Structural Safety and Reliability, Shiraishi, Shinozuka & Wen (eds) © *1998 Balkema, Rotterdam, ISBN 90 5410 978 5*

Application of virtual reality to human evacuation behavior

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ABSTRACT: A simulator using virtual reality (VR) is developed as a new tool to study human evacuation behavior. The system is then applied to study evacuation from a maze. Comparing the results of experiments using the real maze and VR maze, both of which have the same structure, applicability and potential of VR for evacuation behavior are examined. Although there are problems to be solved, it is found that evacuation behavior can be simulated by the VR system, and the training using VR helps smooth evacuation from the maze. Considering the issues related to education of disaster-prevention and disaster-fighting drills, such as human mannerism, decrease of participants and their low volition, and safety of the drill, the VR simulator developed here has high potential and can be a useful tool for disaster mitigation. This simulator can also be applied to study the safety of the structures in the planning and design stages as well as existing ones from the view point of human evacuation.

1 INTRODUCTION

Conventionally, three major ways have been used to understand human behavior; i) investigation of real accidents; ii) experiments using subjects; and iii) computer simulation. By the first method (Morita K. 1973, Osada K. 1980), we can obtain real data during accidents which is very important and significantly different from other two ways. However, the amount of data obtained from such situations is inadequate and it is practically impossible to get the data of the people who were killed during the accidents. Thus, sufficient analyses cannot be carried out based on only the data obtained by the first method. With the second way (Watabe, Y. 1982, Hokugo, A. 1985, Funahashi, K. 1991), because of the safety issues of the subjects, it is difficult to simulate the circumstances in actual disaster situations making it hard to obtain the data under such situations. It is also difficult to carry out the experiment when the objective space is very large or the number of subjects are numerous. The improvement of computer systems has made the third approach more attractive because the application potential has improved greatly during recent years (Ozaki, S. and Matsushita, S. 1992). However, there are many assumptions which define the model and/or estimating of parameters for the simulation model. Consequently, individual personal characteristics of users and detailed information relating to the objective space can not be taken into consideration.

Recently, the improvement of 3-dimensional (3-D) computer graphics, interactive-man-machine interface, and telepresense has caused virtual reality (VR) in which people can feel artificial and virtual worlds as a real world, to attract more interest (Tachi, S. et al. 1991, Yanagida, Y. and Tachi, S. 1993).

Under these situations, we have studied human behavior by both experimental and numerical methods to develop a new integrated model which can supplement the weak points of every method and combine their strong points (Yokoyama, H. et al. 1994, Meguro, K. et al. 1995). A new simulator using virtual reality (VR) technology which is introduced in this paper is one possible example.

The proposed approach is a combined model of the second and third ways, namely, it has a high potential to obtain personal characteristics in disaster and high applicability for disaster-education and disaster-fighting drills. In this paper, following the flow shown in Figure 1, we discuss the reality and reliability of VR simulator and its training effects by comparing the results of evacuation experiment using real and VR mazes both of which have the same scale and structure. And from these results, we

