Non-Player Characters for Evacuation Training in Metaverse: Preliminary Experiment

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Abstract: Evacuation training is indispensable in terms of surviving disasters. Recently, virtual reality technologies have been used to facilitate evacuation training. The authors previously proposed the Evacuation Training in Metaverse (ETM) system. This system is currently being evaluated in a prototyping phase, where many users can spend time in a three-dimensional virtual university campus. In the ETM system, an earthquake occurs suddenly, and the users must determine various actions, e.g., whether to evacuate and where to evacuate. However, the ETM system does not always have a sufficient number of active users. Thus, the ETM system can generate non-player characters (NPC) based on the evacuation logs of previous participants. This paper overviews the ETM system and describes the method used to generate NPCs. In addition, the results of a preliminary comparative experiment are discussed.

Keywords: Non-player character, evacuation training, virtual reality, metaverse

1. Introduction

Natural and manmade disasters can destroy lives, and people are particularly vulnerable to unpredictable disasters, e.g., earthquakes and terrorist attacks. As a result, learning how to survive disasters is becoming increasingly important. To survive disasters, we must evacuate to a safe place quickly; however, speedy evacuation is difficult when facing unanticipated disaster situations. For example, if a recommended evacuation route is impassable, we must determine another route. In addition, when encountering an injured person, we must decide whether to attempt a rescue. Traditional evacuation training does not necessarily simulate such situations. In other words, traditional evacuation training is conducted according to a simple scenario that encourages participants to remember recommended evacuation routes. In addition, we tend to avoid evacuation training because we frequently feel that disasters will not affect us directly. Thus, a new evacuation training paradigm is required to remove such feelings and motivate participation.

A prospective approach is to introduce virtual reality (VR) into evacuation training. VR technologies can express disaster situations realistically using sophisticated three-dimensional (3D) computer graphics and have attracted attention due to their technological novelty. VR-based evacuation training (VRET) can provide participants with simulated evacuation experiences according to various scenarios in a safe environment, and many VRET systems have been proposed (Gagliardi et al., 2023). If VRET is conducted in a virtual world resembling the real world, participants are expected to feel that a disaster is a direct and imminent problem. For example, a VRET system provides simulated earthquake evacuation in a 3D virtual world that is faithfully modeled after a real hospital (Feng et al., 2020). By focusing on fire evacuation, a VRET system can realistically reproduce structure fires by simulating and visualizing spreading fire and smoke, as well evacuees (Lorusso et al., 2022). Another VRET system was designed to train underground rail station employees to guide passengers to exits without encountering fire, while also introducing fire and passenger agent simulations (Wang et al., 2023).

Recently, VR has been popularized by the advent of reasonable consumer VR headsets, e.g., the Meta Quest and HTC VIVE devices. In addition, the metaverse has attracted increasing attention as a social VR paradigm that enables multiple users to communicate and interact in a virtual world. The metaverse can be applied to various fields, including education (Tlili et al., 2022). For example, a university campus has been reproduced as a metaverse to provide lectures via a presentation tool and interactions among avatars (Nagao, 2023). In addition, a multiuser collaborative VR system allows participants to learn how to survive active shooter events (Sharma, 2020).

The authors previously proposed Evacuation Training in Metaverse (ETM) and are prototyping an ETM system that focuses on earthquake evacuation (Mitsuhara & Shishibori, 2022; Oe et al., 2022). The ETM begins when an earthquake occurs suddenly in the metaverse. The ETM system is prototyped using a the Unity game engine that enables cross-platform software development. The target VR headset is the Meta Quest 2 device. The current ETM system, which includes a virtual world that resembles the Tokushima University campus, allows at most 200 users (i.e., avatars) to access the virtual world synchronously. Evacuation processes with many users can generate or emphasize difficult situations. In other words, including many participants can make evacuation training more realistic and lead to higher training effect. For example, if many users rush into a narrow path, the evacuation will be delayed due to congestion. Such simulated evacuation experiences can facilitate effective learning, e.g., “I choose a wider route calmly.” However, many users are not always present in the metaverse, and evacuation training with a smaller number of users may not be realistic or effective.

