An immersive virtual reality experimental study of building occupants' behavioral compliance during indoor evacuations

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Abstract

Evacuation routes and emergency exits are designed in buildings to facilitate evacuations. However, empirical studies have revealed that the majority of people did not take the appropriate paths or use the closest emergency exits. Actual evacuation performance often does not meet the designers' expectations; hence, increasing occupants' compliance with planned evacuation routes becomes a significant concern. This study utilized an immersive virtual reality experiment to investigate emergency wayfinding behavior and explore how to increase occupants' behavioral compliance during evacuation wayfinding. The experimental results indicated that participants had better behavior compliance when they had a longer wayfinding decision-making time. Specifically, four experimental factors were investigated: emergency lighting configuration, the visibility of exit doors, familiarity, and neighbor behavior. The results demonstrated that removing the emergency lighting EL on the non-optimal route had no significant effect on participants' decision-making time or their compliance with the optimal evacuation route. The rest variables had an impact on participants' wayfinding compliance, but their impact on decision-making time was different. The visibility of the exit door increased participants' decision-making time as well as their wayfinding compliance. Participants that were familiar with indoor paths took less time to make route decisions and were more likely to leave via the familiar route. Neighbor behavior did not significantly affect participants' decision-making time, but participants did tend to follow others. In particular, the findings suggest that social influence from other evacuees can be a positive factor affecting occupants' compliance when the evacuation routes do not highly conform to occupants' wayfinding preference.

Keywords: Indoor evacuation, Behavioral compliance, Decision-making, Virtual reality experiment

1 Introduction

The possibility of a safe escape in the event of an emergency is an important aspect of building safety. The performance of indoor evacuation has been emphasized in building design. Currently, performance-based fire engineering design is widely adopted in many countries (Chow, 2015; Maluk et al, 2017). In this approach, the Available Safe Egress Time / Required Safe Egress Time (ASET/RSET) model has been a popular measurement to assess the performance of building fire safety. Occupants should have a shorter RSET (i.e., the time to escape to a safe location) than their ASETs (i.e., the time between the detection time and the onset of hazard) (Poon, 2014). Proper evacuation routes are critical to avoid congestion, reduce occupants' RSET, and minimize the risk of injuries and death (Wang et al, 2013; Zeng et al., 2018). Hence, evacuation routes and emergency exits are often designed in buildings. Also, exit signs are placed along evacuation routes to direct occupants' movement. Occupants are assumed to follow planned routes and exits to achieve expected evacuation performance and meet the requirements of RSET. However, occupants often have poor compliance with the planned evacuation routes (Kobes et al., 2010). When evacuating from fire buildings, most survivors, according to an empirical study covering 400 cases of fire mishaps, were unaware of escape signals (Ouellette, 1993). Only 12% of the survivors in the Daegu subway fire evacuated by appropriate routes and exits (Jeon and Hong, 2009). According to a field experiment by Xie et al. (2012), only 38% of participants who were unfamiliar with the building layout and 30% of participants who were familiar with the layout noticed the exit sign when exiting the building. Hence, behavioral compliance during indoor evacuations is critical to increase the utilization of the designated evacuation routes and improve evacuation performance.

Occupants' evacuation behavior is influenced by the environment in which they are located (Lindell and Perry et al., 2011; Lin et al., 2020a). Building feature is one of the most critical environmental factors. Also, building feature is the only factor that can be controlled by designers to improve building evacuation performance. The illumination of indoor paths is critical for emergency evacuations. Taylor and Socov (1974) found that people preferred brighter paths, and their route choices can be measured as a function of path illumination ratio. Vilar et al. (2013) also suggested that occupants were more likely to use a brighter path at any intersections during evacuations. However, Wang et al. (2022) conducted experiments about evacuations in underground space and found that the presence of natural lighting, rather than path brightness, influenced participants' route selections. The mixed results reveal that the effect of path illumination has to be investigated further. Emergency lighting has been required on indoor paths to provide illumination in the event of a power outage. It's still unknown whether proper emergency lighting setup on indoor walkways may improve occupants' adherence to evacuation routes. Another critical building feature for evacuations is the emergency exit. During emergency wayfinding, emergency exits can provide occupants with clear information about where to leave the buildings. Hence, the visibility of exit doors has a significant impact on occupants' route choices (Haghani and Sarvi, 2017). It is necessary to examine the effect of exit door visibility on occupants' wayfinding compliance in more evacuation situations.

Social influence is a critical environmental factor that affects occupants' evacuation behaviors in face of any disasters (Lazo et al., 2015; McCaffrey et al., 2018; Lin, et al., 2020a). In a fire accident, occupants are more likely to evacuate as a group than individually. Hence, occupants' evacuation behavior can be influenced by other evacuees. Previous studies mainly examined the effect of social influence on evacuees' wayfinding. Some empirical studies demonstrated that occupants were likely to follow others when choosing their evacuation routes or exits (Ronchi et al., 2013; Kinateder et al., 2016, 2018; Lin et al., 2020b; Fu et al., 2021a). However, the occupants do not always follow others during evacuations. When it is crowded, they may avoid the majority (Haghani and Sarvi, 2019). Although many studies have looked into how occupants' wayfinding can be influenced by other evacuees, few studies analyzed how social influence can affect occupants' compliance with the evacuation routes planned by designers.

Familiarity also affects occupants' evacuation behaviors (Kobes et al., 2010; Zimmerman and Sherman, 2011). When there is a fire in a building, people tend to use the familiar rather than the nearest exit (Sime, 1983; Graham and Roberts, 2000; Kinateder et al., 2018). In a controlled experiment, Kinateder et al. (2018) investigated the effect of familiarity on exit choice and discovered that occupants preferred to escape by familiar exits. Also, some studies suggested that occupants usually escape via familiar routes (Kobes et al., 2010; Zimmerman and Sherman, 2011), because familiar paths are perceived as shorter than unfamiliar paths (Løvs, 1998). Snopková et al. (2021) suggested that the effect of familiarity on individuals route choice can be diminished when there was a wider and straight evacuation route. The effect of familiarity on occupants' route choice at intersection during indoor evacuation needs to be further examined in a controlled experiment.

Particularly, any decision process consumes time for processing information (Ariely and Zakay, 2001). Some decisions are made incredibly quickly, almost at the speed of light. These are typically habitual or intuitive decisions that do not require in-depth information processing (Russo et al., 1989). Conversely, there are instances where people take a considerable amount of time to reach a decision. The more analytical and algorithmic the decision-making process is, the more time it tends to require (Ariely and Zakay, 2001). Decision-making time is an indicator to estimate how much effort participants make to seek wayfinding information, assess the environment, or determine their route choices. Besides, decision-making time is a critical aspect of wayfinding choices since people must take quick actions during evacuations. Understanding the time taken for decision-making can significantly enhance our knowledge of wayfinding behavior. Nevertheless, there is a notable gap in existing research regarding the duration of individuals' decision-making processes of evacuation route choices.

To fill the knowledge gaps mentioned above, this study conducts an immersive virtual reality (VR) experiment to explore occupants' behavioral compliance during evacuations. In the experiment, participants evacuated in a virtual building fire accident. Their decision-making time and evacuation route choices at an intersection are collected. Based on this, we investigate the relationship between decision-making time and wayfinding compliance. Also, the effect of emergency lighting configuration, the visibility of exit doors, social influence, and familiarity on occupants' decision-making time and behavioral compliance is examined in a controlled experiment. The results of this study can advance our understanding of the mechanism underlying occupants' behavioral compliance during evacuations, which will help us improve building safety design, evacuation training and planning.

2 Related studies

2.1 Behavioral compliance in indoor evacuations

Behavioral compliance is a critical factor influencing the performance of indoor evacuations. An emergency evacuation refers to an urgent escape from an area with an ongoing or imminent threat, which is important for occupants to reduce injuries and save lives in face of an accident. Consequently, the performance of indoor evacuation is a vital part of building safety and has been emphasized in building design (Chow, 2015; Maluk et al, 2017). In general, to facilitate indoor evacuations, occupants are provided with various facilities to assist them in evacuating, such as exit signage, fire alarm, and emergency exits. Occupants should comply with evacuation instructions from these built-in features (Proulx and Richardson, 2002). For example, occupants should take quick action and start their evacuations when the fire alarm sounds. Also, evacuees need to avoid dangerous areas as much as possible and follow the directions of exit signs (Fu et al., 2021b). On the contrary, even if these features are designed and installed in the buildings, they become ineffective if they are neglected by occupants. Hence, behavioral compliance is critical to achieving the performance of the built-in features that are designed to facilitate indoor evacuations.