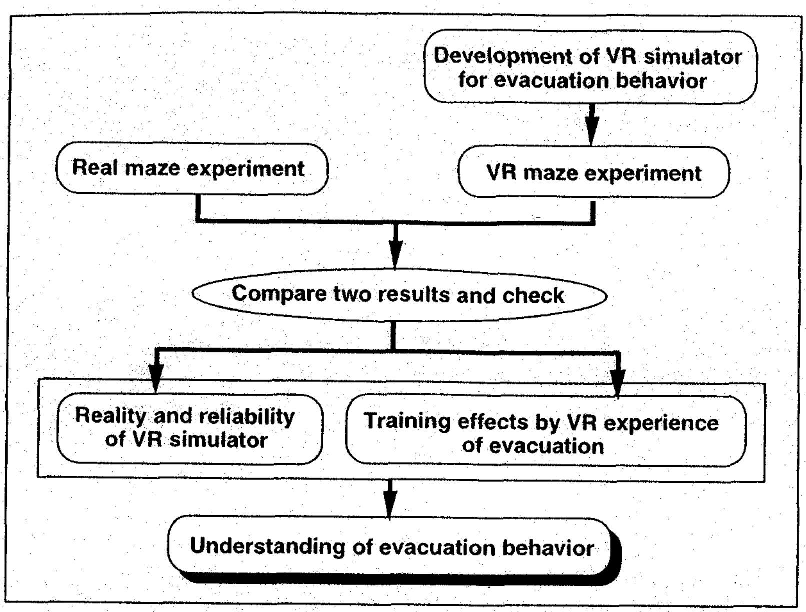


Figure 1 Flow of analysis

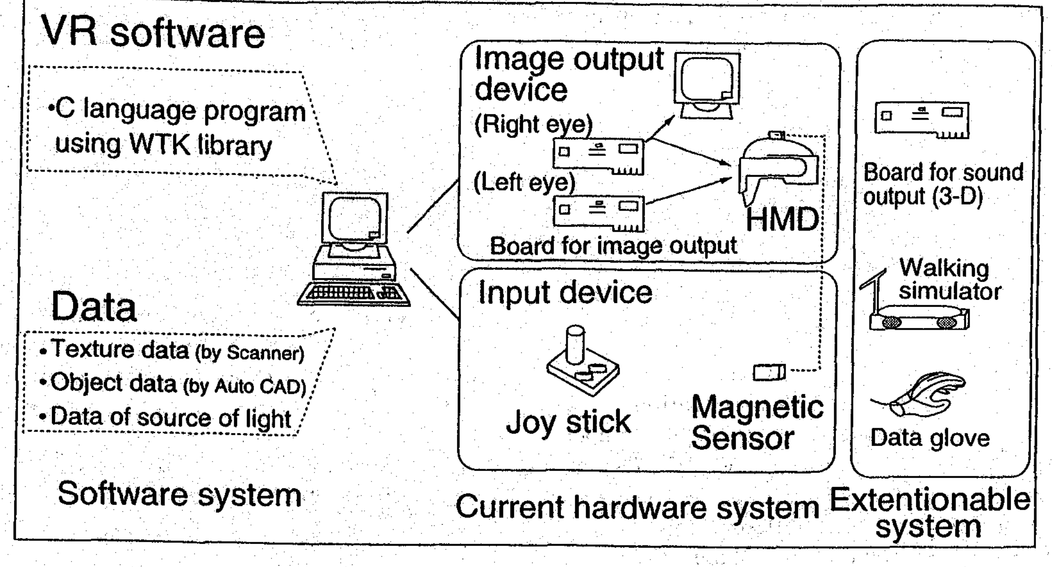


Figure 2 Components of VR system

analyze the human evacuation behavior characteristics from the maze.

2 VR EVACUATION SIMULATOR

The VR evacuation system used in this study is illustrated in Figure 2. We used DOS/V personal computer with image handling board and World Tool Kit (WTK) by W. Industry Co. Ltd. as a tool of VR development. WTK is a C language library composed of about 400 function commands. The VR program was created by selecting the required proper commands from WTK and compiling them using C language. Walls and doors in the VR maze were developed by an Auto-CAD system and some efforts such that photo image scanned were pasted, were performed to raise the reality.

One joystick and a magnetic sensor, set on head mounted display (HMD) which monitors the movement of the head of the subject, are used as the image input devices. HMD is used as the image output device. HMD is the device which provides the subject with 3-dimensional moving images by providing sight angle differences to the image of both eyes. The monitoring data of the movement of the subject's head by a magnetic sensor set on HMD is used to perform coordinate transformation. Shade handling is performed and the image which agrees to the movement of the head is projected to the HMD screens (Figure 2).

The VR system introduced here was developed as the first step of the study for the purpose of simulating sight

