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A virtual reality-based serious game for fire safety behavioral skills training[★]

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ABSTRACT

Fire disasters in tall buildings can cause considerable damage to property, injuries to people and death. An effective way to reduce injuries or death during a fire is to improve human evacuation behavior. Many studies have demonstrated that behavioral skills training can effectively help people of different ages to acquire safety skills for emergencies. Based on virtual reality (VR), serious games (SGs) and behavioral skills training (BST), this study proposes a theoretical model of "VR-SG-BST" as a fire safety training method. Elderly people in care facilities were selected to evaluate the proposed model because their lack of knowledge on fire safety and the associated potential health problems increase the likelihood that they will become victims in a fire. It is expected that engagement and immersion in the SG can improve the elderly's learning performance in fire skills and enhance their interest and sense of fun experienced during fire safety training. The SG could effectively improve the skills of evacuation in an emergency. Hence, this study conducts two parallel investigations: 1) it compares fire safety behavior of the elderly between an experimental and a control group, and 2) it determines the effects of BST for fire safety by comparing only the experimental group in pre- and post-BST phases. The study adopts in situ training (IST) to evaluate the acquisition of knowledge and skills during the experimental stage. The outcomes of the study provide suggestions and guidelines for VR-SG design in the practice of BST.

1. Introduction

Fire safety precautions are critical to protect families within a community. The dangers of fires can lead to disastrous consequences, such as fatal injuries and death[1]. Fires affect the elderly and children the most compared with other age groups, and the chances of accidental death from fires are proportionate to people's age. As one of the leading causes of injury or death for the elderly, fire safety has become a global concern. For example, in Korea, the elderly mortality rate caused by fire accidents is 57.8 per 100,000 people, and when compared with the previous five years, the figure reflects a significant increase in the death rate of elders[2].Moreover, in the United States, 1,200 elders aged 65 or older die from fire accidents each year[3], and in China, according to the Chinese Fire Department, the rate of death among the elderly due to fire is 34.4%[4].

The rate of death from fire in elderly people is higher because their physical conditions limit their capacity to escape the fire in time. In such situations, two main methods prevent fire injuries and deaths. The first is to assist the elderly in terms of movement by using digital appliances and specialized staff[5]. However, this method, which employs nursing staff to assist the elderly to evacuate, relies primarily on the specific circumstance: the elderly need to adapt to different dangerous situations, such as a sofa or bed fire, which could occur at any time, particularly in high-rise buildings[6, 7].The second method is

[★]Only capitalize first word and proper nouns in the title.
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to provide the elderly with behavioral skills training (BST). It is critical to enhance the fire safety skills of the elderly because they are the cohort most affected by fires[8].

Research has demonstrated that BST can be effective for developing a range of safety skills by employing instruction, modeling, rehearsal, praise, and corrective feedback[9]. For example, BST programs can be implemented for teaching personal safety skills to individuals from various age groups and skill levels to respond appropriately to abduction, firearm safety, sexual harassment, wild animal injuries, and fire safety [10–12]. However, some studies argue that the skills developed through BST cannot be used effectively in real-life hazardous situations[13], while other studies suggest that teaching behavioral skills for safety requires more innovative approaches[14].

In the last decade, virtual reality (VR) and serious games (SGs) have emerged as innovative methods for safety training[15]. VR design incorporates "the communication of how the virtual world works, how that world and its objects are controlled, and the relationship between user and content: ideally where users are focused on the experience rather than the technology" (p. 10)[16]. It is particularly effective in creating a 'real' learning environment because a learning environment created by VR technology comprises rich and colorful learning resources and includes more interactive activities[17]. It has been extended as an innovative tool to create immersive 3D environments for BST, which has been applied to virtual training for fire safety[18]. SG refers to a type of video game developed to address real-life issues[19]. Some research suggests that the overall performance of SGs is technically superior when compared with traditional tools such as text and video[20]. Thus, VR-SG has the potential to become an effective method for fire safety training (FST) by providing users with a safe and controlled environment to practice behavioral skills. In addition, VR-SGs allow users to develop safety skills and knowledge that can be transferred to real life[21, 22].

In this study, the elderly is defined as anyone whose age is 60 years and over, which is based on United Nations' standard of old in 1982[23]. The study shows that the memory and cognitive capacity of the elderly decreases from around age of sixty[24], a traditional BST method for fire evacuation training is unlikely to improve their behavior significantly. Therefore, in this study, we explored the effectiveness of using a VR-SG approach to FST to improve the behavioral skills of the elderly. We propose a theoretical model of "VR-SG-BST" for FST using an SG with an immersive 3D virtual environment. Our aim was to examine the effectiveness of VR in training the elderly and how employing BST through a VR-SG can influence the development of fire safety behavioral skills. The study conducted two parallel investigations: one that explored the differences in fire safety behavior between an experimental group and a control group, and another that investigated the efficacy of delivering fire safety BST by studying the experimental group in pre- and post-BST phases. Hence, the control group was used to evaluate the traditional FST method, while the experimental group was used to investigate the effect of the proposed VR-SG-BST model. Presence questionnaires were used to test whether VR environments provide a realistic sense of presence.

2. Virtual Reality and Behavioral Skills Training

In this section, we discuss the relevant research on VR and its approach to FST and BST. First, we explore the concept of VR; second, we address the application of VR to FST; and last we describe the BST model, examine the challenges of incorporating BST into VR-based FST and discuss how the VR-SG approach improves the effectiveness of FST.

2.1. Virtual Reality

VR is a type of simulation technology that uses computer simulation to generate a virtual three-dimensional space with visual, auditory, and tactile sensory functions. Coates[25] defines VR as "electronic simulations of environments experienced via a head-mounted eye goggle and wired clothing enabling the end-user to interact in realistic three-dimensional situations." The definition emphasizes that VR is related to a particular technological system. However, Steuer [26] argues that VR is a form of presence that relies on human experience rather than technological hardware. The concept of presence emphasizes the perception of the surroundings rather than the physical world: users experience a sense of immersion in a virtual world. In this virtual environment, users can observe and move their position without restriction. They are positioned within virtual 3D spaces and can interact naturally with virtual objects through VR devices (helmets and trackers). Some research suggests that VR can effectively help to teach social skills [27] and improve training safety skills in various hazardous situations through an immersive virtual environment[28].