Wayfinding compliance, which refers to evacuating through the escape routes planned by designers, is one of the most crucial behavioral compliances during evacuations. To ensure safe escape in case of indoor emergencies, buildings are often designed with evacuation routes and emergency exits. These evacuation routes and exits allow occupants to leave buildings as fast as possible. Also, emergency exits are often scattered throughout a building. Hence, occupants can use the nearest emergency exits, which avoids possible congestion on the main exit of a building. Also, emergency lighting and exit signs are often deployed on the evacuation route to provide occupants with wayfinding directions and illumination. However, occupants rarely follow the designed evacuation routes and leave by the nearest exit in real fire accidents (Kobes et al., 2010). For example, in the Daegu subway fire, only 12% of the survivors made their evacuations using appropriate evacuation routes and exits (Jeon and Hong, 2009). As a result, buildings are less likely to have an evacuation performance than designers expect.

2.2 Building environments and evacuation behaviors

How humans make a response to emergencies is a crucial issue for building safety design, emergency preparedness, and evacuation planning (Haghani and Sarvi, 2018). However, human behavior is complex; hence, it is very difficult to predict how occupants react in face of an emergency. Identifying and understanding the mechanism behind human emergency behavior has been important for evacuation behavior prediction and building safety design. Darken and Peterson (2001) suggested that occupants keep viewing their surroundings to understand the environments and acquire wayfinding cues when they navigate to their destinations. Through the sensed environmental information, they can assess their progress toward their destinations and adjust their movements if it is required. Besides, the cognitive map is also involved in influencing human behavior during evacuations. The cognitive map was proposed by Tolman (1948) to describe internal representations or stored memories of spatial information about environments. Both primary experience and secondary media can develop people's cognitive maps (Kitchin and Freundschuh, 2002). Golledge (1999) emphasized that a cognitive map plays a key role in wayfinding and always guides humans in their spatial decision-making.

Human evacuation behavior can be also treated as the result of a hierarchical decision-making process (Lovreglio et al., 2016), including three levels: (1) strategic level (choose the destination); (2) tactical level (determine how to go), and (3) operational level (short-range decisions, such as how to avoid obstacles). These evacuation decisions are influenced by many factors. Conroy (2001) classified external wayfinding information as explicit and implicit cues. The explicit cues include all environmental information with clear wayfinding directions, such as exit signs. The implicit cues represent the other environmental information that may influence human wayfinding. For example, path illumination does not provide clear wayfinding information but may affect occupants' route choices (Taylor, 1974; Vilar et al., 2013). Snopková et al. (2021) suggested that individuals' tendency to retrace diminish when the evacuation route is wider and straight. Fu et al. (2021a) summarized the factors influencing human emergency wayfinding into four aspects, including building, social, hazard, and personal factors. Building factors represent the physical environment, such as layout, exit signs, and exit locations. Social factors refer to the interaction between evacuees. Hazard factors reveal the ongoing or imminent dangers due to emergencies. The building, social, and hazard factors comprehensively describe the indoor evacuation environment. Personal factors are used to represent individual characteristics that affect wayfinding behaviors.

2.3 Immersive virtual reality technique for evacuations studies

Previous studies have investigated human evacuation behaviors through various methods, such as evacuation drills (Ma et al., 2012; Fridolf et al., 2016), questionnaires (Lovreglio et al., 2014), and field experiments (Liao et al., 2017; Haghani and Sarvi, 2019). However, using these methods to explore evacuation behavior remains a challenge for researchers. Due to the safety issue, it is impossible to create a real fire and observe participants' evacuation behavior, which limits the selection of research topics. Also, it is challenging for researchers to balance ecological validity and experimental controllability (Kinateder et al., 2014). The advancement in VR techniques provides an alternative method to study human evacuation behaviors under safe and noninvasive conditions. The VR techniques allow researchers to create various physical environments and disaster features in a virtual environment that will be introduced to subjects. Hence, VR experiments can cover lots of topics about emergency human behaviors. Through virtual disaster scenario design, researchers can perfectly control the design factors and the types of subjects' responses (e.g., making decisions on exits or directions, where and when to make decisions). Remarkably, immersive VR techniques significantly improve the feeling of reality in a virtual environment, which provides a safe way to trigger subjects' emotional responses to an emergency and improves ecological validity (Zou et al., 2017). Another advantage of VR experiment is that it is easy and economical to precisely measure human behaviors in a virtual environment, such as the interaction between subjects and the built environment (Ronchi et al., 2016; Olander et al., 2017; Zhang et al., 2021; Natapov et al., 2022) and the interaction between subjects and virtual humans (Kinateder et al., 2018; Lin et al, 2020b).

3 Method

3.1 Participants

In the present experiment, participants were recruited from the University of Florida in Gainesville, Florida. The Institutional Review Board of the University of Florida approved the experiment. Also, participants were required to sign experiment informed consent. Seventy-four participants, including 45 males and 29 females, took and completed the experiment. The participants' ages ranged from 18 to 59, with an average age of 23.52 and a standard deviation of 6.06. Most of subjects were the undergraduate or graduate students at the University of Florida. All subjects had good mobility, no color blindness, and normal or corrected normal vision.

3.2 Immersive Virtual Environments (IVE) Development

The experiment utilized the IVE to simulate an evacuation scenario in case of building fires. Pugh Hall at the University of Florida was selected to create the building model for the IVE. The Pugh Hall is a three-story educational building with classrooms, study rooms, and faculty office rooms. Figure 1 gives the third-floor plan and the fire location. The fire was located on the third floor of the case building. The start locations of participants were also marked in Figure 1. When participants heard the fire alarm and noticed the fire, they need to make their evacuations. The fire was assumed to spread from the room to the corridor (see Figure 1). As a result, the corridor was filled with fire and smoke. The only route choice of participants was to get out of the initial room and then turn right, i.e., the blue path in Figure 1. When they arrived at the intersection, they must make a route choice. At the intersection, there were two route options. Route 1 is required to turn right in the intersection and leave the third floor by stairs 1. Route 2 was to go straight and leave the floor by stairs 2. Route 1 was designed as the evacuation route instead of route 2 for two reasons. First, route 1 was a shorter route to leave the building. Second, there might be congestion in route 2. Route 1 used the outdoor stairs to leave the building. Hence, participants can leave the building through the stairs. However, route 2 used internal stairs. When participants went to the first floor by stairs 2, they still needed to leave the building through the main exit door. However, there were many classrooms and self-study rooms on the first and second floors. During evacuations, most of the students and staff on the first floor would exit the building by the main exit door. It was easy to become very crowded at the main exit door, which slowed down the movement speed and increased the evacuation time. Since route 1 was the optimal evacuation route at the intersection, a ceiling-mounted exit sign with the direction to route 1 is placed at the intersection, as shown in Figure 2.

