Effective Visual Behavior of Railway Drivers for Recognition of Extraordinary Events

Daisuke SUZUKI
Ergonomics Laboratory, Human Science Division

Kana YAMAUCHI
Safety Psychology Laboratory, Human Science Division

Satoru MATSUURA
Hokkaido Railway Company

The purpose of this study is to investigate visual-searching behaviors that are effective for recognizing the extraordinary events based on the eye movements of railway drivers. Track subsidence ahead of drivers was set as an extraordinary event. Two driving scenarios were associated with this extraordinary event, namely high velocity (approximately 90 km/h) and low velocity (approximately 15 km/h). In the high velocity driving scenario, drivers that maintained a longer gaze during each visual search recognized the subsidence easily. In the low velocity driving scenario, drivers that had a wider gazing angle in the horizontal direction during each visual search recognized the subsidence easily.

Keywords: extraordinary event, recognition, visual behavior, driving simulator

1. Introduction

Railway drivers are required to cope with various extraordinary events such as vehicle problems, signal troubles and ground-device malfunctions. Railway companies often conduct vocational-training sessions using a driving simulator to improve drivers’ skills in coping with extraordinary events [1]. When focusing on the manner in which drivers recognize such extraordinary events, visual searching is crucial.

There have been several studies about the visual-searching practices of railway drivers. Groeger et al. [2] investigated the visual behaviors of 10 train drivers and showed that approximately 50% of the time spent approaching signals was used to scan the visual scene. The remaining time was spent fixating on railway signage and infrastructure, locations beside the track and signals. Luke et al. [3] analyzed the visual behaviors of 86 drivers whilst operating in-service trains, revealing that the color of the signal, the color of the next signal, signal type and signal complexity were important factors affecting these behaviors. Naweed et al. [4] examined the tasks and activities of urban passenger-train drivers during daily railway driving in order to understand the nature of the visual demand in their task activities. Their study showed that railway driving in an urban environment requires a mastery of key visual and technical driving skills. Although there have been studies on visual searching in the course of ordinary railway-driving situations, few have examined the relationship between visual searching and recognition of extraordinary events.

In the field of automobile research, there have been several studies attempting to correlate visual searching and drivers’ skill levels. Mourant et al. [5] investigated differences in visual searching by novice and experienced drivers. According to their results, novice drivers frequently sampled the curb in order to verify or estimate vehicle-lane alignment, whereas experienced drivers looked farther than novices. Underwood et al. [6] identified the fixation-sequence modes of drivers with different levels of experience to answer the question of whether their different accident liabilities can be associated not only with their distribution of attention but also with the subject of their attention. Differences in sequences of fixations were found between novice and experienced drivers on the three types of roads (rural, suburban and dual-carriageway), with experienced drivers showing greater sensitivity overall and with some stereotypical transition in the visual attention of the novices. Konstantopoulos et al. [7] focused upon experiential differences in visual attention. The results showed that driving instructors had an increased sampling rate, shorter processing time and broader scanning of the road than did learner drivers. This broader scanning of the road may be explained by the mirror-inspection pattern, which revealed that driving instructors fixated more on side mirrors than did learners.

In this way, these studies indicated that experiential differences led the differences of drivers’ visual-searching behaviors. It is important to examine the relationship between such behaviors and the recognition of extraordinary events. Therefore, the purpose of this study is to investigate effective visual-searching behaviors in terms of recognizing extraordinary events based on the eye movements of railway drivers in the two driving scenarios of high velocity (approximately 90 km/h) and low velocity (approximately 15 km/h).

2. Examination in the high velocity driving scenario

2.1 Method

2.1.1 Apparatus

An analysis was made of simulator-training data for actual drivers. Figure 1 shows a railway-driving simulator
for vocational training made by the Mitsubishi Precision Company, Ltd. An eye tracker equipped with the simulator measured the drivers’ eye movements. Calibration was conducted before the measurement. The sampling rate of the eye tracker was 30 Hz. The front view appeared on a 42-inch display of width 930 mm and height 520 mm. The distance between the display and the driver’s eye point was 900 mm. The visual angle of the display was 54.7° (horizontal angle) and 32.2° (vertical angle).

Overall, 121 drivers of a railway company participated in our study; the ages of these drivers ranged from 23 to 59 years (the mean was 41 and standard deviation was 11 years). The driving experience of the participants ranged from 1 to 33 years (the mean was 16 and standard deviation was 8 years). They participated in our study during periodic training taking place once every six months.

2.1.2 Participants

A multi-task driving scenario was given, with the main task being to stop the simulated train before a ground-device malfunction (Fig. 2). The participants were provided with an operating statement of ground-device malfunction before station Z at station Y. In this task, participants were required to focus on distance posts on their left to identify the exact location to stop. The important sub-task was to recognize an extraordinary event during traveling approximately 90 km/h, namely the subsidence of the railway track on their right (Fig. 3). Participants were required to brake if they recognized this subsidence. In addition, the participants continued driving up to the location of ground-device malfunction.

