حوليات الآداب والعلوم الاجتماعية

ANNALS OF THE ARTS AND SOCIAL SCIENCES

- مجلة فصلية محكمة.
- تصدر عن مجلس النشر العلمي بجامعة الكويت.
- صدر العدد الأول سنة ١٩٨٠م.
- تنشر الموضوعات التي تدخل في مجالات اهتمام الأقسام العلمية لكليتي الآداب والعلوم الاجتماعية.
- تنشر الابحاث والدراسات باللغتين العربية والإنجليزية شريطة أن لا يقل حجم البحث عن ٥٠ صفحة وأن لا يزيد عن ٢٠٠ صفحة مطبوعة من ثلاث نسخ.
- لا يقتصر النشر في الحوليات على أعضاء هيئة التدريس لكليتي الآداب والعلوم الاجتماعية فحسب ، بل يشمل ما يعادل هذه التخصصات في الجامعات والمعاهد الاخرى داخل الكويت وخارجها.
- تمنح المجلة الباحث خمسين نسخة من بحثه المنشور كإهداء.

رئيس هيئة التحرير
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تأثير الإرشادات المرئية في إيجاد مخارج الطوارئ لحالات الحرائق والإنقاذ من الحوادث

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خلاصة

معظم الأبحاث القائمة تتناول مشكلة العثور على طرق الخروج في حالة الطوارئ من وجهة نظر سكان المبنى ونادرا ما يتم دراسة الأمر من وجهة نظر رجال الإنقاذ والمطافئ.

لو كان بالإمكان تقليص الفترة الزمنية لإيجاد طرق الإنقاذ بالنسبة للمنقذين لأمكن تقليل الخسائر المادية والأرواح بصورة كبيرة. لذا ولتحليل احتمالات تفعيل عملية إيجاد طرق النجاة في حالة حريق حقيقية، تم عمل تجارب على حالة كاملة في مكان حقيقي لمعرفة العوامل المتعلقة بحالات الطوارئ مثل سرعة إيجاد طرق الإنقاذ وانماط التصرفات وفعالية الأضواء الإرشادية.

كانت النتائج كالتالي:

1 – نماذج الإنقاذ الحالية تبين أن الجنس (ذكر/أنثى) أولوية البحث تمارين البحث والإنقاذ هي أكثر العوامل تأثيرا على سرعة إيجاد طرق الإنقاذ.

2 – إضافة الأضواء الإرشادية يمكن أن يقلص الوقت المطلوب لإيجاد طرق الإنقاذ بدرجة كبيرة بغض النظر عن خلفية رجال الإنقاذ.

3 – أولوية إيجاد طرق الإنقاذ هو السبب الرئيسي في طول مدة الإنقاذ لذلك فإن برامج التدريب يجب أن تركز على سرعة قراءة الإرشادات بكل أنواعها لزيادة القدرة على عمل خطط للإنقاذ.

A study of assistance of lighting indicators to assist way-finding for firefighting and rescue services

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ABSTRACT

Most existing research discusses way-finding from the view of building occupants, and seldom is the issue explored through the viewpoint of firefighting and rescue. If the time firefighters spend for way-finding can be decreased during a fire, it would reduce loss of life and properties effectively. Thus, in order to analyze possibilities for enhancing way-finding efficacy in an actual fire, this study employed a full scale real space for fire rescue experiments to investigate relevant issues such as firefighting and rescue crews' way-finding, behavioral characteristics and addition of supplementary indicator lighting. The results are as follows: 1. Existing rescue models indicate that gender, search sequence and search and rescue training affect way-finding the most. 2. Addition of fire location indicator lighting can reduce way-finding time greatly and there is no significant difference between firefighters with varying backgrounds. 3. Way-finding sequence is the main reason for the length of rescue time, thus existing training programs should strengthen graphic reading training to increase the ability to establish search and rescue plans.

Keywords: Firefighting and rescue; supplementary indicator lighting; way-finding

INTRODUCTION

Since scales of buildings are growing increasingly and internal routes are becoming more complex, a fire often gives rise to difficulties in way-finding for firefighters. Previous researchers mostly discuss the sheltering safety of indoors persons and seldom explored from the viewpoint of firefighting and rescue. Therefore, how to increase the efficacy in firefighting and rescue and decrease the time spent in way-finding by firefighters at a fire to complete rescue and reduce number of casualties within the shortest time should be an issue worth discussing. Reduction of life and properties losses has always been a critical point in the design of disaster prevention and refuge in the occurrence of a fire, but how to ensure safety during the firefighting and rescue process must also not be neglected. Furthermore, how firefighting crew members arrive at the scene of a fire within the shortest time will have a significant influence on controlling the fire and rescuing the people trapped. In order to analyze the possibilities of increasing way-finding efficacy in an actual fire, this study employed a full scale real space for fire rescue experiments. The results will not only be more similar to realistic needs, but also establish an effective mechanism that would shorten rescue time while taking into account the safety of crew members.