2.2. Virtual Reality–based Fire Safety Training

Traditional FST is highly dangerous, expensive to perform, and unsuitable for elderly people because of their physical condition. VR technology's advantage is that it can simulate the fire scene so that trainees can safely immerse themselves in it. Trainees can actively interact with the learning environment through trial and error, which assists them to acquire knowledge and learn fire safety skills at a low cost and with high safety standards and high accuracy[29, 30]. Simultaneously, the virtual environment of VR technology can approximate the conditions of the real environment. The "reality" of VR allows for immersion, interaction, and imagination, all of which facilitate trainees' active acquisition of knowledge.

Previous studies have explored how the learning environment provided by VR can train professionals to work in complex situations, such as being trapped in mines [31] or stranded out in the open sea, [32, 33] by providing training in emergency response [34] and inspection of fire safety appliances [35] and by studying human behavior in response to a fire [36]. VR has been used for training preparatory fire safety knowledge. For example, Rossler, Sankaranarayanan and Duvall [37] investigate the effectiveness of VR on preparatory fire safety knowledge and skills training for pre-licensure nursing students. Meanwhile, Anghel et al.[38] present a new 3D fire scenario for fire training using immersive VR for firefighters; their study explores fire behavior indicators integrated into the fire evaluation process.

VR in fire safety has frequently been used to train and equip children with fire safety skills [39]. For example, in Smith

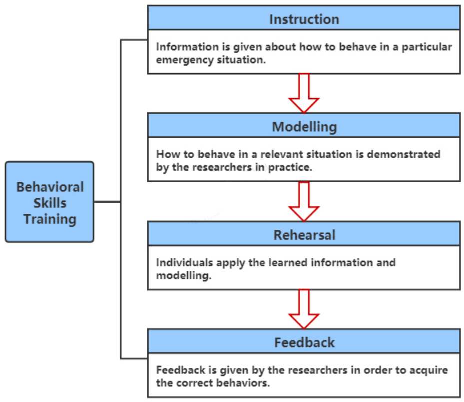

Fig. 1. The behavioral skills training (BST) model.

and Ericson's research [40], VR not only simulated real fire scenes but also helped the trainees learn to escape during fires. Padgett, Strickland, and Coles [41] demonstrate the positive effectiveness of a computer-based VR game in teaching children. Other studies employ immersive VR safety education systems for children with autism spectrum disorder, with promising findings regarding the delivery of safety skills training to children with autism spectrum disorder [42–44]. A few studies explore the VR experience of fire for adults [45]. However, few studies exist that have explored fire safety skills training for the elderly in a virtual environment. Therefore, this study explored the application of VR technology and BST to FST to assist and improve the fire safety skills of the elderly.

2.3. *Behavioral Skills Training*

BST is employed to teach a wide range of behavioral skills in various situations. It is an effective way to promote correct behavioral responses to emergencies, and it can teach people of different ages the necessary skills to deal with emergencies, such as kidnapping, gun safety, sexual harassment, and fire safety.

BST comprises four steps: instruction, modelling, rehearsal, and feedback (Fig.1). The instruction step involves trainers demonstrating the correct behavior for learners to imitate. Modelling provides a targeted description of specific activities, while rehearsal requires the learners to practise the correct behavior after following the instruction and modelling. Ideally, BST provides a rehearsal as realistic as possible to compel the user to perform the correct behavior. Finally, the feedback step provides the learner with the outcome of their rehearsal, which includes praise, correction of errors, and further instruction for improvement.

2.3.1. *Virtual Reality–Behavioral Skills Training for Fire Safety Training*

Çakiroğlu and Gökoğlu [14] propose a BST model based on VR technology (VR-BST) to teach children basic behavioral skills for fire safety. The BST process is a technical means to provide children with the perception of authentic experience and opportunities for self-learning by using in situ training (IST) and in situ assessment (ISA). IST provides intensive behavioral training, while ISA is on-site assessment of acquired skills after safety skills training. The research [14] explored questions such as how much a VR-BST model might benefit the development of fire safety behavior skills and whether the trainee can use the VR-BST model to transfer behavioral skills to real life. The study adopted design-based research methods including analysis, design, and evaluation processes. Ten children were tested based on the VR-BST model. Results demonstrated that the fire safety training of VR technology developed within the framework of a VR-BST method could improve the behavioral skills of children. This positive outcome was enhanced when VR-BST was combined with IST, when most children were able to transfer the skills they ac-quired in VR-BST training to the real world.

Although the VR-BST model may effectively improve fire safety behavior skills for children, it is not clear whether it works for the elderly. Moreover, significantly fewer studies exist that explore fire evacuation or training for the elderly. Therefore, this paper proposes adding the dimension of the SG to the VR-BST model to provide fire safety skills and behavior for the elderly. In many circumstances, fires could occur anywhere. However, this study focused specifically on circumstances in nursing care apartments fires , which elderly people have higher chances of encountering.

2.3.2. *Serious Games and Virtual Reality*

Games-based VR is associated with entertainment, immersion, and interaction. SGs allow users to experience virtual worlds that are unlikely to be artificially constructed in the real world for reasons of safety, cost, and time [46]. SGs have positive impacts on the development of personal skills, for example, in relation to education and health care[47]. Although SGs are associated with entertainment, it is critical that they are used for purposes other than entertainment, such as education. This particular purpose has been coined "edutainment"—that is, edutainment provides education through entertainment. The term refers to any form of education that can be affected by entertainment involving video games[48].

SGs are considered game-based learning. For example, according to Corti[46] , the purpose of SGs is "all about leveraging the power of computer games to captivate and engage end-users for a specific purpose, such as to develop new knowledge and skills" (p. 1). They have been used in many fields, such as assisting patients with autism. Whyte, Smyth, and Scherf's research suggests that SG design principles can effectively improve learning performance [49].

Further, SG can significantly reduce the difficulties and boredom of learning from paper textbooks by providing a more interactive, exciting, and engaging method of learning. This method improves the memorization of the learning content [50], which is particularly critical for the elderly. Therefore, the SG is an ideal method for BST for elderly people since a VR-SG can enhance the learning experience through a highly immersive interaction with a simulated real environment. Moreover, a VR-based SG can provide a more realistic environment compared with traditional methods such as two-dimensional images or video games. Some studies suggest that a VR game can provide realistic scenarios for the elderly to practice self-rescue procedures, including scenarios of high-rise apartments in urban areas [51] .