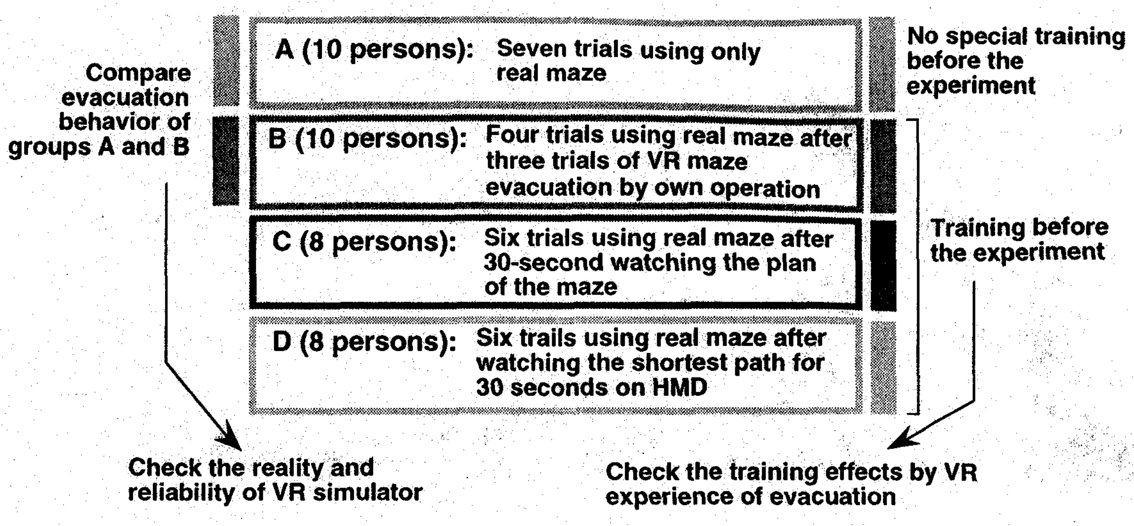
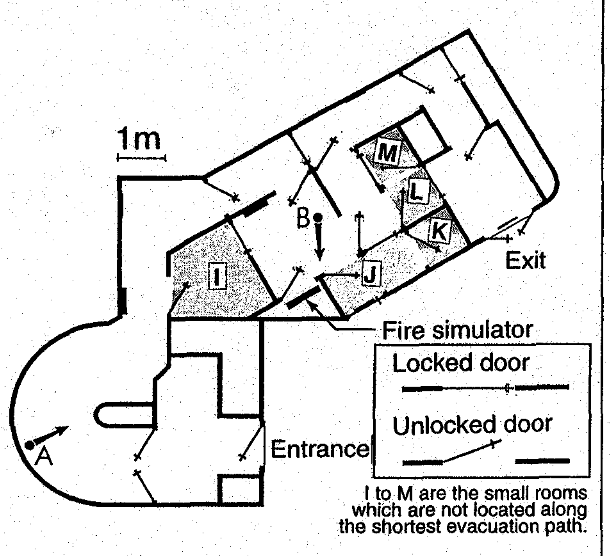
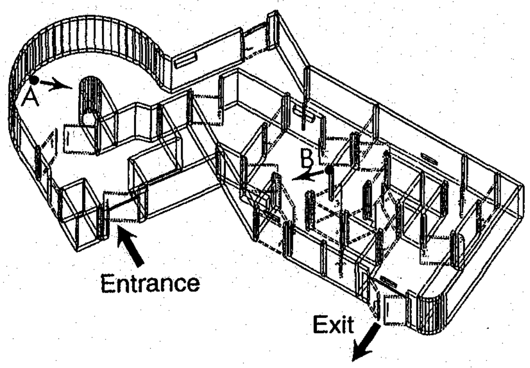


