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Observing Evacuation Behaviours of Surprised Participants in Virtual Reality Earthquake Simulator

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Abstract: Evacuation training should be more realistic. We aim to develop a VR-based evacuation training system that includes gaming elements but completely separates evacuation training and game. In addition, the training system should simulate earthquakes that suddenly occur. Before starting the development, we got interested in observing the evacuation behaviours of participants in a VR earthquake simulator. Thus, we conducted a preliminary comparative experiment that examined the differences between one-participant and two-participant settings in the simulator. As a result, participants tended to keep moving in the one-participant setting and consequently completed evacuation faster. However, participants tended to have more discussion and synchronisation in the two-participant setting, resulting in a slower evacuation. These findings have the potential to be beneficial to development.

Keywords: Evacuation behaviours, virtual reality, a simple earthquake simulator

1. Introduction

Natural or artificial disasters are great threats to human beings. Especially, huge earthquakes bring devastating damages and claim many lives. Since 2010, magnitude 7 or higher earthquakes have occurred approximately 180 times all over the world (United States Geological Survey, 2021). It is unpredictable when and where earthquakes occur. As a result, people must be prepared for unexpected earthquakes. Disaster education helps with preparedness. Evacuation training is a popular form of disaster education held regularly in schools, businesses and communities. Traditional evacuation training, on the other hand, does not provide realistic simulated evacuation experiences. This is because participants (trainees) take a predetermined route to a predetermined safe location (e.g., shelter). In other words, traditional evacuation training does not cover decision making against difficult disaster situations they may encounter during evacuating. For example, when a recommended route is impassable in a real earthquake, people must choose another route to a shelter. Thus, evacuation training should be more realistic.

Information and communication technology (ICT) has recently been introduced in disaster education to heighten learning efficacy and motivation. For example, mobile applications have been developed that provide realistic pseudo evacuation experiences of the tsunami (Yamori & Sugiyama, 2020)(Kawai et al., 2016). These mobile applications can be thought of as supplements to real world evacuation training. Furthermore, virtual reality (VR), which provides high immersion, interactivity and safety, has been introduced in evacuation training to provide realistic virtual evacuation experiences. For example, a VR-based earthquake evacuation training system enhances survival skills (e.g., detecting potential danger) by simulating earthquake (shakes), environment (space and objects), and human realistically (Li et al., 2017). Participant behaviours in VR-based evacuation training have been actively observed. For example, it has been revealed that exit choice behaviours during an evacuation are similar between a VR simulator and a field experiment (Feng et al., 2021). It has been asserted through different experiments that VR-based fire evacuation training should attach importance to behavioural realism (Arias et al., 2019). In addition, VR can be used to investigate factors causing undesirable evacuation behaviours in real disasters (Snopková et al., 2021). We developed a simple VR evacuation simulator (earthquake and fire). We found that participants with unsuccessful evacuation in the first session in the simulator tended to make successful evacuation in the next session (Mitsuhara et al., 2019). If integrated with a digital game, VR can heighten not only training efficacy but also training motivation. For example, there have been VR-based serious games focusing on evacuation (decision making) at earthquakes (Feng et al., 2020a), fire (Rahouti et al., 2021), and aircraft emergency landing (Chittaro & Buttussi, 2020). For wider popularisation, a recent VR-based serious game enables trainers to customise environmental, disaster, narrative, and pedagogical settings (Feng et al., 2020b).

This research aims to create a VR-based evacuation training system that incorporates gaming elements while keeping evacuation training and gaming separate. To be more specific, the training system serves up a game in its default mode to participants (players). Nonetheless, it abruptly switches to emergency mode, forcing the participants (trainees) to evacuate. When an earthquake strikes unexpectedly, some people may become panicked and fail to evacuate properly in the real world. To provide realistic simulated evacuation experiences, the training system should simulate unexpected earthquakes. We conducted a preliminary comparative experiment before developing the system to observe how participants behave in a VR earthquake simulator. We focused on differences between one-participant and two-participant settings in the experiment, assuming that the presence or absence of an accompanier influences participant behaviour.

2. VR Earthquake Simulator

For the experiment, we prototyped a simple VR earthquake simulator as a subset of our VR-based evacuation training system by using a game engine ‘Unity3D’. The simulator focused on earthquake evacuation, where participants escape from the inside of a building. To be immersed in the simulator, the participants wore a binocular opaque head-mounted display (HMD) ‘Oculus Quest 2’ and held double-handed controllers ‘Oculus Touch Hand Controllers’.

