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استخدام علامات خروج متغيرة في حالات الإخلاء من طوارئ الحريق

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الخلاصة

لما كان التصميم الداخلي يزداد تعقيداً كل يوم، أصبحت علامات المخارج أقل قدرة علي المساعدة في إرشادات الإخلاء السريع. تقدم هذه الدراسة مبدأ استخدام علامات مخارج متغيرة وتناقش مدى فعالية هذا المقترح في المساعدة على إيجاد المخارج. نتج عن هذه الدراسة أنه بغض النظر عن هذه المخارج للعامة فإن تمييزهم للمخارج جيد وزادت نسبة الإخلاء الناجح بمعدل (20 %) . ينبغي تأكيد هذه الزيادة بتجارب جديدة في مساحات وظروف أخرى. حتى مع وجود العلامات الحالية فإن توضيح معاني العلامات زاد نسبة الإخلاء الناجح بمعدل (8 %) مما يثبت أن تثقيف العامة له أهمية في حالة الطوارئ. بالنسبة لخصائص التصرفات أثناء إخلاء الطوارئ توصلت الدراسة إلى :

1) يميل الذكور والإناث إلى الإتجاه إلى اليسار.

2) في المساحات والأماكن غير المألوفة هناك اختلاف بسيط بين تصرف الذكور والإناث في اختيار المخارج الفعالة.

Changeable prohibitory exit signs used in choice of fire evacuation route

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ABSTRACT

As interior space of buildings become increasingly complex, current exit signs in fire incidents may not be able to provide timely evacuation guidance. This study proposes a concept of changeable prohibitory exit signs, and discusses the feasibility of using the signs to help with the way-finding. This study has concluded that whether the meanings of such changeable prohibitory exit signs have been explained beforehand, the general public's recognition and understanding of the signs are positively presented, and the evacuation success rate has been increased 20%. However, the increase needs to be further verified with more and extensive experiments in different spatial conditions of environment. Even with the current signs, after explanation of their meanings, the accuracy of way-finding gave an 8% improvement, which proves that education on current signs is also very important. On the behavioral characteristics of evacuation, it is found that (1) both males and females tend to make a left turn; (2) in an unfamiliar space there is a slight but non-statistically significant difference between males and females in choosing effective routes.

Keywords: Changeable prohibitory exit signs; icon recognition; way-finding.

INTRODUCTION

The design of evacuation routes in a building is based on the evacuation passages and escape stairways that make safety zoning for various fire and smoke resistance effects. Also, to make sure the evacuators can quickly reach the safety zones, evacuation signs are installed along the living rooms, corridors and all the way to escape stairways. However, in large buildings, the evacuation routes are usually complex and when they are blocked by fire and smoke, the evacuation will have to rely on the help from a temporary task force. The truth is that a fire in a building can bring about thick smoke which is spread and diffused to challenge the original evacuation route design, making the design incapable of providing effective evacuation guidance in accordance with the changing fire situation and site conditions. In some cases, the evacuation signs could end up providing wrong evacuation information - for example, when an escape stairway is blocked by thick smoke, the emergency exit signs would fail to warn evacuators NOT to enter the stairway, thus causing greater injuries or even loss of lives. Therefore, the aim of this study was to run a full-scale experiment to explore the feasibility of applying changeable prohibitory exit signs to the evacuation way-finding in fire incidents, and analyze the impact of prohibitory signs on behavior of evacuators in the course of way-finding.

For the global standard of prohibitory symbol patterns, the resolution of United Nations Vienna Convention on Road Signs and Signals of 8 November 1968 has its Article 11, Appendix 1C items C3 and C4 regulate the colors and patterns of prohibitory and restrictive signs as well as the norms for texts and icons, which are standard round shape in red, with a tilt line running from upper left to lower right through the center in a 45-degree angle, as the foundation for the symbol pattern (United Nations, 2009). Therefore, regarding symbol cognition, this study attempts to combine two symbols that are highly familiar in many countries, into a new one. As the study is concerned with safety and lives, symbol cognition accuracy is a key part of it. Wogalter *et al*., (2002) and Shieh & Huang (2003) researched into warning signs, and redesigned and rearranged the icons so that people could better understand their meanings. For large emergency exit signs used in a big space, if they are shown in green or red and within a range of about 6 meters, they can be clearly recognized (Ouellette, 1988). Maguire (1985) in his research on human factors engineering and technological icon interface design noted that signs with less space and non-text form could provide proper messages. Meanwhile, Murray *et al*. (1998) discovered that different round-shape prohibitory signs could create different preference levels, a proof that the presentation of signs could affect the cognition results.