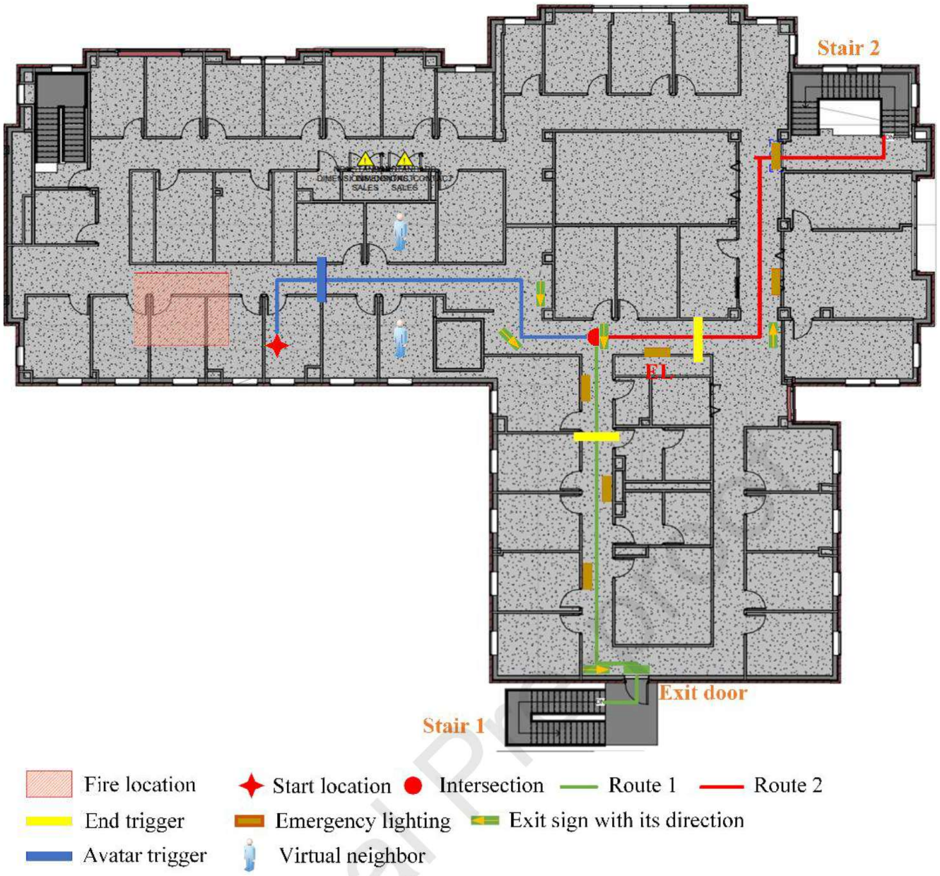
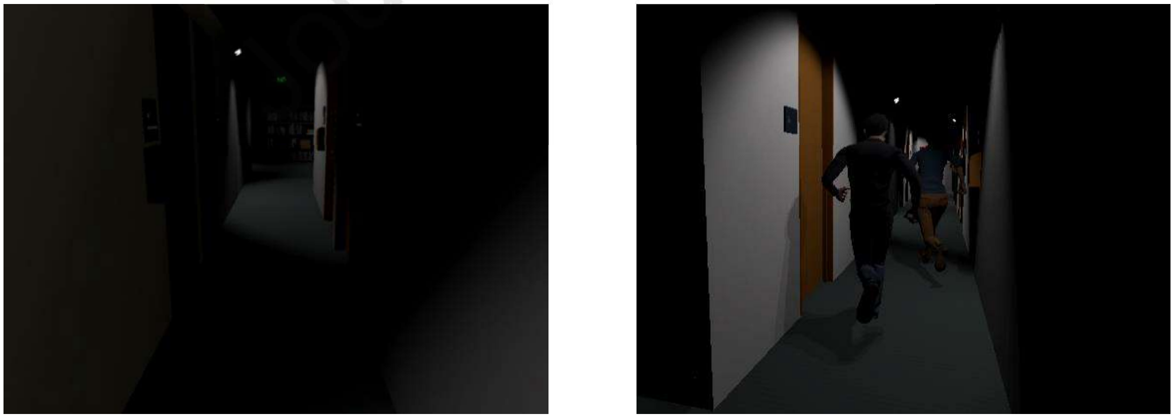


Figure 1. The third-floor plan of the case building

Figure 2. The exit sign at the intersection

Based on the architectural drawings of this building, its 3D model was built in the Autodesk Revit modeling software to accurately match the dimensions and layout of the building. The 3D model was imported into Unity to develop the virtual environment. To improve the simulation quality, lighting, furniture, and signs models were imported. In addition to the building, the particle system of Unity was employed to simulate fire and smoke. The particle system produces the expected visual effect by rendering many small images or meshes, called particles (Unity Documentation, 2021). In the simulation, each particle represents an individual graphical element in the effect of fire or smoke. By simulating every particle collectively, the system can mimic the full effects. Figure 3 shows the fire and smoke simulated by Unity in dark environments. In this experiment, a power outage caused by the fire was simulated and led to a dark environment. Figure 4(a) shows screenshots of the perspective of a player navigating in a corridor on the third floor when the building is in an outage condition. Also, there was the audiovisual stimulus, including the electric spark sound following the light flashing and the power failures, the fire sound with some explosive sound, and fire alarm. Additionally, as shown in Figure 4(b), virtual human characters were included in the IVE to simulate the other evacuees in the buildings. The models for the virtual characters were from the Unity assets and they were animated with walking/running animations. Their evacuation routes are predesigned based on experimental scenarios, and their movement speed was constant at 2.6 m/s.

Figure 3. The virtual fire in the IVE



(a) The dark corridor

(b) The running virtual characters

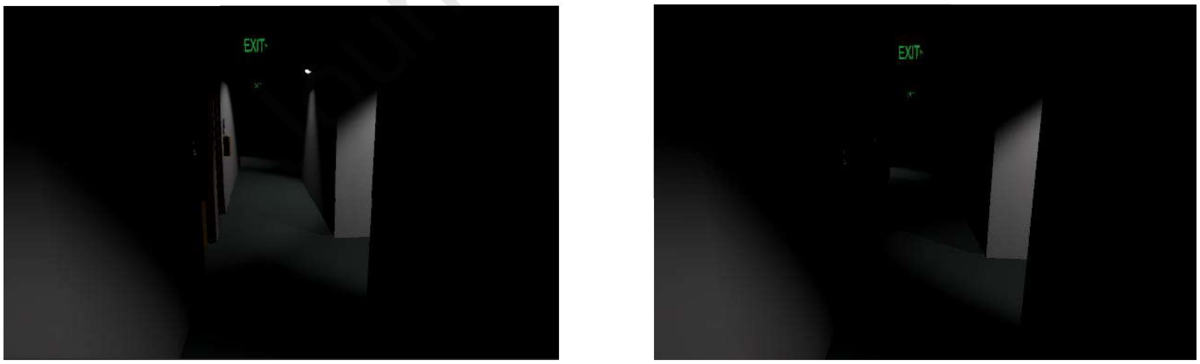
Figure 4. The virtual building under Power outage

3.3 Apparatus

The IVE was generated by a desktop computer (Intel Core i5-8600K, 3.60 GHz, GTX 1060 6GB). Then, the IVE was displayed to participants using the HTC VIVE virtual reality system. The VR system includes a head-mounted display (HMD), two base stations, and two controllers. Through the sensors in the HMD, the location and orientation of the HMD were tracked and synchronized in real time. As a result, participants can rotate their bodies in the real world to change their view and movement direction in the IVE. Instead of moving in the real world, the movement of participants (i.e., move forward, back, left, and right) in the IVE was achieved using a Vive controller. Their movement speed was set at a constant value of 2.5 m/s. In addition, the audio in the IVE was played to participants by the earphones connected to the HMD. Besides, to identify the physiological arousal level of participants, their heart rates were monitored using Innovo Medical CMS 50F Plus Pulse Oximeters.

3.4 Experimental design

To investigate participants' compliance behavior at the intersection (i.e., use route 1 to evacuate), this experiment involved four independent variables, including emergency lighting, the visibility of exit doors, familiarity, and neighbor behavior. This subsection explains the details of the four variables and how they are used to design the IVE. Building features are the physical environment in which people evacuate. A key building feature is emergency lighting. People prefer a brighter path at the intersection during evacuations (Vilar et al., 2013). Emergency lighting is designed to automatically turn on in case of a power outage and illuminate pathways toward exits. Emergency lighting has a critical impact on the brightness of indoor pathways when there is a power outage in buildings. As a result, the deployment of emergency lighting may be utilized to influence occupants' emergency wayfinding and increase their compliance behavior during evacuations. According to the life safety code (NFPA, 2020), emergency lighting is required for the pathways that lead to emergency exits. In the case building, emergency lighting should be deployed on route 1 to illuminate it because route 1 leads to an emergency exit. Hence, the emergency lighting on route 1 was fixed in this experiment. However, route 2 was not the optimal emergency route for people at the intersection. We can change some emergency lighting on non-optimal routes (i.e., route 2) to affect the wayfinding of people at the intersection. An emergency lighting was marked as EL in Figure 3, which was selected to influence the brightness of route 2. Hence, the variable of emergency lighting configuration has two levels, i.e., with or without emergency light EL. Figure 5 shows the intersection with or without the emergency lighting of EL.