Figure 3 Experiment groups

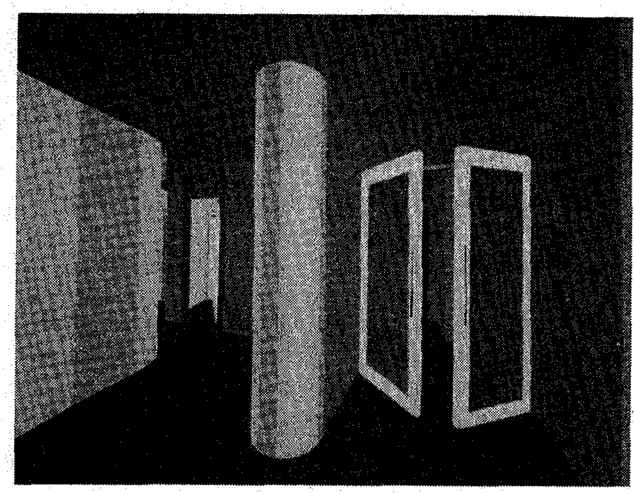


(a) Plan of the maze

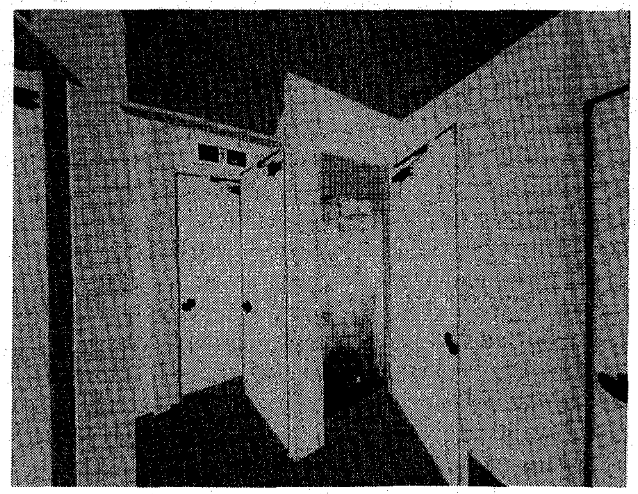


(b) Structure of the maze as seen from the above

Figure 4 The maze use for study



(a) VR scene from the view point of A



(b) VR scene from the view point of B
(Simulated fire can be seen the right)

Figure 5 Scene inside VR maze

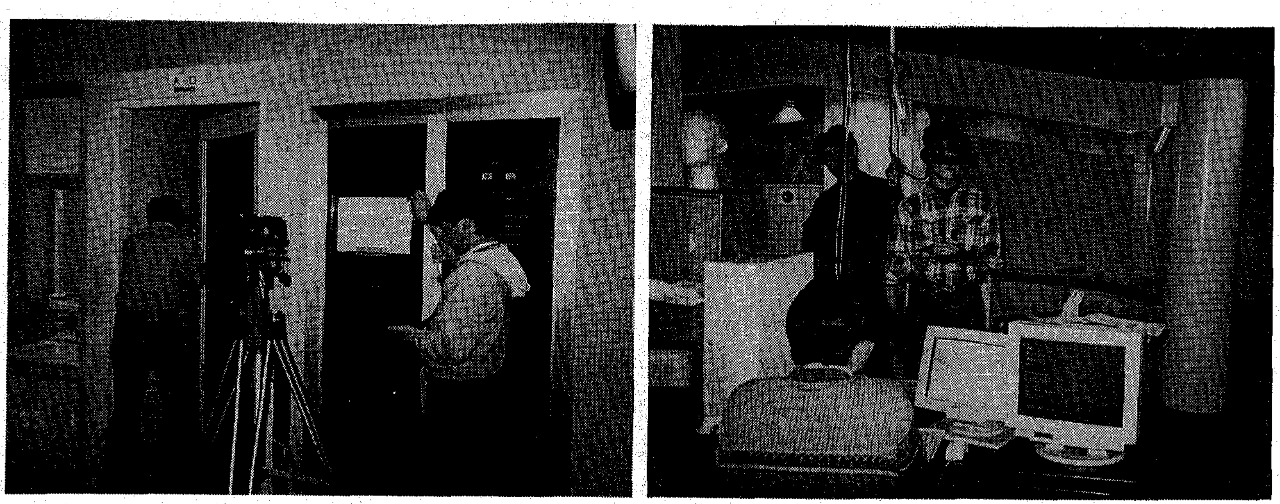

(a) Scene of real maze experiment (b) Scene of VR maze experiment

Figure 6 Scene of real and VR maze experiment

which is thought to be the most important factor during evacuation of the people who are not physically handicapped.

With real evacuation behavior, of course, additional senses such as hearing, touch and smell, etc., are important, and they should be taken into account for more detailed evacuation analysis. The system will be extended to consider senses other than sight.

3 EXPERIMENT USING REAL AND VR MAZE

The experiments were carried out during December 19-20, 1994 and on January 9, 1995. To make the characteristics of the group of subjects homogenous, we used 36 male graduate students of Department of Civil Engineering and Architecture from the University of Tokyo as subjects of the maze experiment. We set up our VR simulator system beside the real maze at Ikebukro Disaster-Drill Center of Tokyo Fire Fighting Agency.