2.1.4 Analysis method

Participants who braked before passing the subsidence were identified as part of the recognizing group (RG), and those who did not brake until after passing the subsidence were identified as part of the non-recognizing group (NG).

Data related to eye movements were recorded using a contactless eye tracker incorporated into the driving simulator. Data were classified as a ‘gaze’ if four or more subsequent frames (0.133 s) were observed with the same point of regard. The gazes were extracted using the Sight Tracker Editor software made by Emovis Corporation.

Gaze analysis began approximately 30 seconds before the subsidence, where the participants had not yet recognized it. The gazes of 66 participants whose eye movements were detected accurately by the eye tracker were analyzed to obtain gaze durations and gaze angles.

2.2 Results

No participant failed to stop the simulated train before the location of ground-device malfunction, which was the main task. The number of participants who recognized the subsidence (RG: recognizing group) was 91 (75%), and the number who did not recognize (NG: non-recognizing group) was 30 (25%). Among the 66 participants whose gazes were analyzed, the number in the RG was 47 (71%), and that in the NG was 19 (29%).

Figure 4 shows the mean gaze duration. The mean
gaze duration in the RG was 1.0 second and 0.6 seconds in the NG. A t-test showed that the mean gaze duration in the RG was significantly longer than in the NG ($p < 0.05$). Figure 5 shows mean standard deviation of gaze duration. The standard deviation of gaze duration in the RG was 1.3 seconds and in the NG was 0.6 seconds. The t-test showed that the standard deviation of gaze duration in the RG was significantly larger than in the NG ($p < 0.05$).

Figure 6 shows the mean horizontal gaze angles. The mean horizontal gaze angle in the RG was -2.1 degrees and -3.6 degrees in the NG. The t-test showed that the mean horizontal gaze angle in the NG was significantly more to the left than in the RG ($p < 0.05$). Figure 7 shows mean standard deviation of the horizontal gaze angle. The standard deviation of the horizontal gaze angle in the RG was 3.3 degrees and 3.6 degrees in the NG. The t-test showed that there was no significant difference between the two.

Figure 8 and 9 are examples of gaze points in the RG and NG. Horizontal axis represents the horizontal gaze angle. The vertical axis represents the gaze duration. Both groups gazed ahead for a long time and left/right for a short time. These visual behaviors indicate that drivers gazed far away for a long time and at traffic lights or signage for a short time. According to the characteristics of both groups, there were long gazes and short gazes in the RG. On the other hand, there were few long gazes in the NG. Gaze angles in the NG were more to the left than that in the RG. In addition, the same tendency was found among other drivers.
2.3 Discussion

In the high velocity driving scenario, gaze duration in the RG was longer than in the NG. Dispersion of gaze duration in the RG was larger than in the NG. The RG gazed far away ahead. A good balance between long and short gazes was an important factor in recognizing the extraordinary event while scanning for a number of other visual targets.

With regard to gaze angle, drivers with a tendency to look to their lower left were usually unable to recognize the subsidence. More specifically, overlooking the subsidence could be attributed to excessively concentrating on the distance posts (which were on the left) because the subsidence was on the right in the driving scenario of this study. The drivers needed to look at the distance posts in order to cope with the ground-device malfunction.

These findings suggest that excessively concentrating on an existing extraordinary event can cause drivers to overlook a potential secondary extraordinary event. In a high velocity driving scenario, the effective visual-search behavior for recognizing an extraordinary event is to mix long and short gazes to search in front and confirm features to the right and left.

3. Examination in the low velocity driving scenario

3.1 Method

3.1.1 Apparatus

The same railway-driving simulator with eye tracker described in chapter 2 was used.

3.1.2 Participants

Overall, 128 drivers of a railway company participated in the study; the ages of these participants ranged from 24 to 65 years (mean was 41 and standard deviation was 12 years). The driving experience of the participants ranged from 0 to 31 years (mean was 14 and standard deviation was 7 years). They participated in our study as part of their periodic training once every six months.

3.1.3 Driving scenario

The main-task of the low velocity driving scenario was to cope with 4 extraordinary events consecutively (Fig. 10). They were stop aspect before a station, sudden change in exit signal aspect, presence of workers on the track, and malfunction of a signal. The important sub-task was to recognize the subsidence of the railway track on their right (Fig. 3) during acceleration from approximately 15 km/h after coping with the 4 extraordinary events. Participants were required to brake if they recognized this subsidence.

3.1.4 Analysis method

The same analysis method as described in chapter 2 was applied. Participants who braked before passing the subsidence were identified as part of the recognizing group (RG), and those who did not brake until after passing the subsidence were identified as the non-recognizing group (NG).

Gaze analysis began approximately 30 seconds before the subsidence, where the participants had not yet recognized it. The gazes of 73 participants whose eye movements were detected accurately by the eye tracker were analyzed to obtain gaze durations and gaze angles.

3.2 Results

The number of participants who recognized the subsidence (RG: recognizing group) was 85 (66%), and the number who did not recognize (NG: non-recognizing group) was 43 (34%). Among the 73 participants whose gazes were analyzed, the number in the RG was 51 (70%), and that in the NG was 22 (30%).