Regarding the issues of way-finding and space cognition, Montello (1991) argued that an asymmetric street structure could easily get people lost in directions, and testers in identifying object positions and spatial orientation (east, west, south, north) made much higher error rate in an asymmetric street than in a street of rectangular design. Passni (1939) contended that cognition of spatial orientation was the most important factor of spatial perception, and “orientation” was an aggregate term of “direction” and “location”, in that the orientation judgment was closely related to the direction judgment, and was an ability to keep moving forward by recognizing the relative relationship so as to identify the current location. Furthermore, Passini (1999) also believed that acquisition of spatial knowledge was key to forming way-finding decision and an important foundation of its success, for people could easily get lost in the course of way-finding if they were given incorrect spatial knowledge, thus making wrong decisions. Evans (1980) pointed out that a regularly structured architecture (a cross shape or two lines intersecting at a right angle) was more useful in helping people identify their orientation than an irregular shape or angle. Montello *et al*., (1999) argued that the spatial competence indicates the ability of using maps, exploring surroundings and describing space with words, in a large range of spaces in the real world. In the course of way-finding, how the inner cognition system of people interact with the outer environment and how the interaction affects the way-finding results have become an issue not to be ignored (Garling *et al*., 1984). In his study of architectural readability concept evaluation modeling, O'Neill (1991a) found that increasing the complexity of a floor plan could reduce the map recognition ability and the way-finding accuracy. Again, O'Neill (1991b) had another study about accurate sign indication for way-finding and the impact of the floor plan structure, where he noted that although an architecture might have sign indicators and floor plan descriptions, if the plan was complicated, the way-finding efficacy could be weakened, even with proper indicating signs. Best (1970) in his study of direction seeking in large buildings found that, it was difficult to choose a path in a hallway with multiple entrances. And Beaumont *et al*., (1984) in his study of building orientation and residents way-finding found that having architectural floor plans and readable signs could simplify the way-finding process.

From the design point of view, the design and lighting of signs can affect their visibility (Collins, 1991). Adding the arrow contrast in signs, enlarging the herringbone shape, or changing the herringbone shape's height-width ratio, can increase the visibility distance (Boyce & Mulder, 1995). In a large space, a larger evacuation sign in green or red can be clearly identified within a range of about 6 meters (Ouellette, 1988). Also, in a series of studies, Collins (1979, 1982) and Collins & Lerner (1982) argued that research on the design and application of signs was mostly focused on the understanding of symbols and discussions on texts and directional indications. Learning and recognition of icons are easier than of languages (Lodding, 1983), and the most famous of this argument comes from the studies of Cairney & Sless (1982), who found that the Australian born locals or its immigrants had better ability of learning and recognizing the messages of warning icons. Icon interfaces have a far higher universality than text interfaces. In other words, icon interfaces literally have no language barriers (Lodding, 1983; Wickens, 1992). Generally, people prefer to use icons as a communication interface, and are more likely to accept the icon interface (Kacmar & Carey, 1991; Nielsen, 1990).

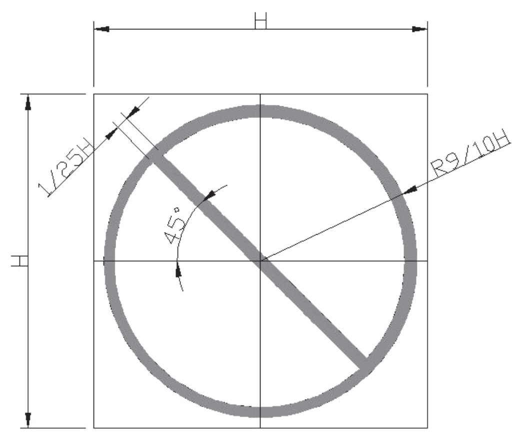
As a result, in trying to avoid multiple overlapping sign installations, which can cause recognition difficulties, this study has transformed an evacuation sign into an "exit guidance icon" (an existing exit sign) and an "entrance prohibition icon" (an existing traffic sign) and combined these two into a new icon (new sign), which uses a red flashing LED to present the prohibitory image, and turns off the light which is usually on for the exit identification, so that recognition of these two symbols can be distinguished. With such an arrangement, this study is able to explore the changes in icon recognition and its related behaviors in the case of the "exit guidance icon" switching to "entrance prohibition icon".

