Trial Study on Visual Recognition of Cross-channel Indication Signs in Limited-visibility Tunnels

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Abstract. For the problem that evacuation personnel cannot find evacuation location and route quickly and accurately when there is a fire in tunnel, by using eye-tracker to record eye data and selecting X-angle and Y-angle space position indicator to research target awareness, and compared and analyzed the visual recognition, orientation and functionality in different cross-channel indicators at different distances for different groups. The trial results showed that cross-channel indicator signs in existing tunnel lack visual recognition and induction. After adding LED-induced flashing signs and evacuation indicator pattern within green and white edges into cross-channel, visual recognition was improved significantly. Evacuation personnel can better evacuate in condition of limited-visibility and unclear direction and can timely find the evacuation location and escape route so that people can improve self-help ability when there is a fire in tunnel.

1. Introduction

Along with the rapid growth of China's infrastructure construction, tunnel, as the key and special infrastructure among all classes of highway, is a control node project in the process of engineering construction and operation management. By the end of 2018, there are 17,738 highway tunnels in China with a mileage of 17.2661 million meters, including 1,058 extra-long tunnels with 4.706 million meters and 4,315 long tunnels with 7.4218 million meters. The construction area of highway tunnels in China is extensive, ranging from "steep mountains" to "offshore deep-water", with huge scale and diverse forms. Accordingly China has entered a peak period of highway tunnel operation management in large areas. Despite achievements has been made in highway tunnels, we are keenly aware of increasing prominent operation management problems [1-3].

In recent years, Quite a few domestic tunnel accidents have taken place. Due to the particularity of highway tunnel structure, tunnel environment is relatively closed, there is only one safety exit for evacuation in case of emergency. In the event of a fire in the tunnel, rapid spread of smoke will reduce visibility. If escape personnel cannot quickly identify the location of emergency exits, it will result in severe casualties, economic losses and social impact. To avoid and minimize casualties caused by tunnel fire, fire protection measures are taken to prevent fire incidents. In addition, how to accelerate evacuation in the event of a fire is attracting increasing attention [4].
2. Current Situation of Cross-channel Indication Signs in Highway Tunnels

Current codes have set forth technical requirements for tunnel cross-channels and cross-channel signs. Cross channels in a unidirectional double-tube highway tunnel shall be spaced 200-400m apart. Cross channel indication signs shall be installed at the crown or on the right side of the channel, 2.5m above the inspection walkway, and sized at 50cm×80cm. At the same time, electric tunnel signs with indications on double sides are recommended [5-7]. Investigation of fire scenes in recent years and on-site trials show that in the event of a tunnel fire escape personnel tend to be in a panic and attempt to look for exit based on vision, however, the evacuation field of escape personnel’s vision is limited after the fire occurs in the tunnel, which affects the escape personnel’s effective identification of evacuation exit sign. Then escape personnel are unable to identify the location of emergency exits and escape routes. This leads to disorderly evacuation and rare successful evacuation by identifying cross-channel indication signs. Clearly, existing design of cross channel signs cannot meet evacuation requirements as narrow visual field. There is consequently an urgent need to design a new cross channel sign in respect of visual recognition, orientation and functionality taking into account actual application scenario [8-10].

3. Visual Recognition Criteria for Indication Signs in Tunnels

In this trial test personnel's eye movement data will be collected by using eye-tracker according to parameters selected based on domestic and foreign literature, considering representative of trial objective and parameters. Spatial position of reflex index in X and Y angles are selected from testing personnel's angle of view is to reflect their recognition of the target. X angle is test personnel's horizontal rotation angle relative to the head; Y angle is test personnel’s vertical rotation angle. The combination of X and Y angles is the spatial position coordinates of test personnel's point of view [11]. Currently, there are three main methods for eye tracker data processing by domestic and foreign researchers. The first method is making an analysis of the data by the artificial division of the field of view; the second one is replaying videos for frame-by-frame statistics; the third one is dividing field of view based on view data clustering analysis and making an analysis of the data. Taking account of study purpose, data processing feasibility and convenience, the first method which involves artificial division of field of view is selected. On-site test personnel's field of view is divided into 6 zones, namely left near field, left far field, near field ahead, far field ahead, right far field and left near field, as shown in Figure 1. Schematic diagram of field of view division for trial. The basis of the division is given in Table 1 Division of field of view for trial and analysis [12-15].