We divided 36 subjects into four groups with different conditions (A: 10, B: 10, C: 8, D: 8 persons) as shown in Figure 3, and measured evacuation time and path and compared them by changing conditions. Namely, A is the group in which no training was carried out before the real maze experiment. In group B, subjects had three VR maze evacuation trials by their own operation before the real maze experiment. Subjects in group C watched the plan of the maze structure for 30 seconds before the real maze experiment, and in group D, moving VR images of shortest evacuation path for 30 seconds were provided before the real maze experiment. Including the training before the real maze experiment, every subject of all the groups had seven trials in total. At the seventh trial, all the lights in the maze were switched off when the subjects entered the maze. The subjects were not aware that the light would be extinguished.

Before entering the real maze, we asked each subject to check the locations of entrance and exit and to evacuate along the center of the pass of the maze by walking at the normal speed. Figure 4 shows the structure of the maze used in the study and an image provided by HMD (for one eye) is shown in Figure 5. Rooms I to M in Figure 5 show the small spaces which are not located along the shortest route.

Figure 6 shows the snap shot of real and VR maze experiment. Because there is a large difference among the subjects in operational technique of VR simulator, we proposed two simple mazes and every subject was instructed by repeating evacuations using these two mazes. This training using simple mazes was completed before the subjects started the VR maze experiment with the same structure shown in Figure 4. By using the experimental trials for operational instruction before implementing the main experiments, we were able to examine the subjects' operational technique of the VR simulator and their learning capacity before the main experiment.

After finishing all the experimental trials, a simple questionnaire survey and interviews were carried out to understand subjects' psychological situation during the experiment which can not be captured by digital data such as evacuation time.

4 EXPERIMENT RESULTS AND CONSIDERATION

The results of the experiments by both real and VR mazes and responses from the questionnaire survey and interview are compared. Based on these results, the reliability of VR simulation developed, and the training effects of virtual evacuation experience by the VR simulator were examined and the characteristics of human evacuation behavior is discussed.

4.1 *Training effects of virtual experience provided by VR simulator*

Figures 7 and 8 show the average evacuation time and walking velocity of each trial. From these figures, it can