Therefore, we propose a theoretical model that combines all instruments—VR, SG, and BST. We refer to this model as VR-SG-BST. Based on this model, we designed and developed a game that is VR-SG based and provides elderly people with FST. This game includes the components of a storyline and rewards to create an engaging learning experience; moreover, it aims to improve the elderly's engagement and correct behavior in FST. BST is applied in the game to teach the correct behavior for the elderly to follow in circumstances with fire. The next section discusses the research methods used in this study.

3. Research Methods

Our proposed game, which is based on the VR-SG-BST, was designed to transform educational theory into practice. It uses design-based research to apply theory to the design practice of a real environment for education and training. Plomp [52] suggests that design that is used for educational purposes aims to develop research-based solutions to complex problems. A design cycle involves analysis, design, evaluation, and revision activities. McKenney, Nieveen, and Van den Akker [53] argue for a process of analysis, design, and evaluation during the development of the FST game. The three steps form a cycle, which initially requires analysis to apply theory to a problem. This is followed by a design stage that entails modeling, testing, evaluating, and revising the approach for an improved product and learning performance. The last step comprises a summative evaluation of the entire process. This step includes the phases of awareness of the problem, suggestions, development, evaluation, and conclusions. Our VR FST environment was evaluated by means of questionnaires.

The BST proposed by the VR-SG-BST model was tested on elderly people who were all living in nursing care apartments in Shanghai, China. The study adopted quantitative research methodology employing survey and questionnaire methods for data collection. Initially, a pilot study was implemented to evaluate the users' immersion, perceptions, and sense of presence experienced regarding the VR-SG.

As stated in the introduction, this study conducted two parallel investigations. One explored the differences in fire safety behavior between an experimental group and a control group; the other investigated the efficacy of delivering fire safety BST by comparing only the experimental group in its pre- and post-BST phases. Thus, the first experiment compared traditional training methods with the proposed VR-SG-BST method, while the second tested the proposed VR-SG-BST model by comparing the fire safety behavior of participants from the experimental group before VR-SG-BST was given (a stage referred to as 'pre-VR-SG-BST') and after VR-SG-BST was given (a stage referred to as 'post-VR-SG-BST').

3.1. The Theoretical Model

The concept model presented in Fig.2 below presents the relationship between VR-SGs and BST. The characteristics of

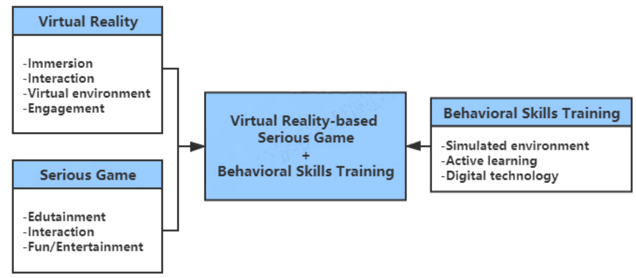

Fig. 2. Framework of virtual reality–based serious game behavioral skills training.

VR-SGs and BST enhance interactivity, engagement, and a sense of presence, which are integrated with the methods suggested by the VR-BST model. VR involves the characteristics of immersion, interaction, virtual environment, and engagement. Hence, it provides an ideal way to represent realistic situations, which is an essential part of learning. The characteristics of the SG allow users to experience more fun and engage better with the game-like learning environment [54]. Therefore, this proposed model attempts to create a fun learning environment for BST that increases engagement. In contrast to other approaches for BST, this model, in the form of edutainment, emphasizes a game quality. The key to this model is the combination of VR and SG as the main devices to generate an immersive, engaging, and entertaining virtual environment that integrates behavioral skills in FST. In our study, this resulted in the creation of the I-Escape game, which all participants played at strategic points in the study.

3.2. Participants

Thirty elderly people aged between 60 and 80 years old were recruited for the study (M = 68.77, SD = 5.917). Their previous experience of gaming and knowledge of fire safety were considered main elements influencing the design and implementation of the proposed VR-SG-BST model. All candidates were in reasonably good health and none had difficulty with movement. None relied on walking aids, such as crutches or walking frames. Owing to their age, we sought and received the candidates' families' approval to participate in this study. Participants were selected based on their health condition, their experience with VR, and their knowledge of FST. All participants were residents of a retirement apartment that included nursing care facilities. The half of the participants had received previous FST, 10 participants had encountered fires before and five participants had experience of gaming.

3.3. Design process

The participants were divided into two groups – a control group and an experimental group – resulting in 15 participants for each group. The study was designed so that all participants played the I-Escape game. Before participants played I-Escape, they were informed about how to use the environment and were given a tour of the VR system. It was important to allow participants to become familiar with the user interface (UI) and learn

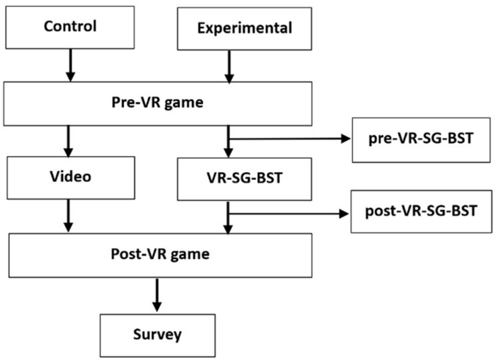

Fig. 3. Flowchart of the investigative process.

how to manipulate the game in the virtual environment. Subsequently, all participants learned basic fire safety procedures using the same scenarios, which took between 5 and 10 minutes to complete. The scores were recorded. In this study, the fire sources were divided into two parts: indoor fires using residential furniture, such as in the kitchen; and fires external to the living area, such as corridor passages and elevators. Next, the control group watched a video of a fire safety presentation on basic fire safety knowledge, which was based on national and international regulation. A LCD monitor was used to display the video, which lasted about 8 minutes. The video training was animation with three parts, which included introduction, fire safety knowledge and escape skills. Mean-while, the experimental group played I-Escape according to the VR-SG-BST model. After that, both groups were asked to complete a user experience survey. Fig.3 provides a flow chart outlining the training process for both groups.

Hence, at the beginning of this study, both groups (experimental and control groups) played I-Escape without receiving any training. Then, both groups were given training – the experimental group according to the VR-SG-BST model and the control group according to traditional training. Subsequently, both groups played I-Escape again. Finally, a survey was given to both groups. Thus, the difference in focus between the experimental and the control groups was that the experimental group received VR-SG-BST training while the control group instead received traditional video training.