From this perspective, we introduce non-player characters (NPC) into the ETM system to simulate the presence of many users in the metaverse system. Note that many VRET systems have introduced NPCs. For example, Feng et al. (2022) developed a VRET system for earthquake evacuation in a hospital environment that included doctor and visitor NPCs. They found that the participants tended to follow a doctor NPC without making independent decisions. Liu et al. (2023) examined the effects of video-based emergency evacuation training by observing whether participants followed NPCs in a VR emergency simulator. In VRET systems, NPCs are preprogrammed based on evacuation behavior models (e.g., Dijkstra’s algorithm). We believe that such models do not necessarily represent realistic evacuation behaviors, e.g., panic and upset. Thus, we propose a method that generates NPCs from participants’ evacuation logs.

The remainder of this paper is organized as follows. Section 2 overviews the ETM system. Section 3 presents the method used to generate NPCs. Section 4 reports on a preliminary comparative experiment conducted to examine real participants and NPCs. Section 5 concludes the paper, including suggestions for future work.

2. ETM System

The ETM system has the fundamental metaverse functions, e.g., a 3D virtual world, synchronous multiuser access, and voice communication.

2.1 Requirements

In addition to the fundamental functions, the ETM system satisfies the following requirements for earthquake evacuation training.

High-fidelity 3D virtual world: The ETM system’s virtual world, i.e., the 3D university campus, should be identical to the real-world university campus. Thus, the 3D virtual world was modeled in reference to actual building blueprints. In the high-fidelity 3D virtual world, students can take a class or converse with other users as if they were in the real-world classroom. In other words, the 3D virtual world should be familiar and comfortable. Figure 1 shows screenshots of the 3D virtual world.

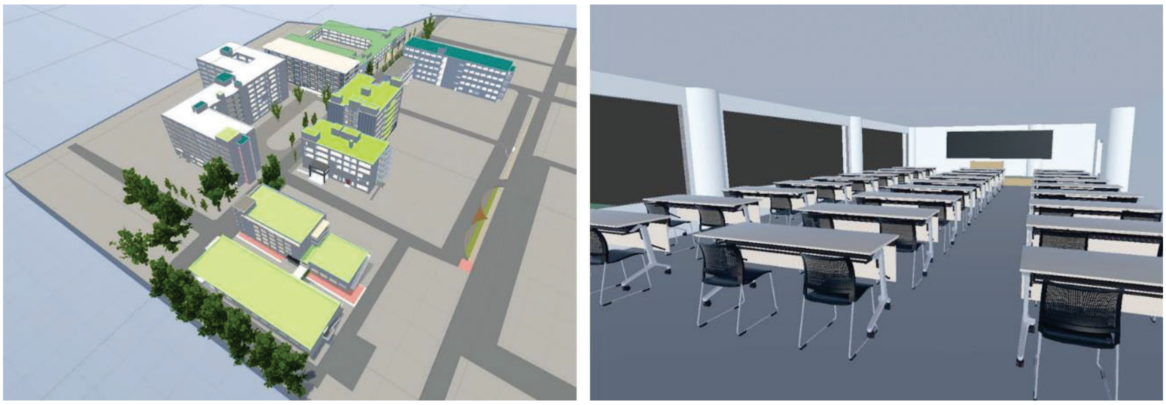

Figure 1. 3D virtual world (left: panoramic view; right: a classroom).

Avatars: Metaverse users may want to use favored avatars (e.g., an animal or a robot) to represent their identities. In addition, the users may expect that avatars have superhuman abilities, e.g., flying, teleportation, or immortality. However, the ETM system focuses on evacuation training; thus, the avatars should resemble users in appearance (e.g., the face and clothes) and abilities (e.g., movement speed and arm strength). For example, a user whose leg is injured should be represented in a squat down position with reduced movement speed. Such avatars can make evacuation training more realistic and effective. Figure 2 shows screenshots of different avatars in the ETM system. Currently, the system uses 3D avatars created by the Ready Player Me avatar modeling service (https://readyplayer.me/).

Figure 2. Avatars (left: standing; right: squatting down).

Sudden earthquake: The ETM system should simulate the sudden occurrence of an earthquake event. In Japan, several seconds before a large magnitude earthquake occurs, an early warning system signals the occurrence via smartphone, television, radio, etc. Thus, the ETM system functions according to the warning. Several seconds later after the warning signal, the virtual world begins to shake. In other words, the ETM system suddenly shifts from normal conditions to emergency conditions in the virtual world, and this sudden shift to earthquake conditions facilitates realistic and effective evacuation training.