2.1 Virtual World

We modelled a six-floor office building with a rooftop deck in an urban area using three-dimensional Unity assets (Figure 1). Participants can walk down a street and enter the building in the virtual world other buildings have no entrance.

The office building has three entrances on the first floor. There are two stairways between each floor, and one stairway between the sixth floor and the rooftop deck. In a room on the fourth floor, the participants can play a simple game that allows shooting a gun at static targets using the controllers.

Figure 1. Screenshots of the Virtual World.

2.2 *Earthquake Simulation*

A large earthquake occurs unexpectedly while participants are playing the gun shooting game. In other words, the earthquake never happens unless the participants play the game. To convey the earthquake realistically, the simulator employs the following audiovisual effects.

1. Sounds earthquake early warning.
2. Expresses strong shakes that continue for fifteen seconds:
   - Swings the HMD's screen—the swing is adjusted to avoid VR sickness.
   - Sounds a roar.
   - Shakes objects (e.g., desk-top items and chairs) and collapses some light objects.
3. Expresses floors with obstacles (littered objects). To secure evacuation routes, the participants can grab and throw the obstacles by operating the controller.
4. Expresses shake-caused fires together with burning sounds at the following locations:
   - Around one entrance on the first floor, the participants may head to another entrance to evacuate outside.
   - The participants may take another stairway to move between the two floors around one stairway on the third floor (to the fourth floor).
   - The participants may take another stairway to move between the two floors around one stairway on the fifth floor (to the sixth floor).

After the shakes, the participants must decide what to do. The participants do not have to evacuate but mostly will start evacuating necessarily. The simulator does not promote their decision or limit evacuation time. Even if touching fire, participants do not suffer damage (e.g., decreasing moving speed by injury). Figure 2 shows the floor map indicating fire locations and screenshots showing after-shake situations.

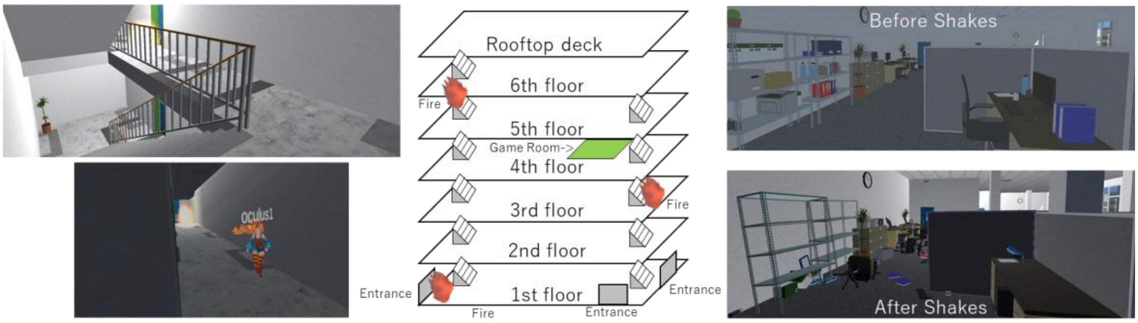

Figure 2. Floor Map of the Building.

3. Experiment

We carried out a preliminary comparative experiment to see how participants behaved in the simulator. We were particularly interested in whether an accompanier could influence evacuation behaviours, that is, whether differences could emerge between one-participant and two-participant settings. This focus is critical in determining whether the training system should use a single trainee or multiple trainees.

3.1 *Settings*

3.1.1 *Participants*

We collected participants by saying that they could play a VR game. The participants were nine undergraduate students (between the ages of 21 and 23) who majored in computer science and experienced once or no VR before. We divided the participants randomly into two groups:

- Group A (*N=3*): One-participant entered the simulator with no accompanier. In other words, the participants in this group would evacuate alone.

- Group B (*N=6*): Two participants simultaneously entered the simulator. Thus, the participants in this group were divided into three subgroups: B1, B2 and B3. It was expected that two participants in each subgroup would evacuate together.

3.1.2 Procedure

For the experiment, we prepared a small compartment in a laboratory. First, all participants wore the HMD and held the controllers. Then, they walked through the virtual world for a while and reached the gaming room—they never imagined that an earthquake would occur in the VR game. Regarding Group B, two participants in each subgroup simultaneously used the simulator while keeping a safe distance within a conversing range in the compartment.