Existing research has conducted refuge guidance discussions based on the general public, and carried out studies by transforming interpretations of signs into behavior (way-finding). The same goes for the concept of this study. However, the primary difference is the crew members with multiple fire experiences, and whether their mental model from sign cognition to behavioral change is unique or the same as the general public. Thus, the relevant research on this issue can be classified into three dimensions: 1. Interpretation of sign cognition or meaning; 2. Characteristics of way-finding; 3. Construction of supplementary signs. These dimensions are explained later. In other research related to sign cognition, Piamonte (2001) discovered that the test results of sign cognition levels were helpful to the design and improvement of signs. Murray (1998) found that different circular banning signs would generate varying preference levels, so the representation of a sign would affect the result of cognition. Wogalter (2002) and Shieh (2003) studied warning signs to enhance the understanding of users toward warning signs through design and arrangement of graphics. Petiot (2004) also used the semantic differential method to analyze the relationship between communication and understanding of sign meanings. In research on graphic interface design of ergonomics and technology design, Maguire (1985) discovered signs could use less space and non-written symbols to provide suitable messages. When a larger escape sign was used in a large space, it could still be identified clearly within 6m if it presented in green or red (Ouellette, 1988). Collins and Quillian (1969) proposed

that the knowledge system of human beings is a hierarchical network. The issue of how human internal cognitive systems interact with the external environment during way-finding, thereby influencing way-finding performance, should be addressed (Garling, Book & Lindberg, 1984). Thus, there is a close relationship between the representations and cognition results of signs.

Passini (1999) has proposed three phases of way-finding. The acquisition of spatial knowledge is the primary referential guidance for forming way-finding strategies, as well as being an important basis for determining whether the way-finding is successful. This is because when people receive incorrect spatial knowledge and make incorrect path judgments during the way-finding process, they get lost, which normally leads to anxiety caused by lack of mental coordination. Montello (1999) proposed that asymmetric street structures tend to cause people to lose direction. On asymmetric streets, the rate of test subjects pointing out incorrect object positions and spatial locations was higher than that on a street with right angle arrangements. From the viewpoint of Evans (1980), people are more likely to feel well oriented in buildings consisting of regular structures (such as a crisscross or a right angle) than in those with irregular structures and/or angles. Best (1970) identified a positive relationship between the number of choice points (hallway intersections) within a building and way-finding difficulty. Nichols *et al.* (1992) reported that the primary cause of way-finding difficulties in transportation centers is the complexity of possible paths. O'Neill (1991a) found that incremental increases in floor plan complexity reduce both the accuracy of one's cognitive map and one's way-finding performance. O'Neill (1991b) also found that floor plan complexity reduces way-finding performance, despite the presence of directional signage. These research studies explain communication of a certain message or meaning through sign graphics, and the same goes for the reading cognition of way-finding graphics.

Regarding additional supplementary signs, Tang *et al.* (2010, 2011) constructed the sign supplementary equipment (doorframe LED) and used VR (virtual reality) and full scale space to verify various application situations. Preliminary results had been acquired to prove significant results of supplementary indicator lighting toward escape guidance. However, if this path guiding concept could be applied in fire rescue, it would shorten effectively the rescue time and find the fire source in time to put out the fire, but whether this concept could have the same guidance results for rescue personnel in an actual fire was unknown. Therefore, this study applied the supplementary indicator lighting at the location of a fire starting home for discussion. This study used a full scale real space for fire experiments to discuss the firefighters' way-finding, behavioral characteristics and supplementary indicator lighting. The concrete objectives were as follows:

1 - Discuss the relevance between crew members' way-finding and background conditions in a fire, and analyze the physical contents of the impact of background conditions on way-finding.

2 - Discuss the effects of with and without additional supplementary indicator lighting on way-finding, and propose concrete suggestions for supplementary indicator lighting in firefighting and rescue. Furthermore, to identify behavioral characteristics of crew members as an important reference for education and training of future members to increase rescue efficacy.

METHODS

Full scale space

Full scale real space is difficult to acquire due to limitations in general space, thus the experiment used a building that was about to be demolished. The large building was mainly for residence. Its standard plane floor had two staircases, one elevator, and four residence units with three rooms, two living spaces and two bathrooms; the layouts were symmetric and configuration areas were equal. The experiment was conducted on the seventh floor, each residence having an area of 90.00 m^2, the area of staircases and stairs was 15.00 m^2, the total area of a single floor was 393.12 m^2, and the ceiling height was 2.70 m. The four residences are labeled clockwise according to left to right direction as rescuers exit the escape ladder. The Left back, right back, right front, left front are labeled A, B, C and D, respectively. Label D shows the residence in which the fire started in this experiment (Figure 1).

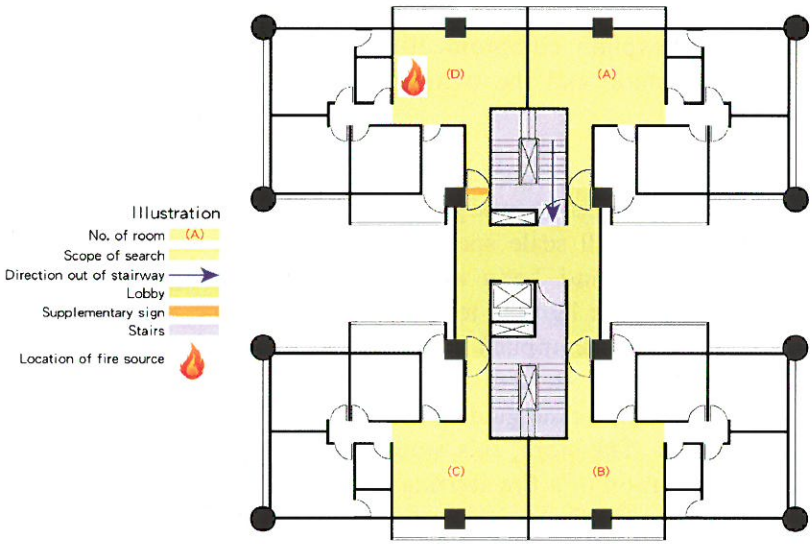

Fig. 1. Floor plan of experiment

Experiment space scenario and environmental limitations

The experiment was carried out on the seventh floor and its spatial scenario and environmental conditions were as follow:

1 - There are two types of experimental scenarios: (1) smoke in existing environment, and (2) smoke in environment with supplementary indicator lighting added (Figures 2-5 this is the view of apartment door from the corridor.) (Indicator lighting equipment is doorframe LED light installed on the staircase side of the doorframe of the household on fire.). The purpose of adding indicator lighting was to label the location of the residence where the fire started so that members could reach the location of fire source as soon as possible to put out the fire, as well as search for trapped civilians within the shortest time.

2 - All experiments were simulations of real fires, and the fire source is limited to one location with flammable kerosene (Figure 6). This experiment discusses the impact of smoke on the search by firefighters, thus the heat release rate is not within discussion.

3 - When the supplementary indicator lighting added was activated, it flashed on and off in the ratio of 1:1, and its average brightness was above 150 cd/m^2; the color is green (Figures 7 and 8).

4 - Assuming the power of the building had been cut off at the occurrence of the fire, the smoke needed for the experiment was controlled with lighting. The staircases had emergency lighting and the illuminance measurement location was the illumination on the ground of the fire escape exit; the illumination was controlled to be under 2 lux (Figures 9 and 10).

5 - The fire source was set in one of the four residences, with the door open (assuming that the people had escaped without closing the door), leading to smoke spreading to the staircase; the fire escape door is closed.

6 - To prevent effects from external lights, the experiment was conducted at night.

7 - The staircase windows were shut so the smoke from the fire would not spread through the windows or other channels; the same applied for the fire source location.

8 - This arrangement simulated the most dangerous scenarios, assuming the smoke exhaustion equipment at the staircase was not activated, and the emergency broadcasting and lighting equipment were set according to different situations.

9 - In addition, in order to save the time of search and rescue personnel, the search scope was limited to the living room of each residence, not including the bedrooms and bathrooms; the actual search scope are as indicated in Figure 1.

LED supplementary signal illumination specifications

The method by Tang *et al.* (2011) is adopted for supplementary indicator lighting specifications, in which flash to time ratio is 1:1 when the supplementary indicator lighting is activated, the average brightness is over 150cd/m^2, and the color is green.

Fig. 2. Apartment door before installation of fire indicator lighting

Fig. 3 .Apartment door after installation of fire indicator lighting

Fig. 4. Apartment door before smoke indicator lighting comes on

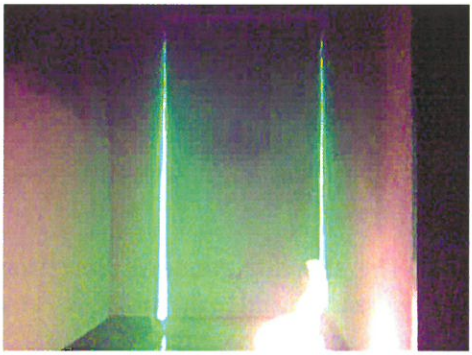

Fig. 5. Apartment door after smoke indicator lighting comes on

Fig. 6. Creating smoke with kerosene

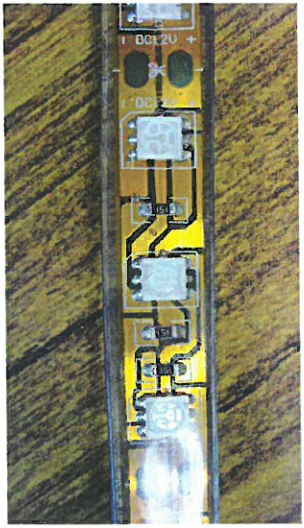

Fig. 7. Photo of supplementary indicator lighting equipment before activation

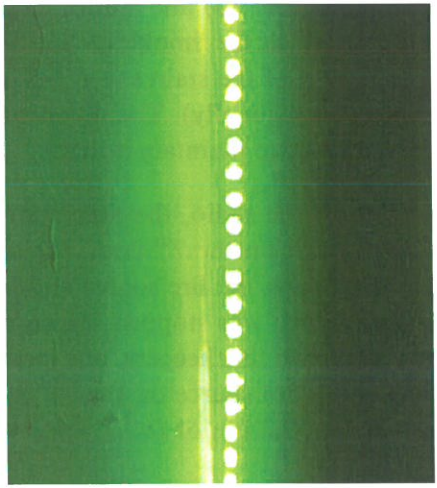

Fig. 8. Photo of supplementary indicator lighting after activation

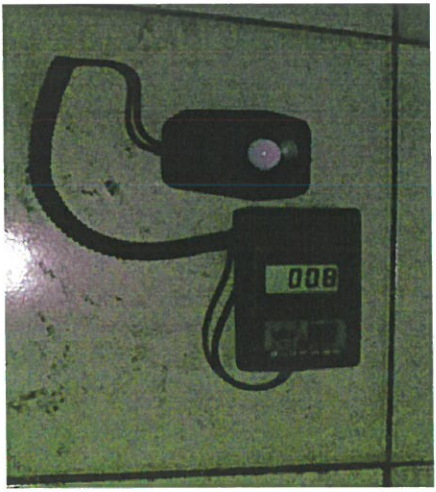

Fig. 9. Emergency lighting shown without smoke (8 lux)

