Research on Specific Eye Movement Mode of Qualified Railway Driver

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Abstract: The eye movement mode is one of the core indicators of train driving, and it represents the pros and cons of the driver's driving behavior. In order to gain a deeper understanding of the specific eye movement patterns of qualified drivers during driving, this study compared the eye movement indicators and patterns of 8 qualified drivers and 12 unqualified drivers (intern drivers) on a simulated driving assignment. The results show that qualified drivers put more cognitive processing on the track ahead, while the intern drivers are more interested in the driving monitoring interface; qualified drivers put more attention on the net voltmeter gauge and speedometer, wind pressure gauge, CIR operation terminal. And qualified drivers view the check signal lights more. Through the Markov clustering algorithm, it is found that the qualified driver group performs “the clustering mode centered on the ahead track” stably, while the intern driver group performs “the clustering mode centered on the driving monitoring interface” less stably. These conclusions will provide a theoretical basis for the subsequent research on “improving driver training system”.

1. Introduction

Train driving is a task that requires a lot of visual participation, and has higher requirements for drivers' attention and distribution. The driver needs to pay attention to all the inside and outside of the locomotive in the high-speed train at the same time, ensuring that the current position, speed and
acceleration are under control, predicting the future demand, and immediately responding to the unpredictable events which have no rules in the external environment[1]. The current research suggests that: (1) Driving a train requires a sensing strategy that is skilled in handling multiple mission requirements in a limited time[2]; (2) More than 78% of the train driver's gaze time is about road conditions, especially the road in front of the train and signals on both sides of the road[3]; (3) In the cab, the train drivers focus more on the speed meter and timetable[4]; (4) Compared with the younger drivers, the older drivers see the instrument for less time and the total line of sight is shorter[5].

We believe that the eye movement pattern should be one of the core physiological indicators to distinguish the driver's driving behavior. Therefore, finding a specific eye movement mode in a qualified driver's driving is one of the direct means to analyze and study driving behavior, but there are still few studies involved. In this paper, the qualified drivers and unqualified drivers (intern drivers) were tested, and their visual behavior during the simulated driving process was studied to find the difference between the two eye movement patterns, so as to analyze the unique eye movement patterns of qualified driver, and provide a theoretical basis for the follow-up "improvement of driver training methods".

2. Material and Methods

2.1. Research subjects

Eight qualified train drivers (1 high-speed rail drivers, 7 electric locomotive drivers) and twelve intern drivers were randomly selected at the Zhengzhou Railway Bureau. Qualified drivers have a driving age of 3-5 years, an average of 4.2 years; unqualified drivers are intern drivers, they all have train simulator driving experience, but have not completed the actual driving process independently (hereinafter referred to as "intern driver"). The ages of the two groups were qualified drivers (25.38±2.20) years old and internship drivers (23.42±1.73) years old. There was no significant difference between the two groups (T=2.12, p>.05).

2.2. Research tools

HXD3C locomotive simulation training system: It can simulate driving in about 20 minutes. During the driving process, there will be driving tasks such as signal speed control, lifting bow, whistle and effect parking.

Framed Eye Tracker Tobii Glass 2: Includes both the headset and the recorder, operating with computer control software. During the experiment, the driver wears the eye tracker for the entire simulated driving process.

2.3. Research design

On the simulated driving platform, the participants first carried out the driving practice of the 171 line (about 20 minutes) and were familiar with the equipment. Subsequently, the participants wore the eye movement recorder and carried out an experimental operation of the analog driving of the 173 line (about 20 minutes). In order to prevent the practice effect, the 171 line and 173 line settings are different.

2.4. Indicator measurement

During the experiment, the eye tracker will track and record the driver's viewpoint, eye-jumping process and eye-tracking trajectory at 30 frames per second. In order to study the driver's attention to different areas, the author manually encoded the instruments in the locomotives and the regions of road condition into 20 areas of interest (see Table 1). The experiment will record the following eye movement indicators of the driver: the first visit time point, the fixation count, the total fixation duration, the average fixation duration, the activities of eye movement and so on. At the same time, the author checks each driver's attention point by frame, and obtains the eye hopping sequence and eye movement trajectory of each driver in different interest areas (see Figure 1). By comparing the
sequence of interest areas, the eye hopping sequence is encoded as a random matrix and graphically represented (see Figure 2). The nodes in the figure represent different AOIs, the weight of the lines connecting the pair of points is proportional to the probability of saccades between them.