To implement the above design concept, this study takes a full-scale space experiment which first actuates a chain ignition of the fire detectors, and then switches the light of the emergency exit sign into a red flashing LED to present a prohibitory image, warning evacuators NOT to enter the smoke diffused area. With this experiment, this study is able to observe the feasibility of applying the changeable prohibitory exit sign to way-finding. There are three specific purposes of doing this: (1) to examine the recognition contents of the existing exit signs; (2) to observe the correlation between the recognition of changeable icons and its effectiveness of way-finding; and (3) to identify the characteristics of way-finding behavior.

THE FULL-SCALE EXPERIMENT

The experiment space is part of a new building not in use yet. This building has 21 stories above the ground and 3 stories below, and the 10th floor with an area of 1687.42m_2 being used for the experiment. This floor has 2 living spaces and 3 shared spaces which have not been filled with smoke yet. The escape stairway has an exit sign installed (from now on referred to as ‘Exit’) as shown in Figure 1, and its corridor is equipped with a red flashing changeable prohibitory exit sign (referred to as ‘C.P. Exit’) of size 218mm x 218mm x 6mm, as shown in Figure 2, 3, and 4. The floor plan with deployment and numbering of the passages, exits and signs in the experiment space is shown in Figure 5.

Fig. 1. Exit



* H stands for the vertical height of the icon.

Fig. 2. C.P. Exit prohibitory image

Fig. 3.C.P. Exit (not actuated)

Fig. 4. C.P. Exit (actuated)

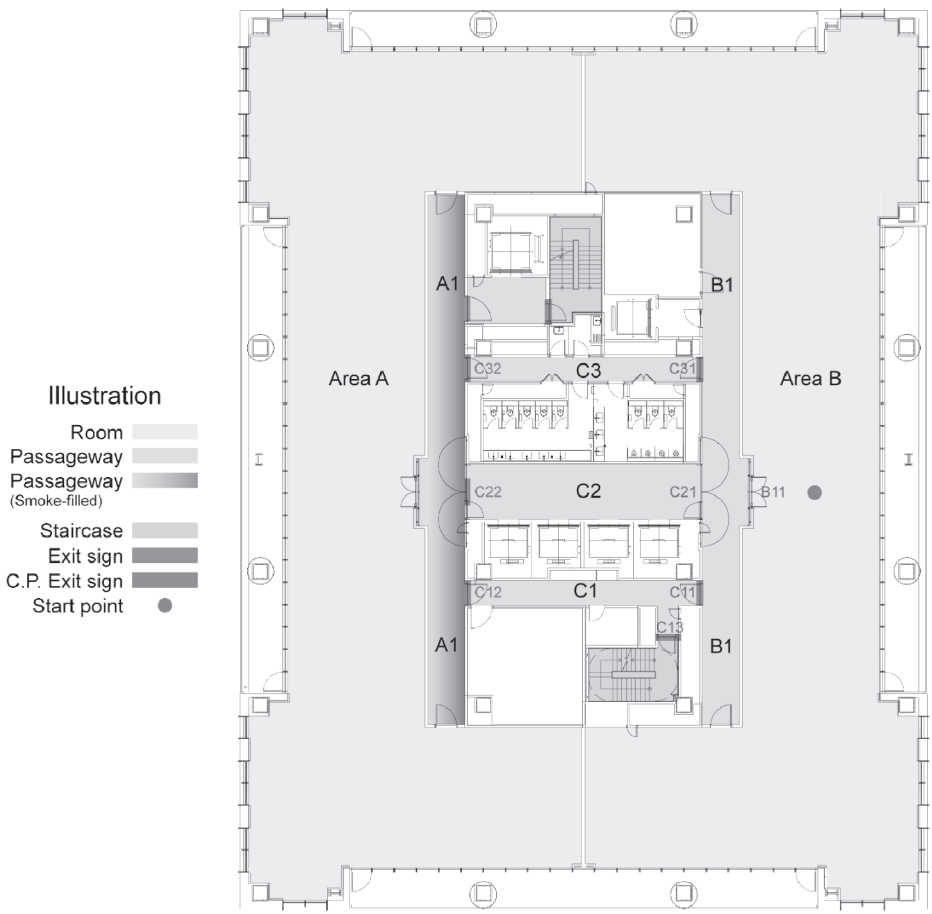


Fig. 5. The experiment floor plan

Explanation: On the tops of Exit C11, C13 and C31 are the existing "exit signs" (See Figure 1 for details.) while on the tops of Exit C12, C22 and C32 are the "changeable prohibitory exit signs" (See Figure 3 and 4 for details.)