- Group A: After confirming that a participant was playing the game for a while, we started the experiment by sounding earthquake early warning.
- Group B: After confirming that two participants were playing the game together, we started the experiment. In other words, the two participants were in the same room when the experiment started.

We video-recorded the simulator screen that participants saw by using the HMD's mirroring function. In addition, during the experiment, we voice-recorded their utterances. When we realised that a participant had not begun evacuating within 5 min, we informed the participant that the simulator was coming to an end (VR game). Following their use of the simulator, all participants were given a questionnaire that included 5-degree Likert scale questions and free-descriptive questions.

3.2 Results

All participants tried to evacuate immediately after the shakes stopped, and eight participants completed evacuation. In Subgroup B2, one-participant (P6) dropped out due to VR sickness, but another participant (P7) kept evacuating alone.

3.2.1 Evacuation Time

From the recorded videos, we measured evacuation time for three participants in Group A and five participants in Group B. Table 1 shows evacuation times of participants (P1, P2, and P3) in Group A and participants (P4 and P5, P7, and P8 and P9) in Group B. Regarding Subgroups B1 and B3, we measured evacuation time at the timing when both participants completed evacuation.

Table 1. *Evacuation Time (P: Participant)*

Group A	Time (s)
P1	278
P2	241
P3	204
Mean	241.0
Group B	Time (s)
P4 and P5 (Subgroup B1)	334
P7 (Subgroup B2)	294
P8 and P9 (Subgroup B3)	409
Mean	345.6

All participants in Group A completed evacuation faster than every participant in Group B. Group A's mean evacuation time (241.0 s) was approximately 100 s lower than that (345.6 s) in Group B.

3.2.2 Utterance

During the evacuation, participants in Group A did not utter anything except for ‘Oh’ and ‘Oops’. On the other hand, participants in Group B uttered mainly when they had to make decisions (e.g., ‘What do we do?’ and ‘Which is better to go?’) Occasionally, the participants uttered to point out the danger (e.g., ‘Let's detour to avoid fire.’) Participants (P8 and P9) in Subgroup B3 uttered to synchronise evacuating pace (e.g., ‘Please wait’ and ‘Come on this way.’)

3.2.3 Questionnaire

Table 2 shows the mean values and standard deviations of the participants' answers to the questions. Concerning participants' self-evaluation about evacuation (Q1), the mean values were 4.33 and 4.80 in Groups A and B, respectively—P6 did not answer this question due to drop out. The mean values of their sensed uneasiness (Q2) were 4.33 and 2.83 in Groups A and B, respectively. The mean value of Group A was 1.5 point higher than that of Group B. Concerning their sensed urgency (Q3), the mean values were 4.33 and 3.33 in Groups A and B, respectively and the mean value of Group A was approximately 1 point higher than that of Group B. Concerning their sensed confusion (Q4), the mean values were 3.0 and 4.5 in Groups A and B, respectively and the mean value of Group A was 1.5 point lower than that of Group B. Concerning their sensed scare (Q5), the mean values were 4.0 and 2.33 in Groups A and B, respectively and the mean value of Group A was approximately 1.7 point higher than that of Group B. Concerning their sensed fun (Q6), the mean values were 4.67 and 4.33 in Groups A and B, respectively.

Table 2. *Questionnaire Result*

Question	Group A Mean (SD)	Group B Mean (SD)
Q1. Do you feel that you made a successful evacuation?	4.33 (0.22)	4.80 (0.22)
Q2. Did you feel uneasy during the evacuation?	4.33 (0.22)	2.83 (0.81)
Q3. Did you feel urgent during evacuation?	4.33 (0.22)	3.3 (1.22)
Q4. Did you feel confused during the evacuation?	3.0 (0.0)	4.5 (0.25)
Q5. Did you feel scared during the evacuation?	4.0 (0.67)	2.33 (0.56)
Q6. Did you feel fun during evacuation?	4.67 (0.22)	4.33 (0.22)