Table 1. Areas of Interest (AOIs) sequence

| i  | AOI                                           | i  | AOI                                           |
|----|----------------------------------------------|----|----------------------------------------------|
| 1  | The track ahead                              | 11 | Department ticket                            |
| 2  | The wind pressure gauge                      | 12 | Department flag                              |
| 3  | The net voltmeter and speedometer            | 13 | Signal light                                 |
| 4  | The driving monitoring interface             | 14 | Signal board                                 |
| 5  | The traction gauge                           | 15 | Driving performance tips                     |
| 6  | CIR operation terminal                       | 16 | Timing tips                                  |
| 7  | Horn and brakes                              | 17 | The tips of raise or drop pantograph         |
| 8  | The area of pantograph, cylinder pressure indicator, light switch | 18 | Reminder                                     |
| 9  | Driver controller                             | 19 | Parking pole                                 |
| 10 | The check signal light                       | 20 | Platform                                     |

2.5. Data processing

2.5.1. Data processing tool

The eye movement trajectory sequence collected in this study was processed by Markov clustering algorithm (MCL algorithm) using Matlab mathematics software, and the eye movement data was analyzed by SPSS14.0.

2.5.2. The MCL algorithm description

The MCL algorithm (van Dongen, 2000, 2008) is an unsupervised graph clustering algorithm using random walk. Eye tracking images are often difficult to observe and often use qualitative analysis, while the MCL algorithm calculates clustering of each gaze hot spot according to the saccade probability between the gaze hot spots on the picture to illustrate the eye movement mode. Markov found that if there are multiple linked dense areas between random access nodes on the graph, they
might stay in that area instead of moving between areas with fewer links. If the nodes on a graph walk randomly several times, such a group of nodes will form a cluster in the graph. The MCL process simulates the process of random walks, and strengthens or weakens the current activity through expansion and inflation to find the cluster structure in the graph. Expansion refers to the use of the usual matrix product to obtain the power of the matrix, that is, through the product to calculate the probability of walking between nodes after the constant \( e \) times of random walk. The connection between different clustering regions can be enhanced by extension. In a random walk probability matrix \( M \in \mathbb{R}^{m \times m} \) (\( m \) nodes in the graph), the \((p,q)\)th element in \( M^e \) represents the probability of walking from node \( p \) to node \( q \) through the constant \( e \) times. The process of \( e \)-power simulates the expansive flow of random \( e \)-walking. If \((M^e)_{pq}\) is large only if both \( p \) and \( q \) are located in the same dense region of the graph, then \( e \) must be small. Therefore, the parameter \( e \) is usually set to 2. In order to avoid invalid extensions during the expansion process, a self-loop is added to the diagonal elements. However, the phenomenon of probability averaging may occur through expansion, so the process of inflation is required. Inflation is inflating each value in the probability matrix by \( r(>1) \) power, which strengthens the tight points and weakens the loose points. The mathematical definition of inflation is as follows, assuming a random matrix \( M \) and a non-negative real number \( r \), the matrix after the inflation process is \( \Gamma_r(M) \).

\[
\Gamma_r(M)_{pq} = (M_{pq})^r / \sum_{i=1}^{m}(M_{iq})^r
\]

\( \Gamma_r \) gives the inflation operator, and the power coefficient \( r \) is called the inflation parameter. For values where \( r \) is greater than 1, inflation will change the probability and tend to be more likely to walk. The effect of the inflation operator can be changed by different \( r \) settings. Increasing the inflation parameter can make the inflation operator stronger, thereby increasing the particle size or tightness of the cluster. Each step of the MCL process defines a random matrix. The iterative steps of expansion and inflation will eventually lead to the separation of the graph into different segments without paths, and the resulting set of segments is interpreted as a cluster of graphs.