(a) With the emergency light EL (b) Without the emergency light EL

Figure 5. The intersection with or without the emergency light EL.

In the present experiment, the other building feature is the exit door. Occupants' emergency wayfinding is affected by exit visibility (Haghani & Sarvi, 2017). People are more likely to choose a route when they find that the route leads to an exit. In the case building, the exit door was exit door 1, which is on route 1 and near stair 1 (see Figure 3). As shown in Figures 3 and 6(a), exit door 1 was invisible to participants at the intersection. By changing the location of the exit door, the experiment created a scenario in which the door is visible at the intersection (see Figure 6(b)). As a result, this experiment includes two levels of exit door visibility: invisible and visible.

(a) Invisible (b) Visible

Figure 6. The visibility of exit door on the route 1

In addition to the building features, two other variables were also included in the present experiment: familiarity and neighbor behavior. Familiarity refers to the extent to which participants were familiar with indoor paths and building layouts. In the present experiment, two levels of familiarity were designed: unfamiliar or familiar with route 2. Route 2 was selected since it was the common route for occupants in the case building to reach the start room or leave the building. There are only office rooms on third floor of the case building. In this experiment, all of the participants were unfamiliar with the third floor of the case building before the experiment. The familiarity was achieved through a task in the training session. The task was to use route 2 to go to the start room and leave the building three times. The participants who took or did not take the task before the experiment test can have different familiarity with route 2.

Neighbor behavior in this experiment refers to the route choice of evacuees who evacuate with participants. Two virtual neighbors (i.e., a male and a female) were included in this experiment. Their initial locations were marked in Figure 3. The behaviors of two virtual neighbors were controlled by a preprogrammed script. When participants evacuated through the corridor and passed by the trigger (see Figure 3), the virtual neighbors left their initial rooms and started evacuations. Through this setting, virtual neighbors were always in front of the participants. Virtual neighbors' route choices at the intersection can be always observed by participants. There were three levels of neighbor behavior, including no neighbors, and neighbors using routes 1 or 2 for evacuation. The two neighbors were evacuated together; hence, their route choices at the intersection were always the same. Figure 7 shows the intersection in the scenarios of no neighbors and neighbors using routes 1 or 2.

(a) No neighbors (b) Neighbors using route 1 (c) Neighbors using route 2

Figure 7. The virtual neighbors

To reduce the number of experimental trails and required subjects, the orthogonal design was used to do the experiment design for the four independent variables. The orthogonal design can reduce experimental trails while preserving the ability to examine the main effect of experimental variables (Tang et al., 2016; Zheng et al., 2021). This study employed IBM SPSS (SPSS, 2021) to create an orthogonal design for the current experiment. The orthogonal array $L_{12}(2^2 \cdot 6^1)$ was used. Within this framework, familiarity and emergency lighting were treated as two-level variables. Meanwhile, neighbor behavior and exit door visibility were combined in a fully crossed manner, forming a six-level variable. Consequently, the experiment had 12 trials. Each trial is made up of a combination of different levels of the variables. Table 1 shows all the experimental trials. According to the definition of each trial, we built different virtual evacuation scenarios. The distinction between these scenarios lies solely in the experimental variables, with all other environmental aspects remaining consistent across all trials. Due to the VR techniques, we can precisely control experimental environments, which ensured that our experiment eliminated the effect of other variables. Besides, since the building layout was fixed in the present experiment, taking multiple test trials may increase participants' familiarity with the building, which meant that participants may have different familiarity in different test trials. To avoid this issue, each participant took only one test trial and was randomly assigned to one of the 12 test trials in Table 1. The detailed experimental procedure is explained in the next subsection.

Table 1. The design detail of all experimental trials

No.	Familiarity	Neighbor behavior	Exit door visibility	Emergency lighting
1	Familiar	No neighbors	Invisible	Without EL
2	Familiar	Route 1	Visible	With EL
3	Familiar	Route 2	Invisible	With EL
4	Familiar	No neighbors	Invisible	With EL
5	Familiar	Route 1	Visible	Without EL
6	Familiar	Route 2	Visible	Without EL
7	Unfamiliar	No neighbors	Visible	Without EL
8	Unfamiliar	Route 1	Invisible	Without EL
9	Unfamiliar	Route 2	Invisible	Without EL
10	Unfamiliar	No neighbors	Visible	With EL
11	Unfamiliar	Route 1	Invisible	With EL
12	Unfamiliar	Route 2	Visible	With EL

Two dependent variables were measured in the present experiment. One dependent variable is the decision-making time that participants took to select their route at the intersection. A longer decision-making time meant that participants spent more time sensing and assessing the environment and making their judgments on which path to go next. In this experimental study, the decision-making time was measured as the time during which participants stayed in the decision-making area shown in Figure 8. Since routes 1 and 2 have different movement directions at the intersection, the time required for passing the decision-making area can be different when using routes 1 and 2. That is to say, even if people have determined their route choices and do not need to make any decisions at the intersection, they may take different times to pass the decision area when using routes 1 and 2. It is necessary to eliminate this error. Since the movement speed was fixed in the IVE, the time required for passing the decision area can be measured easily. With the determined choices before going to the intersection, the times for staying in the decision area when using routes 1 or 2 were measured five times. The average was used to estimate the time required to pass the decision-making area without making choices, which were 1.14 and 0.89 seconds for routes 1 and 2, respectively. Then, the time used by participants to make their decisions can be obtained from the time spent in the decision area minus the time needed to pass the decision area using routes1 or 2.

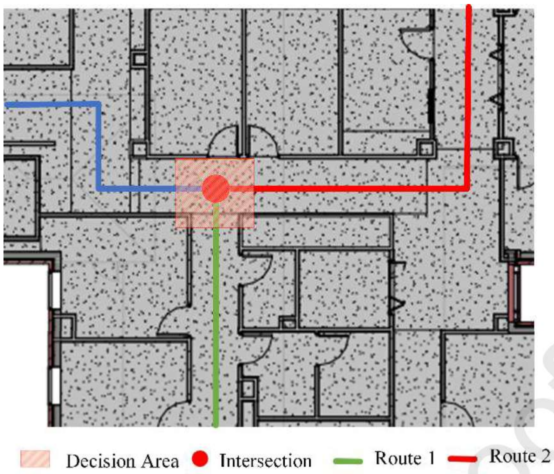


Figure 8. The decision-making area at the intersection.

The other dependent variable is the route choice at the intersection. When participants passed by the end triggers as shown in Figure 1, participants' route choices were automatically recorded by the preprogrammed script.

3.5 Experimental procedure

The present experiment was conducted in Rinker Hall at the University of Florida. All participants were asked to read and sign the experiment's informed consent. The pre-game questionnaire was then provided to participants to collect their basic demographic information.

The participants were instructed that they can stop the experiment at any time when they felt uncomfortable in the IVE. Participants were asked to take the VR glasses, earphones, pulse oximeter, and controller to start with a training session. In the training trials, participants can freely move on the first floor of the case building, which familiarized them with how to navigate in the virtual building using the VR controller. The training would end when participants said that they were familiar with the movement in the IVE. To be specific, all of the participants were unfamiliar with the third floor of the case building before the experiment. An extra task was used to make the difference in familiarity. Participants who were assigned to the 1-6 test trials in Table 1 were required to take the task in their training sessions. The task was to use route 2 (see Figure 3) to go to the start room and back to the main exit on the first floor three times. Through this task, participants taking the 1-6 test trials were familiar with route 2 before their test trials. However, participants taking 7-12 test trials were not familiar with route 2 since they did not have any tasks during their training. In the test session, the fire alarm started 8 seconds after the game started and was continuously broadcast. With the sound of a fire alarm, a power outage happened, which resulted in turning on the emergency lighting (See Figure 4). Additionally, the fire sound was continuously broadcasted and diminished with the distance to the fire location. The participants were told to evacuate immediately after the fire alarm. When participants passed by the end trigger, the test trial would end automatically and save their route choice. 74 participants finished their training and test sessions, which gave a total of 74 analyzable test trials. After the experiment, participants were instructed to finish a post-experiment questionnaire. The questions were designed based on the IVE presence scale proposed by Sanchez-Vives and Slater (2005).