The experiment design

The experiment scenarios

This experiment takes two scenarios, each of which has 120 and 111 participants respectively from a total of 231 participants. All the testers start from Area B to make horizontal evacuation, when they get the instruction to move one person at a time. Each tester goes for the experiment only once without repetition. The scenarios are described as follows:

1. Scenario I: does not reveal to participants the meanings of Exit and C.P. Exit.
2. Scenario II: informs participants of the meanings of Exit and C.P. Exit beforehand.

The experiment configuration

1. The numbering

Passage	A1	B1	C1	C2	C3
Entrance/Exit		B11	C11	C21	C31
			C12	C22	C32
			C13		

2. Types of the evacuation results:

(1) Type 1: calculate the entire evacuation time.

A. When the tester passes the C13 escape stairway, the timing stops (a successful evacuation).

B. When the tester opens the Exits C12, C22 and C32 and moves toward A1 passage, the timing stops (failed evacuation).

(2) Type 2: calculate the time till evacuation stops.

A. When the tester observes the C.P. Exit at C1, C2 and C3 and raises his hand before heading back, the timing stops (correct sign recognition).

3. C.P. Exit deployment: They are installed at C12, C22, C32, and the link-triggered detector is installed at the A1 passage, as shown in Figure 1.

4. Evacuation path: Based on the above evacuation result types, there can be following 8 evacuation routes:

Route 1: B11→B1 passage→C11→C13 (a success).

Route 2: B11→B1 passage→C11→C1 passage →C12→A1 passage (a failure).

Route 3: B11→B1 passage→C11→C1 passage →C12→ returning to C1 passage (a success)

Route 4: B11→B1 passage→C21→C2 passage →C22→A1 passage (a failure).

Route 5: B11→B1 passage→C21→C2 passage →C22→ returning to C2 passage (a success).

Route 6: B11→B1 passage → returning at C31 (a success).

Route 7 : B11→B1 passage→C31→C3 passage →C32→A1 passage (a failure).

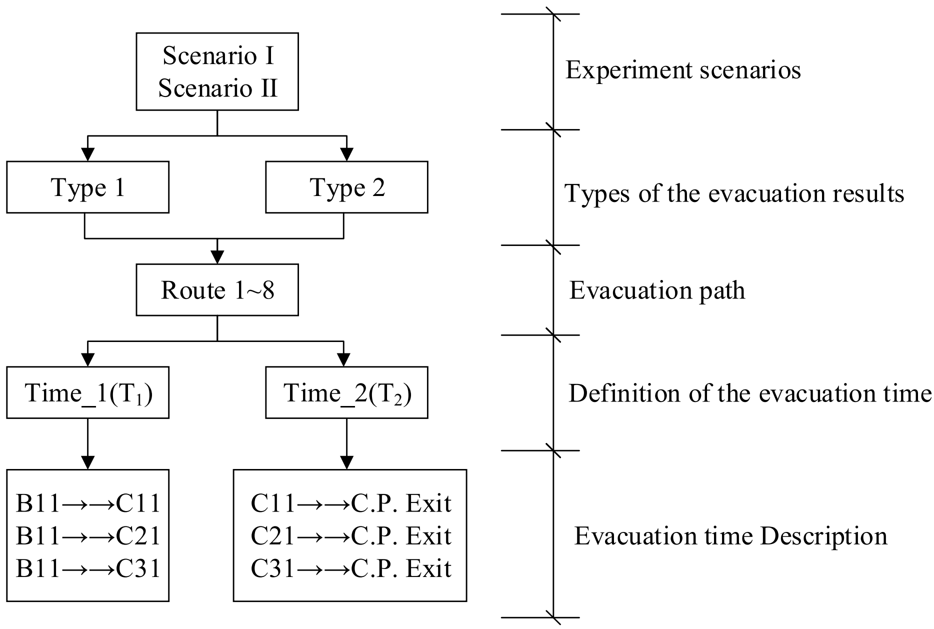
Route 8: B11→B1 passages →C31→C3 passage →C32→ returning to C3 (a success).

Definition of the evacuation time

To effectively control the impact of the sign on evacuation behavior, the evacuation time and node are taken as the control variables applied to the Phase I evacuation behavior (recognition of existing exit signs) and Phase II evacuation behavior (changeable prohibitory exit signs), which are defined as follows:

1. Phase I evacuation time: In the beginning of the experiment, whether it is a directly or repetitively back-and-forth pushing open any of the Exit doors, i.e. B11→→C11or C21 or C31, the time measured is called Phase I first evacuation time of action, based on the existing signs (referred to as Time_1(T1)).