Reflection: Evacuation training frequently ends when the participants reach a designated safe location. To enhance the effect of training, the participants should also reflect on their evacuation (e.g., the evacuation route and speed) after reaching the designated safe location. With sufficient reflection, the participants are expected to obtain ideas or their own rules to realize more successful evacuation, e.g., “We should move more speedily on a wider route.” Thus, the ETM system should provide a function to support this reflection process.

2.2 Modes

The ETM system has three modes, i.e., the normal time, emergency time, and reflection time modes. In the normal time mode, the users can act freely in the 3D virtual campus. When a sudden earthquake event occurs, the mode switches to the emergency time model, where the users can also act freely. In other words, the users can self-determine whether to evacuate. Here, some users may begin an evacuation process, and the other users may choose to not evacuate. Users who begin the evacuation process are considered the participants in the ETM. After a predetermined amount of time passes in the emergency time mode, the mode switches back to normal time, i.e., the evacuation training finishes. In the normal time mode, the participants can freely enter the reflection time mode. Figure 3 illustrates the transitions between these three modes.

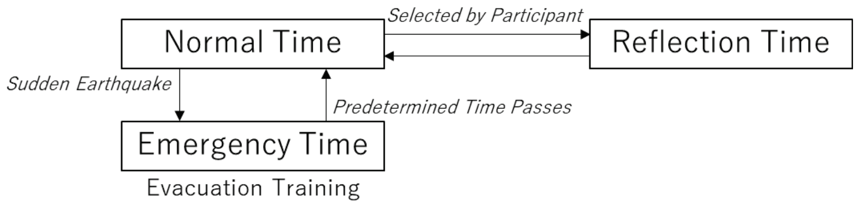

Figure 3. Mode transition.

2.2.1 Normal Time Mode

Regardless of the time mode, the ETM system must accommodate multiple simultaneous users that can move and communicate in the virtual world. To achieve this, the ETM system utilizes network frameworks provided by Photon. Photon Fusion can synchronize multiple users in a virtual world (a conceptual room for synchronization created by a host computer) via a server on the Photon Cloud Network. In addition, Photon Voice supports voice chat in the virtual world.

2.2.2 Emergency Time Mode

When a large magnitude earthquake occurs in Japan, the ETM system receives information about the earthquake from the Japan Meteorological Agency and generates an earthquake in the virtual world by shaking the 3D university campus environment, and the emergency time mode is initiated. This shaking influences the 3D objects in the virtual world; however, this increases the rendering load (especially with the Meta Quest 2 device). To reduce the rendering load and shake-induced VR sickness, the ETM system can omit rendering the shakes. Disaster situations occur in the virtual world based on a scenario that describes the type (e.g., fire and smoke) and location (x, y, and z coordinates) of the disaster situations.

In the emergency time mode, the participants move to a safe place, e.g., a building exit. Note that the ETM system does not present any message to indicate evacuation locations or routes. If the user has a microphone, the participants can communicate via voice; thus, they may evacuate cooperatively. When recognizing non-evacuating users, the participants may underestimate the necessity of evacuation and stop evacuating. This situation is caused by the cognitive biases (e.g., normalcy bias and conformity bias) observed in real-world evacuation situations.

The ETM system evaluates the success or failure of evacuation by determining whether each participant reached a safe location within the predetermined time. In the emergency time mode, the ETM system records all participants' evacuation logs.

2.2.3 Reflection Time Mode

The participants can begin reflecting on their evacuation process by selecting an evacuation log listed on a menu. In the reflection time mode, the participants' logs are visualized such that they can observe their evacuation behaviors objectively from a first-person or third-person perspective. Figure 4 shows screenshots of the reflection time mode.