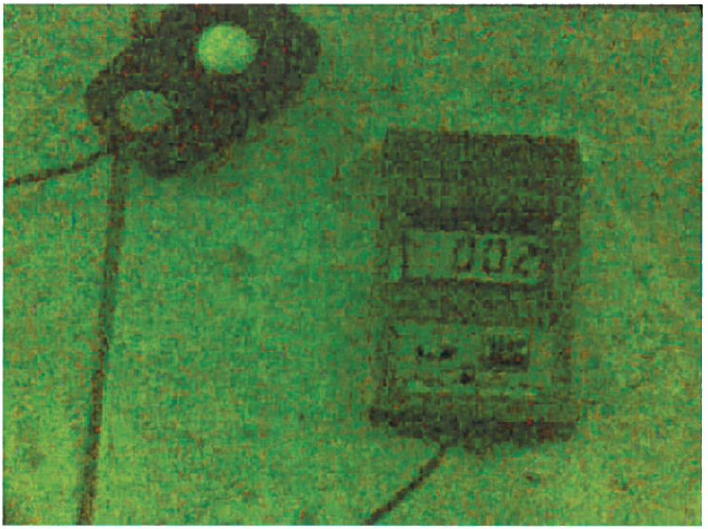

Fig. 10. Emergency lighting shown without smoke (2 lux)

Experiment procedures

1 - All firefighters wore standard firefighting hats, shoes, gloves, oxygen tanks, masks, radios and flash lights (Figures 11, 12 and 13) and waited on the fifth floor for basic information (Table 1). Once the smoke of the floor experimented has lowered the illuminance level of the staircase to below 2 lux, they commenced the rescue operation (individually). The illuminance during the experiment was measured periodically to maintain its level.

2 - When the start command was given through the radio, the time started. Once crew members reached the emergency exit on the 7^{th} floor, the time was recorded as that of Phase I. After they reach the fire source and find the dummy, the way-finding ended and the clock was stopped, which was recorded as the time of Phase II. (There were two timekeepers, one located within the emergency staircase and one at the fire source on the 7^{th} floor; there were no other personnel on the floor of the fire or in the staircases and lobbies.)

3 - Test subjects were notified to climb ladders with normal walking pace and search according to experience. No running or walking rapidly was required. These actions were based on search method in actual fires.

4 - Experimental scenarios were divided into scenarios with/without supplementary indicator lighting system (Figures 14 and 15).

5 - Although the two timekeepers were located on the 7th floor, they were only responsible for recording time and were not give any instructions or suggestions regarding refuge.

Table 1. Experiment record

Item	Contents			
Gender	☐ Male	☐ Female		
Age	☐ 20-29	☐ 30-39	☐ 40-49	☐ 50-59
Experience in firefighting	Yrs.			
Trained in rescue team	☐ Yes	☐ No		
Worked in rescue unit	☐ Yes	☐ No		
Search training	☐ Yes [In mm yy]		☐ No	
Experience in searching in fire with heavy smoke	☐ Yes [In mm yy]		☐ No	
Search sequence	(Label with A, B, C, D according to search sequence)			
Time required	Departing on 5F to reaching 7F emergency exit			sec.
	Exiting 7F emergency exit to finding survivor (dummy)			sec.

Note: 'Search sequence' refers to the sequence of space selection made by personnel after entering the staircase from stairs.

Fig. 11. Geared firefighter

Fig. 12. Geared firefighter

Fig. 13. Flashlight used by firefighters

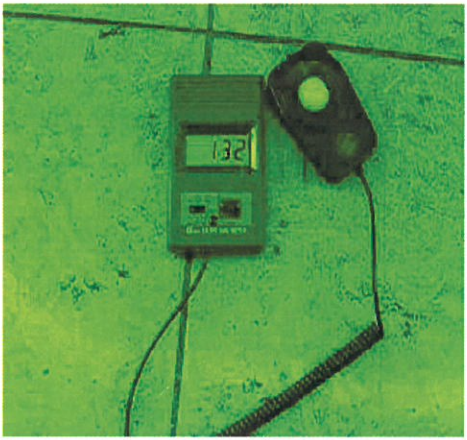

Fig. 14. Non-smoke supplementary indicator lighting equipment's illuminance (132 lux)