4 Results

4.1 The decision-making time

Figure 9 gives the distribution of participants' decision-making time. In this study, participants' decision-making time was calculated from the time spent in the decision area minuses the time needed to pass the decision area (see Fig. 8). In particular, the time needed to pass the decision area for routes 1 and 2 was measured five times respectively and then was simply estimated as the average. Hence, if some participants did not spend time on route choice and directly went straight or turn right at the intersection, their time spent in the decision area might have been slightly less than the average. That is the reason that some measured decision-making time is in the range $(-0.2, 0)$ as shown in Figure 9. Overall, the participants' decision-making time was less than 5 seconds, except for one participant who took more than 8 seconds on the route selection at the intersection and whose decision-making time can be treated as an outlier. Hence, this outlier was excluded from the decision-making time analysis. Also, the Shapiro-Wilk test of normality showed that participants' decision-making time was not normally distributed ($p = 0.000 < 0.001$). Hence, non-parametric tests were used in the following tests.

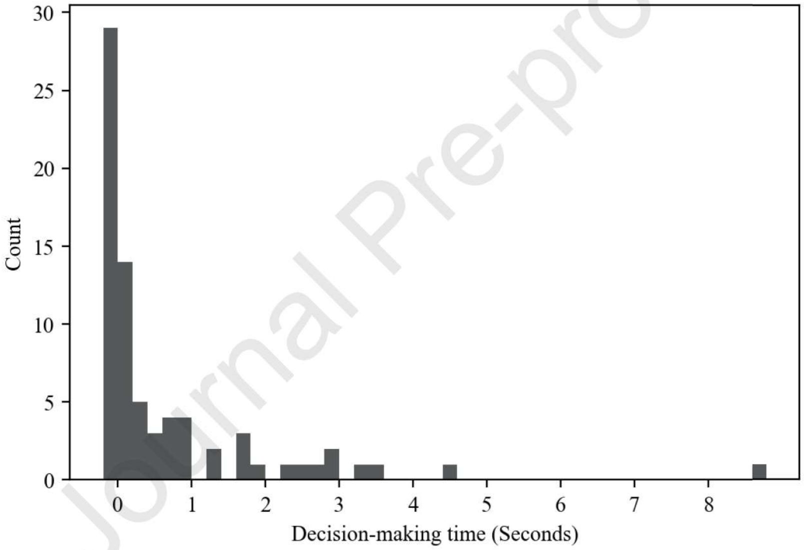


Figure 9. The distribution of participants' decision-making time

Table 2 gives the decision-making time of participants who used routes 1 and 2. The mean decision-making time of participants using routes 1 and 2 was 1.14 seconds (SD = 1.31) and 0.26 seconds (SD = 0.66). Furthermore, the Mann-Whitney U test indicated that the decision-making time of participants using routes 1 and 2 was significantly different ($p = 0.001 < 0.01$).

Table 2. Participants' decision-making time when using routes 1 and 2

Route choice	Decision-making Time		*p*-value
	Mean	SD	
Route 1	1.14	1.31	0.001
Route 2	0.26	0.66	

The results showed that the change in the emergency lighting configuration did not significantly affect participants' decision-making time. As shown in Table 3, the mean decision-making time of participants was 0.85 seconds (SD = 1.32) and 0.34 seconds (SD = 0.60) in the scenarios with or without emergency light EL. The Mann-Whitney U test suggested that the decision-making time of participants in different emergency lighting configurations was not significantly different ($p = 0.337 > 0.1$).

Table 3. Participants' decision-making time under different lighting conditions

Lighting configuration	Decision-making Time		*p*-value
	Mean	SD	
With EL	0.85	1.32	0.337
Without EL	0.34	0.60	

The experimental results demonstrated the significant impact of exit door visibility on participants' decision-making time at the corridor intersection. Table 4 gives participants' decision-making time under different exit door visibility. When the exit door was invisible or visible, participants' mean decision-making time was 0.55 seconds (SD = 1.04) and 0.62 seconds (SD = 1.04), respectively. The Mann-Whitney U test suggested that the decision-making time of participants in the scenarios of invisible or visible exit doors was marginally different ($p = 0.074 < 0.1$).

Table 4. Participants' decision-making time under different exit door visibility

Exit door visibility	Decision-making Time		*p*-value
	Mean	SD	
Invisible	0.55	1.04	0.074
Visible	0.62	1.04	

The experimental results also demonstrated that familiarity had a significant influence on participants' decision-making time. As shown in Table 5, when participants were familiar with route 2 before their evacuations, they took a mean decision-making time of 0.26 seconds (SD = 0.69). However, when participants were unfamiliar with any routes, their mean decision-making time was 0.86 seconds (SD = 1.20). The Mann-Whitney U test indicated that participants' decision-making time was significantly different when they were familiar or unfamiliar with the route before their evacuations ($p = 0.022 < 0.05$).

Table 5. The decision-making time of participants with different familiarity

Familiarity	Decision-making Time		*p*-value
	Mean	SD	
Familiar	0.26	0.69	0.022
Unfamiliar	0.86	1.20	

The results indicated no effect of neighbor behavior on participants' decision-making time. As shown in Table 6, when there were neighbors using route 1, neighboring using route 2, or no neighbors during the evacuations, participants' mean decision-making time at the corridor intersection was 0.56 seconds (SD = 1.02), 0.44 seconds (SD = 1.00), and 0.74 seconds (SD = 1.10), respectively. The Kruskal-Wallis test demonstrated that participants' decision-making time was not significantly different under different neighbor behaviors ($p = 0.273 > 0.1$).

Table 6. Participants' decision-making time under different neighbor behavior

Route choice	Decision-making Time		*p*-value
	Mean	SD	
Neighbors using route 1	0.56	1.02	0.273
Neighbors using route 2	0.44	1.00	
No neighbors	0.74	1.10	

4.2 The route choices

The results showed no significant effect of the emergency lighting configuration change on participants' route choices at the intersection. Figure 10 gives participants' route choices under different lighting conditions. When the emergency light EL was on, 37.14% of participants chose route 1 for evacuations. When the emergency light EL was removed, 35.90% of participants still used route 1. The Chi-Square test revealed that participants' route selections between the two emergency lighting scenarios did not change substantially ($\chi^2(1) = 0.01, p = 0.912 > 0.1$).

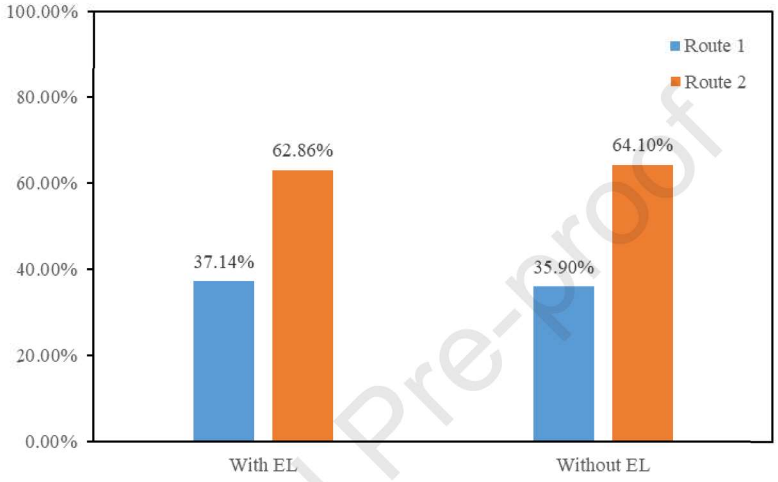


Figure 10. Participants' route choices under different lighting conditions

The results showed there was a marginal effect of exit door visibility on participants' route choices at the intersections. Figure 11 shows participants' route choices at the intersection when the exit door 1 was visible or invisible. When exit door 1 was invisible, 27.03% of participants used route 1. When the door was visible, the participants' use of route 1 increased to 45.95%. The Chi-Square test indicated that participants' route choices under the two different conditions of exit door visibility were marginally different ($\chi^2(1) = 2.86, p = 0.091 < 0.1$).