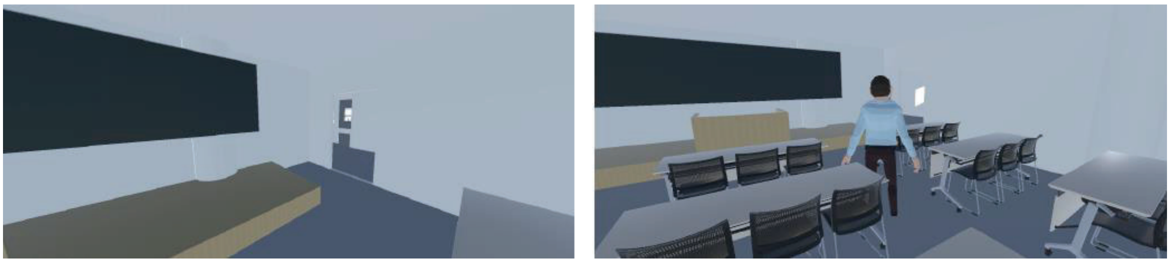

Figure 4. Reflection time mode (left: first-person perspective, right: third-person perspective).

3. NPC Generation

The ETM system can heighten realism and training effect by including many users (avatars) in the virtual world. However, many users are not always present the virtual world; thus, the ETM system must be able to increase the number of users in the virtual world as required by generating NPCs based on evacuation logs.

3.1 NPC Generation based on Evacuation Logs

In video games, NPCs frequently perform intelligent actions, and artificial intelligence (AI) technology is actively used to provide such realistic behavior. In crowd evacuation simulation systems, NPCs are referred to as agents and are frequently preprogrammed based on behavior models. If preprogrammed NPCs are introduced into the ETM system, participants can be induced to fail in evacuation. For example, if NPCs are preprogrammed to rush to a short but narrow path, the participants may follow these NPCs and become stuck in a crowded path. The ETM system attempts to provide participants with simulated evacuation experiences and promote effective reflection, especially in terms of evacuation failures. When introducing preprogrammed NPCs that induce failure, the ETM system can provide a better training effect.

The NPCs generated based on evacuation logs are expected to represent realist evacuation behavior and influence the participants' evacuation behavior. For example, past participants who were panicked or upset may be represented as NPCs moving back and forth, which could induce emotional instability in the participant. An advantage of this NPCs generation method is that various beneficial situations can be represented without requiring complex behavior models. However, a disadvantage is that the ETM system cannot necessarily induce participants to fail in evacuation because NPCs cannot be controlled. In this study, to avoid the need for behavior models, we generate NPCs based on participant evacuation logs.

The ETM system enables participants to conversate via voice chat; however, the system does not currently record voice conversations, which means that the NPCs can only represent visual aspects. In real evacuation situations, conversation among evacuees can influence their evacuation behavior. For example, if an evacuee loudly proclaims an evacuation route, other evacuees may follow that route even though safer evacuation routes may be available. We consider that NPCs in the ETM system should focus on visual and auditory aspects.

3.2 Recording evacuation logs

In the emergency time mode, the ETM system collects participants' evacuation logs (for both users and NPC participants), i.e., each avatar's location and rotation (relative angle) in 3D coordinates, and it transfers the collected logs to the server every 0.1 s. On the server, a log recorder module stores the received logs as text files for each scenario.

3.3 Reproducing evacuation logs

In the emergency time mode, the ETM system generates NPCs based on the data in the evacuation logs. Here, every 0.1 s, a log reproducer module on the server fetches the evacuation logs of the current scenario to influence the behavior of the corresponding NPCs. The ETM system renders NPCs with hand and leg animations when moving, which is limited within the viewing field of each avatar to reduce rendering load for the Meta Quest 2 device. Note that the rendered NPCs are not semitransparent characters (e.g., ghost characters in video games). Currently, NPCs are rendered as a few fixed avatars that do not resemble real users. Figure 5 shows the mechanism of generating NPCs with screenshots of NPCs.