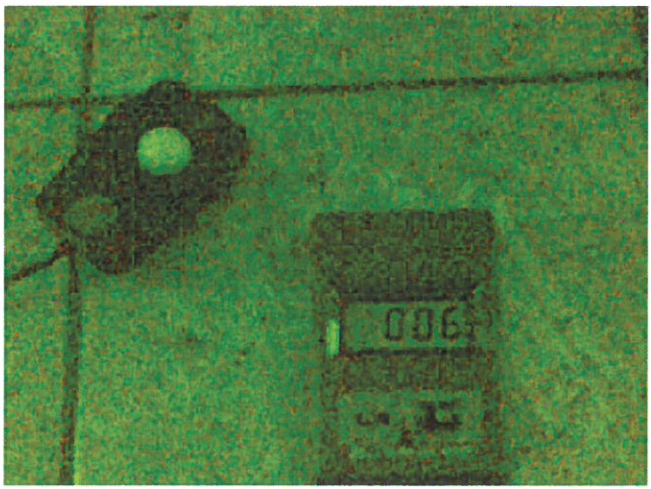

Fig. 15. Smoke supplementary indicator lighting equipment's illuminance (6 lux)

Experiment participants

Real space and fire were used in this experiment, and the study was carried out from the point of view of firefighting and rescue. Therefore, the subjects

participating in this experiment were firefighters from Taipei City Fire Department. This experiment was included as part of the firefighters' training programs as training sessions are arranged every quarter for these hard-working firefighters. The subjects participating in this experiment all had first-hand firefighting experience in real life, and were briefed that the experiment was a simulation of a real fire scenario. They were told to locate the fire source as soon as possible while staying safe during the process. Two instructors stood by in the smoke space to ensure the safety of experiment participants.

This experiment was divided into two scenarios, with/without supplementary indicator lighting. Each scenario had 60 subjects participating, thus a total of 120 subjects, and the ratio of male to female was 4:1 in both scenarios. All test subjects were firefighters currently engaged in rescue work. The following limitations were set to meet the requirements of the experiment:

1 - All subjects needed to be free of color blindness or other eye disease.

2 - All experiment participants performed the experiment only once.

3 - Individuals who had already performed the experiment were required not to notify others of the search results and could not participate in the experiment more than twice.

4 - Individuals had to leave the site immediately after the experiment and could not to discuss it with others.

5 - Investigations prior to the experiments indicated that all personnel were unfamiliar with the on-site environment.

EXPERIMENTAL RESULTS AND ANALYSIS

The purpose of this study was to discuss the impact of crew member background on way-finding and the addition of supplementary indicator lighting installation toward way-finding ability. According to the experimental results, the way-finding results in existing environment under a scenario with smoke but with no lighting, is first explored to understand the current situation and as an analytical basis for improvement. Next, the increment in way-finding ability after installation of supplementary indicator lighting is investigated. Finally, a cross-discussion on the two scenarios is carried out to propose concrete suggestions for firefighting and rescue training. For statistical analysis, a t-test was used for bivariate analysis. Regression analysis was used for investigation of the influence of the background conditions. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS).

Existing environment

Time required for way-finding

The results show that, of the 48 males (80%) and 12 females (20%) in the experiment of existing environment, the average overall stairway moving time was 21.7s (S.D. 4.13s), of which the maximum and minimum times were 29.00s and 15.00s, respectively. The average times for male and female were 21.38s (S.D. 4.48) and 23.00s (S.D. 2.00), respectively. It can be seen from the relationship between the average values and standard deviations (and using a t-test) that there was no significant difference between males and females. The test subjects had to wear firefighting suits and carry oxygen tanks, which weighed as much as 20kg. This is quite a heavy load judging from the height and weight of eastern people. Therefore, we know that this result should be related to basic physical load ability and how to consider both the safety of crew members and the weight of equipment as an issue worthy of review by public departments. Furthermore, for the time of horizontal way-finding, the overall average time was 79.00s (S.D. 52.60), the maximum time is 216.00s and the minimum time is 16.00s; the average times for males and females was 79.67s (S.D. 54.25) and 76.33s (S.D. 50.02), respectively. However, it is worth noting that the difference between the maximum and minimum values is 200s (approx. 13.5 fold), indicating way-finding training should be strengthened to reduce the difference and enhance rescue efficacy. Thus, establishment of a set of more effective training standards should be an urgent issue.

Way-finding sequence

How subjects determine the way-finding sequence after they enter the lobby from the stairs is an important issue discussed in this study. In particular, when the environmental illuminance is lower than 2 lux and under low visibility, how firefighters grasp spatial characteristics effectively to search for survivors within the shortest time is extremely important. Since the test subjects did not know the spatial layout, the results of the search sequence showed that 28 subjects (46.7%) moved from left to right (22 subjects went clockwise following path No. 1: A→B→C→D, 6 subjects followed path No. 3: A→B→D), 22 subjects (36.7%) moved from right to left (18 subjects went counterclockwise following path No. 2: D, 4 subjects following No. 4: D→C→B→A→D). The remaining subjects conducted searches in an irregular manner (16.6%, see Table 2). This indicates that most people choose to search according to certain rules (83.4%) in an environment with low illumination. It is known from post-interviews that, because firefighters face diversified spatial layouts, there is no rule on where to start a search and in which direction in the current firefighting training, but to

search one by one according to a certain sequence is regulated. The results of this experiment show that only a few individuals lost their sense of direction in the environment, leading to chaotic searches. It was discovered in the post-interviews with these people that the problem could be improved if their flashlights could provide better illumination. Therefore, besides continuance of strengthening regular training, adequate adjustment toward the efficacy of equipment is also an important issue.

