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Design and evaluation of radiation disaster prevention map based on evacuation behavior

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ABSTRACT

An effective disaster prevention map ensures public safety and efficient evacuation during emergencies. Emergency evacuation information design in Taiwan is in its nascent stages. This study focuses on individuals' understanding, behavior, and decision-making during disaster prevention to devise suitable disaster prevention map norms. We examined the Emergency Planning Zone's existing disaster prevention methods and surveyed the community to understand their disaster prevention concepts and needs. We conducted two experiments: the first tested the comprehension of existing disaster prevention maps and identified their issues, while the second evaluated a redesigned map based on Experiment 1's findings. We discovered that all age groups agree on needing accurate, fast information and diverse evacuation route options. Experiment 1 revealed disproportionate assembly point icons on the existing map, leading to navigation difficulties. The map also failed to mark landmarks, road names, and blocked intersections accurately. The redesigned map in Experiment 2 addressed these issues, showing that improving map information design aids recognition and memory, and bridges wayfinding behavior gaps in people with different spatial abilities. We suggest marking evacuation routes on maps, placing corresponding signs on-site, and locating assembly points near landmarks for easier navigation.

1. Introduction

Given the Fukushima nuclear accident in Japan in 2011, the Atomic Energy Commission of Taiwan's Executive Yuan announced in October of the same year that the emergency response plan area for nuclear plants No. 1, No. 2, and No. 3 was an administrative area of 8 km [1]. According to the "Nuclear Accident Emergency Response Law," local governments should follow the basic plan for an emergency response to nuclear accidents and public protection actions in the accident area [2]. Making disaster prevention promotional materials and online disaster prevention manuals, posting evacuation maps on bulletin boards, and setting up evacuation boards are essential maintenance items for evacuation operations [3]. The local governments adjust the disaster prevention map operations to adopt measures for local conditions. The Fire Department Act of the Ministry of the Interior [4] includes the principles of " good legibility" and "completeness of content" in the principles of making manuals for disaster prevention maps. The "diversity" of people and the environment must be considered in safety measures in public spaces, such as using disaster prevention maps [5] and setting signage for guidance [6]. The content and effectiveness of evacuation route guidance are limited to the accurate presentation of information and the effectiveness of people's movement [5].

Although the production principles are clearly stated in the regulations, evacuation behavior is diverse and complex, and there may

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be other different behavior characteristics during emergency movement [7]. It is known from experience [8] that if an emergency occurs in a public space, it is often challenging to cause serious casualties due to evacuation. When an emergency occurs in a public area, the public's top priority is to find an emergency escape route as soon as possible. Therefore, how to move safely and quickly in a public environment is a crucial design issue. Although there are currently evacuation route maps in many public places in Taiwan, whether the information is easy to understand remains to be clarified. Most of them focus on the presentation of information, lack field verification, and cannot truly understand the efficacy of evacuation maps. In addition to paying attention to the presentation of information required for reading, map design also needs to check whether people's wayfinding behavior corresponds to their spatial cognitive map, to know whether people can move in space reliably and freely. Therefore, we must consider people's emergency movement behavior characteristics and strategies to define disaster prevention maps' content and design conditions. And further evaluate the public's understanding and action effectiveness of disaster prevention map design, complete design verification, and design specifications to improve the efficiency of independent disaster prevention and disaster response in the future.

Wayfinding behavior, which has been developed for a long time, is one of the methods commonly used to check whether people move smoothly in the environment. When people move into an unfamiliar environment, they will be temporarily lost due to insufficient awareness of the environment [9]. Therefore, environmental characteristics that facilitate wayfinding must be integrated into easy-to-search information. Environmental characteristics convenient for wayfinding include [10]: differentiation, degree of visual access, the complexity of the spatial layout, etc. This attention to human behavior in the space will be the key to the design.

1.1. Spatial cognition and wayfinding behavior

The original explanation of wayfinding is the process by which people understand their external environment in some way and make decisions from it [11]. After years of research on the explanation and evolution, the more specific explanation in recent years: Including people's perception of the external environment after receiving various information from the environment, through psychological interpretation and transformation into a strategy for movement planning, and put it into practice at a specific location, the process of solving movement problems in space [12]. Wayfinding is an interdisciplinary study of environmental psychology and cognitive psychology, and it is a cognitive process for people to use existing knowledge in space to reach the destination from the starting point [13]. When people move into an unfamiliar environment, they will temporarily get lost due to insufficient awareness of the environment [9]. The wayfinding can include three parts, the drafting and decision-making of the mobile plan, the execution of the mobile plan, and the process of processing environmental information [14]. Many scholars have also proposed that wayfinding is not a single linear information processing process but an information processing process in which the mind interacts and makes decisions after continuously receiving environmental information from various sources. On the other hand, wayfinding is also the behavior of continuously evaluating and making decisions to go to the goal through the continuous path selection process, comparing the relative relationship and cognition between oneself and the space in which you are located [15].

The three stages of the wayfinding process [12] are the establishment of Cognition Mapping, Decision-Making, and Decision-Execution Process. Spatial orientation in establishing cognitive maps is an important step in establishing cognitive maps; through spatial orientation [16], people can establish comparisons and modify cognitive maps to achieve their goals.

When planning a wayfinding and executing a wayfinding plan, people will compare the spatial information of the area with the images in their minds to confirm whether they are moving in the correct direction [17]. If an error occurs, it will reposition itself, re-correct the proposed plan, and execute it repeatedly until it reaches its destination (Kevin Lynch, 1960). Therefore, each person will have individual differences in wayfinding decisions due to personal experience and ability. Common ways to evaluate wayfinding ability include [18]: the number of backward and wrong turns and the time required for wayfinding tasks. Among them, spatial knowledge is closely related to personal wayfinding ability. Spatial knowledge affects wayfinding performance. Spatial knowledge is divided into three categories [19]: 1) Landmark Knowledge, Procedural Knowledge or Route Knowledge, and Survey Knowledge. Therefore, investigating spatial knowledge related to personal experience is necessary to research before the wayfinding experiment; in this study, "The Purdue Visualization of Rotations Test [20] " was used to distinguish individual differences by spatial ability.

Allen [21] also compared the differences in wayfinding with different degrees of familiarity with the region. Significant differences existed in the landmarks and wayfinding strategies used by those familiar with the region and those not. Downs & Stea [11] believed that after encountering an unfamiliar environment, they will start the process of cognitive map from the spatial knowledge developed from the learned space. Therefore, in addition to language, existing spatial knowledge will be used to find the way because of the differences in the background of travelers. Although Down and Stea's [11] cognitive map model can clearly define the relationship between human and environmental information and decision-making in the brain, it shows that people receive environmental information in a real environment, then start to evaluate, organize, remember, and finally make action decisions. However, due to differences in personal experience and background knowledge, people have different judgments of intelligence, which will also cause differences in cognitive maps and behaviors in the brain [22]. This is why some people find their way quickly and correctly while others get lost in the environment.

1.2. Wayfinding in virtual environments

With the development of virtual environment technology, more and more wayfinding experiments are carried out in virtual environments. The virtual environment technology can improve the controllability of the experimental environment and various factors and accurately collect behavioral data such as pedestrian positions and reaction times. Many researchers have used virtual reality for wayfinding experiments [23]. With this technology, the financial cost and the time spent on experiments can be drastically reduced

[24]. Researchers found that people's wayfinding in the two is similar when comparing the cognitive process and spatial knowledge in the virtual environment with those in the real world. The subjects' responses can be recorded in detail in the virtual environment for finer-grained behavioral observations, which are more difficult to achieve in the real world [15]. Through the virtual environment technology, the variables required for the experiment can be arbitrarily controlled in the computer to construct a difficult field to achieve in the real world. O'Neill [18] used virtual buildings with different layout complexities to explore their impact on wayfinding performance Impact.