The terms pre-VR game and post-VR game refer to the two stages of playing the I-Escape game (i.e., pre and post the relevant training given). The term VR-SG-BST is used for the experimental group only. Accordingly, the stage before the experimental group received VR-SG-BST is referred to as 'pre-VR-SG-BST' and the stage after the experimental group received VR-SG-BST training is referred to as 'post-VR-SG-BST' .

4. Virtual Reality–based Serious Game Design

The key aims of this study were exploring how to design a VR-SG for FST. In the following sections, we discuss the virtual environment and SG design procedure for BST.

Fig. 4. Fires in the room.

Fig. 5. Moving inside the room using teleporting.

4.1. Interactive Virtual Environment

In this study, head-mounted displays (HMDs) were used to display the virtual environment. The Unreal Engine 4 (UE4) software was used to design and develop a virtual environment for FST. The 3D virtual environment was created by UE4 and HTC Vive HMDs was used to display the VEs. The "I-Escape" game was designed and implemented, which is an interactive VR-SG intended to train and evaluate behavioral skills. The first person perspective was adopted in the game for an immersive virtual environment. In this model, participants were required to wear HMD devices to observe and navigate in the virtual environment. They used two controllers to explore the virtual environment from the first-person viewpoint, which improves the sense of presence. Participants were able to listen to auditory voice instructions as well as simulated sounds for the alarm, fire, walking, and calling for help.

We designed real objects in the virtual environment to increase the feeling of presence during the learning activities. A true-to-life residential fire situation was applied in the game, for example, a room equipped with a television, a residential lounge, door handles, and a fire alarm device. The use of an FPS model enhanced user experience and participants' engagement. To provide a realistic environment, this study adopted 3ds Max modeling software to build a virtual environment, and the VR-SG was developed through UE4 development software. Several particle systems were used in the I-Escape game to create visual effects. Flames were used to show fires inside the room and a larger and fast-moving blaze indicated a fire had started (Fig.4). In the game, participants could move freely by using HTC controllers (Fig.5).

Fig. 6. Finding a towel in the kitchen.

Fig. 7. Shutting down the power.

Fig. 8. Moving downstairs to the safe areas.

4.2. Virtual Reality–Serious Game Design Procedure

The fire safety game for elderly people, I-Escape, was designed based on the proposed VR-SG-BST model. The game comprises various activities organized according to fire safety skills required in a high-rise building. It includes the following gaming tasks: identifying fire hazards in the rooms of high-rise apartments; finding a route to the stairs; finding the emergency alarm and calling for help; staying away from the fires; and moving to safe areas. Since elderly people can suffer from health problems that could affect the use of the game device, nursing staff could assist the elderly to use the VR game. Training was conducted during the process of playing the game, individually with participants and the staff.

During the VR game, participants were required to perform tasks under the same scenarios when fires occurred inside the bedroom. For example, they were required to navigate inside the room and identify where the fire was. Then, they needed to sound the medical alarm to call for help from the nurses' station. Meanwhile, they needed to keep away from the fire – and smoke if this was present – and move toward the front door. In the case of smoke, the fire alarm was activated using a sound effect. Participants then needed to move to the kitchen and find a towel to cover their faces(Fig.6). They needed to keep moving to reach the front door, which they would then open, and they would then move to the stairs. In some cases, participants needed to lower their body (or stoop), which allowed them to pass through the hazard safely and therefore more quickly. Participants needed to shut down the power (Fig.7). They were instructed not to use the elevators. If nurses were in the corridor, they asked for help. If not, they moved to the stairs and exited the building. Once participants had moved to a safer area, the game was over (Fig.8). Fig.9 shows the completion of the game.

When playing I-Escape, the control group was not provided any assistance to complete it; however, the experimental group was provided BST for fire safety in this virtual environment. For example, for the experimental group the instruction, modeling, rehearsal, and feedback phases of the BST were conducted before, during, and after the game. The nursing staff assisted during the entire process. Depending on participants' health conditions, the rehearsal phase was repeated at least three times. After this, participants were exposed to the different fire situations, and their behaviors exhibited in the virtual environment for respective fire situations were observed. IST was conducted during this phase. At this point, if participants were unable to demonstrate the correct behavior or they presented an incorrect behavior, feedback was immediately provided to show them the appropriate behavior. Feedback continued until the participants could fully demonstrate the correct behaviors.

4.2.1. Game Components

Components implemented in the VR-SG included participant's scores, challenge, time bonus, the level of the game, rewards, game tasks, and the duration of the game. In consideration of the age and health of the elderly participants, large icons were used in the game design. This game approach assisted the elderly in reducing their memory load. The levels of the game were presented as stars, and the duration of each game scenario was recorded. Once participants had completed a task successfully, they passed that level and were awarded yellow stars with sound effects. Remaining stars were colored gray. At the completion of the game, the scores and time to completion were displayed and participants could select either to quit or restart the game. There are three levels in each game scenario, which has three levels of game challenges. Each challenge is 20 points and the highest challenge is 60 points. When the game is completed, a user interface is presented. The tasks in each game scenario are displayed as picture icons at the top of the interface. When the tasks are achieved, there is a tick in the icon. Fig.10shows the user interface that the participant has completed all game tasks and the score is 90, the challenge is 60, the time bonus is 80, and the participant has completed all levels. The time to completion is also displayed. When a participant completes the game in less time, a higher score is awarded. Table1 shows the target behaviors exhibited during the game.

Table 1. Fire situations and target behaviors

Fire Situations	Target Behaviors
Sound the medical alarm to call for help	- The participant stays away from the flames after encountering the fires inside the room. - The participant sounds the medical alarm to inform the nurses or staff. - The participant shuts down the power and moves to outside the room.
Room exit is blocked by fire	- The participant stays away from the flames after encountering the fires inside the room. - The participant sounds the medical alarm to inform the nurses or staff. - The participant moves to the balcony quickly and safely and stays away from the fires as far as possible.. - The participant waits for nurses and staff in the corridor.
Corridor/stairs exit are closed/disabled by fire	- The participant stays away from the flames after encountering the fires inside the room. - The participant sounds the medical alarm to inform the nurses or staff. - The participant leaves the building using the other exit quickly and safely. - The participant waits for nurses and staff outside the building.
All exits of the residence are closed/disabled during the fire	- The participant stays away from the flames after encountering the fires inside the room. - The participant sounds the medical alarm to inform the nurses or staff. - The participant quickly and safely moves to the balcony/terrace that is the farthest from the fires. - The participant asks for help by notifying of the fires in a loud voice.