3.3 Consideration

The evacuation times for Groups A and B were different. Participants in Group A, who had to make decisions on their own, tended to move quickly. On the other hand, participants in Group B tended to pause to discuss evacuation routes and synchronise evacuation pace by waiting for another participant (accompanier). As a result, Group A participants finished evacuating faster than Group B participants. In addition, two of the participants in Group A tended to pass through fire toward the entrance or the rooftop deck. This tendency may result from evacuation in the virtual world; the participants may have felt able to pass through the virtual fire. Regarding Group A, the mean value of Q1 was high (4.33), indicating that the participants gained the wrong successful experience by passing through the virtual fire. From the mean values of Q2–Q5, we can assume that participants in Group A felt a certain degree of reality. However, we think that the simulator should not have allowed participants to pass through the virtual fire. VR can provide safe evacuation training, but its safety may have prompted them to take reckless behaviours that should be refrained in real disasters. Regarding Group B, the mean value of Q1 was quite high (4.80), indicating that cooperative evacuation in the virtual world increases self-evaluation about evacuation. The simulator did not give (display) time limit, and therefore participants in both groups could evacuate without any concern for time. If given a time limit, participants in Group B might not have taken cooperative evacuation behaviours (i.e., discussion and synchronisation) and instead have taken reckless behaviours.

We examined the reality of evacuation by asking about adverse emotions with Q2–Q5, supposing that the high mean values of these adverse emotions represent the high degree of reality. The mean values of Q2, Q3, and Q5 indicated that participants in Group A felt more uneasiness, urgency and scare than those in Group B. Regarding Group A, we think that the high mean values resulted from evacuating alone though two participants may not have felt the reality enough against the virtual fire itself. Regarding Group B, we think the low mean values resulted from cooperative evacuation behaviours that can alleviate uneasiness, urgency and fear. On the other hand, the mean values of Q4 indicated that participants in Group B felt more confusion than those in Group A. We believe that the discussion and synchronisation added to the confusion. Although no verbal conflicts were observed in the experiment, participants in Group B may not have explicitly stated their evacuation policy or desire for self-determination due to evacuation in the virtual world (safe, no-time-limit situations). If participants had verbal disagreements, they would not consider the evacuation to be successful. Although participants in Group B occasionally uttered to avoid danger, apparent collaborations were not observed; this experiment prepared no situations where they needed to collaborate. If participants overcome difficult situations collaboratively, they will feel more successful evacuations.

The mean Q6 values in both groups were positive. This suggests that our VR-based evacuation training system can motivate people to participate in training regularly. Furthermore, using the free-descriptive question, participants demonstrated the following lessons learned from the simulator evacuation. Based on the lessons, we anticipate that the training system will improve training efficacy.

- Group A: 'Daily, I should think how to evacuate when familiar routes are collapsed.', 'Earthquake can make fire.'
- Group B: 'I have to learn evacuation routes in advance.', 'Obstacles may prevent prompt evacuation.', 'I have to cooperate with an accompanier when evacuating.', 'I have to calm down and evacuate'.

We confirmed that differences arose between Group A (one-participant) and Group B (two-participant). In the one-participant setting, participants tended to keep moving and consequently completed evacuation faster. In the two-participant setting, participants tended to have discussion and synchronisation and consequently completed evacuation slower. Furthermore, participants in Group A tended to feel uneasiness, urgency and scare more than those in Group B. This result indicates that the presence of an accompanier can lead to calm evacuation behaviours. On the other hand, participants in Group B tended to feel confusion more than those in Group A. We suppose that similar evacuation behaviours can be seen in real disasters. However, it might be rare to evacuate alone in real disasters, and when many people simultaneously evacuate, situations may get more complicated. As a result, we believe that VR-based evacuation training should provide various simulated evacuation experiences in terms of disaster factors (e.g., damage intensity) and human factors (e.g., accompanier). Participants should repeat evacuation training in a variety of ways of simulated situations.

3.4 Limitation

The experiment was insufficient because the participants were a small group of university students. We should recruit more people from diverse demographics by proving the validity of the differences and considerations. Although participants in both groups felt a sense of reality in the simulator, we should strive for a higher level of reality to realise VR-based evacuation training. Participants in Group A, for example, were exposed to fire, which can result in death and injury in real world disasters. The VR-based evacuation training must discourage participants from doing such reckless behaviours. Moreover, the experiment lacked various disaster situations, including worsening disaster situations according to the time change. Participants may change evacuation behaviours depending on disaster situations. Real disasters can cause fire and collapse and blackout, toxic gas, the injured (rescue), etc. Therefore, we should cover various disaster situations in VR-based evacuation training. In addition, we should consider whether to introduce the concepts of death, injury and other types of damage.