Virtual environments also offer a way to simulate emergencies without causing physical harm. Shi et al. [25] used a virtual environment to simulate a fire scene to understand how firefighters develop spatial cognition and memory while on duty. They found that in a limited amount of time, routing and survey information in the environment can help better remember building layouts and reduce the total driving distance. In Jing Lin et al.'s [26] research on fire emergencies in virtual space, increasing the number of exposures to the scene will improve the evacuation performance of the participants in the virtual fire situation and improve their wayfinding ability. However, people did not reduce their psychological stress of emergency testing due to repeated exposure to the scene. Many scholars have also used virtual environments to investigate the behavior patterns of the public in emergencies in different environments and found that using the guidance of auxiliary lights in underground parking lots can help reduce people's cognitive load when evacuating [27]. In the evacuation of subway stations in emergencies, the completeness of spatial knowledge significantly impacts evacuation time, distance, and speed. Therefore, for those without full spatial knowledge, it may be necessary to take some measures to provide these passengers with other directions and guide them to make other choices [28]. These findings help to improve understanding of evacuation behavior and provide the correct information in emergencies to improve public evacuation efficiency.

1.3. Wayfinding information systems

In the wayfinding system design, environmental information can be divided into static and digital [29]. Static environmental information includes but is not limited to, fixed signs and printed maps. Static information systems such as signs and printed maps have proven to be important references that allow way finders to navigate their environment [21,30]. However, if signs and other environmental information are not effectively designed and placed thoughtfully, the user's ability to obtain wayfinding information will suffer [31,32]. Because of this, pathfinders rely on memorizing routes and actively exploring spaces to find their destination. Mobile devices are helping the wayfinding process, but they are not the ultimate solution to all wayfinding problems [33]. It is not feasible to completely transform the wayfinding system from a static information medium to a digital information medium. Both wayfinding information systems have their pros and cons. Static wayfinding information system has low manufacturing cost, and information is always visible. The disadvantage is that it is not easy to maintain [5] and has only a single information level [34]. The mobile wayfinding information system can present different levels of information according to the needs. The disadvantage is that it depends on the Internet or any other location recognition system. Therefore, there is still a need for static wayfinding information.

1.4. Summary

In the past, map design research mainly explored the difference between map makers and users. However, experiments focusing on map viewing and wayfinding movement still need in-depth research, and relevant design specifications are derived based on evidence. Maps are not equally helpful to all travelers since map reading is an acquired skill, and various mobility behaviors vary among users [35,36]. This study used wayfinding behavior experiments to test the advantages and disadvantages of the existing refuge map design and conducted design verification after optimization. The experiment was conducted during the COVID-19 alert period, so the virtual environment displayed on the desktop screen was used to conduct remote experiments with the subjects.

2. Current situation investigation

2.1. Questionnaire survey

Before conducting the wayfinding experiment, this study wanted to understand the degree of understanding of nuclear accident knowledge, emergency response strategies, and attitudes of Emergency Planning Zone (EPZ) residents and general residents to evacuation-related strategies, so a questionnaire survey was adopted. The questionnaire design consisted of two parts, one was the basic information of the respondents, including gender, age, education level, occupation, daily means of transportation, number of cohabitants, living area, etc., and another was an attitude scale (Likert five scale). A total of 68 questions included nine aspects: understanding of nuclear accident knowledge, the importance of information content, evacuation preparation strategy, nuclear accident response strategy, decision-making tendency, subjective effectiveness of nuclear safety training, nuclear safety training willingness, awareness of official information sources, and the degree of agreement with the source of information used to confirm the radiation dose.

The questionnaire survey adopted paper and electronic questionnaires. Paper questionnaires were used to survey residents within the EPZ. The research team used the times of local disaster prevention drills to conduct one-on-one face-to-face surveys on the people who participated in the activities and took intentional sampling. The electronic questionnaire was edited and published the questionnaire questions through the Survey Monkey online questionnaire platform and distribute through the online community. This part was convenience sampling and snowball sampling.

2.2. Analysis results

102 samples were recovered in this survey, 100 valid samples, including 54 females and 46 males. The age group was mostly between 20 and 29, with 51 people.

Nine aspects were designed with five Likert scales. Respondents ticked the boxes from strongly disagree, somewhat disagree, normal, somewhat agree, and strongly agree. The coding scoring method was strongly disagree converted from one point to strongly agree and five points. The frequency distribution of the results of each question.

After conducting item analysis, factor analysis, and reliability analysis on 68 items, the Cronbach Alpha value of five items finally reached 0.835, and greater than 0.7 indicated that the reliability of these five items was high, and they belonged to the aspect of “the importance of information content.” It included “I think it is important to provide accurate and rapid information.” and “I think publicity measures other than disaster prevention and administrative broadcasting are important.” In the “Nuclear Accident Response Strategy” aspect, “I will pay attention to nuclear disasters Evacuation news or broadcast ($M = 3.8$)" and “I will use other evacuation routes for evacuation in the event of a nuclear accident or traffic jam (3.9)" had the highest average agreement. In the evacuation preparation strategy, the question “I will evacuate according to the government’s measures” had the highest degree of agreement ($M = 4.5$); and in the decision-making tendency, “listen to the local government broadcast to determine the evacuation strategy” the average degree of agreement ($M = 4.57$) was also the one with the highest degree of agreement among the 11 questions in this aspect. These results showed that the sample’s willingness to cooperate with the government in the evacuation was high. On the significant questions, each age group agreed on the importance of “providing correct and prompted information,” which was also reflected in the sample’s demand and recognition for “official government information.” Television and radio were characterized by “quickness,” and government officials represented the “correctness” of information sources.

Based on the survey results and knowing that people relied on the information provided by the government and had a high degree of willingness to cooperate with evacuation operations, we reviewed the evacuation guidelines in the current asylum leaflets. In the guidance content, the first action after finishing preparations at home and leaving the house was to go to the “assembly point” [37]. The local government set up the assembly point, fixed at a certain place on the evacuation route, by erecting signage. The location of these assembly points was marked on the distributed evacuation map (Fig. 1). Therefore, this study aimed to confirm whether the marking design of the assembly point on the evacuation map could enable people to find the location effectively. We designed two experiments to observe the wayfinding performance in the task, found out the defects of the existing map design, and verified the

Fig. 1. The upper left picture was the nuclear accident disaster prevention guidelines issued by the government, and the upper right picture was the experimental area we selected; the lower row from left to right were the site photos of assembly points No. 28, 27, and 26.

design after optimization.

3. Method

3.1. Purpose

We used a task-oriented experimental approach to observe wayfinding behavior and performance and conducted two experiments. In Experiment 1, we wanted to know if the disaster evacuation guidance map presented in the "Nuclear Accident Disaster Prevention Guidelines" issued by the New Taipei City Government Fire Department could provide effective use and successful wayfinding for non-resident tourists. Through the experimental observation of the subjects' wayfinding behavior records and interview results, the emergency evacuation information needed by tourists in the evacuation process and the design conditions for future disaster prevention map optimization were summarized. Also, in addition to whether map design affects wayfinding performance, we wanted to know whether the frequency with which people used the map affected wayfinding performance.

3.2. Experimental process

Experiment 1 used existing maps as materials. After the subjects were recruited, they were divided into two groups, and the groups were randomly assigned by the equal method, namely the fixed-point (node) reading group (NR group) and the continuous reading group (CR group), with equal numbers of people in both groups. Group NR only viewed the map at the assembly point. The map is provided by the observers sharing the screen. There was no limit to the viewing time of the subjects, but the window was closed after leaving the assembly point. Group CR used the tablet computer to refer to the map during the wayfinding process continuously.

The experiment was carried out in three stages. In the first stage, the subjects were asked to fill out a questionnaire including a basic data survey and spatial ability scale; in the second stage, they spoke in the virtual interactive environment of Protopie and conducted an online simulated wayfinding experiment. After practicing the route, subjects completed three tasks according to the instructions played by the observers in the evacuation situation simulation broadcast, including Task 1 to find assembly point No. 26, Task 2 to find assembly point No. 27, and Task 3 to find assembly point No.28. Finally, the third stage of a semi-structured interview was conducted. Fig. 2 shows the ideal route.

