavioural skills training structure, and then apply it to an immersive virtual environment afforded by VR devices, to provide scenarios for the practice of fire safety self-rescue procedures in high-rise apartments.

In this paper, VR technology is used to design and develop a virtual environment. Under the framework of behavioural skills training, it provides the fire safety knowledge and training required for high-rise apartments. It can help stimulating learners’ motivation by providing an enhanced learning experience through situational learning and promoting knowledge transfer to the handling of a fire safety emergency.

The development of virtual reality technologies has made it possible to develop highly realistic fire escape environment for high-rise apartment in metropolitan areas. It suggests that some new models could be adopted to construct a learning environment based on virtual reality in order to provide fire safety training. With this in mind, this study will apply behavioural skills training methods to teach correct behaviour in special circumstances. As the framework for design and implementation, a model of “VR-Gesture BST” is proposed for fire safety skills training. This model can be used to most of trainees, including both professional and amateur fire safety training.

Figure 2. The framework of virtual reality-Gesture based technology.
In this study, Perception Neuron motion capture device from Noitom was adopted and tested [19]. The research methods and outcomes of evaluation will be discussed in the following.

4. Research Methods
The fire safety training on the VR-BST model through gesture-based technology was designed to transform educational theory into teaching practice, using design research to apply theory to the development of a real environment for education and training. McKenney, Nieveen and Akker [20] argue for a process of analysis, design and evaluation during the development of the fire safety training. The three steps are a cycle that initially requires analysis in order to apply theory to a problem, followed by a design stage, involving modelling, testing, evaluating and revising the approach for an improved product and stronger learning outcomes. The final step involves summative evaluation of the whole process.

The behavioural skills training proposed through the VR-Gesture BST framework was tested with ten adults who were all living in high apartments in Shanghai, China. The study adopted qualitative research methodology with interview and questionnaires methods to collect data. A Pilot study was implemented to test the users’ immersion and perception in the VR and motion capture device.

4.1 Participants
Ten adults aged between 18 and 50 years old were recruited for the study. Computer games, virtual reality and fire experience were considered as main elements when designed and implemented the proposed VR-Gesture BST framework. Participants were selected based on their experience of fire escape, prior knowledge of fire safety training, body movement ability and health conditions. Participant information is listed in Table 1.

Table 1. Information about the participants

| Participants | Gender | Age | Fire safety training experience |
|--------------|--------|-----|---------------------------------|
| P1           | F      | 20  | Yes                             |
| P2           | F      | 21  | No                              |
| P3           | M      | 20  | No                              |
| P4           | M      | 19  | No                              |
| P5           | M      | 30  | Yes                             |
| P6           | F      | 28  | Yes                             |
| P7           | M      | 21  | No                              |
| P8           | M      | 25  | No                              |
| P9           | F      | 34  | Yes                             |
| P10          | M      | 41  | Yes                             |

4.2 Interview
Interview has been used to collect data on trainee’s experience with the VR-BST approach with motion capture device. The experience of participants with their perceptions of the VR-BST was digitally voice recorded and each interview was about 20 minutes. The interview questions were designed for perception of interactive with the virtual environment for immersion.

4.3 Pilot study
The pilot study was conducted with 20 participants. Participants received training for fire safety and then they were asked to complete some tasks. Participants were advised to explore the virtual environment and find the emergency alarm, moving to the stairs as soon as possible. Participants’ perceptions of the virtual learning environment was evaluated a questionnaire. After the completed the
tasks, a questionnaire was used to evaluate the quality of immersion within the environment. Witmer, Jerome and Singer [21] developed a “Presence Questionnaire” (PQ) as a method for testing perceived levels of immersion in virtual reality environments. The term “Presence” refers to, “the effect felt when controlling real-world objects remotely as well as the effect people feel when they interact with and immerse themselves in VEs” [22]. It is an ideal way to test the participants’ perception of the VR environment. The outcome of the questionnaire suggests that all participants had a high degree of presence in the virtual environment. They stated that they had perceived a sense of realism.

4.4 Data collection
Data from the Perception Neuron motion capture system were collected for analysis of body performance. The results of the study show that most of the trainees have a correct performance after the training. However, their fire safety skills can be improved based on these body data. Therefore, it suggests that gesture-based technology can effectively collect data of the trainee performance. It could be used for further training, in particular in professional fire fighter training.

5. Conclusion
This study proposed a framework combined VR-BST approaches adopted motion capture device to teach the behavioural skills. The results from the study demonstrated that behavioural skills training can be enhanced through VR based design within the framework of a VR-Gesture BST approach. The study showed that motion capture system has positive outcomes in improving training performance. The training could improve the correct responses and action to identify fire hazards in a real life situation. The immersion generated by the virtual environment and the sense of presence can be critical factors in enhancing behaviour skills. The results of the study demonstrated that the proposed framework of the fire safety virtual reality technology could be an alternative approach to increasing the learning ability through behavioural skills training. The motion capture device used in VR based BST training not only demonstrates more accuracy in natural body manipulation but also help to evaluate the action and body gesture for the improvement of the performance. It suggests that the findings from this study can be applied to further research on virtual learning environment using motion capture device under the proposed theoretical framework.

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