2. Phase II evacuation time: It starts from the tester's pushing any of the passage doors to enter the passage, i.e. entering C11, C21 and C31, until the tester spots the C.P. Exit and takes a turn or returns. This measured time is called reaction time for the recognition of the changeable prohibitory sign (referred to as Time_2 (T2)); and if the tester pushes any of the passage doors to enter the passage (i.e. entering C1, C2 or C3) and then pushes the door to the smoke-filled area (i.e. pushing C12, C22 or C32), the experiment will come to a close as a failure because the sign was not seen, and therefore Time_2 will not be measured.



Note: Time_1(T_1) stands for the time of evacuation from B11 to C11, C21, or C31; Time_2(T_2) stands for the time of evacuation from the C11, C21, or C31 spot to the C.P. Exit and then turning back.

Fig. 6. The diagram of correlation between evacuation time and route

Participants in the experiment

Scenario I has 120 participants and Scenario II has 111 participants, making a total of 231 effective participants (one participant was excluded for his learning recognition disability). The participants consist of students and the general public. In scenario I, there are 81 males (67.5%) and 39 females (32.5%), with 92.5% as the majority in the age range 20-39.In scenario II, there are 84 males (73.7%) and 30 females (26.3%), with 86.8% as the majority in the age range 20-29. None of the testers had color blindness or other eye diseases, and after vision correction, their visual acuity fell between 0.8 and 1.2. Each of the testers took part in the the experiment only once, and was not allowed to observe the performance of the other participants.

The research restrictions

This study is subject to the following restrictions:

1. None of the testers were recruited from the architecture and fire-fighting professions, and therefore the profession criterion was not considered in this study.

2. The testers were mostly aged 20-29 - a highly concentrated group, and hence the age was not considered in this study.
3. The testers were accompanied by 2 followers who wrote down the evacuation time and made a video recording, but gave no evacuation guidance. Therefore, any impact related to the tester's psychological state was excluded.
4. The experiment was carried out in a newly built space, and there were no objects (furniture) in it.
5. The corridor behind the passage installed with the C.P. Exit had simulated smoke diffusion, without being able to take into account the authentic state of mind under a real fire, and therefore the psychological discomfort was a simulation under an experimental scenario, not a real one.
6. This study was designed to discuss the recognition of exit signs, and therefore samples with learning recognition disability were excluded.

RESULTS AND DISCUSSION

After one of the participant samples with learning recognition disability was excluded, the effective samples included 120 testers for scenario I and 111 testers for scenario II, making a total of 231 testers. Whether or not the testers were informed of the meanings of Exit and C.P. Exit was taken as the variables to survey and analyze the testers' recognition of the signs, as well as their first evacuation time (T1) and reaction time (T2). The results are described as follows:

The Phase I evacuation behavior

Analysis of Phase I evacuation behavior (recognition of existing exit signs) lies in the observation of whether the general public understand the existing exit signs as well as their choice of first evacuation direction, behavioral changes after recognition of Exit, and the time needed for Phase I evacuation (T_1). The analysis is described as follows:

1. Choice of first evacuation direction

In the first choice of a direction from the living rooms to corridor, regardless of gender and scenario, 79.2% of all the testers tend to take a left turn, which consists of 79.6% of the males and 78.3% of the females (see Table 1 and Fig. 7). In Scenario I, there is no discrepancy between males and females of all the testers in the first choice of evacuation direction ($p=0.73>0.05$), which indicates that this case is featured with the tendency of turning left (consists of 63.0% of the males and 76.9% of the females), which might be caused by the sign on the left side, which is 1.0m closer than the sign on the right side. However, in Scenario II, the choice of direction reveals a discrepancy (p=0.001) (consists of 96.3% of the males and 80.0% of the females), which shows that after the meanings of the signs are explained, the testers will pay particular attention to reading the signs which therefore changes their behavior. Also, the sign on the left side can be more clearly seen, thus the rate of turning left is higher than in Scenario I.

Table 1. The first evacuation directions

Item		First evacuation directions									
		To the left			Straightforward			To the right			Total
		Count	Individual %	Percentage to Overall	Count	Individual %	Percentage to Overall	Count	Individual %	Percentage to Overall	Count
Overall	M	129	79.6	79.2	6	3.7	3.9	27	16.7	16.9	162
	F	54	78.3		3	4.3		12	17.4		69
Scenario I	M	51	63.0	67.5	6	7.4	7.5	24	29.6	25.0	81
	F	30	76.9		3	7.7		6	15.4		39
Scenario II	M	78	96.3	91.9	0	0.0	0.0	3	3.7	8.1	81
	F	24	80.0		0	0.0		6	20.0		30

Note: (1) Overall is the sum of the two scenarios; 2. for the directions “To the left”, “Straightforward”, and “To the right”, see the Start Point denoted in Figure 5.