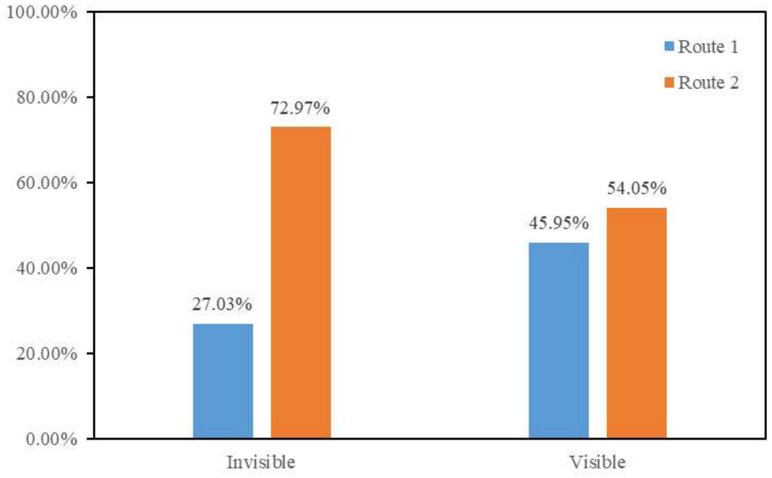


Figure 11. The route choice of participants under different visibility of the exit door.

The present experimental results demonstrated that route familiarity had a significant impact on participants' route choices. The route choices of participants who are familiar or unfamiliar with route 2 before the evacuations were summarized in Figure 12. For the participants who were unfamiliar with route 2, 51.28% of them used route 1 for evacuations. For the participants who were familiar with route 2, only 20.00% of them evacuated by route 1. Hence, participants increased the use of a route when they were familiar with it, which resulted in less use of other unfamiliar routes. A Chi-Square test revealed that the route choices between the participants with route familiarity and unfamiliarity were significantly different ($\chi^2(1) = 7.79, p = 0.005 < 0.01$).

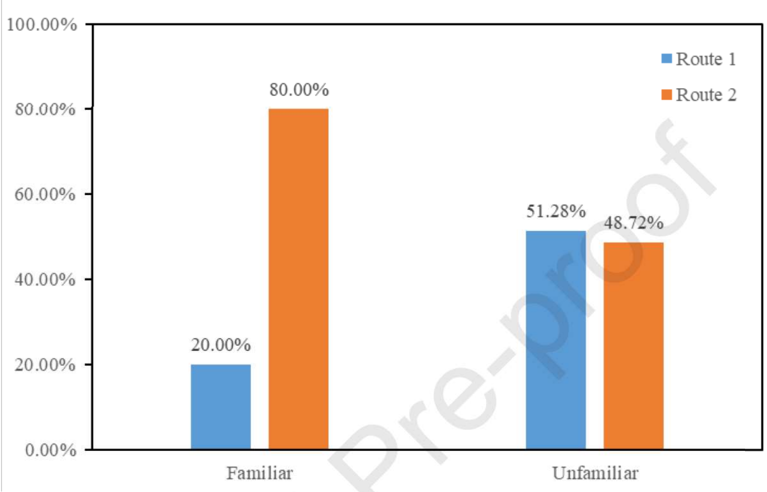


Figure 12. The route choices of participants with different familiarity.

The route choices of participants under different neighbor behaviors are given in Figure 13. In the scenarios of neighbors using route 1, neighbors using route 2, and no neighbor, the percentage of participants who chose route 1 was 60.00%, 16.67%, and 32.00%, respectively. Participants' use of route 1 increased when the virtual neighbors chose route 1 and decreased when the virtual neighbors evacuated through the other route. The route choices were compared using a Chi-Square test, which showed that there was a significant difference between participants' route choices in the event of various neighbor behaviors ($\chi^2(1) = 10.25, p = 0.006 < 0.01$). In particular, a pairwise comparison was conducted to examine the route choice difference between any two neighbor behaviors. The Chi-Square test revealed that participants' route choices were significantly different between no neighbors and neighbors using route 1 ($\chi^2 = 3.95, p = 0.047 < 0.05$), and between neighbors using routes 1 and 2 ($\chi^2 = 9.69, p = 0.005 < 0.01$). However, participants' route choices under no neighbors and neighbors using route 2 were not statistically different ($\chi^2 = 1.56, p = 0.212 > 0.1$).

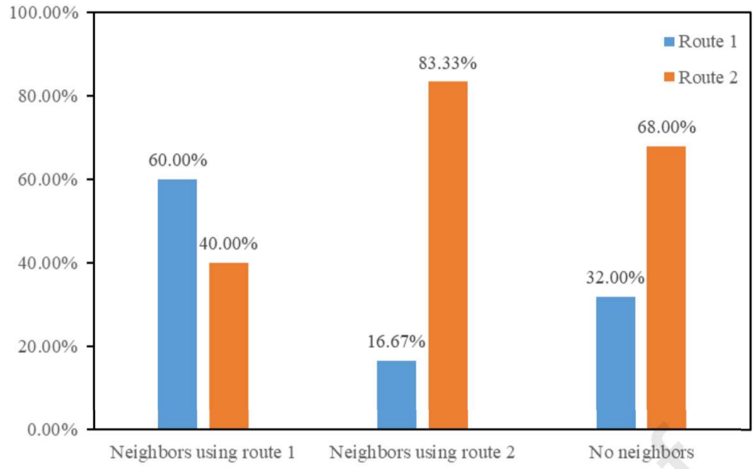


Figure 13. The route choices of participants with different neighbor behaviors.

4.3 The post-experiment survey

Participants' evaluation of the IVE is given in Table 7. The IVE used in this study was highly realistic in terms of the fire alarm (Mean = 4.57/5 with SD = 0.55), smoke (Mean = 4.10/5 with SD = 0.99), fire and fire sound (Mean = 4.03/5 with SD = 1.05), and the virtual neighbors (Mean = 4.04/5 with SD = 0.96). Participants had a feeling that there was a real fire accident when they were in the IVE. Also, Participants believed that their evacuation-related actions (Mean = 4.06/5 with SD = 0.91) and thoughts (Mean = 4.00/5 with SD = 0.99) in the tests were comparable to their actions and thoughts in a real fire accident. However, participants gave a low score for their emotional response (Mean = 2.96/5, SD = 1.25), which meant that the emotional response of participants was not comparable to the emotional response in a real fire accident. The overall assessment (Mean = 3.90/5 with SD = 0.85) indicated that participants' evacuation behaviors in the experiments were close to what they would do during a real building evacuation.

Table 7. The presence assessment results

Items	Mean	SD
The fire alarm in the VR game sounded like the real fire alarm that you have heard.	4.57/5	0.55
When I saw the smoke in the VR, I had the feeling that there was a real fire accident in the building.	4.10/5	0.99
The fire and fire sound in the VR made me feel that there was a real fire accident in the building.	4.03/5	1.05
I had the feeling that the evacuation with the other persons was happening.	4.04/5	0.96
My emotional response (e.g., urgent, stress, fear) was the same as in a real fire situation.	2.96/5	1.25
My evacuation behavior was the same as in a real situation.	4.06/5	0.91
My thoughts in relation to the evacuation were the same as in a real situation.	4.00/5	0.99
Give an overall assessment of how the VR evacuation is close to a real building evacuation.	3.90/5	0.85

The mean pre-game and after-game heart rates of participants are 79.70 (SD =13.13) and 89.46 (SD = 14.42). The Shapiro-Wilk test of normality suggested that the heart rate of participants had a normal distribution ($p = 0.224 > 0.05$). Hence, a paired-samples t-test was used to determine whether the pre-game and after-game heart rates were different. The paired t-test showed that the difference between pre-game and after-game heart rates was significantly different ($t = -9.09, p = 0.000 < 0.001$). Hence, the present experiment successfully invoked participants' physiological responses in the IVE.