4. Conclusion

This paper described observing participants' evacuation behaviours in a VR earthquake simulator. We discovered that the VR earthquake simulator provides realistic pseudo evacuation experiences and influences participant evacuation behaviours depending on the presence of an accompanier in a preliminary comparative experiment between one-participant and two-participant settings. The experiment had limitations, but the results are useful to discuss ideal VR-based evacuation training.

Today, terrible disasters (e.g., earthquakes, floods, and wildfires) occur all over the world, and we must prioritise evacuation training as a means of surviving disasters. But, unfortunately, some people may be uninterested in disasters and evacuation training. To make matters worse, the COVID-19 pandemic is preventing people from communicating in person. In other words, it is getting difficult to conduct traditional evacuation training in the real world. In this situation, VR-based evacuation training will attract much attention due to its novelty and get more indispensable in terms of no-contact-with-person training. Therefore, we aim at a VR-based evacuation training system where participants can gain pseudo evacuation experiences online, i.e., individually in their own private space.

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References

Arias, S., Wahlqvist, J., Nilsson, D., Ronchi, E., Frantzich. H. (2020). Pursuing behavioral realism in Virtual Reality for fire evacuation research. *Fire and Materials*, *45*(4), 462-472, DOI: 10.1002/fam.2922.

Chittaro, L. & Buttussi, F. (2020). Learning safety through public serious games: A study of "Prepare for Impact" on a very large, international sample of players. *IEEE Transactions on Visualization & Computer Graphics*, DOI: 10.1109/TVCG.2020.3022340.

Feng, Y., Duives, D.C., & Hoogendoorn, S.P. (2021). Using virtual reality to study pedestrian exit choice behaviour during evacuations. *Safety Science*, *137*, DOI: 10.1016/j.ssci.2021.105158.

Feng, Z., González V.A., Mutch, C., Amor, R., Spearpoint, M., Thomas, J., Sacks, R., Lovreglio, R., and Cabrera-Guerrero, G., (2020a). An immersive virtual reality serious game to enhance earthquake behavioral responses and post-earthquake evacuation preparedness in buildings. *Advanced Engineering Informatics*, *45*, DOI: 10.1016/j.aei.2020.101118.

Feng, Z., González V.A., Mutch, C., Amor, R., Rahouti, A., Baghouz, A., Li, N., Cabrera-Guerrero, G. (2020b). Towards a customizable immersive virtual reality serious game for earthquake emergency training. *Advanced Engineering Informatics*, *46*, DOI: 10.1016/j.aei.2020.101134.

Kawai, J., Mitsuhara, H., & Shishibori, M. (2016) Tsunami evacuation drill system using motion hazard map and smart devices, *Proc. of 3rd International Conference on Information and Communication Technologies for Disaster Management (ICT-DM2016)*, 1-7.

Li, C., Liang, W., Quigley, C., Zhao, Y., & Yu, L.F. (2017). Earthquake safety training through virtual drills. IEEE Transactions on Visualization and Computer Graphics, 23 (4), 1275-1284. DOI: 10.1109/TVCG.2017.2656958.

Mitsuhara, H., Tanimura, C., Nemoto, J., & Shishibori, M. (2019). Failure-enhanced evacuation training using a VR-based disaster simulator: A comparative experiment with simulated evacuees, *Procedia Computer Science*, *159*, 1670-1679, DOI: 10.1016/j.procs.2019.09.337.

Rahouti, A., Lovreglio, R., Datoussaid, S. & Descamps, T. (2021) Prototyping and validating a non-immersive virtual reality serious game for healthcare fire safety training. Fire Technology, DOI: 10.1007/s10694-021-01098-x

Snopková, D., Ugwitz, P., Stachoň, Z., Hladík, J., Juřík, V., Kvarda, O., & Kubíček. P. (2021). Retracing evacuation strategy: A virtual reality game-based investigation into the influence of building's spatial configuration in an emergency. *Spatial Cognition & Computation*, DOI: 10.1080/13875868.2021.1913497.

United States Geological Survey (2021). *The USGS Earthquake Hazards Program*, Accessed September 1, 2021, https://earthquake.usgs.gov/.

Yamori, K. & Sugiyama, T. (2020). Development and social implementation of smartphone app Nige-Tore for improving tsunami evacuation drills: Synergistic effects between commitment and contingency. *International Journal of Disaster Risk Science*, *11*, 751–761, DOI: 10.1007/s13753-020-00319-1