Fig. 9. Game finish.

Fig. 10. An user's interface displayed in the end of the game.

4.2.2. Navigation and Manipulation

Some studies suggest that participants prefer to explore a virtual room on their own rather than be passive observers in the VR environment[55]. In this study, participants used HTC controllers to explore the virtual environment. The right controller was used to remove obstacles, and the teleporting mode was used to move around the environment in the game. The left controller was used to manipulate the menus. Two controllers were used in any combination of the given manipulating objects, such as using a fire extinguisher or ringing the alarm. This approach allowed participants to face any wall of the immersive environment without needing to adjust how they were using the VR device. During the game, all participants mentioned problems with navigation and feeling unfamiliar with using the VR controllers. Consequently, it took more time than expected to teach participants how to use the HTC Vive equipment. Although most participants could complete the tasks during the training, the time taken for this was also longer than expected. Some participants stated that they felt dizzy during the game, and some participants asked to remove the HTC HMD after only one minute of gameplay.

4.2.3. User Interface Design

A UI allows participants to interact with a virtual environment[56], for example, by exploring the environment, moving, and walking. A good UI provides users with information immediately, transforms quickly into the virtual environments, and allows users to complete tasks accurately, while a bad UI can largely reduce users' experience, even causing them to give up. Laurel and Mountford[57] highlight the UI design principles of being user-oriented, consistent, providing immediate feedback, among others. Further, some research demonstrates that a virtual menu is an effective tool for interacting with a virtual environment[58]. Different from two-dimensional interface design, a VR UI is designed as a floating menu that is virtually presented in front of users.

Considering the elderly's eye health issues, such as presbyopia or blurred vision, large texts and images were used in the menu. This helped the elderly to read and reduced their struggle. Dizziness is a frequent problem for elderly people. To reduce the sensation of dizziness, we used dimmer lights and avoided too many colors in the menu design. The UI was designed to be as simple as possible so that it not only enhanced the realistic environment but also improved the user's experience. The interviews demonstrated that most participants were satisfied with the interface design of the VR-SG. For example, one participant stated, "I can see the text and icons, yes, I can recognize the icons."

4.2.4. Presence Questionnaire

Participants' perception of the SG-based virtual environment was evaluated by a questionnaire. The questionnaire is one of the simplest ways to collect data during SG research[59]. In this study, a questionnaire was used to evaluate the quality of immersion within the virtual environment. Fig.11 shows that a participant wears a HMD device playing the game.

Some research suggests that a sense of "presence" is a principal factor in the evaluation of the VR environment[60]. Witmer, Jerome, and Singer developed a "presence questionnaire" (PQ) as a method to test the perceived levels of immersion in VR environments[61]. 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."[62]. The PQ is an ideal way to test participants' perception of the VR game environment, and therefore we adopted it in our study. The PQ employs a 7-point Likert type scale; in which 7 indicates the highest degree of presence and 1 indicates the lowest degree of presence.

Participants' PQ scores for this study are listed in Fig.14, where each line represents the score of a participant. The figure indicates that most participants experienced a high degree of presence in the game's virtual environment. For example, in answering the question about the sense of realism experienced, most of the participants rated above 6, that meaning most participants experienced a sense of realism in the virtual environment.

4.2.5. Statistical methods

This study uses the following statistical methods: one-way ANOVA tests was used to analysis the results of pre- and post-VR-SG-BST stage and the accuracy of behavior for the experimental group. We also applied Pearson correlation to analysis the influence on the participants with gaming experience, prior fire training and ageing.

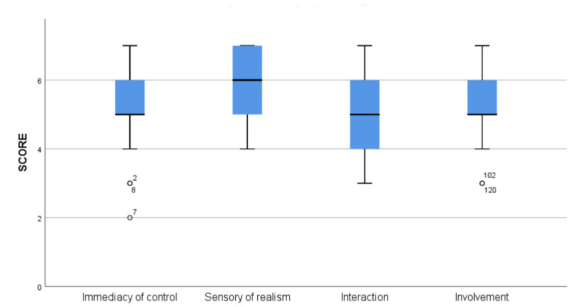

Fig. 11. The presence questionnaire score.

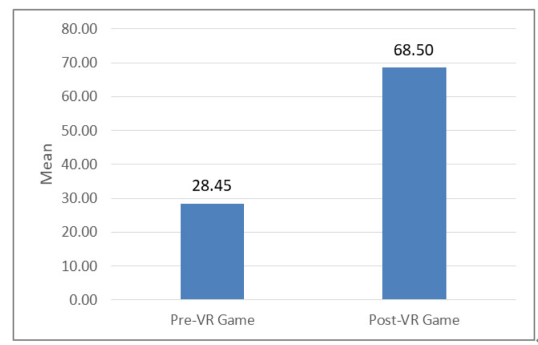

Fig. 12. Mean scores of pre- and post-VR-games by two groups.

5. Results and Discussion

Based on the proposed theoretical model, this section analyzes how the VR-SG affected BST for the elderly. Firstly, we compared mean scores in the two stages (pre-VR game and post-VR game) of this study, and then we analyzed the correction rate of behavioral skills from the comparison of two groups (control and experimental groups). Specifically, we analyzed data from the experimental group in pre- and post-VR-SG-BST. Secondly, the date from the prior fire training, gaming experience and ageing are analyzed.