In this study, the obtained driver's eye movement trajectory is processed by the sequence of AOIs, and then regions a random matrix, and Markov clustering algorithm is applied to it. The non-diagonal elements in the matrix are obtained by calculating all the saccades of different interest regions in the sequence and scaling each column to obtain a sum of 1, that is, the \((i, j)\)th element represents the probability from a region of interest (AOI \( j \)) to another region of interest (AOI \( i \)). As a self-loop, the diagonal element is the ratio of the average fixation duration of each AOI to the average fixation duration of all AOIs. Figure 2 shows the random matrix graph of the driver's D1 eye trajectory map (no self-loop). The nodes in the graph represent different AOIs, and the line weights between the nodes are proportional to the saccade frequency between them. As shown, all eye movement trajectories contain overly complex transformation structures and cannot find any meaningful patterns. The MCL algorithm can analyze the complex eye movement trajectory in the driving process through the cluster structure to extract important eye movement patterns.

3. Results

3.1. Qualitative analysis

3.1.1. Comparison of eye movement hot spots between qualified drivers and intern drivers
Through the hot point maps of the fixation count and the total fixation duration in different driving experience groups (see Fig. 3 and Fig. 4), it shows that the main visual gaze point of the qualified driver during the driving process is on the track ahead and driving monitoring interface. However, there are still differences between the two groups with different experiences in the focus of the hot spot. The qualified drivers focus obviously more on orbital observation than the intern drivers. It shows that experienced drivers spend more cognizance on external environmental observations, while inexperienced drivers tend to focus on the driving monitoring interface.

3.1.2. Comparison of eye movement track between qualified drivers and intern drivers

Due to the long monitoring time and large amount of data, the overall trajectory of the driver's eye movement is confusing (see Figures 5 and 6). However, it shows that the qualified driver's eye movement trajectory has a smaller radiation area and the target is more clearly.

3.2. Quantitative analysis of eye movement data

3.2.1. Analysis of variance of eye-moving interest area between qualified driver group and intern driver group

After collecting the total fixation duration (TFD), average fixation duration (AFD), and fixation count (FC) indicators for 20 AOIs, the independent sample t-test was used to analyze the findings (see Table 2): ① the total fixation duration and average fixation duration of AOI₁ and AOI₃ of the qualified driver group are significantly higher than that of the intern driver group (p<0.01), but the difference in the fixation count was not significant; ② the total fixation duration and fixation count of AOI₂ and AOI₆ are significantly higher in the qualified driver group than in the intern driver group(p<0.01), but the difference in the average fixation duration was not significant; ③ the total fixation duration and fixation count of AOI₈ in the intern driver group are significantly higher than in the qualified driver group (p<0.001); ④ the average fixation duration of the AOI₁₉ is significantly higher in the qualified driver group than in the intern driver group (p<0.01), but fixation count is significantly lower than that
in the intern group (p<0.001).

Table 2. Significant differences in eye movement data between qualified drivers and intern drivers

| AOIi | Index | The qualified driver group (X±S) | The inter driver group (X±S) | T |
|------|-------|---------------------------------|-----------------------------|---|
| AOI1 | TFD (s) | 378.01±30.57 | 233.06±77.08 | 5.861*** |
|      | AFD (s/n) | 0.42±0.06 | 0.29±0.08 | 3.985*** |
| AOI2 | TFD (s) | 44.00±4.58 | 28.38±16.75 | 3.062*** |
|      | FC (n) | 129.25±19.50 | 85.75±46.38 | 2.889** |
| AOI3 | TFD (s) | 15.26±4.07 | 9.19±3.03 | 3.833** |
|      | AFD (s/n) | 0.23±0.03 | 0.19±0.05 | 2.364** |
| AOI4 | TFD (s) | 298.80±75.40 | 410.16±54.10 | -3.858*** |
|      | FC (n) | 887.00±219.90 | 1301.83±170.73 | -4.750*** |
| AOI5 | TFD (s) | 10.47±2.72 | 4.26±3.09 | 4.617*** |
|      | FC (n) | 56.13±7.08 | 27.83±17.52 | 4.308*** |
| AOI6 | AFD (s/n) | 0.28±0.03 | 0.20±0.05 | 3.423** |
|      | FC (n) | 6.38±2.62 | 0.35±0.25 | -4.544*** |

3.2.2. Eye movement mode MCL Analysis of qualified and internship drivers

The MCL algorithm is used to process the random matrix extracted from the eye track of the drivers. The expansion coefficient e is set to 2, and the inflation coefficient r is used as the independent variable. As the increase of inflation coefficient, the cluster produced by MCL process is becoming smaller, so the strength of cluster can be tested. As under different inflation coefficients, the difference in eye movement clustering of driver is shown in the table below. The nodes in the figure represent AOIs, the different clusters are drawn in different colors, and the links from other nodes are clustered in the center of the cluster in shades of color. If the cluster consists of only one node, the node is also filled with dark colors, and the gray nodes represent areas of interest that the driver has never viewed.