![Figure 1. Schematic diagram of field of view division for trial](image_url)
Table 1. Division of field of view for trial and analysis

| Division of field of view | X angle (°) | Y angle (°) |
|---------------------------|------------|------------|
| Left                      |            |            |
| Near field                | Y < -X (X ≤ -20) | |
| Far field                 | Y > -X (X ≤ 20) | |
| Ahead                     |            |            |
| Near field                | -20 < X < 20; 0 ≤ Y < 20 | |
| Far field                 | -20 < X < 20; Y ≥ 20 | |
| Right                     |            |            |
| Near field                | Y < X (X ≥ 20) | |
| Far field                 | Y > X (X ≥ 20) | |

4. Trial Program

4.1. Design of cross-channel indication signs in tunnels

To address problems of tunnel evacuation, this trial based on static and dynamic states is to test the identifiability, conspicuousness and functionality of cross-channel indication signs. The trial is divided into two projects of cross-channel evacuation signs. The first project is cross-channel indicator and LED strobe guidance sign. In this project, LED strobe guidance sign is set up for on either side of the cross channel with evacuation patterns of white edge lines drawn within 10m of the cross channel. The second project is conventional electro-optic indication sign in tunnel for pedestrian. Color patterns within 10m of the cross channel are illustrated in Figure 2. An example of cross-channel signs on trial site is given in Figure 3.

![Figure 2. Schematic of color patterns within 10m of cross channel](image)

![Figure 3. Example of cross-channel signs on trial site](image)

4.2. Trial environment and sample

In order to truly represent an evacuation scenario and avoid interfering with the trial data, 1:1 tunnel system is selected as the trial site and smoke cakes are used to create a limited-visibility environment in the event of a tunnel fire by generating smoke. The main purpose of the trial is to test the actual
effect of various cross-channel signs on people's visual recognition and functionality under different conditions; and actual tunnel occupants are highly random. Therefore, in this trial college students aged 19-24 in a male/female ratio of 6:4 are selected as test personnel [16].

4.3. Trial conditions and procedures
Based on the abovementioned two projects of cross-channel indication signs, 4 trial conditions are proposed, namely no smoke + cross-channel indication sign + LED strobe guidance sign (condition 1), no smoke + cross-channel indication sign (condition 2), smoke + cross-channel indication sign + LED strobe guidance sign (condition 3) and smoke + cross-channel indication sign (condition 4), as shown in Table 2 Trial conditions.

| S/N  | Observation distance/m | Tunnel environment condition |
|------|-------------------------|------------------------------|
| Condition 1 | 20, 50, 100 and 120 | Without smoke |
| Condition 2 | 20, 50, 100 and 120 | Without smoke |
| Condition 3 | 20, 50, 100 and 120 | With smoke |
| Condition 4 | 20, 50, 100 and 120 | With smoke |

Data are acquired on site by two means: 1) Eye movement parameters are measured as test personnel with eye-tracker approaches the cross-channel emergency exit, and the distance that test personnel initially identify the cross-channel sign is recorded; 2) Test personnel are asked to fill in a questionnaire to provide information at different distances to the cross channel under different conditions. The questionnaire includes three aspects of horizontal channel indicator signs, namely, identification, significance and functionality. Each survey is divided into five levels. Figure 4 shows an eye-tracker used in the on-site trial.

![Eye-tracker](image)

Figure 4. Eye-tracker for on-site trial

| Identifiability | Conspicuousness | Functionality |
|-----------------|-----------------|---------------|
| A. Most clear (all details of the sign such as character and edge are clearly visible) | A. Very conspicuous (very easy to discover at first glance) | A. Most comprehensible (very easy to understand its meaning) |
| B. Clear (details on lighting fixture panel are visible) | B. Conspicuous (easy to discover with a little attention) | B. Comprehensible (easy to understand and can affirm) |
| C. Relatively clear (image features identifiable) | C. Relatively conspicuous (can be discovered with much attention) | C. Relatively comprehensible (roughly comprehensible with some effort) |
| D. Fuzzy (image features hard to identify) | D. Inconspicuous (not easy to discover; easy to ignore) | D. Incomprehensible (not easy to understand the meaning of the sign but can be guessed) |
| E. Not identifiable (image not visible) | E. Very inconspicuous (cannot be discovered) | E. Vague (totally incomprehensible) |
Based on trial safety, data accuracy and effectiveness, the trial procedures are as follows: (1) introduce trial purpose and precautions to test personnel and record test personnel’s basic information including uncorrected and corrected visual acuity; (2) Test personnel wears eye-trackers and adjusts equipment parameters and prepares for trial data recording. 3) Test personnel with eye-trackers approaches the emergency exit from 120m away; (3) A total of 20 test personnel are divided into 4 groups (A, B, C and D) of 5 members. Each group performs the trial under different conditions in the following sequence: Conditions 1, 2, 3 and 4 for Group A; Conditions 2, 1, 4 and 3 for Group B; Conditions 3, 4, 1 and 2 for Group C; Conditions 4, 3, 2 and 1 for Group D.