5.1. Comparison of the Two Groups in Pre-VR game and Post-VR game

The VR game I-Escape was used to measure participants' learning and its design was based on behavioral skills in fire safety. For example, participants earned points when they exhibited a correct behavior in a fire, while an incorrect behavior in a fire did not earn them any points. The mean scores from the participants during the pre-VR-game and post-VR-game stages are shown in Fig.12, which included two groups. The figure reveals that participants in the post-VR game received scores 40% higher than they did in the pre-VR game. When considering the two groups separately in the pre-VR game, no significant differences between them were evident. All participants had similar scores before they received FST, where $p = 0.682$ (> 0.05) in Table2. However, there was a significant difference in scores evident in the post-VR game between the control group and the experimental group, as shown in Table2. The results from one way ANOVA test shows the statistically significant differences in the results obtained for the two groups under study, where p

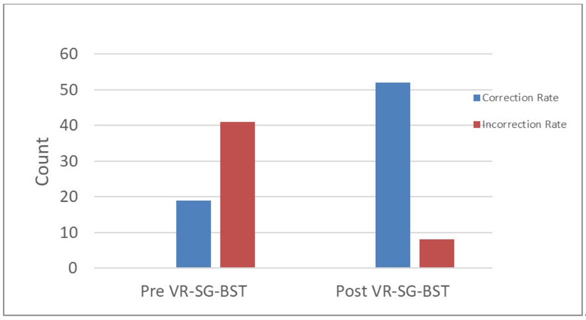

Fig. 13. The correction rate of pre- and post-VR-SG-BST stages for the experimental group in basic fire safety skills.

= 0.001 p = 0.001(< 0.05). Thus, FST using VR-SG-BST produced better results than training based on traditional methods, such as class and video presentation.

To evaluate the behavioral skills of participants, this study explored the effect of the VR-SG-BST model after training. Only the experimental group received VR-SG-BST training. Fig.13 shows the incorrect rate was 36.6% higher than the correct rate in the pre VR-SG-BST stage, while the incorrect rate was 74.4% lower than the correct rate in post VR-SG-BST stage. We then checked the whether the correction rate of the behaviors has statistically significant differences between pre VR-SG-BST and post VR-SG-BST stages. We performed a one way ANOVA test and the result showed that F = 53.767 and p = 0.000 (< 0.05) in Table 3. Therefore, the result shows the statistically significant differences in the behavioral skills from the pre- and post-VR-SG-BST model for the elderly.

For evaluate the difference of the behavioral skills between the experimental group and control group, we firstly compared the mean scores of two groups. Fig.14 represents the results of the mean scores of the behavioral skills in the pre-VR game stage for both groups. It indicates that most participants from both groups had interacted with fires before the training. There were 12 participants who tried to extinguish the fire when they first encountered it in I-Escape, and eight participants attempted to examine the fire sources in the kitchen; their behaviors were expected. However, five participants' behaviors were somewhat unexpected. When they first encountered the fire, they remained in the fire environment and even entered the fire. According to their statements before the training, they believed that the fire would not hurt them; however, during training, they realized that the fire was highly dangerous, and that people should stay away from it. We found that average accuracy of the behavioral skills for participants in the control group was higher than the experimental group in the pre-VR game stage μ_C = 4.75, μ_E = 4.25). However, according to the one-way ANOVA (Table 4), this difference was not statistically significant (p = 0.845), which means that there was not a clear difference before the participants received the video FST and the proposed VR-SG-BST training. For the post-VR game stage, Fig.15 shows that the average accuracy of the behaviors displayed by the control group was μ_C = 9.25, and for those by the experimental group was μ_E = 13.75. In this case, the one-way ANOVA test resulted in p = 0.003, and therefore this difference was statistically significant (Table 5). The results suggest that the VR-SG-BST model, which was used in the experimental group, has a better effect on the behavioral skill training. This indicates that the VR-SG-BST model can be an effective method to improve the elderly's behavioral skills during a fire.

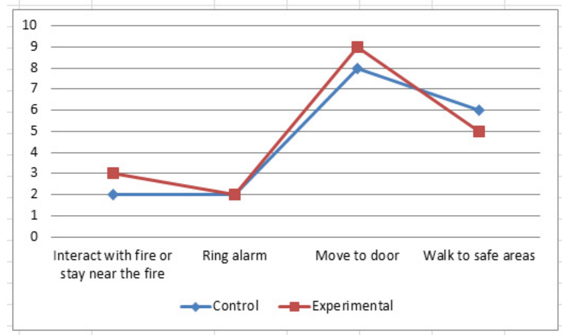

Fig. 14. Mean scores of basic fire safety skills in pre-VR-game.

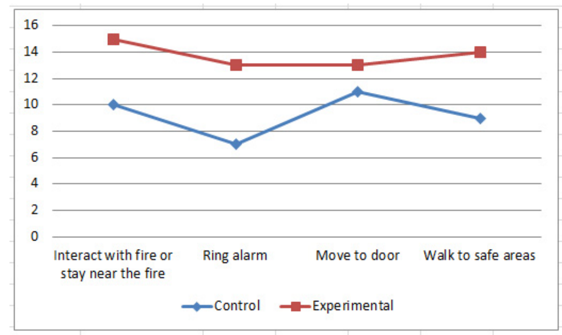

Fig. 15. Mean scores of basic fire safety skills in post-VR-game.

Regarding each behaviors tested in this study, we analyzed the pre-VR game results from both groups and checked which behavior from the participants was the common displayed. Table 6 shows that the behavior of ringing the alarm and interact with fire in the control group was 12.5% correction rate, which was the lowest rate. Table 7 shows that the behavior of ringing the alarm in the experimental group was 10.5%, which was the lowest correction rate. The behavior of moving to door was highest correction rate for both groups, which was 43.8% in the control group and 47.4% in the experimental group. The results suggest that ring the alarm and interacting with the fire was the most common incorrect behavior displayed by the elderly participants during a fire. The behavior displayed with highest correction rate by the elderly was moving to door. It suggests that moving to door in a fire was a common correction behavior the elderly displayed before received any FSTs.

5.2. *Fire safety training and gaming experience*

In this study, three participants reported having fire drill (FD) experience and 15 participants reported having FST experience. To understand how the previous FST experience influenced their VR-SG-BST training, the data from participants were analyzed. In the post-VR-SG-BST stage, most participants were able to gain a higher score in the game, indicating complete and correct fire safety behavior. However, the results from Table

Table 2. Results of the ANOVA test for the pre- and post-VR game between two groups.