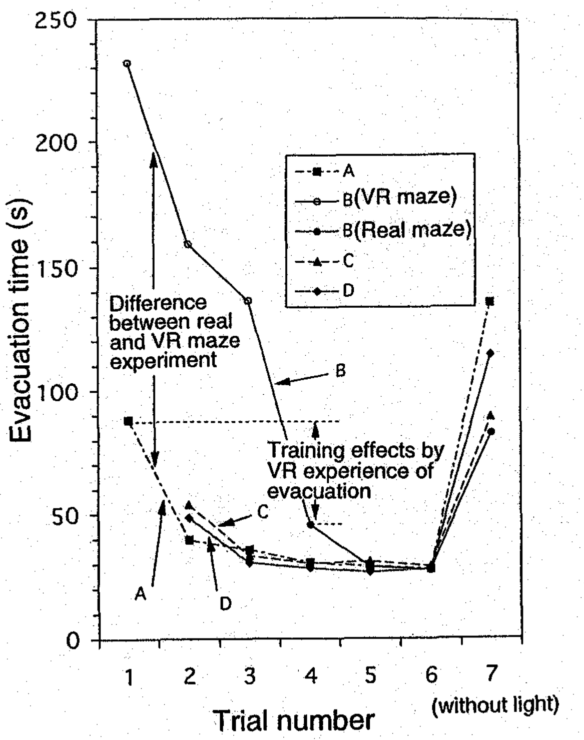


Figure 7 Average evacuation time of each group

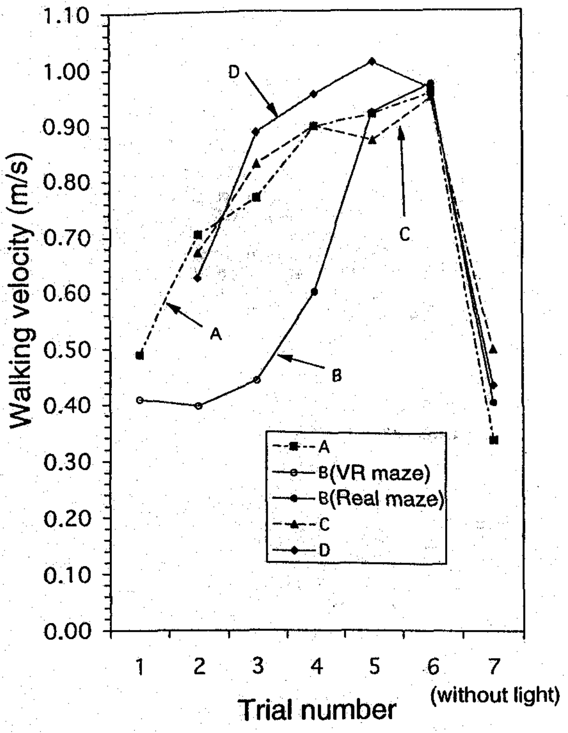


Figure 8 Average walking velocity of each group

be noted that with repeating trials evacuation time tends to be shorter and walking velocity becomes higher. Also, subjects who had some experience before the real maze experiment (2nd trial of group A, the first real maze trial of groups B, C and D) could evacuate from the maze in shorter time and with a faster velocity as compared with the first trial of group A who had no experience beforehand.

The first trial of group A had an average evacuation time of 88 seconds. Other groups including the second trial of group A, are shorter by 34 to 48 seconds (Figure 9). A similar trend can be seen from evacuation path length. The path of the first trial of group A was 41.8 m while the results of the others were 27.2 m (2nd of A), 26.8 m (B), 33.1 m (C) and 27.7 m (D). Therefore, to examine whether virtual experience by the VR simulator has training effects for the real maze evacuation behavior, we applied a statistical method, in which average evacuation time vs. number of trials is assumed to obey the t-type distribution. It was proved that subjects trained with VR could evacuate faster than those subjects who had no training beforehand.

Because group B's first trial had an evacuation time similar to the second trial of real maze experiment of group A, it can be noted that training effects of three trials of the VR experience correspond to that from one real experience in case of the maze used here. And since group D (who watched moving VR images of shortest path) was able to evacuate faster than group C, who studied the plan of maze structure, we can conclude that virtual experience by moving VR images has high training effects for real maze evacuation. Before the experiment, we thought that group C could evacuate most smoothly and the training effects of watching plan was the best among B to D. However, the average evacuation time of group C is longer than those of groups B and D, and deviation of group C was large. From the questionnaire survey and interviews, we found that this result came from large ability difference of imaging 3-D space from 2-D plan. Considering the conditions that the subjects participated in this experiment were graduate students of departments of civil engineering or architecture, who took the courses of geometry and drawing, their capacity of imaging 3-D space from 2-D plan is certainly much higher than ordinary people. From this result, evacuation guidance for ordinary people should be carried out by moving image showing the route to exit in addition to the conventional 2-D plan illustrating the evacuation route. For example, hotels depict evacuation route on a 2-D plan, however, an alternative to show the evacuation route from the room to exit including surrounding 3-D circumstance by moving images on TV.

4.2 *Reality and reliability of VR simulator*

To examine the reality and reliability of the VR simulator developed, we investigated the route selection at three junctions in the maze of the subjects in the first trial using real maze experiment (Figure 10). At the first junction, subjects of both real and VR maze group tend to go straight when the right side is close to the exit. At the other two junctions, the same tendency can be observed. Based on these results, we can say that the VR simulator developed here can simulate the route selection in evacuation behavior qualitatively.

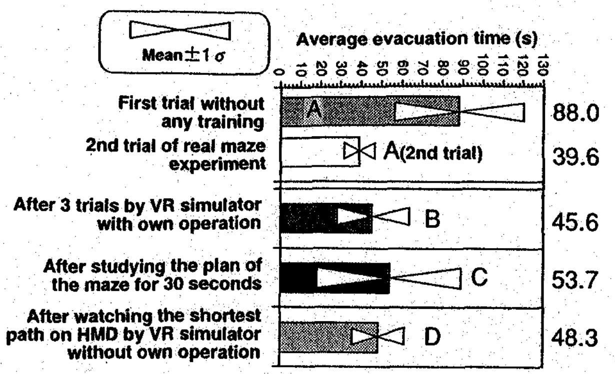
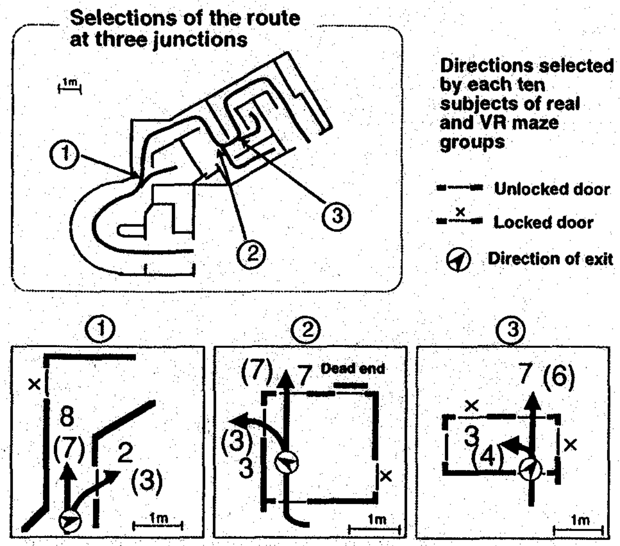