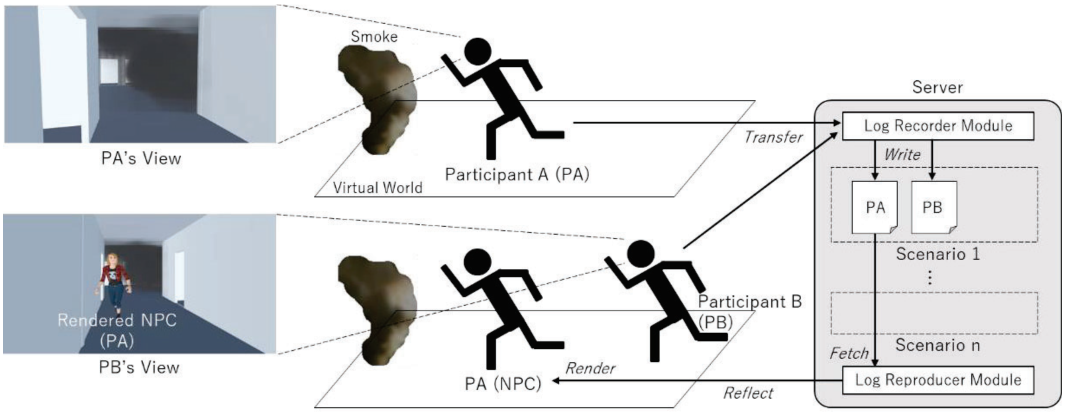

Figure 5. NPC generation mechanism.

4. Preliminary Experiment

A preliminary experiment was conducted to investigate and compare the influence of NPCs in the ETM system.

4.1 Experimental settings

4.1.1 Participants

In this experiment, 12 participants (Tokushima University students who typically spend time at the university campus) were expected to move without disorientation inside the 3D virtual campus. The participants were divided into two groups. In each group, three participants wore an immersive head-mounted display device (i.e., a Meta Quest 2), and the other participants (who were prone to VR sickness) used a desktop PC.

Group A (*N* = 6): Six participants evacuated simultaneously by operating their avatars in the virtual space. In other words, Group A was a multiuser setting.

Group B (*N* = 6): Each participant performed the evacuated using their avatar with five NPCs generated from Group A's evacuation logs (i.e., the evacuation route and body orientation). In other words, Group B was a single-user setting.

4.1.2 Procedure

The experimental procedure was identical for both groups, except for the presence or absence of NPCs. In the emergency time mode, the participants' evacuation logs and voices were recorded. The experimental procedure is summarized as follows.

I. The participants spawned outside a six-floor lecture building.
II. According to the experimenter's request, the participants moved to the fifth floor of the building. This step allowed the participants to practice operating their avatars.

III. When all participants (including the spawned NPCs) entered a lecture room on the fifth floor, an earthquake early warning was issued. Several seconds later, the corresponding earthquake occurred, and the emergency time mode began.
IV. Immediately after the shaking stopped, a fire alarm went off.
V. The participants were allowed to behave freely. Here, some participants may evacuate to safe places (i.e., building exits), and others may not evacuate. In the building, the participants encountered different earthquake-caused situations (e.g., scattered chairs, fire, smoke, and an injured person). Figure 6 shows the layout of the prepared disaster situations in the building.
VI. A successful evacuation was realized if the participants reached a safe spot within five minutes from Step III; otherwise, the participants failed to evacuate.
VII. Finally, the participants answered a questionnaire comprising five-point Likert scale questions and free descriptions.

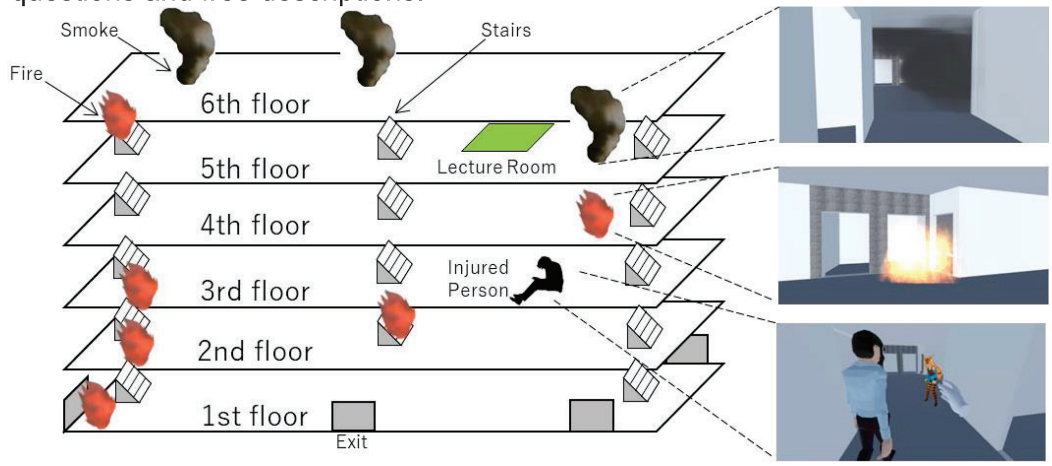

Figure 6. Building layout and disaster situations.