		Sum of Squares	df	Mean Square	F	Sig.
Pre-VR game	Between Groups	12.033	1	12.033	0.171	0.682
	Within Groups	1970.833	28	70.387		
	Total	1982.867	29			
Post-VR game	Between Groups	2340.833	1	2340.833	13.750	0.001
	Within Groups	4766.667	28	170.238		
	Total	7107.500	29			

Table 3. Results of the ANOVA test for Correction Rate of pre- and post- VR-SG-BST

Correction Rate	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.075	1	9.075	53.767	0.000
Within Groups	19.917	118	0.169		
Total	28.992	119			

Table 4. The accuracy of behaviors displayed by two groups in pre-VR game

Pre-VR game	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.008	1	0.008	0.038	0.845
Within Groups	25.583	118	0.217		
Total	25.592	119			

Table 5. The accuracy of behaviors displayed by two groups in post-VR game

Pre-VR game	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.633	1	1.633	9.236	0.003
Within Groups	20.867	118	0.177		
Total	22.500	119			

Table 6. The accuracy of behaviors displayed by control group in pre-VR game

BEHAVIOR	Indicators	Correct Behavior	Incorrect Behavior	Total
Interact with fire OR stay close to fire	Count	2	13	15
	% within BEHAVIOR	13.3%	86.7%	100.0%
	% within Control Group	12.5%	29.5%	25.0%
Ring alarm OR call for help	Count	2	13	15
	% within BEHAVIOR	13.3%	86.7%	100.0%
	% within Control Group	12.5%	29.5%	25.0%
Move to door	Count	7	8	15
	% within BEHAVIOR	46.7%	53.3%	100.0%
	% within Control Group	43.8%	18.2%	25.0%
Walk to safe areas	Count	5	10	15
	% within BEHAVIOR	33.3%	66.7%	100.0%
	% within Control Group	31.3%	22.7%	25.0%
Total	Count	16	44	60
	% within BEHAVIOR	26.7%	73.3%	100.0%
	% within Control Group	100.0%	100.0%	100.0%

Table 7. The accuracy of behaviors displayed by the experimental group in pre-VR game

BEHAVIOR	Indicators	Correct Behavior	Incorrect Behavior	Total
Interact with fire OR stay close to fire	Count	3	12	15
	% within BEHAVIOR	20.0%	80.0%	100.0%
	% within Experimental Group	15.8%	29.3%	25.0%
Ring alarm OR call for help	Count	2	13	15
	% within BEHAVIOR	13.3%	86.7%	100.0%
	% within Experimental Group	10.5%	31.7%	25.0%
Move to door	Count	9	6	15
	% within BEHAVIOR	60.0%	40.0%	100.0%
	% within Experimental Group	47.4%	14.6%	25.0%
Walk to safe areas	Count	5	10	15
	% within BEHAVIOR	33.3%	66.7%	100.0%
	% within Experimental Group	26.3%	24.4%	25.0%
Total	Count	19	41	60
	% within BEHAVIOR	31.7%	68.3%	100.0%
	% within Experimental Group	100.0%	100.0%	100.0%

8 indicates that the P-value in the analysis is greater than 0.05 ($p = 0.181$ in pre-VR-SG-BST; $p = 0.499$ in post-VR-SG-BST). Therefore, there was no statistically significant difference found between pre- and post-VR-SG-BST stages for participants with FST/FD experience.

The findings of this study suggest that the participants' previous fire safety experiences were not a major influence on the development of behavior training in the VR environment. This is contrary to other research findings, such as the study by Smith and Trenholme[63] . We found that the participants with experience in fire safety performed behaviors with similar accuracy to those who did not have any experience in fire safety skills training. A reason for this could be the limitations of the elderly's memory and physical responses. For example, the elderly participants might have forgotten what they had learned from their previous FST. Consequently, this demonstrates that it is critical to train the elderly in fire safety, especially those living in residential care homes. The participants' FST received previously was based on classroom training (teacher–learner forms). Therefore, for the elderly, the classroom training methods imposed greater limitations regarding the transferal of skills or knowledge to the virtual environment, and further, into real life.

In this study, five participants indicated gaming experience. We found that those with prior experience found it easier to use the VR controllers than those without. These participants had faster manipulation speeds and could complete the training in much less time, as demonstrated in Table 9. Pearson Correlation analysis resulted in $p = 0.000$ in manipulation speed and $p = 0.002$ in time to completion game, and therefore, there is statistically significant correlation between those with gaming experience and the learning performance according to the analysis. Similar to the findings of Backlund, et. al. [24], this suggests that gaming influences the elderly's learning performance. However, the analysis showed that $p = 0.297$ in IST imposed, which means that the number of IST imposed has no statistically significant correlation to gaming experience.

5.3. Age and learning performance

To understand whether age is a key factor influencing learning performance for the elderly, the participants were divided into three groups (60-67, 68-75, and 75+) based on their age. We first checked if there is statistically significant difference between age and game scores. The one-way ANOVA test showed that $p = 0.101$ in pre-VR game and $p = 0.286$ in post-VR game (Table 10). This result indicated that the difference was no statistically significant. After that we checked two main factors in SG based learning: time to completion and manipulation speed. The results from one-way ANOVA show $p = 0.889$ (Time to Completion) and $p = 0.584$ (Manipulation Speed) (Table 11). It indicated that there was no statistically significant difference between age and learning performance, demonstrating that age did not play a significant role in learning ability and manipulation of the game.

5.4. User Experience Results

The user experience survey was used to obtain data about the participants' experiences of the VR-SG-BST. The survey asked for participants' opinions about the most preferred parts of the training process. Data were collected with a 5-point Likert scale, and the results of this survey are presented in Fig. 16. Overall, most participants experienced fun and enjoyed playing the game. Most participants believed that the game helped them remember the principal issues of fire safety (scores were over 4.0). These results indicate that learning by playing the game was more interesting than learning by video training. The most popular aspect of the training was that it was fun: participants enjoyed playing the game. Just above half of responses indicated participants felt they learned something new from the training (scores were just over 2.50).

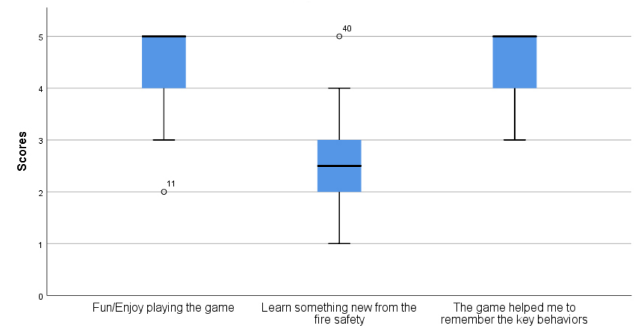

Fig. 16. Survey question results – what participants liked most.