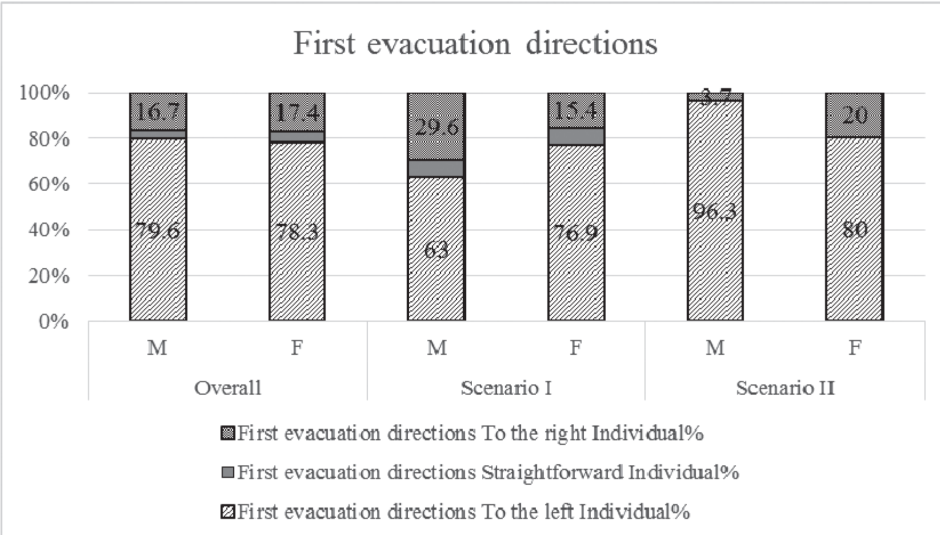


Fig. 7. The first evacuation directions

2. The Phase I evacuation behavior

In Scenario I, the percentage of choosing effective evacuation route is 67.5%, where the male percentage is 70.4% and female 61.5%. In Scenario II, the percentage is 75.7%, where the male is 77.8%, and females 70.0%; for the total testers, the percentage is 71.4%, where the male is 74.1% and female 65.2% (See Table 2 and Fig. 8). The results do not reach a significant level. As for the evacuation time (T1) in Phase I, Scenario I has the maximum value of 107.02 seconds and minimum value of 5.72 seconds, average 14.26 seconds, with a standard error of 16.99, and the maximum value is about 18.7 times the minimum value. Scenario II has the maximum value of 85.33 seconds and minimum value of 7.33 seconds; average 18.30 seconds, with a standard error of 18.57, and the maximum value is about 11.6 times the minimum value. This examination results do not reach a significant level, either.

Comparison of the two scenarios reveals an 8% increase in choosing an effective route and the difference between the maximum and minimum values also decreases. This explains that letting the meanings of the signs be known helps to raise the percentage of effective routes. However, the slight increases of standard error and average value show that some of the samples have lower stability. It is inferred that this has something to do with whether the testers can fully understand the signs explained. For this experiment they are given the sign explanation only once, thus the learning ability of the testers determines their understanding, and some of the testers may have no idea about what the existing exit signs stand for before the experiment.

Furthermore, the examination result reveals that, in both scenarios, gender makes no difference in choosing effective routes. This explains that both genders have a similar ability to understand the exiting signs, probably because they are commonly seen in daily life and, as a result, a single educational instruction is enough to communicate a common understanding of the signs. Of course, giving more time for explanation (education), this should be able to reduce any discrepancy of understanding due to the participants' different learning abilities. Also, it is now known that continuous explanatory propaganda of the meanings of the exit signs is necessary.