Experiment 2 summarized the problems of existing maps based on the findings of Experiment 1 and redesigned disaster prevention maps as materials. We used the same three stages as Experiment 1 and maintained the same route and evacuation tasks. In addition, in Experiment 2, we additionally wanted to know whether people's use of 2D maps and 2.5D maps also affected wayfinding performance, so the subjects were divided into four groups: 50 subjects each used 2D and 2.5D in Group NR %; the subjects using 2D and 2.5D in Group CR also accounted for 50% each. The above four groups had the same number of people. Please refer to the step-by-step diagram of the two experiments (Fig. 3). We observed the subjects' task performance wayfinding behavior, recorded the content of the speech, and evaluated the effectiveness of the new map and user evaluation.

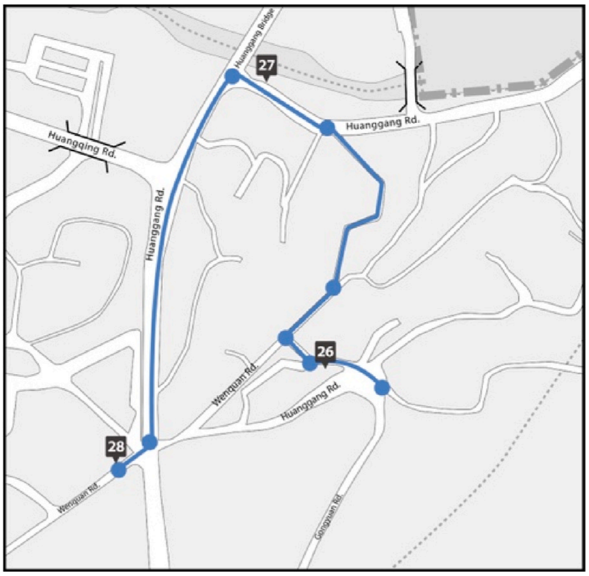

Fig. 2. The ideal route plan is the shortest route.

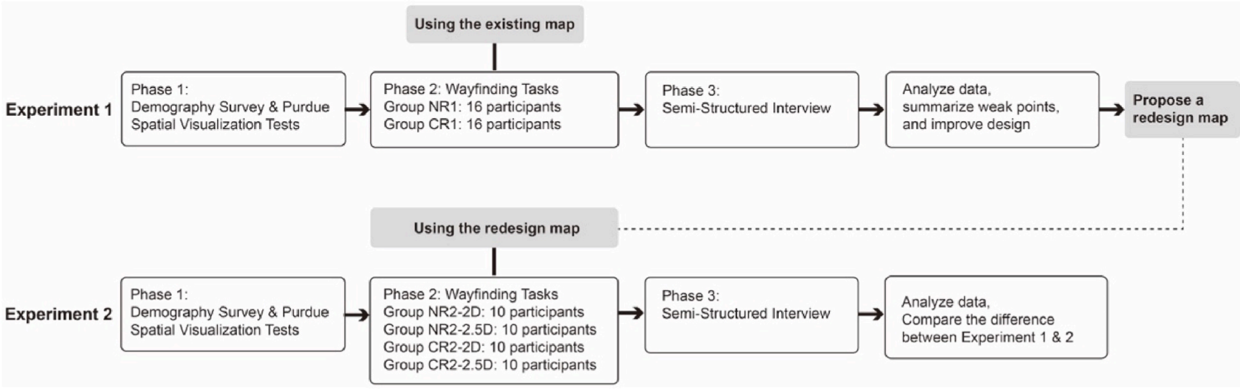

Fig. 3. Step diagram of Experiment 1 and Experiment 2.

3.3. *Task performance statistics and behavioral mapping*

This experiment was conducted online, considering that the subjects would affect the task completion time due to the gap in network speed, so the task performance statistics method did not refer to the task completion time. We observed the behavior and utterances of the subjects during the task, counted the number of times of difficulty in wayfinding, and divided them into three indicators: backtracking, hesitation, and expectation gap. "Backtracking" was counted by the actual backtracking action; "hesitation" was determined by the subject's pause or speech to express doubt; "expectation gap" was determined by the subject's utterances and questioning after finishing the task. The lower the value of the three indicators when completing the task, the smoother the task and the higher the wayfinding efficiency. We calculated these performances and tested the results of the two experiments, as well as individual differences in high and low spatial ability, with independent samples T-tests.

In addition, we used the behavioral mapping method to record and drew the walking route of the subjects on the map. Behavioral mapping is an individual difference in the high and low spatial ability to observe and record behavior at a specific time within a defined context. It is a valuable method for documenting environmental behavior because it does not rely on user self-reports [38,39]. Behavioral mapping can simultaneously capture observed behaviors and information about the environmental location and context in which the behaviors occur [40]. Fig. 4 is the map we draw the movement track on it.

3.4. *Experimental scope*

Nuclear Power Plant No. 1 (Jinshan Nuclear Power Plant) and Nuclear Power Plant No. 2 (Kuosheng Nuclear Power Plant) EPZ are mainly located in Jinshan, Shimen, and Wanli districts. Along the coast are sea-viewing spots such as Jinshan Hot Spring Area,

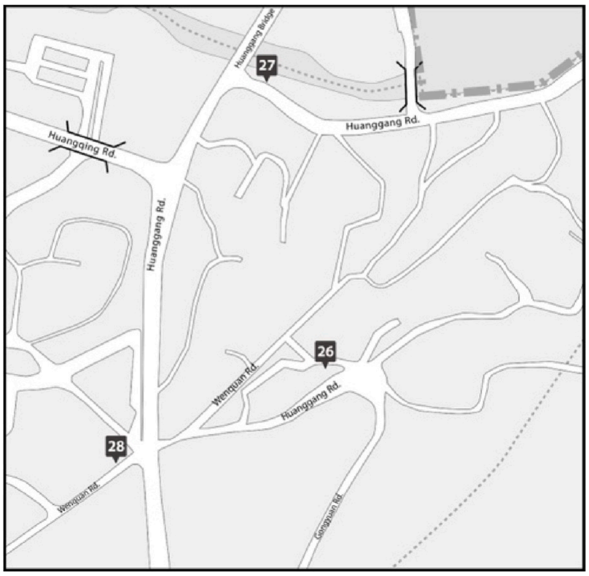

Fig. 4. The map for behavioral mapping.

Baishawan, and Yehliu Scenic Spots, often attracting tourists to go on a tour. Among them were 1951 registered households in Jinshan District, Huanggang village. According to the 2019 tourist statistics on the North Coast of the Tourism Bureau Administrative Information Network of the Ministry of Communications, the average number of daily tourists in the EPZ of Jinshan Nuclear Power Plant and the EPZ of Kuosheng Nuclear Power Plant in this area was about 4202 per day. There were 1181 people for sightseeing and recreation every day [2], which is the largest number of people in the emergency response area of New Taipei City that is within the scope of the EPZ of the two factories at the same time. Therefore, this study chose this area as the experimental range (Fig. 5).

First, we limited the scope of wayfinding to Huanggang village, starting from the Shitoushan Park Trail's (獅頭山公園步道) entrance, including assembly points 26, 27, and 28. Through these nodes, we found that it has at least several routes to reach (Fig. 6). Experiment 1 recruited 32 public who did not live, work, or study in the local area (Jinshan District and Wanli District) as subjects, aged 20 to 50; while Experiment 2 recruited 40 subjects aged 20 to 29.

To familiarize the subjects with the task, before officially starting the task, we let subjects practice with the blue path (Chinshan Visitor Center to Shitoushan Park) (Fig. 6). We performed three tasks after getting familiar with the experiment process, starting from the Shitoushan Park Trail's entrance. First, they had to look for assembly point No. 26, then for assembly point No. 27, and finally, find assembly point No. 28 to complete all tasks. The location of the assembly point was considered complete after finding the signboard position of the target assembly point and facing it.

3.5. *Materials and equipment*

3.5.1. *Make a virtual scene with ProtoPie*

The virtual wayfinding screen in the experiment was made using ProtoPie 5.3.2 version. The researchers took photos on the spot for all the routes to the area and took the shots with the same focal length lens, the same lens size, and the same eye height. We took an average of about five steps at a normal walking pace. After the photos were taken, they were fine-tuned in post-production to make them consistent in line of sight and then imported into ProtoPie. We arranged the photos according to the route from the start point to the endpoint and set up a round black translucent interactive interface in the lower right corner (Fig. 7). This interface allowed the subjects to simulate forward, backward, left, or right by operating the direction keys on the keyboard. When they walked into the wrong route, a prompt indicated that the road was blocked, reminding them to return and choose the route again.