4.2 Results

4.2.1 Evacuation Behavior

All participants successfully evacuated to exits on the first floor. In other words, the participants avoided going toward the top floor, and they detoured around fire and smoke. In addition, all participants encountered an injured person but did not identify any way to rescue the person from their location. However, this is a current limitation of the ETM system, which does not include interactive functions to perform rescue activities.

For Group A, participants A1–A3 communicated verbally to promote caution (e.g., “Watch out”) and discussed whether to rescue the injured person (e.g., “Should we rescue the injured?”). In contrast, participants A4 and A5 did not communicate. Here, participant A6 evacuated independently without communication, except for indicating “I have to crouch down,” which was communicated when the earthquake occurred.

For Group B, nearly participants evacuated silently except for words spoken when surprised (e.g., "Wow!"). When encountering the injured person, participant B1 spoke to themselves, “I cannot rescue the injured alone. I do save my own life.” Note that no participant in Group B followed the NPCs reproduced from Group A’s evacuation logs.

4.2.2 Questionnaire

The questionnaire was administered to identify and describe the participants’ emotions during the emergency time mode. Table 1 shows the mean values and standard deviations for each group’s answers. For all emotions, the mean values of Group A were higher than those of Group B; however, no significant differences were observed between the two groups in the results of a t-test. In addition, only the participants in Group B were asked about the realism of the NPCs, and all participants provided neutral responses. In terms of VR sickness, we calculated the mean values for the HMD and PC devices, which were 3.83 and 1.17, respectively. However, no significant difference was observed in the results of a t-test.

Table 1. Mean values of questionnaire answers (five-point Likert scale)

Emotion	Group A (*N* = 6)	Group B (*N* = 6)	HMD (*N* = 6)	PC (*N* = 6)
Anxiety	4.17 (*SD* = 0.74)	3.50 (*SD* = 1.37)	N/A	N/A
Fear	4.00 (*SD* = 0.63)	3.83 (*SD* = 1.46)	N/A	N/A
Surprise	4.50 (*SD* = 0.83)	3.67 (*SD* = 1.50)	N/A	N/A
NPCs' Reality	N/A	3.0 (SD = 0.0)	N/A	N/A
VR Sickness	N/A	N/A	3.83 (*SD* = 1.60)	1.17 (*SD* = 0.41)

Question example: *Did you feel anxiety during evacuation?*
Options: 5: *Definitely yes*; 4: *Yes*; 3: *Neutral*; 2: *No*; 1: *Definitely no*.

The participants in Group B provided reasons for the scores assigned in terms of the realism of the NPCs.

- Participants B1 and B6: *It was realistic that NPCs were going back and forth or directing to stairs.*
- Participants B1, B5, and B6: *It was unrealistic that NPCs were evacuating silently.*
- Participants B3 and B4: *It was unrealistic that some NPCs did not start evacuating though a fire alarm went off.*

The participants in both groups were asked to freely describe the lessons learned during the evacuation training. The participants identified the following lessons.

- Participants A1, A3, A6, and B1: *I should remember evacuation routes.*
- Participant A2: *I must make some plans of evacuation routes in advance and cultivate my judgement. Because a disaster may make impassable routes.*
- Participant A4: *I must calm down and behave when evacuating.*
- Participant A6: *I had a sense of ease if I can evacuate with someone else.*
- Participant B2: *I would like to acquire knowledge of disaster management.*
- Participant B3: *I should think beforehand what to do when a disaster suddenly occurs.*
- Participant B4: *I could demonstrate evacuation since the disaster occurred in the building I usually come.*
- Participant B6: *In a real fire event, I will have no time to stop to consider evacuation routes since the fire can quickly spread.*
- Participant B6: *To prepare for real fire events, I would like to train myself to take good decisions. For example, should I call for help toward the outside when I have no idea about evacuation route? What if the fire occurs at night?*

4.3 Considerations

The participants in Group A (i.e., multiple avatars operated by real users) felt stronger emotions than those in Group B (i.e., a single avatar operated by a real user). If evacuation realism is shown as anxiety, fear, and surprise, the avatars should not be represented by NPCs. In other words, all avatars should be operated by real users. For Group A, we found that the participant conversations may have heightened emotions more than the specific disaster situations (e.g., fire and smoke) because decision making can become complicated or difficult through conversations. For example, when discovering an injured person, the participants may encounter conflicts in terms of opposing opinions, i.e., whether or not to perform a rescue.