In addition, the search sequences and search time were tested using regression analysis to analyze the relationship between search sequence and time required. The results show that way-finding sequence had a significant impact on search time ($p = 0.001 < 0.05$). Thus, way-finding time can be grasped efficiently with an appropriate way-finding plan, and implementation of regular training will be helpful to the establishment of way-finding plans during rescue. The way-finding sequence in Table 2 suggests that 9 sequences are generated this time, and 4 of them are more effective strategies (Nos. 1 to 4) and the others are of irregular types (Nos. 5 to 9). Therefore, two important strategies can be identified for way-finding: (a) searching in an unfamiliar space in a clockwise or counterclockwise pattern are both better way-finding strategies (Nos. 1 to 4), both of which prevent disorientation in space effectively; and (b) since a rescue mission takes a matter of seconds, firefighters are used to rushing into a fire situation and often neglect a proper searching strategy. It is suggested therefore that firefighters should observe closely (or make a quick judgment) when entering the lobby from a staircase before commencing searching so as to avoid missing the location of the fire source (or those who are stranded).

Table 2. Percentages of way-finding sequence (existing environment)

No.	Search sequence	Frequency	Percentage
1	A→B→C→D	22	36.7
2	D	18	30.0
3	A→B→D	6	10.0
4	D→C→B→A→D	4	6.7
5	B→A→D	2	3.3
6	B→C→D	2	3.3
7	B→C→A→D	2	3.3
8	C→A→B→D	2	3.3
9	C→B→A→D	2	3.3

Note: Residence D is where the fire source and dummy are located. The test subjects have to end the experiment by locating both.

Impact of firefighter crew backgrounds

Before the experiment, this study collected data on the different backgrounds of crew members, of which there are four major items: 1. Participation in rescue training; 2. Experience in rescue unit; 3. Participation in search and rescue training; 4. Experience in heavy smoke. The objective was to analyze whether these backgrounds influenced the search time and to understand whether relevant training is helpful and is a basis for future improvement. The results of tests on the above mentioned items (Table 3) show that rescue training, employment unit and heavy smoke experience have no significant relationship to search time, but search and rescue training ($p=0.049$) affects search time significantly, indicating the search and rescue training for crew members has indeed achieved it purpose of reducing way-finding time. The content of rescue training that firefighters receive is only partially related to search requirements, thus there is no significant relationship. Experience in heavy smoke is also not related to search time, indicating that the importance of strengthening educational training is greater than accumulation of actual rescue experience.

Table 3. Test results of search time (existing environment)

	Search and rescue training	Rescue training	Employment time in rescue unit	Experience in heavy smoke
Search time (p = Significance)	0.049	0.095	0.971	0.069

Furthermore, in order to understand whether a correlation exists between the experimental variables, discussion is carried out with regression analysis, in which the time required for searching is set as the dependent variable, while the remaining variables are independent variables (x_1 Gender, x_2 Age, x_3 Years of experience, x_4 Rescue training, x_5 Employment in rescue unit, x_6 Search and rescue training, x_7 Experience in heavy smoke, x_8 Search sequence, x_9 Stairway moving time). The results are as follows:

$$y=-0.482x_1+0.366x_2-0.817x_3+0.006x_4-0.047x_5-0.200x_6+0.143x_7+0.366x_8+0.403x_9 \quad R^2=0.590$$

The result was that x_1 Gender ($p=0.012$), x_6 Search and rescue training ($p=0.037$), x_8 Search sequence ($p=0.050$) and x_9 Stairway moving time ($p=0.033$) reached significance level, indicating that these four factors have greater impact on the time required for searching. The gender and stairway moving time are consistent with the results of the aforementioned test in that the 20kg equipment will give rise to difference in genders, leading to different

stairway moving times and affecting indirectly the search time. Therefore, basic physical training is a primary issue. Only by maintaining certain physical conditions can a firefighter face adverse circumstances during a rescue, regardless of gender or number of years of experience. In terms of gender difference, the comparison between genders and that from the previous section suggests insignificant difference in gender if investigating on 1. Stairway moving time and 2. Horizontal way-finding time. However, the regression analysis on both the stairway moving time and the way-finding time indicates difference between genders; i.e. the longer the way is, the more significant the gender difference becomes. Therefore, proper arrangements should be made for different genders during a rescue mission. Males should be placed in the front and females at the back when dealing with a large space.

In addition, it can be known from the regression analysis that future educational training should focus on strengthening search training, including the establishment of search plan (search training) and direction determination training (search sequence), even for the individuals who have more actual experiences. Besides, firefighting and rescue is a team work, and everyone should receive regular professional training, regardless of their experiences, to be able to maximise their effectiveness during a rescue.

Environment installed with supplementary indicator lighting

Time required for way-finding

In the experiment of an environment installed with indicator lighting, the average overall stairway moving time of 48 males (80%) and 12 females (20%) was 25.63s (S.D. 5.66), the maximum value is 35.00s and the minimum value was 15.00s; the average times for males and females are 25.96s (S.D. 5.95) and 24.33s (S.D. 4.50), respectively. It is known from the relationship between the average values and standard deviations that there is no significant difference between males and females, which is inconsistent with the results of the former section. This will be discussed in the next section. As for the horizontal way-finding time, the overall average was 36.60s (S.D. 20.59), the maximum value was 95.00 and the minimum value was 14.00s; the average times for males and females were 34.00s (S.D. 20.11) and 47.00s (S.D. 20.90), respectively. The difference between the maximum and minimum values was 81s, which is 119s less than an environment without indicator lighting. Thus, it is known that indicator lighting installation can provide good guidance for way-finding. Detailed analysis will be described.