3.5.2. *Evacuation situation simulation script*

To allow the subjects to simulate the nervousness of emergency evacuation, the observers told the subjects at the beginning of the experiment: "Suppose you are a tourist and take the bus to the Chinshan Visitor Center. After getting off the bus, you will take the park road. Walk in the direction of Shitoushan Park. You will see a map when you arrive at the trail's starting point in Lion's Head Mountain Park." When the subject reached the target location, the observer played a pre-recorded broadcast to guide the subject to the target locations to simulate emergency wayfinding in a nuclear disaster. The content of the broadcast was: " (Alarm) Attention everyone, there is a radiation leakage accident at a nuclear power plant. Please go to assembly point No. 26 immediately!" It was played again after finding assembly point No. 26 and a broadcast recording: "There are too many people at the rally point 26. Please change to rally point 27 immediately. Please change to assembly point 27 immediately." Similarly, the broadcast was played again when they reached assembly point 27, requiring the subjects to go to assembly point No. 28.

3.5.3. *Equipment and experimental operation*

Due to the impact of the Covid-19 epidemic, both experiments were conducted online, using the Cisco Webex Meetings conference software, and the subjects entered the conference through the URL and watched the screen images shared by the researcher. Subjects

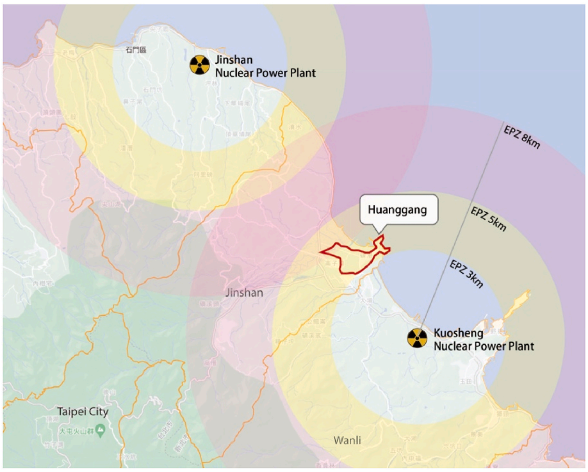

Fig. 5. Huanggang Village (the area inside framed in red color) was selected as the experimental scope.

Fig. 6. Experimental path map (the blue path is the practice path, and the red path is the experimental path range).

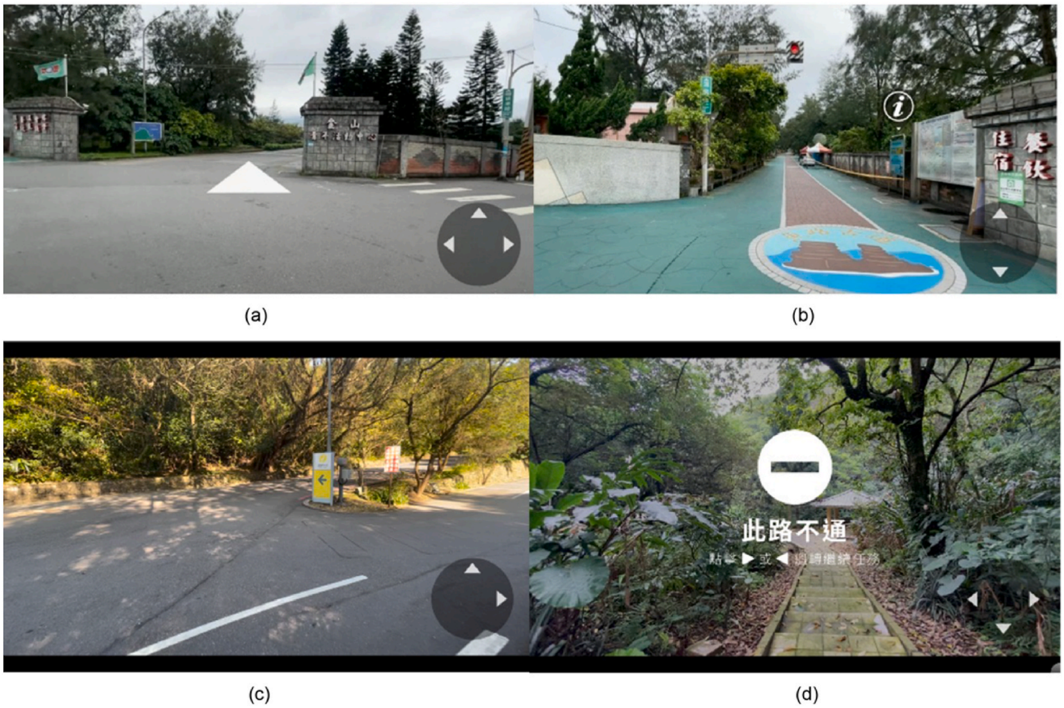

Fig. 7. Screenshot of the experiment. The triangle on the road surface represented continuing forward, and the direction disc at the bottom right of the screen represented the route that could be advanced. For example, (a) showed three paths to choose from in front of the subject; (b) move forward or backward, (c) showed only two paths to choose from, and (d) prohibited the subject from going forward but could go backward, left, or right.

saw the virtual scene on the screen (Fig. 7). During the task, the subject needed to inform the researcher to decide on the walking direction, and the researcher acted on behalf of the subject to operate the arrow keys. During the whole task process, the subjects were asked to think aloud, and the observer recorded the experimental process using screen recording and, at the same time, recorded the subjects' utterances.

4. The result of experiment 1

4.1. Task 1 (find assembly point 26) performance

The experiment found that the subjects made 21 times backtracking, 19 times hesitation, and 26 times expectation gaps. The behavioral mapping (Fig. 8) showed that most subjects were on Huanggang Road near the assembly point of No. 26 (Huanggang Rd.) (磺港路). A few subjects deviated from this area around the circle to search back and forth. When observing the location where the incident occurred, it could be found that many subjects hesitated when facing the first four-way intersection and could not determine which route led to assembly point No. 26. They turned back and forth between these choices. 28% (9 subjects) did not find it when they passed the No. 26 signage. After they missed it, they turned back to look for it, and in the process, they had much hesitation and a sense of expectation gap. In addition, since Chengtian Shrine (承天宮) was provided as a landmark in the experimental map, 50% (16 subjects) mentioned that Chengtian Shrine (承天宮) was used as a landmark in the experiment or interviews to help find the target location.

In the comparison between the two groups, the performance of Group NR was 14 times backtracking, ten times hesitation, and 13 times expectation gap. The performance of Group CR was seven times turning back, nine times hesitation, and 13 times expectation gap. The number of Group NR was higher than that of Group CR in backtracking and hesitation.

Through the spatial ability scale filled out by the subjects before the test, we used the mean plus or minus one standard deviation to distinguish the subjects into those with high and low spatial abilities. The experimental results showed that in Task 1, the number of trackback and expectation gaps in the high-spatial-ability group is less than in the low-spatial-ability group. Still, the number of hesitations was more than that of the low-spatial-ability group.

4.2. Task 2 (find assembly point 27) performance

In Task 2, the subjects made 41 times backtracking, 66 times hesitations, and 45 expectation gaps. The data showed that finding assembly point No. 27 was the subjects' most difficult task. Through the movement path of the subjects (Fig. 9), it could be found that the footprints of the subjects were almost all over the entire experimental path after starting from the assembly point No. 26. The subjects needed to wander at each intersection before they could choose the correct route to the assembly point No. 27.47% (15 subjects) preferred to choose the original road and return to the starting four-way intersection after starting from No. 26 to make a new choice. 75% (24 subjects) chose to take Huanggang Rd. (磺港路) to reach assembly point 27. However, no subjects were found to rely on Huanggang Rd. Bridgehead (磺港路橋頭) as a landmark to help them find their way. We found that 38% (12 subjects) noticed Huanggang Rd. (磺港路) street sign in the scene during the wayfinding process and used it to help find the way, and 19% (6) of the subjects noticed Huangqing Rd. (磺清路) street sign. 44% (14 subjects) saw the icon of the assembly point No. 27 wrongly marked on the map and thought that No. 27 signage would appear on the left-hand side of Huanggang Rd., thus causing hesitation and expectation gap.