Table 2. Phase I evacuation behavior

Item		**Choice of evacuation route**						
		Effective			**Ineffective**			**Total**
		Count	**Individual %**	**Percentage to Overall**	**Count**	**Individual %**	**Percentage to Overall**	**Count**
Overall	M	120	74.1	71.4	42	25.9	28.6	162
	F	45	65.2		24	34.8		69
Scenario I	M	57	70.4	67.5	24	29.6	32.5	81
	F	24	61.5		15	38.5		39
Scenario II	M	63	77.8	75.7	18	22.2	24.3	81
	F	21	70.0		9	30.0		30

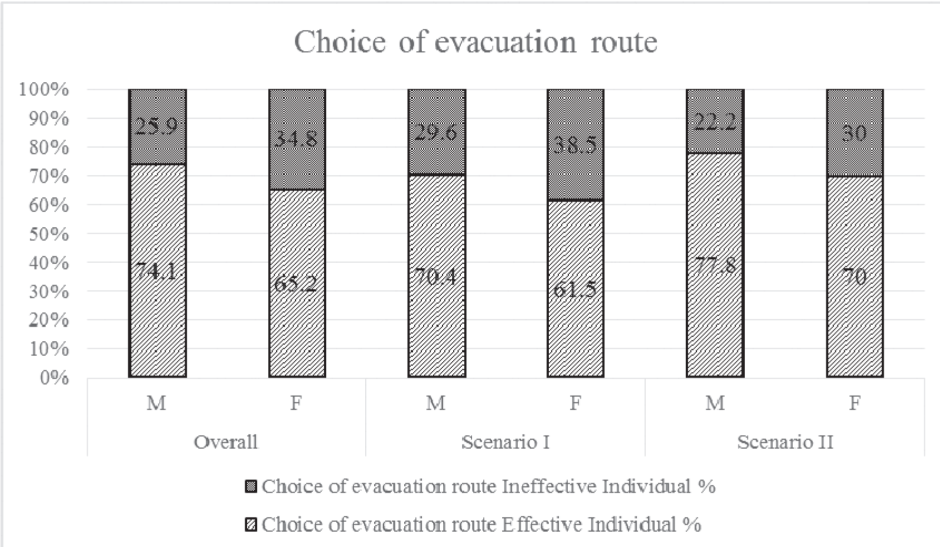


Fig. 8 . Phase I evacuation behavior

Phase II evacuation behavior

On choosing effective evacuation routes (changeable prohibitory exit signs), Scenario I has a 77.5% effective choice, where the male percentage is 77.8% and female is 76.9%; while Scenario II has a 100% effective choice, where both the males and females make 100% effective choices. As for all the participants, the percentage of effective choice is 88.3%, where the male percentage is 88.9% and female is 87% (Table 3 and Figure 9). This proves that after the signs are well explained, the testers can make correct choices of evacuation route with the guidance of the signs, and both the educational information and changeable prohibitory exit signs can reach good results. This outcome is important for the new signs, where those that are difficult to read can bring in negative effects, and signs with different recognitions between males and females need to be redesigned until recognition consensus is reached under different background conditions.

For the reaction time (T_2), Scenario I has the maximum value of 14.52 seconds and minimum value of 2.57 seconds, averaged 5.56 seconds, with a standard error of 2.97, and the maximum value is about 5.6 times the minimum value; while Scenario II has the maximum value of 18.3 seconds and minimum value of 2.35 seconds, averaged 5.34 seconds, with a standard error of 2.95, and the maximum value is about 7.8 times the minimum value. So we know that for the changeable prohibitory exit signs, whether their meanings are explained, all the testers can read and react to the signs similarly, and therefore we can regard the design of the new signs as an initial success, and no redesign is needed, at least for now. However, the use of the signs is essentially about safety and lives, and therefore their legitimacy in different space conditions need more comprehensive experimental verification.