Way-finding sequence

We know from the experiment of the existing environment discussed in the previous section that, when the environmental illumination is lower than 2 lux and the visibility is low, firefighters could only search along walls clockwise or counterclockwise, which increases search time. Thus, adding guidance signs appropriately is an important issue. After a guidance sign was installed at the front of the household on fire, the number of crew members finding the fire source directly increased greatly from 18 to 52 individuals (86.7%) (counterclockwise D), and only 8 individuals (13.7%) found the fire source indirectly (B→D, A→B→D, B→A→D) (Table 4). This indicates that most people could understand immediately the guiding meaning of a supplementary indicator lighting after it is activated, thus shortening the time required for way-finding greatly. In addition, the relationship between the search sequence and required time after sign installation show it had a significant impact on way finding sequence and search time ($p = 0.001 < 0.05$). This is consistent with the experimental results of existing environment.

Table 4. Percentages of way-finding sequence (sign installation)

Search sequence	Number of times	Percentage	Accumulated percentage
D	52	86.7	86.7
B→D	4	6.7	93.3
A→B→D	2	3.3	96.7
B→A→D	2	3.3	100.0

Impact of backgrounds

Regarding background influence, the aforementioned four factors were analyzed. The results show (Table 5) that the rescue training, employment unit, heavy smoke experience and search and rescue training do not have a significant relationship with the search time. Over 80% of the individuals found the fire source directly because the search is reduced greatly after sign installation. This result illustrates the efficacy of good guidance provided by supplementary indicator lighting, thus differences in the backgrounds of crew members are not apparent.

Table 5. Test results of search time (sign installation)

	Rescue training	Employment in rescue unit	Search and rescue training	Experience in heavy smoke
Search time (p = Significance)	0.533	0.179	0.507	0.486

The results of regression analysis are as follows:

$y = 0.198x_1 + 0.511x_2 - 0.493x_3 + 0.310x_4 - 0.009x_5 - 0.292x_6 + 0.036x_7 + 0.524x_8 + 0.271x_9$ $R^2 = 0.541$

The result was that only search sequence x_8 ($p = 0.020$) reaches the level of significance, indicating only search sequences influences search time after supplementary indicator lighting is activated, and the remaining conditions have no direct correlation with search time.

Comparison of the two scenarios

Time required for way-finding

Since the stairway moving process did not have the assistance of supplementary signage, so there was no difference in time taken for the two scenarios. However, there was significant difference in the horizontal way-finding time, which decreased from the original (non-sign environment) 79.00s to 36.60s and the standard deviation also decreased from 54.25 to 20.59. The number of individuals finding the fire source directly increased from 18 to 52, indicating the newly installed sign provided good assistance in way-finding, which could be helpful in enhancing greatly the success rate of rescues. Furthermore, installation of supplementary indicator lighting did not show gender differences, indicating the feasibility of the equipment's applicability.

Table 6. Comparison of way-finding time

	Stairway moving time			Horizontal way-finding time		
	Male	Female	Average	Male	Female	Average
Scenarios 1	21.38 (S.D. 4.48)	23.00 (S.D. 2.00)	21.70 (S.D. 4.13)	79.67 (S.D. 54.25)	76.33 (S.D. 50.02)	79.00 (S.D. 52.60)
Scenarios 2	25.96 (S.D. 5.95)	24.33 (S.D. 4.50)	25.63 (S.D. 5.06)	34.00 (S.D. 20.11)	47.00 (S.D. 20.90)	36.60 (S.D. 20.59)

Way-finding sequence

Most individuals tended to search clockwise when there was no sign, but the situation was different after the installation of supplementary indicator lighting.

A comparison of the two scenarios showed that 86.7% reached the household on fire directly after installation, while only 30.0% reached the target when there was no sign. Thus, the supplementary indicator lighting elaborated its impact on the determination of the ability of search crews, indicating that a sign can be helpful to actions. By comparing Table 2 and Table 4, we know that the addition of signs can change existing search modes significantly to reduce the time required for searching. In general, behavioral models cannot be changed easily once they are established. However, this experiment indicates that, under a dark environment, adequate lighting can change immediately the existing search model. Therefore, promotion of this newly added equipment can provide effective guidance, and the reduction in search time will not give rise to problems in understanding the new signs.

Table 7. Comparison of way-finding sequences

	Number of direct arrivals at fire source (Residence D)	Number of incorrect ways
Scenarios 1	18 (30%)	10 (16.5%)
Scenarios 2	52 (86.7%)	2 (3.3%)

DISCUSSION AND SUGGESTIONS

The time is critical for reducing life and properties losses during a fire, so how to shorten the way-finding time when rescuing is a very important issue. The results of this study show installation of fire location signs can reduce way-finding time greatly. Besides basic physical strengthening, regular training should also include the establishment of better search and rescue plans to reduce search time effectively. The main results are as follows.