Figure 9 Average evacuation time of the first trial of real maze experiment



Values in the figure show the number of subjects who selected the direction. Values in parenthesis are the result of VR maze experiment.

Figure 10 Comparison of route selection between real and VR maze experiment

Next, we compared the experimental results (evacuation time, path and velocity) of groups A and B (Figure 11). From the figure, average evacuation time, path length and velocity of the VR maze experiment are respectively about 2 to 3 times, 1.5 to 2.5 times and 0.7 to 0.8 times as much as that of real maze experiment. As the trial number increase, evacuation time and path length shorten becoming more like the real experiment while the evacuation velocity does not have as good of a match. Although the difference at the first trial is small compared to the second and third trials, the velocity increases in the real maze experiment, but the increasing ratio of the VR maze experiment is small. Possible reasons for these differences are maximum velocity adopted in the experiment, operational difficulty of the VR simulator and the view angle of HMD, etc.

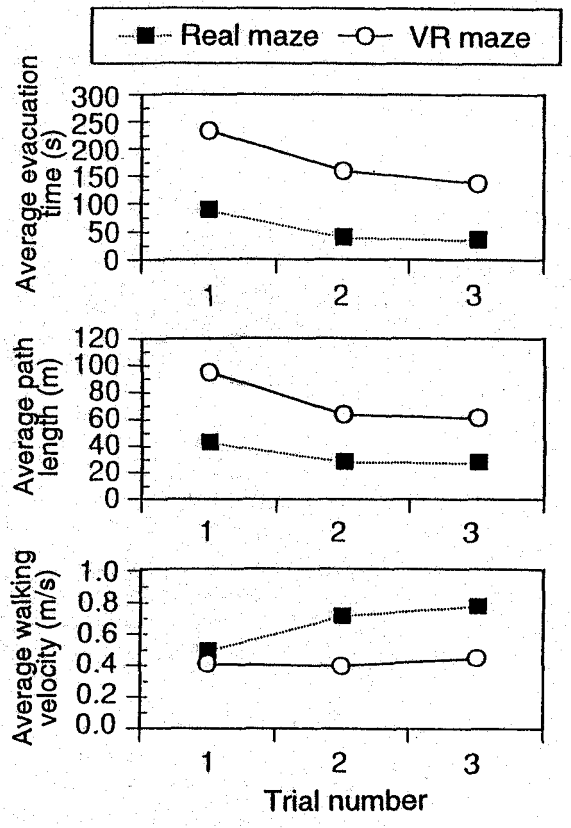


Figure 11 Comparison of average evacuation time, path length and walking velocity between real and VR maze experiment

4.3 *Evacuation behavior in disaster*

From Figures 7 and 8, we can conclude that every subject mastered the shortest route and that he could evacuate very smoothly due to training trials. At the seventh trial without light, however, it took several times longer time for evacuation. Therefore, we plot the relation between the evacuation time without light and the maximum evacuation time among the six trials (Figure 12). Figure 13 shows the relation between the number of small rooms (Nr=0-5) which the subject entered during experiments. We can assume that the subject whose maximum evacuation time or Nr is large was wandering in the maze to find the exit. During his search for the exit, he was able to learn the whole structure of the maze as well as the shortest path. This experience helps him to evacuate smoothly under the condition of no light. While the subject whose maximum evacuation time is short or Nr is small, could evacuate very smoothly with light, and it means that those subjects could not learn the whole structure of the maze excluding the shortest route as well. From the interview, we learned that the latter group was confused and lost direction under the condition of no light. Considering the purpose of evacuation drills, that is disaster mitigation, the important factor is not the number of trials, however, its content is much more important. We know that there is strict limitation of evacuation drills due to the safety issue of the subject, but this result pointed out