The performance of Group NR is 28 times backtracking, 36 times hesitation, and 25 times expectation gap, which is higher than that of Group CR's 13 times backtracking, 30 times hesitation, and 20 times expectation gap. The number of backtrackings was significant in the independent samples *t*-test ($P = .041 < 0.05$), suggesting that subjects in Group NR were more likely to experience difficulties in

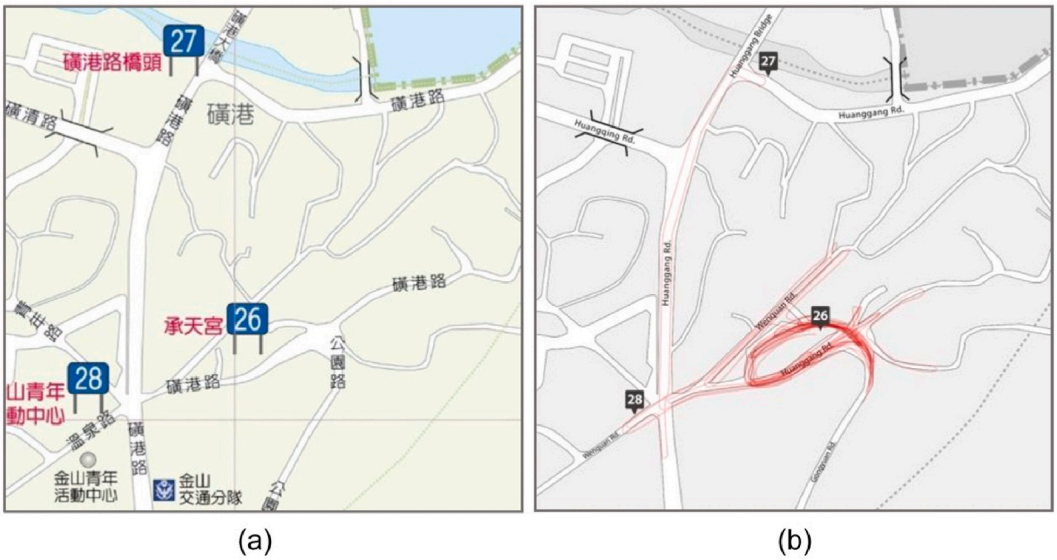

Fig. 8. (a) is the map used in Experiment 1 (existing map); (b) is the behavior mapping of Task 1.

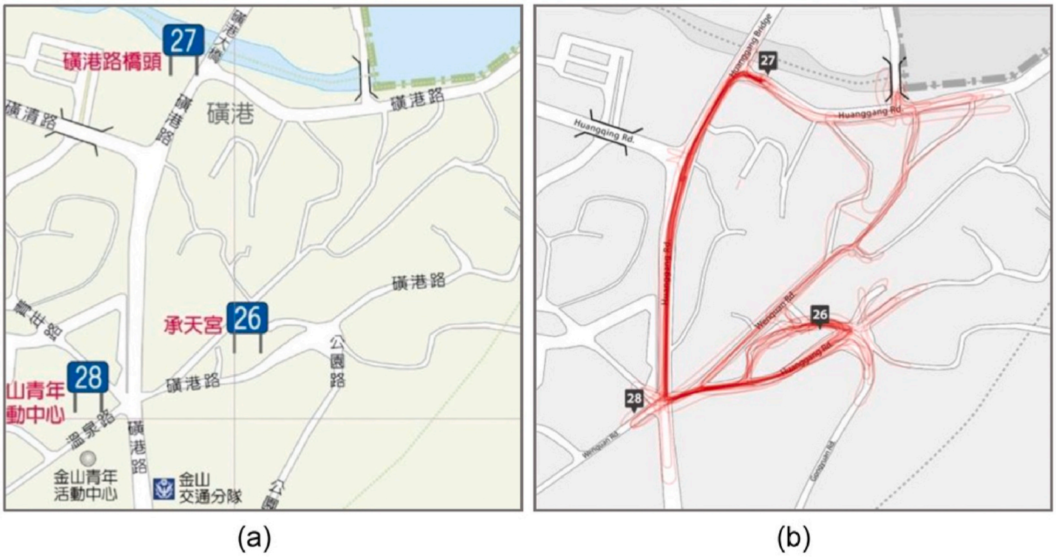

Fig. 9. (a) is the map used in Experiment 1 (the existing map); (b) is the behavior mapping of Task 2.

this task. Regarding behavioral mapping, nine subjects in Group NR chose to return to the original four-way intersection to make a new choice, and 14 subjects chose to take Huanggang Rd. to the 27th assembly point. The subjects of Group NR might be more inclined to make safe and conservative wayfinding choices.

In the comparison between the high and low spatial abilities, it was found that in Task 2, the high-spatial-ability people had more hesitation than the low-spatial-ability people, and the number of backtrackings and expectation gaps was less than the low-spatial-ability people. The number of expectation gaps was significant in the test ($P = .049 < 0.05$).

4.3. Task 3 (find assembly point 28) performance

In Task 3, the subjects had 23 times backtracking, 27 times hesitation, and nine expectation gaps. The task aimed to walk from assembly point No. 27 to assembly point No. 28. Most subjects turned back from Huanggang Rd. (磺港路) to find assembly point No. 28, only a few subjects will make choices that deviate significantly from this area. The places where the difficulty in finding the way was mainly concentrated at the large four-way intersection on Huanggang Rd., and the subjects were likelier to make wrong choices at this intersection. 22% (7 subjects) went into the intersection marked by Chinshan Youth Activity Center (金山青年活動中心) by

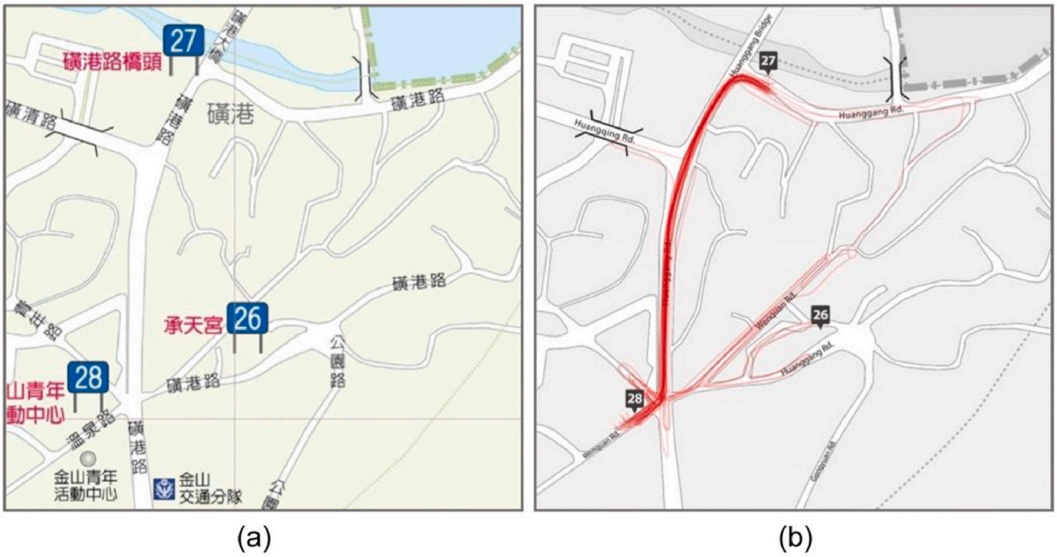

Fig. 10. (a) is the map used in Experiment 1 (the existing map); (b) is the behavior mapping of Task 3.

mistake, resulting in more hesitation and an expectation gap. 22% (7 subjects) found assembly point No. 28 during Task 2, so they could return to find assembly point No. 28 without hindrance. 31% (10 subjects) mentioned that Chinshan Youth Activity Center (金山青年活動中心) was used as a landmark to help find the target location. 66% (21 subjects) mentioned the Wenquan Road (溫泉路) street sign and used them to help find their way (please refer to Fig. 10).