5 Discussion

This study explored what influenced occupants' behavioral compliance in indoor evacuation wayfinding through an immersive virtual reality experiment. The effect of emergency lighting, exit door visibility, familiarity, and neighbor behavior on occupants' wayfinding decisions were discussed in this section. In the following, we also discussed the limitation of this study and the prospects.

5.1 Decision-making time and behavioral compliance during emergency wayfinding

The experimental results revealed that there was a significant difference in decision-making time between participants who evacuated by routes 1 and 2. As shown in Table 2, participants had a longer decision-making time when they followed the exit sign at the intersection and used route 1. The overall framework for human navigation put forward by Jul and Furnas (1997) states that when navigating, occupants keep an eye out for environmental information. The occupants evaluate their surroundings and their progress toward their destinations using the detected environmental information. Then, occupants make judgments to guide their actions, such as their movement directions. Hence, when participants take a longer decision-making time, they made more effort to seek wayfinding information, assess the environment, or determine their route choices. A longer decision-making time may mean a more deliberate decision, which results in more possibility to identify and follow the correct evacuation routes. In the present experiment, route 1 was to turn right, but route 2 only needed to go straight. Individuals pay attention to the area with the longest line of sight during wayfinding and have a tendency to conserve linearity throughout their journey (Dalton, 2003; Emo, 2014). As a result, compared to route 2, the conditions of route 1 can be only perceived and assessed when participants stepped into the decision-making area. When participants quickly passed by the decision-making area, they were easy to ignore route 1 and go straightly.

The experimental findings show that occupants are likely to have better behavioral compliance when taking a longer decision-making time in some evacuation situations, which can result in better evacuation performance. The finding is somewhat counterintuitive. In general, evacuation time is expected to be minimized, which often means that evacuees should take quick action. However, participants who evacuated by route 1 took one more second on average to make their route choices but would spend much less time in the whole evacuation since route 1 was shorter and less likely to be congested. In other words, a fast route choice could be a slow evacuation. When selecting an evacuation route, evacuees need to make a correct choice instead of only a quick choice. In the experimental case, even though route 1 was a much better evacuation route, it was easy to be ignored compared with route 2. Hence, it was certainly worth taking a little more time to seek emergency wayfinding information and make route choices at the intersection. This finding has significant implications for building safety. For building design and evacuation route planning, occupants' behavior compliance must be taken into consideration. Ideally, evacuation routes should be highly consistent with occupants' wayfinding intuition and preference, which means that they do not need to make any deliberate decisions and can always quickly choose the correct routes. However, in the real world, many indoor evacuation routes are not perfect because designers must take into consideration the functional and aesthetic needs of buildings. For example, occupants are not familiar with many evacuation routes because these routes are not frequently used in daily life. For these imperfect evacuation routes, how to increase occupants' behavior compliance is critical to improving indoor evacuation performance. Our finding shows that participants with longer decision-making time were more likely to identify and choose these evacuation routes. Hence, when an evacuation route is not highly consistent with occupants' wayfinding intuition, it is necessary to consider how to increase occupants' decision-making time and avoid them passing by a decision-making area quickly and ignoring correct evacuation routes. Also, this should be emphasized in evacuation training. Occupants need to make quick responses to indoor emergencies. However, they should not make too quick decisions when choosing their evacuation routes. It is always worth taking some time and effort to proactively perceive the environment and seek emergency wayfinding information before making route choices.

5.2 The influence of emergency lighting on decision-making time and behavioral compliance

The change in emergency lighting on the non-optimal route (i.e., route 2) did not have a significant influence on participants' decision-making time and did not increase participants' compliance with the designed evacuation route (i.e., route 1) as expected. In the experiment, participants did not have a significant difference in both their decision-making time and route choices between different emergency lighting conditions. Hence, there was no significant impact of path brightness on participants' evacuation route decisions. In previous studies, Taylor and Socov (1974) found that people were more likely to choose a brighter path and their route choices can be measured as a function of path illumination ratio and the location of the brighter side. Vilar et al. (2013) suggested that people are more likely to choose a brighter path at a "F-type" intersection when the paths had different brightness. If the paths at a "F-type" intersection had equal brightness, route choices were random. These findings were not supported by this experiment. As shown in Figure 5, the brightness of route 2 was much lower than route 1 when the emergency light EL was removed. However, removing emergency light EL did not significantly influence participants' decision-making time and reduced the usage rate of route 2. There are several possible reasons, which need to be further investigated and examined. First, route 2 was not completely dark since there were still other emergency lights on it. Wang et al. (2022) conducted an experiment and found that the existence of natural lighting influenced occupants' emergency wayfinding in underground spaces, but there was no relationship between lighting brightness and wayfinding behavior. As shown in Figure 5(a), participants can still see a little light on route 2 after removing the emergency light EL, which may result in that participants were still willing to use route 2. Second, there was an exit sign on route 2, which was visible to participants at the intersection (see Figure 1). The existence of the exit sign demonstrated that route 2 was also a feasible route to exits. When the emergency light EL was removed, the visible area was reduced, which meant fewer objects that participants could pay attention to in the environment. The exit sign on route 2 became more conspicuous. When participants detected the exit sign on route 2, they were likely to use route 2.

5.3 The influence of exit door visibility on decision-making time and behavioral compliance

The visibility of the exit door had a marginal influence on participants' decision-making time and compliance with the designed evacuation route. The experimental results showed that participants had longer decision-making time and were more likely to use route 1 when the exit door on route 1 was visible to participants at the intersection. The longer decision-making time revealed that participants were more hesitant and made more deliberate decisions when deciding which route to go at the intersection. This may be related to participants' decision-making process. The decision to choose a certain path at an intersection is made in a dynamic and dispersed manner (Brunyé et al, 2018). Individuals frequently make an effort to prepare a choice before acting (Ajzen, 1985; Klein, 1993), which means that people frequently decide and actively seek out navigational information before approaching a junction. However, when participants stepped into the decision-making area and detected the exit door, they obtained new information about emergency wayfinding. As shown in Figure 6(b), a visible exit door provided participants with clear information about how to exit the case building. Hence, they needed to reassess available route options before choosing their evacuation routes, which resulted in a longer decision-making time. Also, the information perceived from the exit door may increase participants' confidence in route 1. As a result, participants were more likely to use route 1 for evacuations. This finding is consistent with previous findings in exit choice. Haghani and Sarvi (2017) conducted a field experiment about emergency exit choice and suggested that the visibility of an exit can significantly increase occupants' use of the exit during evacuations. Hence, appropriate locations of exit doors are important to increase their visibility and improve occupants' compliance with an evacuation route.

5.4 The influence of familiarity on decision-making time and behavioral compliance

Familiarity with indoor paths significantly influenced participants' decision-making time and behavioral compliance during their emergency evacuations. The experimental results demonstrated that participants who were familiar with route 2 took less time to make their route choice at the intersection and were less likely to use route 1. The shorter decision-making time at the intersection revealed that participants with familiarity took less time to perceive their environments and seek wayfinding information when passing by the decision-making area. According to the cognitive map hypothesis, navigation behaviors are influenced by people's cognitive maps, which refer to a unified representation of the spatial environment (Tolman, 1948; Jul and Furnas, 1997; Epstein et al., 2017). Participants who took the test trials with No. 7-12 were instructed to go and leave the start room by route 2 three times before their tests. This training task allowed them to be familiar with route 2 and build their cognitive map of the building. According to their experience and cognitive map, they were more likely to treat route 2 as the correct evacuation route and make their route choices before entering the decision-making area (Brunyé et al., 2018). Yantis (1998) suggested that attention in individuals is governed by top-down control, wherein their attention is consciously guided by their own experiences and intentions. Participants in the familiar group, initially considering route 2 as the primary evacuation path, were less likely to seek environmental wayfinding cues and explore alternative routes frequently. Consequently, they proceeded through the intersection swiftly. However, the participants who took the test trials with No. 1-6 were unfamiliar with the layout of the third floor. They are more likely to seek wayfinding information at the intersection before choosing their routes and were more hesitant to make their choices. This meant that they were more likely to explore different routes and were more likely to use route 1.