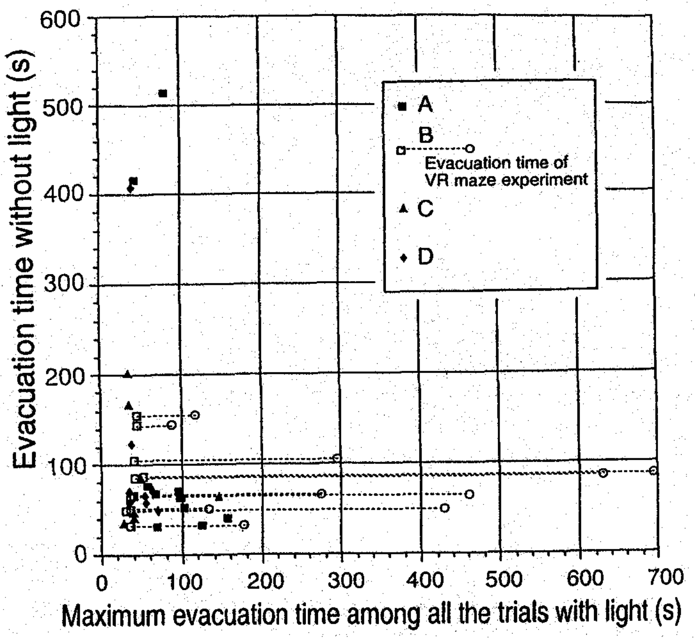


Figure 13 Relation between evacuation time without light and maximum evacuation time with light

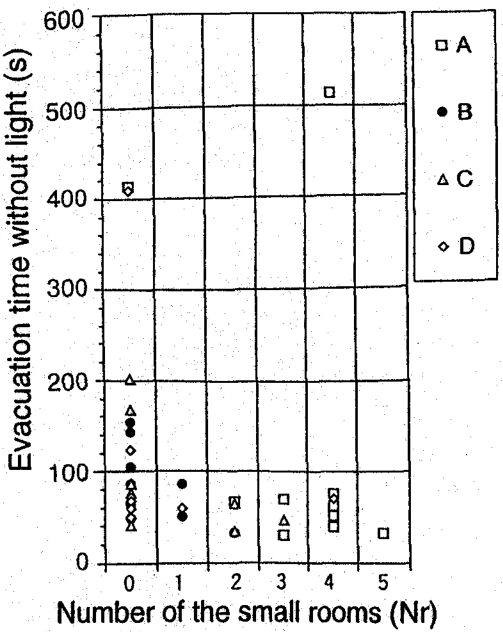


Figure 14 Relation between evacuation time without light and the number of the small rooms which are not located along the shortest path length and walking velocity between real and VR maze experiment

that it is very important to carry out the drill based on the situations and conditions in case of disaster. We should recognize that we may face similar situations in our disaster drills or in daily life. For example, an evacuation drill for studying only the shortest path, routine use of a subway and the underground facilities, etc. may create trouble for users in disaster.

5 CONCLUSIONS

We can conclude that the urban space and the structure are safe only when the safety of the people using the facility is secured in both the usual and unusual use. In this paper, to study the human behavior which is indispensable for the above issue, we developed the virtual reality evacuation simulator and examine its usefulness and potential.

Evacuation experiment using real and VR maze both of which have the same structure were performed and the results were compared. From this study, it was recognized that the virtual experience obtained by the VR simulator can help people evacuate from the real maze. Although there are issues which need to be resolved such as defining up of maximum velocity and operational problems, it was proved that the VR simulator has applicability to human evacuation behavior.

The potentials of the VR simulator for disaster education or disaster fighting drill is very high because it is impossible for us to have experience of disaster in daily life and once a disaster occurs we will face a terrifying and risky situation. The experiment using VR simulator is very useful since it can be, also, a tool to obtain the individual human characteristics which are very difficult to get and very important for computer simulation. Considering the issues related to education of disaster-prevention and disaster-fighting drills, such as human mannerisms, the decrease of participants and their low volition, and the safety of the drill, training using the VR simulator will become more popular. Moreover, the proposed model can be applied to the space and structure in the planning and design stages as well as to existing ones from the view point of human evacuation.

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