The mean value of the NPC realism was 3.0; however, negative reasons were relatively dominant. Participants B1 and B6 showed both positive and negative reasons. In terms of the positive reason, these participants indicated that the NPCs' movements may have contributed to increasing realism, which can be considered an advantage of the NPCs generated using the participants' evacuation logs. In addition, none of the participants in Group B followed the NPCs, and participants B3 and B4 described the corresponding negative reason. The participants did not follow the NPCs because the NPCs were moving back and forth inside the lecture room, which delayed the evacuation. We consider that the participants in Group B felt that this behavior was unrealistic; thus, the participants were not motivated to follow the NPCs. However, in a real evacuation situation, some people may not start evacuating immediately due to cognitive biases even though they have perceived an early earthquake warning and/or fire alarm. This indicates that non-evacuating NPCs can be realistic occasionally. Thus, silent NPCs reduced realism, as indicated by participants B1, B5, and B6. We also believe that the NPCs should reproduce the participants' recorded voices to improve realism, and more evacuating and non-evacuating NPCs should be included.

Focusing on the participants' behavior in terms of the injured person, participants evacuating individually did not attempt a rescue. The participants may have recognized that they could not have rescued the person by themselves. Note that two or three participants in Group A did attempt to rescue the injured person. The participants may have felt that the rescue was possible because they were able to discuss and cooperate. The observed situations in the experiment are expected to occur in real evacuations; thus, we consider that the ETM system should implement interactive functions to facilitate rescue activities in order to further improve realism.

Expected results were observed regarding VR sickness. Immersive HMDs can provide high levels of immersion; however, measures must be taken to mitigate the effects of VR sickness. Thus, the ETM system should be compatible with three types of devices, i.e., HMDs, PCs, and smartphones.

In each group, five participants described the lessons learned during the experiment. These lessons can be considered as the effects of the simulated evacuation experience using the ETM system. If the participants reflected on their evacuation using the ETM system's reflection function, the effects would be strengthened even further.

4.4 Limitations

In this study, the number of participants was insufficient to clarify the influences of the NPCs in the ETM system. The number of generated NPCs was insufficient to influence participants' evacuation behavior and emotions. In addition, the appearance of avatars and NPCs lacked sufficient visual realism. These limitations may have been reflected in the experimental results.

5. Conclusion

This paper has described the ETM system with a focus on generating NPCs based on evacuation logs. The generated NPCs are expected to influence the participants' evacuation behaviors and emotions. However, a preliminary experiment revealed that the generated NPCs did not influence evacuation behaviors and emotions sufficiently compared with avatars operated by human participants. This unexpected result may have been caused by the small number of participants in the experiment. Thus, a larger-scale experiment with many participants should be conducted.

Note that the ETM system is still in the prototyping stage and must be improved from various perspectives. For example, interactive functions that simulate rescue activities should be implemented because this is a likely occurrence during real evacuations. In terms of the NPCs, the following important tasks should be addressed.

- As the number of evacuation logs increases, more NPCs must be rendered in consideration of the overall rendering load. Thus, the ETM system should determine the maximum number of rendered NPCs or implement effective conditions to select which NPCs should be rendered.
- The NPCs should be able to communicate with participants because conversation content can potentially influence evacuation behavior. It has been shown recently that generative AI technologies can realize dynamic conversations between NPCs and

players in video games, and such technology can be implemented in the ETM system to make evacuation training situations more realistic.

- NPCs may need to be preprogrammed to intentionally create difficult situations where participants cannot make decisions quickly. For example, if human participants observe NPCs taking actions, e.g., jumping across a large crack in the floor, the participants may be motivated to perform similar actions. We believe that the ETM system can introduce NPCs as good examples of what not to do to facilitate effective training.

The authors plan to complete the development of the ETM system with these considerations in mind.

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