Table 3. Markov cluster structure of eye movement track for drive

| AOIi | The qualified driver group | The inter driver group | T |
|------|-----------------------------|------------------------|---|
| D1   | r=2                         | r=4                    | r=8 |
|      | ![Image](image1.png)        | ![Image](image2.png)   | ![Image](image3.png) |
| D2   | ![Image](image4.png)        | ![Image](image5.png)   | ![Image](image6.png) |
| D3   | ![Image](image7.png)        | ![Image](image8.png)   | ![Image](image9.png) |
In Table 3, there are two kinds of cluster modes. One is AOI1 as the mode of the largest cluster. In the eye movement gaze movement, the driver will look at the track ahead after looking for other AOIs; The other is the AOI4 as the largest cluster mode. In the eye gaze movement, the driver will turn his attention to the driving monitoring interface after looking for other AOIs. The former is the eye movement mode of the qualified driver, and the latter is the eye movement mode of the intern driver. With the shrinking of clusters, there are also clusters based on AOI1 in the eye movement mode of some intern drivers, but comparatively smaller, they are still mainly based on AOI4 cluster mode.

In addition, with the change of the inflation coefficient r (Fig. 7), by comparing the clusters number of the two groups, it can be seen that the qualified driver group maintains the same or similar cluster
structure under the high inflation coefficient as the group under the low inflation coefficient, but the basic eye movement mode remains unchanged; while the intern driver group produces more clusters, that is, the line of sight may directly shift from one interest area to another, without going through the core AOI4, so they would deviate from the basic model more easily than the qualified driver.

Fig. 7. Comparison of the number of clusters between qualified driver group and intern driver group

4. Discussion
At present, China's railways system has entered the "high-speed rail era" which covers almost every city and town. New technologies and new equipments are emerging one after another. The requirements for qualified railway talents are getting higher and higher. Railway drivers are as the enormous asset of the talent team, so their overall quality and professional skills are critical for the safe operation of railway, and the talent gap is huge. Throughout the relevant research and practice in China and abroad, there are still many problems in driver selection and training: the selection of drivers generally has the tendency of “attaching more importance to physique rather than psychology”; the training process is more likely to use the “master-apprentice-style” training mode with strong subjectivity, random process, uncertain results and low efficiency. The author believes that only by thoroughly studying the differences in the driving behaviors of qualified drivers and intern drivers, and revealing the core and essential characteristics of qualified driving behavior from physiological to psychological aspects, can the railway driver selection criteria and training system be established more scientifically and effectively.

This paper compares the eye movement index data of qualified drivers and intern drivers, and finds that there are significant differences between their eye movement hot spots and eye movement modes: intern drivers are more interested in the driving monitoring interface, while qualified drivers put more cognitive processing on the front track; in addition, qualified drivers have paid more attention to the net voltmeter gauge and speedometer, wind pressure gauge and CIR operation terminal than the intern driver; when parking, the qualified driver is more likely to concentrate on the parking pole. This shows that from driving to parking, from inside the vehicle to outside the vehicle, there are wide-ranging similarities and differences between the eye movement data of qualified drivers and intern drivers.

Through the MCL algorithm, we analyze the visual trajectory patterns of the two groups of drivers and find two typical modes: one is a clustering mode centered on the ahead track as the center , which is represented by qualified drivers, and qualified drivers can execute the mode more stably ; the other is a clustering mode centered on the driving monitoring interface as the center , which is represented by
the intern driver, and the intern driver is relatively unstable in the execution mode. This shows that the qualified driver's driving behavior has a fixed eye movement mode, while the unqualified driver's eye movement mode is not fixed. The author believes that the stable eye movement pattern of qualified drivers represents a set of reasonable driving behaviors, which can be obtained through the scientific training process, and which will lay a solid foundation for our subsequent research on improving the training mode of railway drivers.

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