Correlation between way-finding and backgrounds

In general, way-finding time can be reduced to half if a fire location sign (lighting) is installed, but such installation does not show significant differences in tests of various backgrounds, indicating that the installation may not only shorten way-finding time effectively but also avoids problems in determination of way-finding strategy. Furthermore, when there is no sign installed, the factors of the nine backgrounds affecting way-finding time are as follows: 1. Gender; 2. Search sequence; 3. Search and rescue training. After the sign is installed, only the search sequence is related to the way-finding time. As to whether experiences in firefighting influence the speed of search, there seems to be no significant relationship in the results of this study. However this is not intended to underestimate the importance of firefighting experience as discussed in the next section.

Suggestions for firefighting training

Suggestions for current firefighting training that has not installed fire location signs:

1 - Searching in an unfamiliar space in a clockwise or counterclockwise pattern are both better way-finding strategies (Nos. 1 to 4), both of which prevent disorientation in space effectively; and

2 - Since a rescue mission is a matter of seconds, firefighters are used to rushing into a fire scheme and often neglect a proper searching strategy. It is suggested therefore that firefighters should observe closely (or make a quick judgment) when entering the lobby from a staircase before commencing searching so as to avoid missing the location of fire source (or people stranded in the building).

3 - Strengthening basic physical training should be the major issue as gender is still the main reason affecting speed, but it is necessary to consider gender characteristics in adjusting rescue missions of crew members.

4 - Way-finding sequence is the major reason which determines the length of routes, thus the training of complete rescue route planning should not be neglected, and graphic information (exits, entrances, corridors, stairs) reading training beforehand can enhance the ability to develop search and rescue plans.

5 - Search and rescue training is helpful to the promotion of responding abilities in fires, thus full scale rescue training must be carried out continuously on a regular basis.

As the development of buildings shift toward diversification, complexity, and high elevation, the rescue work in a fire will become more difficult. Therefore, besides strengthening firefighting and management measurestowards different types of spaces (e g. a plaza), installing fire location signs appropriately to assist firefighting and rescue services will shorten the time of search and rescue so that life and property losses may be reduced.

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REFERENCES

Best, G. A. 1970. Direction-finding in large buildings. In D. Canter, Ed., *Architectural Psychology*. London: RIBA Publications, 72-91.

Collins, A. M. & Quillian, M. R. 1969. Retrieval time from semantic memory, *Journal of Verbal Learning and Verbal Behavior*, **8**(2): 240-247.

Evans, G. W. 1980. Environmental cognition. *Psychological Bulletin*, **88**(2): 259-287.

Garling, T., Book, A. & Lindberg, E. 1984. Cognitive Mapping of Large-scale Environments. *Environment and Behavior*, **16**(1): 3-34.

Maguire, M. C. 1985. A review of human factors guidelines and techniques for the design of graphical human-computer interfaces. *Computers and Graphics*, **9**(3): 221-235.

Montello, D. R. 1991. Spatial Orientation And The Angularity Of Urban Routes A Field Study. *Environment and Behavior*, **23**(1): 47-69.

Murray, L. A., Magurno, A. B., Glover, B. L. & Wogalter, M. S. 1998. Prohibitive pictorials: Evaluations of different circle-slash negation symbols. *International Journal of Industrial Ergonomics*, **22**: 473-482.

Nichols, F., Canete, I. & Tuladhar, S. 1992. Designing for Pedestrians: A CAD Network Analysis Approach. In Y. E. Kalay, Ed., *Evaluating and Predicting Design Performance*. New York, NY: Wiley & Sons.

O'Neill, M. J. 1991a. Evaluation of a conceptual model of architectural legibility. *Environment and Behavior*, **23**(3): 259-284.

O'Neill, M. J. 1991b. Effects of signage and floor plan configuration on way-finding accuracy. *Environment and Behavior*, **23**(5): 553-574.

Ouellette, M. J. 1988. Exit signs in smoke: design parameters for greater visibility. *Lighting Research and Technology*, **20**(4): 155-160.

Passini, R. 1999. *Wayfinding: backbone of graphic support systems. Visual Information for Everyday Use*, London: Taylor & Francis.

Petiot, J. F. & Yannou, B. 2004. Measuring consumer perceptions for a better comprehension, specification and assessment of product semantics. *International Journal of Industrial Ergonomics*, **33**(6): 507-525.

Piamonte, D. P. T. 2001. Understanding small graphical symbols: a cross-cultural study. International Journal of Industrial Ergonomics, **27**: 399-404.

Shieh, K. K. & Huang, S. M. 2003. Factors affecting preference ratings of prohibitive symbols, *Applied Ergonomics*, **34**(6): 581-587.

Tang, C.-H., Kuo, E.-S., Chen, C.-J., Chuang, Y.-J. & Lin, C.-Y. 2007. A Basic Study on the Application of Emergency Icons to Emergency Exits during a Fire, *Journal of Applied Fire Science*, Vol. **17**(3): 261-275.

Tang, C.-H., Lin, Y.-C., Yuang S.-Y., Huang, C.-H., Chuang, Y.-J. & Lin, C.-Y. 2008. A Case Study on Emergency Evacuation and a Simulation of Department Stores and Shopping Malls during a Fire, *Journal of Applied Fire Science*, **18**(2): 117-134.

Wogalter, M.S., Conzola V.C. & Smith-Jackson. 2002. Research-based guidelines for warning design and evaluation. *Applied Ergonomics*, **33**(3): 219-230.

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