The results of this experiment are also consistent with the affiliation hypothesis. The affiliation hypothesis suggests that people tend to move to the familiar during evacuations (Sime, 1983). This study examined this hypothesis in occupants' route choices at an intersection via an immersive VR-based controlled experiment. Among participants previously unfamiliar with route 2 before the experimental tests, 51.28% opted for route 1 during evacuations. Conversely, among those acquainted with route 2 beforehand, only 20.00% chose route 1 for evacuations. The results demonstrate that familiarity with route 2 correlated with increased usage of route 2 and decreased utilization of route 1. Occupants tend to evacuate by their familiar routes. Hence, when designed evacuation routes are frequently used by occupants, familiarity can significantly increase occupants' compliance with the evacuation routes. However, if evacuation routes are rarely used in daily life, familiarity becomes a critical factor that reduces occupants' compliance with the evacuation routes.

5.5 The influence of neighbor behavior on decision-making time and behavioral compliance

Neighbor behavior significantly influenced participants' route choices at the intersection, but there was no significant difference in decision-making time under different neighbor behavior scenarios. As shown in Table 6, participants had the long decision-making time when there were no neighbors and had the shortest decision-making time in the scenarios where neighbors evacuated by route 2. However, such a difference was not significant. This demonstrated that participants were always willing to take time to assess their surroundings and make route decisions at intersections, regardless of the presence or absence of virtual evacuees in the experiment. Therefore, it is evident that participants did not simply follow others blindly during their evacuation process.

Participants' actions also supported the social influence theory. Participants were more likely to utilize route 1 when the virtual neighbors evacuated through route 1, as seen in Figure 13. The social influence hypothesis states that individuals will follow others and act in a similar manner to avoid standing out by disobeying social conventions or by utilizing the actions of others to interpret reality and direct their behavior (Deutsch and Gerard, 1955). In the present experiment, participants did not know virtual neighbors or have any social interaction with the neighbors. Hence, it was unlikely to build strong social norms between participants and virtual neighbors to influence participants' route choices. Instead, participants were more likely to be influenced by informational social influence. People use social cues to recognize risk and make evacuation choices (Lindell and Perry et al., 2011; Urata and Pel, 2018). Participants observed what the neighbors did and used their choices to speculate about the correct route. However, participants' decision-making time was not significantly affected by the existence of virtual neighbors, which suggested that participants did not blindly believe their neighbors' choices. Instead, they used information from a multitude of sources to guide their decisions. More specifically, the participants' route selections did not change substantially between the situations of no neighbors and neighbors that took route 2. This finding suggested that social influence was not significant when neighbors selected a route which has been preferred by participants in the scenarios of no neighbors. The results support our previous finding of social influence on occupants' risky route decisions (Fu, et al., 2021a). If an evacuation route is highly consistent with occupants' preference, the possibility that occupants use the route for evacuations would not significantly increase by social influence (i.e., the others also use it to evacuate). On the contrary, if an evacuation route is not highly consistent with occupants' wayfinding preference, the use of the route can be increased significantly when others use it. From this point of view, social influence is a negative factor to increase occupants' compliance with well-designed routes but is a positive factor for evacuation routes that are not well-designed to conform to occupants' wayfinding preferences.

5.6 Limits and prospects

There are still several limitations with this study that need to be resolved in future research. First, the ecological validity of VR experiments needs to be examined. VR technology provides a convenient and safe way to simulate indoor fire accidents but still cannot reproduce real accident experiences. The IVE developed in the present experiment provided participants with only visual and auditory perceptions about fire accidents. No temperature and olfactory stimulation were provided considering participants' health and limited devices. In the post-experiment survey, the results showed that the experimental IVE was highly realistic and had a high level of presence. Participants' heart rates also indicated that the IVE invoked their physiological responses. Hence, it is reasonable to believe that participants' wayfinding decisions in the IVE are close to their decision in real-world fire evacuations. However, participants did not have a high emotional response (e.g., urgent, stress, fear) as they may have in a real fire accident. It is still necessary to verify the results of this study in real fire evacuations. Second, the interaction between the experimental factors this study only investigated the main effect of the experimental factors and the effect of emergency lighting on occupants' compliance with evacuation routes should be further investigated. In the present experiment, the participants did not have a significant difference in their decision-making time and route choices in the scenarios with or without emergency light EL. This is not consistent with the previous finding of the effect of path brightness on route choice, which may be caused by several reasons. For example, route 2 was not completely dark because route 2 still had emergency lights in the distance and also had a visible exit sign at its next intersection. Hence, the effect of emergency lighting on occupants' wayfinding is complex and needs to be examined in more wayfinding situations. Third, this study only investigated the effect of social influence on occupants' behavioral compliance in a small group. It requires further examination of whether the results are consistent with occupants' behavioral compliance in a large group or a crowded environment. Besides, participants were not unacquainted with neighbors in our experiment, and did not interact with or evacuate with virtual neighbors as a group. Further research can examine the social effect in the acquainted group situations. Fourth, all the participants were recruited at the University of Florida. Most of the participants were undergraduate or graduate students. Also, all participants had good mobility and visual ability. Hence, the age composition and physical conditions of the samples in the present experiment are not consistent with the general population, which may limit ecological validity. The findings of this study are reasonable to be applied to young adults with good mobility and visual ability. Future research can examine the results of this study in wider populations and include more factors that may influence occupants' behavior compliance during evacuations. Fifth, the interaction of experimental variables on occupants' behavioral compliance is unclear. This study utilized an orthogonal design to design experimental trials. It allows for reducing the number of experimental trials and testing the effectiveness of many variables simultaneously in a single experiment and does not influence the main effect of each experimental variable. However, the interaction of experimental variables cannot be examined in this experiment. The interaction effect is important to have a comprehensive understanding of human emergency wayfinding and how to increase occupants' behavioral compliance during evacuations.

6 Conclusion

This study focused on examining the decision-making time taken by occupants to make route choices and their behavioral compliance during indoor evacuation via an immersive VR experiment. Also, four experimental variables were included: emergency lighting configuration, the visibility of exit doors, familiarity, and neighbor behavior. The main effect of the experimental variables on occupants' decision-making time and route choice was examined in a controlled experiment. Based on this, this study analyzed how these variables influence occupants' behavioral compliance when making route choices. The main findings include:

(1) Participants with a longer decision-making time were likely to have better evacuation behavioral compliance for some wayfinding situations. When a planned evacuation route is not highly consistent with occupants' wayfinding intuition and preference, a longer decision-making time, which often means more wayfinding information-seeking behaviors, can increase the possibility of identifying and following the correct routes. Instead, a fast route decision may give rise to a wrong route choice and thus result in a slow evacuation. Hence, it is always worth taking some time to proactively seek emergency wayfinding information before making evacuation route choices.

(2) Removing the emergency lighting EL on the non-optimal route did not significantly affect participants' decision-making time and failed to increase their behavior compliance with the optimal evacuation route.

(3) The visibility of an exit door increased participants' decision-making time and significantly influenced their route choices. Increasing the visibility of an exit door via deploying it at an appropriate location can increase occupants' behavioral compliance during evacuations.

(4) Familiarity had a significant influence on participants' decision-making time and route choices. Occupants who are familiar with building layouts take less time to make their route choices and are more likely to evacuate by the familiar routes. When the planned evacuation routes are not frequently used in daily life, familiarity can be a critical factor that increases the possibility of ignoring the evacuation routes and negatively affects occupants' behavioral compliance.

(5) The social influence did not influence participants' decision-making time but significantly affected their route choices, which revealed that occupants made rational decisions and did not follow others blindly. Besides, social influence is a negative factor to increase occupants' compliance with well-designed routes but is a positive factor affecting occupants' compliance with evacuation routes that do not highly conform to occupants' wayfinding preferences.

The experimental findings provide the basis for understanding occupants' behavioral compliance and assessing the extent to which occupants would follow a planned evacuation route. Also, the findings help architects adjust building design to improve the performance of building evacuations.

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