During the post-VR-SG-BST stage, over half the participants reported that they felt fear in the virtual environment, which indicated a greater level of realism and immersion. In addition, the PQ scores suggested that most participants experienced a high degree of presence in the virtual environment, demonstrating that VR-SG training can achieve a more powerful learning experience than can traditional FST methods. Thus, in fire training for the elderly, using an immersive virtual environment could result in learning gains, in particular by applying BST during the training.

Further, the most impressive finding was that participants used a towel to cover their faces to avoid damage from the heavy smoke, which might produce poisonous gas. We believe that teaching this behavior in the virtual environment was an extremely useful method of training in fire escape skills. Another skill that participants demonstrated was bending their bodies, or stooping, when moving towards the corridor. This skill was particularly important when encountering fire inside a room because it could protect the elderly from the harmful poisonous gas. However, most participants did not know how to do this in the virtual environment. One participant stated, "I don't know how to bend", while another said, "where is the button to push?" This issue could be explained by the UI design. Also, participants might have expected to use the game controllers to manipulate the UI rather than physically engaging themselves in the activity. However, four participants successfully lowered their bodies and moved to the corridor with a towel covering their faces. This finding suggests that an immersive VR application has a high level of "built-in" capabilities for human–computer interaction, which can enhance the ability of a truly "hands-

Table 8. The correlation between Pre-VR-BST and Post-VR-BST stages.

Experimental Group	Indicators	Pre-VR-SG-BST	Post-VR-SG-BST
With FST/FD Experience	Pearson Correlation	0.365	0.189
	Sig. (2-tailed)	0.181	0.499

Table 9. The correlation between gaming experience and manipulation speed, time to completion, and IST.

Experimental Group	Indicators	IST Imposed	Manipulation Speed	Time to Completion
With Gaming Experience	Pearson Correlation	-0.289	.875**	.739**
	Sig. (2-tailed)	0.297	0.000	0.002

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 10. Statistical results comparing age and game scores in pre- and post-VR game

Game Score	Age Groups	Sum of Squares	df	Mean Square	F	Sig.
Pre-VR Game	Between Groups	1111.667	2	555.833	2.503	0.101
	Within Groups	5995.833	27	222.068		
	Total	7107.500	29			
Post-VR Game	Between Groups	175.450	2	87.725	1.310	0.286
	Within Groups	1807.417	27	66.941		
	Total	1982.867	29			

Table 11. Statistical results comparing age and learning performance.

Learning Performance	Age Groups	Sum of Squares	df	Mean Square	F	Sig.
Time of Completion	Between Groups	0.391	2	0.196	0.118	0.889
	Within Groups	44.849	27	1.661		
	Total	45.240	29			
Manipulation Speed	Between Groups	0.039	2	0.019	0.548	0.548
	Within Groups	0.950	27	0.035		
	Total	0.989	29			

on" training experience when compared with traditional video games. Thus, the results indicate that an immersive VR application for FST produces greater benefits of embodied interaction than does traditional training.

6. Conclusion

Training elderly people in fire safety skills can be challenging because they need to be able to reproduce correct behaviors in special situations. Providing the elderly with correct behavior training in a classroom setting that does not automatically translate to a real-world situation is unlikely to be successful. However, BST is an effective way to reduce the number of deaths in a fire, and the VR-SG approach shows promise for offering an alternative FST method for the elderly. In this paper, a theoretical model has been proposed that integrates VR-SG with BST to teach behavioral skills. The model has the potential to correct the behavior skills of the elderly in dangerous situations. Two groups (experimental and control groups) were recruited to compare traditional training methods and the proposed VR-SG-BST method. An additional investigation was conducted on the proposed VR-SG-BST model: using only the experimental group, pre-VR-SG-BST and post-VR-SG-BST data were analyzed to determine how the model influenced the behavior of the elderly before and after receiving VR-SG-BST.

The results from the study demonstrate that behavioral skills can be improved through a VR-SG approach to FST developed within the proposed model. The study showed that IST applied to the VR-SG-BST model is more likely to increase the effect of correcting behaviors, which suggests that an immersive VR environment has an advantage over other traditional methods of training for the elderly. The study demonstrated that VR-SG FST could improve the ability of the elderly to identify fire hazards in a real-world situation. The VR-SG design allows the elderly to experience a realistic virtual environment for high-risk safety training, which is difficult to achieve in a regular video game. However, this study only explored the video based FST, which is the limitation of this study. Other traditional FST methods, such as classroom training, could be explored in the future.

Further, the results indicate that the game components adopted in the VR environment effectively attracted the elderly's attention and improved their engagement in the training. The study shows that any experience of elderly people in FST did not lead to a significant behavioral difference between pre-VR-SG-BST and post-VR-SG-BST, suggesting that previous fire safety experience of the elderly may not help them improve their behaviors in a fire. This finding indicates that FST for the elderly is not only necessary but critical to increase their chances of survival in emergencies. While a sense of presence experienced by the participants in the VR environment could be a key factor in the development of their behavioral skills, the levels of sense of presence expressed by participants were variable.

The study found that previous gaming experience could effectively improve the elderly's behavior during training. For example, elderly people with gaming experience demonstrated a faster response and could complete the training in less time than those without gaming experience. For the age, the results show no significant differences in game scores, manipulation speed and time to complete the tasks between the different age groups, thus demonstrating that age did not play a significant role in learning ability and manipulation of the game.

Overall, the proposed model offers an alternative approach to improving the elderly's learning ability through BST. Hence, the findings from this study can be applied to further research on the virtual learning environment using SG components. In the future, how best to ensure sustained demonstration of correct behavioral skills needs to be explored. Other game components could be improved to introduce more interest to the SG for repeated training. This would include introducing not only more hazards but also different hazards that could appear in varying locations in the next version of game design. Further, new VR technologies could be explored, such as augmented reality. Augmented reality devices would introduce a lighter helmet and a mixed environment to users. This approach would integrate the realistic and virtual environments and help elderly people to identify potential fire hazards in their residential homes. The augmented reality light helmet could effectively reduce the difficulties associated with wearing the equipment. Consequently, the results of this study present a significant contribution regarding the use of BST in FST for the elderly.

Acknowledgments

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A Virtual Reality−based Serious Game for Fire Safety Behavioral Skills Training

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