5. Trial Results and Analyses

5.1. Condition 1: no smoke + cross-channel indication sign + LED strobe guidance sign
From eye-tracker data and questionnaire survey it is known that under Condition 1 most test personnel identified the cross-channel indication sign and LED strobe guidance sign at a distance of 100m, as shown in Figure 5. Over 60% of test personnel considered that basic features of the signs are relatively identifiable at a distance of 80m from the cross-channel sign + LED strobe guidance sign. Over 60% of test personnel considered that basic features of the signs are relatively conspicuous at a distance of 120m from the cross channel. Statistics of identifiability and conspicuousness of cross-channel sign + LED strobe guidance sign in the tunnel are given in Figure 6.

![Figure 5. A test person's eye-tracker data under Condition 1](image)

![Figure 6. Statistics of identifiability and conspicuousness under Condition 1](image)

5.2. Condition 2: no smoke + cross-channel indication sign
From eye-tracker data and questionnaire survey it is known that under Condition 2 most test personnel identified the cross-channel indication sign at a distance of 80m, as shown in Figure 7. Over 60% of test personnel considered that basic features of the signs are relatively identifiable at a distance of 60m from the cross-channel sign + LED strobe guidance sign. Over 60% of test personnel considered that basic features of the signs are relatively conspicuous at a distance of 100m from the cross channel. Statistics of identifiability and conspicuousness of the cross-channel sign in the tunnel are given in Figure 8.
Figure 7. A test person's eye-tracker data under Condition 2

Condition 2: no smoke + cross-channel indication sign

Identifiability statistics

Conspicuousness statistics

Figure 8. Statistics of identifiability and conspicuousness under Condition 2

5.3. Condition 3: smoke + cross-channel indication sign + LED strobe guidance sign

From eye-tracker data and questionnaire survey it is known that under Condition 3 most test personnel identified the cross-channel indication sign and LED strobe guidance sign at a distance of 40m, as shown in Figure 9. Over 60% of test personnel considered that basic features of the signs are relatively identifiable at a distance of 60m from the cross-channel sign + LED strobe guidance sign. Over 60% of test personnel considered that basic features of the signs are relatively conspicuous at a distance of 80m from the cross channel. Statistics of identifiability and conspicuousness of cross-channel sign + LED strobe guidance sign in the tunnel are given in Figure 10.

Figure 9. A test person's eye-tracker data under Condition 3
5.4. Condition 4: smoke + cross-channel indication sign
From eye-tracker data and questionnaire survey it is known that under Condition 3 most test personnel identified the cross-channel indication sign only at a close distance, as shown in Figure 11. Over 60% of test personnel considered that basic features of the signs are relatively identifiable at a distance of 40m from the cross-channel sign. Over 60% of test personnel considered that basic features of the signs are relatively conspicuous at a distance of 60m from the cross channel. Statistics of identifiability and conspicuousness of the cross-channel sign in the tunnel are given in Figure 12.

Figure 12. Statistics of identifiability and conspicuousness under Condition 3

6. Conclusions
- Existing cross-channel indication signs in tunnels provide insufficient visual recognition and guidance. Even though escape personnel notice the existing cross-channel indication signs, they cannot confirm the functionality of them.
- Adding LED strobe guidance signs and evacuation indicator pattern within green and white edges at the cross channel, the trial shows that visual recognition of emergency exit in the tunnel is significantly improved, thereby it can help escape personnel locate emergency exits and escape routes in the event of a tunnel fire leading to limited-visibility and unclear direction.
3) With a lack of traffic safety education in tunnels, escape personnel have a poor understanding of safety facilities in the tunnel. Consequently, more efforts are required to improve universal education of tunnel safety facilities.

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