Figure 11 shows mean gaze durations. Mean gaze duration in the RG was 0.7 second and in the NG was 0.7 second. The t-test showed that there was no significant difference between the two. Figure 12 shows mean standard deviations of gaze duration. The standard deviation of gaze duration in the RG was 0.8 second and in the NG was 0.8 second. The t-test showed that there was no significant difference between the two.

Figure 13 shows mean horizontal gaze angles. The mean horizontal gaze angle in the RG was -2.9 degree and
in the NG was -3.0 degree. The $t$-test showed that there was no significant difference between the two. Figure 14 shows the mean standard deviation of horizontal gaze angles. The standard deviation in horizontal gaze angle in the RG was 4.5 degree and 3.5 degree in the NG. The $t$-test showed that the standard deviation of the horizontal gaze angle in the RG was significantly larger than in the NG ($p < 0.05$).

Figure 15 and 16 show examples of gaze points in the RG and the NG. As in chapter 2, the horizontal axis represents horizontal gaze angle and the vertical axis represents gaze duration. It was found that the horizontal gaze range in the RG was larger than in the NG and there was no difference in gaze duration. In addition, the same tendency was found among other drivers.

![Mean standard deviation of horizontal gaze angle in the low velocity driving scenario](image1)

**Fig. 14** Mean standard deviation of horizontal gaze angle in the low velocity driving scenario

![Mean gaze durations in the low velocity driving scenario](image2)

**Fig. 11** Mean gaze durations in the low velocity driving scenario

![Mean standard deviations of gaze duration in the low velocity driving scenario](image3)

**Fig. 12** Mean standard deviations of gaze duration in the low velocity driving scenario

![Mean horizontal gaze angles in the low velocity driving scenario](image4)

**Fig. 13** Mean horizontal gaze angles in the low velocity driving scenario

### 3.3 Discussion

In the low velocity driving scenario, the horizontal gaze range in the RG was larger than in the NG. Drivers in the RG gazed at the landscape or the railway track in addition to ahead area. Wide movement in the gaze point was important for drivers to be able to confirm a number of visual targets and recognize the extraordinary event. Given the subsidence appeared after the stretch with various extraordinary events and driving at 15 km/h or less, drivers in the NG may have concentrated too much on accelerating.

These findings suggest that imbalanced gaze distribution can cause drivers to overlook an extraordinary event. In a low velocity driving scenario, the effective visual-search behavior for recognizing an extraordinary event is sweeping, moving the gaze point from right to left.
4. Conclusions

The purpose of this study was to clarify the difference in the visual behavior of drivers who recognized and or did not recognizing an extraordinary event. A high and low speed scenario were set. In the high velocity driving scenario, the recognizing group gazed far away with long time gazes. In the low velocity driving scenario, the recognizing group gazed widely with short gazes. These findings are useful to educate drivers how to orientate their gaze whilst driving.

In the future this study will focus on how an effective feedback method of gaze data can be used to educate effective visual-searching behaviors.

References

[1] Endoh, H., Omino, K., “Practical system for implementing vocational training program for improving train driver skills for coping with abnormal situations,” Quarterly Report of RTRI, Vol. 54, No. 4, pp. 237–242, 2013.

[2] Groeger, J.A., Bradshaw, M.F., Everatt, J., Merat, N., Field, D., “Pilot study of train drivers’ eye-movements,” University of Surrey Technical Report for Rail Safety and Standards Board, London, 2003.

[3] Luke, T., Brook-Carter, N., Parkes, A.M., Grimes, E., Mills, A., “An investigation of train driver visual strategies,” Cognition, Technology & Work, Vol. 8, No. 1, pp. 15–29, 2006.

[4] Naweed, A., Balakrishnan, G., “Understanding the visual skills and strategies of train drivers in the urban rail environment,” Work, Vol. 47, pp. 339–352, 2014.

[5] Mourant, R.R., Rockwell, T.H., “Strategies of visual search by novice and experienced drivers,” Human Factors, Vol. 14, No. 4, pp. 325–335, 1972.

[6] Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., Crundall, D., “Visual attention while driving: sequences of eye fixations made by experienced and novice drivers,” Ergonomics, Vol. 46, No. 6, pp. 629–646, 2003.

[7] Konstantopoulos, P., Chapman, P., Crundall, D., “Driver’s visual attention as a function of driving experience and visibility,” Accident Analysis and Prevention, Vol. 42, pp. 827–834, 2010.

Authors

Daisuke SUZUKI, Ph.D.
Senior Researcher, Ergonomics Laboratory,
Human Science Division
Research Areas: Safety Ergonomics, Human Factors

Kana YAMAUCHI, Ph.D.
Senior Chief Researcher, Head of Safety Psychology Laboratory, Human Science Division
Research Areas: Psychometrics, Educational Psychology

Satoru MATSUURA
Senior Staff, Transport Department, Hokkaido Railway Company
Research Areas: Driver's Instruction