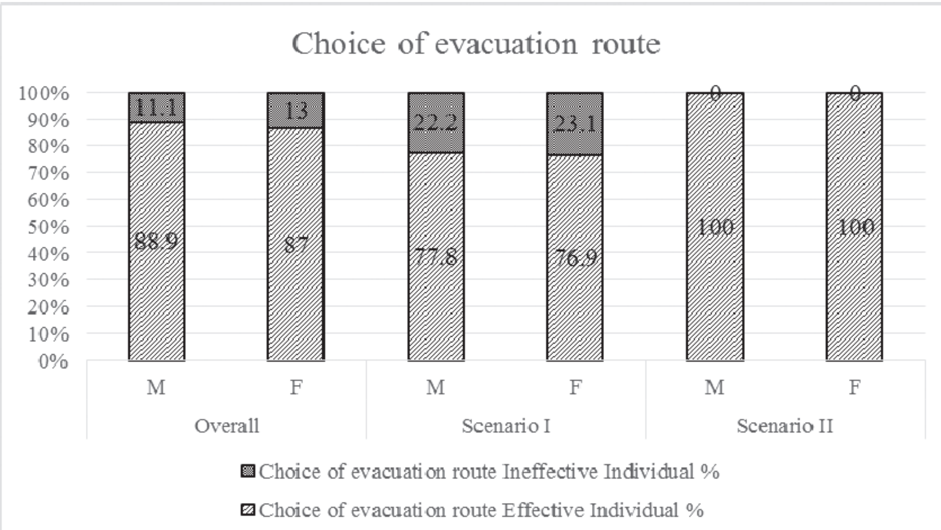


Fig. 9 . Phase II evacuation behavior

The overall evacuation behavior

This study has experimented with current and new signs under two scenarios and determined the correlation between the icon recognition and behavior changes, described as follows:

1. In Scenario I (signs not explained): There are 72 testers who choose effective routes, i.e. 60.0% of all the testers. There are 9 testers whose choice is effective in the first phase and ineffective in the second phase, i.e. 7.5% of the total; and there are 21 testers whose choice is ineffective in the first phase and effective in the second phase, i.e. 17.5% of the total. Meanwhile, there are 18 testers whose choices are wrong in both of phases, i.e. 15% of the whole sample.

2. In Scenario II (signs explained beforehand): There are 84 testers who choose effective routes, i.e. 75.7% of all the testers, and there are 27 testers whose choice is ineffective in the first phase and effective in the second phase, i.e. 23.4% of the total. In fact, in the second phase, all the testers chose effective routes.

3. For the overall 231 testers: There are 156 testers who choose effective evacuation routes in both phases, i.e. 67.5% of all the testers. There are 9 testers whose choices are effective in the first phase and ineffective in the second phase, i.e. 3.9% of the total. There are 48 testers whose choices are ineffective in the first phase and effective in the second phase, i.e. 20.8% of all. Meanwhile, there are 18 testers whose choices are ineffective in both phases, i.e. 7.8% of all; for testers who choose effective routes in both phases, the two appear medium positive correlation (correlation coefficient = 0.307).
4. Regardless of gender, phase, and partial or overall samples, all the testers tend to take left turns.
5. Males have stronger exit sign recognition than females, which meets the ISO accuracy rate of 67%. However, the overall recognition rate of 71.4% is not high enough in dealing with safety and lives. Therefore, more efforts are needed to make the signs highly recognizable to the public.
6. The C.P. Exit recognition accuracy rate meets the ISO standard rate of 67%. As for the recognitions by males and females, whether or not the C.P. Exit signs are explained beforehand, they are almost equal (in Scenario I, the percentage of males is 77.8% and of females is 76.9%; in Scenario II, both males and females are 100% accurate. For the whole group of testers, males are 88.9% correct and females are 87% correct).
7. The participants in the experiment are non-architecture or fire-fighting professionals, thus the factor of profession-related recognition is excluded. However, the gender ratio is imbalanced (in Scenario I, males account for 67.5% and females for 32.5%; in Scenario II, males account for 73.7%, and females for 26.3%). As for the age factor, the overall testers are mostly aged from 20 to 39 (86.8%), a very high concentration, and the experiment records are taken based on the age intervals, without a coherent detailed categorization, making the analysis accuracy not quite reliable. Therefore, it is recommended that in future studies, age should be evenly distributed and the experiment records should break down to each single age.

CONCLUSIONS AND RECOMMENDATIONS

Since inner space of modern architecture is getting more complex, the existing exit signs may not be able to provide intended assistance in fire incidents. Therefore, this study proposes a changeable prohibitory exit sign, which can be automatically actuated by fire detectors in a timely manner and properly change their indication for accurate evacuation guidance. By way of a full-scale space experiment, it is proved that whether the changeable prohibitory exit sign is explained beforehand, the public positively recognize the sign without reading discrepancy. For the evacuation success rate, after the meanings of the signs are explained, it is increased from 77.5% to 100%, showing that the design is initially successful, and has no need for modification. However, as the signs are about safety and lifesaving, more experiments with comprehensive criteria are needed to further verify their efficacy under different space conditions and to make further refinements to them, as required. As for the existing signs, explanation of their meanings beforehand can also make an 8% improvement on the route choosing accuracy - evidence that it is also very important to continue propagating the meanings of the signs.

In addition, based on the node behavioral records, the analysis of behavioral characteristics from the icon recognition reveals that (1) under the space environment of this research, from the living room to corridor, the testers with different backgrounds and under different scenarios tend to take a left turns; (2) in an unfamiliar space, males make a slightly better choice of effective routes than females.

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