The task performance of Group NR was 16 times backtracking, 14 times hesitation, and six times expectation gap, which was also higher than those of Group CR's seven times backtracking, 13 times hesitation, and three times expectation gap. Four of them walked into the intersection marked with Chinshan Youth Activity Center (金山青年活動中心) by mistake, and 3 of them found the assembly point No. 28 in Task 2. Compared with Group CR, the difference is not obvious.

We found that the number of expectation gaps in Task 3 of high-spatial-ability people was lower than that of low-spatial-ability ones. Still, the number of backtracking and hesitation were higher than those of low-ability people. The number of hesitations was found to be significant in the test ($P = .028 < 0.05$). Although low-spatial-ability individuals were more likely to take the wrong intersection marked Chinshan Youth Activity Center ($P = .018 < 0.05$), they were able to find the correct intersection leading to Assembly Point 28 after turning back. Those with high spatial ability wandered more at other intersections.

4.4. Discussion: flaws of existing maps

4.4.1. Flaw 1: assembly point icons are too large and not positioned correctly

Due to the location of the assembly point marked on the experimental map, it was presented by a larger-scale icon. The subjects needed to wander back and forth to find the exact target location at the nearby intersections, thus increasing the number of times of difficulty in finding the way. For example, in Task 1, the subjects could not determine precisely which route the assembly point was on but had to go around to find it and even passed the 26th assembly point without noticing it.

In Task 2, the subjects thought that the location of the No. 27 sign on the map was the location of the assembly point and thought that the No. 27 assembly point should appear on the left side of Huanggang Rd., resulting in more hesitation and expectation gap.

In Task 3, the subjects could not correctly judge which route the assembly point No. 28 would appear through the map, so they made wrong decisions. Therefore, the exact location of the assembly point should be marked on the map, and the scale of the illustration should be reduced to reduce the burden of the user's wayfinding. Please refer to Fig. 11.

4.4.2. Flaw 2: failing to label reference landmarks and road names properly

Each assembly point in the experimental map provided nearby landmark information, such as Chengtian Shrine (承天宮), Huanggang Rd. Bridge (磺港路橋頭) and Chinshan Youth Activity Center (金山青年活動中心). In the experiment, it could also be found that the subjects used Chengtian Shrine and Chinshan Youth Activity Center as the basis for judging the route, so providing landmarks on the map can improve the wayfinding efficiency. However, because the map did not indicate the exact location of the landmark but directly marked the relevant landmark next to the assembly point sign, some subjects thought that the landmark was the location of the assembly card, resulting in backtrackings, hesitation, or expectation gaps. Therefore, we needed to mark the exact relative position of the landmark and the assembly point separately. In the experiment, it could also be found that the subjects matched the street names provided on the map and the street signs that appeared in the scene as the basis for judging the route. Therefore, exact street names must be provided in the map design.

Fig. 11. Three main flaws of the existing map.

4.4.3. Flaw 3: the icon blocks the intersection

In the interviews, the subjects said that the markings on the map that had nothing to do with the task increased the burden of wayfinding, significantly when the icons blocked the key intersections, making it impossible to know the actual route conditions. Especially on the No. 26 sign, the subjects felt lost because they were unsure about the route before Chengtian Shrine (承天宮) or simply turned back to the starting intersection to reselect, confirmed Lynch [41] mentioned that if the wayfinder makes a mistake, he will reposition his location, re-correct the proposed plan, and execute it repeatedly until he reaches the destination. Therefore, in addition to increasing the readability of the information on the map and marking each location, it is still necessary to avoid markings blocking key intersections to improve the wayfinding efficiency of the subjects.

4.4.4. Flaws in the existing map caused the subjects to be unable to remember the route

In the experiment, we divided the subjects into two groups according to how many times they could view the map. Group NR produced more wayfinding difficulties in all task performances than Group CR. When Group NR subjects found that the reality did not match their expectation, they could only find the target location by constantly going back and forth to various intersections. Therefore, if the public could only rely on the map information provided by the assembly point to move, how to ensure the correctness of the information on the map is very important.

5. Experiment 2

5.1. Materials

Firstly, the base map is modified based on the disaster prevention guidance map in the “Nuclear Disaster Prevention Guidelines” issued by the Fire Department of the New Taipei City Government, and the area of the provided map was reduced to the blocks required for the task. The route was also re-updated to a more accurate one according to the situation. We adopt the appearance of the assembly point signage to design the icon (Fig. 12).

The map no longer only provides a rough area but accurately marks the actual location of the assembly point stands to reduce user confusion. We have retained two important building landmarks, Chengtian Shrine (承天宮) and Chinshan Youth Activity Center (金山青年活動中心), and marked them separately from the assembly point. All markings on the map used grayscale colors, and priority was given to not blocking key intersections, and road names were also arranged in a more clearly readable form. On the 2D map based on this, a 2.5D version was added. That is, the map was tilted out of a perspective angle, and the positions of the assembly points and landmarks were marked three-dimensionally above. Among the various inclination angles, 60° with the most significant inclination angle but still clearly visible route name was selected as the experimental sample map of the 2.5D version [42] (Fig. 13).

5.2. The results of experiment 2

5.2.1. Task 1 performance (Looking for Assembly point No. 26)

In Experiment 2, the subjects experienced 25 times backtracking, 18 times hesitations, and 13 expectation gaps in Task 1. Regarding the average number of occurrences, the performance of the two maps in Experiment 2 was better than that of Experiment 1 (Fig. 14). In the independent sample *t*-test, the number of imagined gaps was significant ($P = .003 < 0.05$). It showed that improving the map in Experiment 2 helped reduce the gap between the subjects' understanding of the map and the reality in Task 1.

The behavioral mapping chart showed that the subjects in Experiment 2 no longer deviated seriously from the situation of assembly point No. 26. However, it was still challenging for the subjects to choose the right intersection at the four-way intersection (Table 1). They needed to turn back and forth between these choices to find the route to assembly point 26. In the first experiment, 28% of the subjects had the problem of missing the number 26 plate but not seeing it. This improved to 13% in Experiment 2 and was significant in the independent samples *t*-test ($P = .049 < 0.05$). In Experiment 2, 50% (20 subjects) mentioned that they would use Chengtian Shrine (承天宮) as a landmark to help find the target location, which was the same proportion as in Experiment 1. It could be seen that the

Fig. 12. Assembly point icon design (a) and real assembly point signage (b).

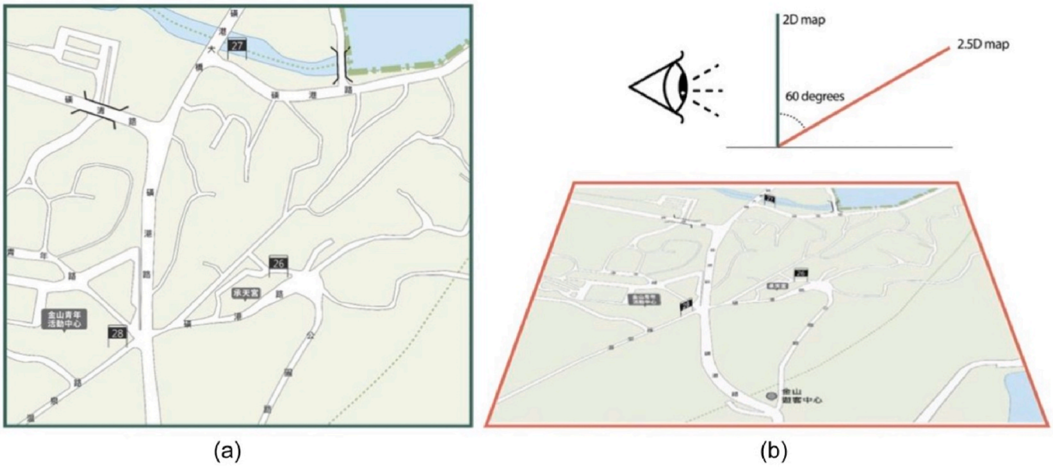

Fig. 13. Materials used in Experiment 2; (a) is redesigned map 2D and (b) is 2.5D.

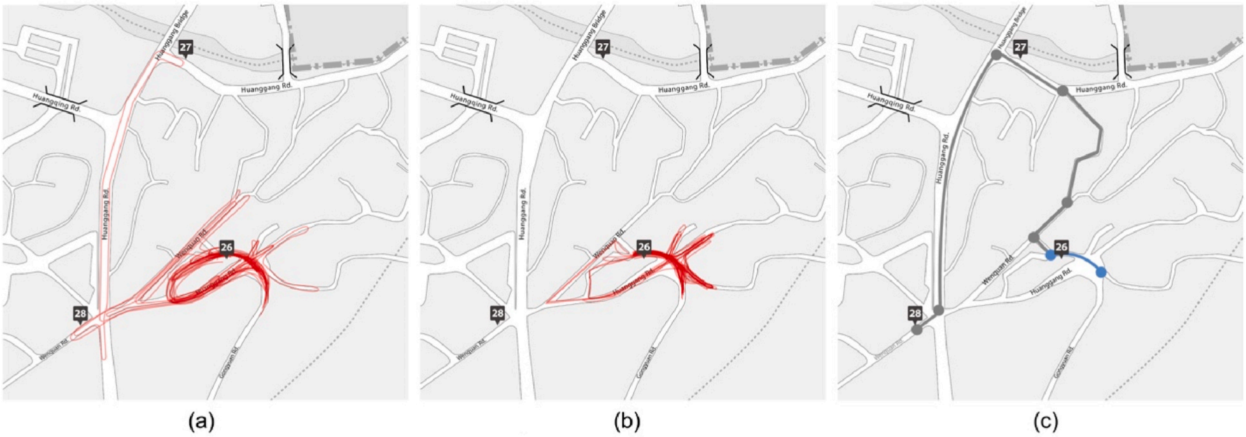

Fig. 14. Comparing the route plans of Task 1. (a) Task1 in Experiment 1: Participants' individual route plans; (b) Task 1 in Experiment 2: Participants' individual route plans; (c) ideal route plan.

Table 1
Experiment 1 and experiment 2 behavior comparison.

Behavior comparison	Expt. 1	Expt. 2	P value
missed No.26 signage	28.13%*	12.50%*	.049
referred Chengtian Shrine (承天宮) as landmark	50.00%	50.00%	.500

Note: *p < .05.

change of the landmarks in Experiment 2 did not affect the user's willingness to refer to the Chengtian Shrine (承天宮) to help find the assembly point.

Group NR subjects had a higher frequency of various wayfinding difficulties than Group CR ones. The number of backtrackings was significant in the independent sample *t*-test ($P = .033 < 0.05$). Group CR subjects were more able to choose the correct route to the assembly point No. 26 at the four-way intersection, and a higher percentage of them mentioned the Chengtian Shrine (承天宮) as a landmark to help find their way.

In addition, the 2D group subjects outperformed the 2.5D group in all task performances, although no significant difference was found in the statistical analysis. Although fewer wayfinding difficulties occurred in Task 1 in the 2D group, the difference was not noticeable, and no significant difference was found in the route and behavior.

Those with low-spatial-ability had slightly more difficulty finding their way in Task 1 than those with high-spatial-ability, but no significant difference was found in the test. Regarding the behavior, it was found that subjects with low spatial ability were more likely to miss No.26 signage ($P = .039 < 0.05$). Please refer to Table 2.

5.2.2. Task 2 performance (Look for Assembly point 27)

Task 2 of Experiment 2 was still the most difficult task among the three tasks, but the number of times the subjects had trouble finding their way was significantly less than that of Experiment 1 (Fig. 15). A total of 23 times turning back, 54 times hesitation, and 14 times expectation gaps occurred. In experiment 1, each subject experienced an average of 1.28 reentry times, which decreased to 0.58 times in experiment 2 ($P = .009 < 0.05$), and the average number of hesitations also decreased from 2.06 times to 1.35 times ($P = .022 <. 05$), the average number of imaginary falls decreased from 1.41 to 0.35 ($P = .000$). It shows that modifying the map in Experiment 2 helps improve the wayfinding efficiency of the subjects in Task 2. After comparing the paths, it was also found that although the subjects would still wander at intersections with multiple route options during the task, they no longer deviated seriously from the No. 28 plate. In addition, in Experiment 1, 47% of the subjects chose to return to the original four-fork intersection to make a new choice after starting from No. 26, and this ratio dropped to 35% in Experiment 2. In the first experiment, it was found that the number of subjects who mistook the No. 27 plate on the left-hand side of Huanggang Rd. also decreased significantly, from 43.75% to 22.50% ($P = .028 < 0.05$). In Experiment 1 and Experiment 2, 75% of the subjects chose to take Huanggang Rd. to the assembly point No. 27. The design of the map in Experiment 2 did not affect the preference of the subjects in choosing the route. Please refer to Table 3.

In addition to the same number of expectation gaps as Group CR, Group NR had fewer backtracking and hesitation times than Group CR, although it was insignificant. Regarding the behavior and route choice, it was found that Group NR subjects chose to take Huanggang Rd. and avoid the alleys with many turns, so they had fewer backtrackings and hesitation.

The times of backtrackings and hesitation in the 2D group were lower than those in the 2.5D group but insignificant. The behavioral mapping showed that the subjects who used the 2.5D map were likelier to wander around the four-way intersection of Huanggang Rd. The subjects in the 2D group were more able to find the correct route to assembly point 27. In Task 2, the number of backtrackings, hesitation, and expectation gaps in the low-spatial-ability group was more than in the high-spatial-ability group. Still, there was no significant difference in the test. Please refer to Table 4.

5.2.3. Task 3 performance (Look for Assembly point No. 28)

Task 3 of Experiment 2 became the task with the least wayfinding difficulties among all the tasks, with six times backtrackings, 17 times hesitation, and five times expectation gaps. Regarding the average number of occurrences, the performance of the two maps in Experiment 2 was better than in Experiment 1 (Fig. 16). Significance was found for both the number of backtracking ($P = .003 < 0.01$) and the number of hesitations ($P = .049 < 0.05$) in an independent-sample *t*-test. Although some subjects still made wrong route choices at four-way intersections, this situation was much reduced compared to Experiment 1, and there was no longer a serious deviation from No. 28. In the first experiment, 22% of the subjects accidently went to the intersection marked with Chinshan Youth Activity Center. In Experiment 2, this proportion also dropped to 10%. However, since assembly point 28 is located next to Huanggang Rd., 33% of the subjects accidently explored its location during Task 2, which may be why the subjects of Task 3 could easily find the No. 28 signage. 58% of the subjects mentioned in the experiment or interview that Chinshan Youth Activity Center was used as a landmark to help find the target location, a significant increase compared to 31% in Experiment 1 ($P = .013 < 0.05$). Please refer to Table 5.

In group comparison, the number of hesitations in Task 3 Group NR was lower than that of Group CR, but the number of backtracking and expectation gaps was higher than that of Group CR. However, the difference in performance between the two groups was not significant. The performance of the 2.5D group in Task 3 is slightly better than that of the 2D group, but the difference is insignificant. In Task 3, those with low spatial ability experienced more hesitations and expectation gaps than those with high spatial ability, but the number of backtrackings was less than those with low spatial ability. No significant difference was found in the results of observation of routes and behaviors. Please refer to Table 6.

6. Discussion

We found that whether the map of Experiment 2 was the 2D version or the 2.5D version, the performance of the three tasks is better than the existing map of Experiment 1, and it is significant in multiple data. This showed that the redesigned map in Experiment 2 did help reduce the chances of backtracking, hesitation, and expectation gap during the wayfinding process of the subjects to the assembly point and improve the wayfinding efficiency. When we marked the location of the assembly point in the redesigned map, we marked the assembly point signs separately from the important landmarks and placed them at precise positions, replacing the shortcomings of the original landmarks and assembly points that were marked together and the location was too rough. The research results showed that this method helped to reduce the subjects' misjudgment and did not affect the subjects' willingness to use landmarks to help determine the route. This result also verified that landmarks were easier to perceive than other spatial objects and had obvious advantages [9,43–45], and it is recommended that evacuation assembly points should be located close to the landmark, the landmark acts as a spatial reference point. This helps people locate, orient, and navigate faster in complex space environments during emergency evacuation [46–50].

However, the icons on the map need to avoid blocking key intersections. We found that the subjects decided to turn back because the icon blocked the intersection and were unsure about the road conditions. This situation has been improved in the redesigned map. Therefore, it can be known that the clarity of map information can enhance the user's confidence when exploring unfamiliar routes. In addition, the existing map and the redesigned map on the assembly point icon used a design that matched the assembly point signage, allowing users to quickly determine the target they were looking for, consistent with previous research results [51]. However, it may be

Table 2
The performance of each group of Task 1: the average number of times of the three indicators (times/number of subjects).

Indicators	Expt. 1	Expt. 2	P value	Group NR	Group CR	P value	2D Map	2.5D Map	P value
backtracking	0.66	0.63	.447	0.9*	0.35*	.033	0.55	0.7	.312
hesitation	0.59	0.45	.237	0.6	0.3	.07	0.4	0.5	.313
expectation gap	0.81**	0.33**	.003	0.4	0.25	.187	0.2	0.45	.067

Note: *p < .05; **p < .01.

Fig. 15. Comparing the route plans of Task 2. (a) Task 2 in Experiment 1: Participants' individual route plans; (b) Task 2 in Experiment 2: Participants' individual route plans; (c) ideal route plan.

Table 3
Behavior comparison between Experiment 1 and Experiment 2 (number of people who took part in the behavior/total number of people).

Behaviors	Expt. 1	Expt. 2	P value
return to the 4-way intersection	46.88%	35.00%	.157
chose Huanggang Rd.	75.00%	75.00%	.500
thought the No.27 signage was on the left	43.75%*	22.50%*	.028
referred to Huanggang Rd. street sign	37.50%*	57.50%*	.047
referred to Huangqing Rd. street sign	18.75%*	5.00%*	.033

Note: *p < .05

Table 4
Task 2 Performance of each group.

	Expt. 1	**Expt. 2**	**P value**	**Group NR**	**Group CR**	**P value**	**2D Map**	**2.5D Map**	**P value**
Avg. backtracking	0.66	0.63	.447	0.9*	0.35*	.033	0.55	0.7	.312
Avg. hesitation	0.59	0.45	.237	0.6	0.3	.07	0.4	0.5	.313
Avg. expectation gap	0.81**	0.33**	.003	0.4	0.25	.187	0.2	0.45	.067

Note: *p < .05; **p < .01.

confusing if such an icon appears at the angle between two routes. Solving this uncertainty needs further empirical research or conveying this uncertainty through design on the map [52] is also a way.

Although the redesigned map in Experiment 2 improved the overall wayfinding performance, the subjects still experienced backtracking, hesitation, and expectation gap. Most of these behaviors occur at multi-way intersections, so in the future design of evacuation maps, it is possible to emphasize the "suggested routes" at intersections to improve wayfinding efficiency. In addition, we found from the two experiments that regardless of the map design, the subjects would prefer to choose a straight and wide road when facing an unfamiliar environment when finding their way for emergency evacuation. This echoes the research of some scholars, and that is the area where people prefer "straight line" and "openness" in terms of selected characteristics [53,54]. The subjects did not choose the shortest path on the map, consistent with the view that how pedestrians perceive, integrate, respond, and make decisions are not fixed but change with the environment [55]. Therefore, in the map's design, it should be ensured that the information on the road is correct and precise, and the relevant street signs should be assisted to improve the wayfinding efficiency.

Overall, in addition to verifying the efficacy of the redesigned map, the research also understood several factors that affect

(a) (b) (c)

Fig. 16. Comparing the route plans of Task 3. (a) Task3 in Experiment 1: Participants' individual route plans; (b) Task 3 in Experiment 2: Participants' individual route plans; (c) ideal route plan.

Table 5
Behavior comparison table of Task 3 in Experiment 1 and Experiment 2.

Behaviors	Expt. 1	Expt. 2	P value
accidently found No. 28 in Task 2	21.88%	32.50%	.162
went into the Chinshan Youth Activity Center	21.88%	10.00%	.084
refer to Chinshan Youth Activity Center as a landmark	31.25%*	57.50%*	.013
refer to the Wenquan Road street sign	65.63%***	20.00%***	.000

Note: *$p < .05$; ***$p < .001$.

Table 6
Experimental performance of each group in Task 3.

	Expt. 1	Expt. 2	P value	Group NR	Group CR	P value	2D Map	2.5D Map	P value
Avg. backtracking	0.72**	0.15**	.003	0.2	0.1	.194	0.2	0.1	.194
Avg. hesitation	0.84*	0.43*	.049	0.4	0.45	.389	0.45	0.4	.389
Avg. expectation gaps	0.28	0.13	.104	0.2	0.05	.08	0.15	0.1	.321

Note: *$p < .05$; **$p < .01$.

wayfinding as follows:

6.1. The effect of time spent reading a map on wayfinding behavior

In the three tasks of Experiment 1, the subjects were also divided into Group NR (only reading the map at the node) and Group CR (continuously reading the map) according to the duration of reading the map. In Experiment 1, Group CR's task performance was better than Group NR, but the gap between the two groups was reduced in Experiment 2. In some task performance, the task performance of Group NR is even better than that of Group CR. When the map becomes concise and easy to understand, even if the user can only look at the map at the assembly point, he/she can still reach the destination smoothly by remembering the information provided on the map through careful route planning. This also reflects the importance of map information on assembly point signage.

6.2. The effect of map perspective on wayfinding behavior

In the study, we used a 2.5D map to verify a more accurate illustration of the position of assembly points. Although the task performance of Experiment 2 showed that the difference between the 2D group and the 2.5D group was not significant, the performance of the 2D group was slightly better than that of the 2.5D group, which was different from the general wayfinding behavior [42]. Therefore, precisely marking the 2D map of the assembly point's location and the landmark's location is still recommended on the evacuation map. Compared with the map perspective affecting the performance of evacuation wayfinding, more critical is whether the map can be viewed at any time during an emergency evacuation, how much wayfinding information can be obtained in the field, and the accuracy of the information presented on the map.

6.3. Effects of high and low spatial ability on wayfinding behavior

Overall, the subjects with high spatial ability performed slightly better than those with low spatial ability in task performance, but the difference was insignificant. Compared with Experiment 1, the gap between the behaviors of people with different spatial abilities became smaller in Experiment 2. Therefore, in this study, the information presented on the map still mainly affects the efficiency of emergency evacuation wayfinding.

7. Conclusion

When marking the location of various facilities on the evacuation map, it is necessary to confirm the accuracy of the location of each icon or name on the map, and it is recommended that the assembly point can be set near prominent landmarks. In the map's design, priority should be given to ensuring that the information on the road route is correct and assisting relevant road signs to improve wayfinding efficiency. Evacuation maps should be designed to reduce unnecessary details to improve map clarity. The location of this study is in a high-risk area, and the evacuation route should be marked on the map. Corresponding signs should be set in the scene to strengthen guidance to solve the decision-making difficulties caused by multi-way intersections. Optimizing the accuracy and clarity of the evacuation map's information design will help people recognize and remember the map. It can bridge the gap between different spatial abilities in wayfinding behavior.

7.1. Research limitations

The execution of the study coincided with the outbreak of the Covid-19 epidemic, and we were unable to conduct the wayfinding experiment on-site and instead took it online. If the wayfinding can be carried out on the ground, perhaps the data on the evacuation time can be better grasped.

Ethics declarations

This study was reviewed and approved by Research Ethics Committee, National Taiwan University, with approval number: 202006ES026. All participants/patients provided informed consent to participate in the study.

Author contribution statement

Meng-Cong Zheng: Conceived and designed the experiments; Performed the experiments.
Ching-I Chen: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Chih-Yung Chen: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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