Analysis of driver vigilance under special conditions of Qinghai-Tibet

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Abstract. The Qinghai-Tibet Highway is one of the highest highways in the world. Under this special condition, analysing the drivers' vigilance can help to reduce the traffic accidents. In this paper, the simple reaction time (RT) and the Schulte table test time (ST) of 12 drivers before and after 60 minutes' driving were collected in the driving simulation experiment done at the altitudes above 3500m. The vigilance indicator VI was established and the optimal scale regression was used to analyse VI and its influencing factors. The study found that the experimental phase and driver age had a significant impact on driver vigilance while the experimental location and experimental period had no significant impact. The driver vigilance of different age groups at the beginning of the experiment was better than that at the end of the experiment. Vigilance of the drivers aged 40 and below at the end of the experiment was better than that of the drivers aged over 40 at the beginning of the experiment. The research results can provide some suggestions for safe driving along Qinghai-Tibet Highway.

1. Introduction

Driving a car is a daily task but also a complicated task. This task has high requirements for the drivers' ability to capture, memorize and process information. Such abilities require the drivers to maintain a relatively high level of vigilance [1]. Identify relevant factors that affect driver vigilance can avoid accident risks to a certain extent and improve traffic safety.

At present, scholars from all over the world have made some progress in the researches about driver vigilance [2-6]. Ting et al. [7] believed that driver fatigue caused by long-term driving was one of the main reasons for the drivers' decreased vigilance; Campagne et al. [8] found that the drivers' age had a certain effect on driving errors and driver vigilance level; Bergasa et al. [9] built a fuzzy classifier to infer the degree of driver vigilance based on indicators such as the percentage of closed eyes (PERCLOS), the duration of closed eyes, and the frequency of blinking; Xiong et al. [10] analysed the impact of factors such as the traffic lights and the risk information on driver vigilance; Ma et al. [11] proposed a dynamic impact model of driver vigilance that took into account various factors such as music complexity, driving scenarios and driver individual differences.

The conditions of low-pressure and dilute oxygen on the Qinghai-Tibet Highway have a certain impact on the drivers' psychological state [12] which may lead to a decrease of driver vigilance. The lack of driver vigilance can easily result in serious traffic accidents, but there are relatively few studies on this particular area under the special conditions. This paper took Qinghai-Tibet Highway as a typical case, analysed the factors effecting driver vigilance and how the degree of driver vigilance change under different factor levels. The analysis results might help to formulate forward-looking coping strategies of driver vigilance and avoid driver vigilance to a certain extent.
2. Methods

2.1. Subject
To make the study relevant to the actual situation of the Tibetan Plateau, the 12 drivers selected in this paper were all local male residents. The subjects were between 25 and 55 years old, and their driving experience were more than three years.

2.2. Experiment design
In order to ensure safety, driving simulation experiment was selected to conduct research. UC-Win / Road software was used to build a driving simulation scene. The experimental road was a two-way two-lane one similar to the Qinghai-Tibet Highway, and the roadside environment was monotonous. The driver's decreased vigilance would lead to a decrease in its reaction ability and inattention. The main data types collected in this experiment were simple reaction time (RT) and Schulte table test time (ST). RT was an important indicator of the driver's reaction ability [7] and ST mainly reflected the change of driver's attention [13]. Both tests were completed through the mobile APP. In the simple reaction time test, when the subjects determined that they were ready, they clicked the "Start" button on the screen, and a "Stop" button will appear on the screen after a random time. "Stop" button disappeared when the driver clicked the screen again. RT was the times between two clicks. The unit was milliseconds.

A 5x5 standard table was used in the Schulte table test. Numbers from 1 to 25 were randomly arranged in the table. Participants were required to click on the corresponding positions in order from the smallest number to the largest number at the fastest speed, and ST was the final completion time. The unit was second.

2.3. Experimental process
In this paper, two experiment locations (elevation are 3500m and 4100m respectively) and two experiment time periods (8:00~12:00 and 13:30~18:00) were set. The subjects were randomly assigned to the corresponding experiment locations and time period.

When the subjects arrived at the experiment location, they needed to be determined that they were in a good physical and mental state. If they were found to be in a state of fatigue or hyperactivity (such as yawning, excessive or too little language and movement, etc.), the experiment could not start. The specific experimental process was as follows:
- Step 1: The driver learnt the operation of the driving simulator. After learning, the driver rested for about 10 minutes in order to restore a better state;
- Step 2: Perform simple reaction time test and Schulte table test on the driver;
- Step 3: The driver operates the driving simulation software. In this process, the drivers were required to drive carefully just as in the real driving environment;
- Step 4: When the driving time reached 60min, the experimenter once again conducted a simple reaction time test and Schulte table test on the drivers.

2.4. Data analysis
SPSS 19.0 was used to analyse the data. The basic idea was to establish vigilance indicator (VI) based on RT and ST, and then use the optimal scale regression method (Catreg) to analyse VI and its related influencing factors.

2.4.1. Construction of vigilance indicator
VI was built based on measurements RT and ST. The entire construction process included indicator weights determining, dimensionless data processing and final construction of VI.
- Indicator weights determining
  Certain instabilities exited in the simple reaction time test and Schulte table test. When constructing VI, the weights were mainly allocated based on the stability of the RT and ST indicators. The
stabilities were measured by the coefficient of variation. The formula for calculating the coefficient of variation was

\[ CV = \frac{SD}{M} \]  

Where: \( CV \) was the coefficient of variation of the indicator; \( SD \) was the standard deviation of the indicator; \( M \) was the mean of the indicator.

Indicator with higher coefficients of variation was given lower weight, the weight calculation method was

\[ a_r = \frac{CV_r}{(CV_r + CV_h)} \]  

\[ a_s = \frac{CV_s}{(CV_s + CV_h)} \]

Where: \( a_r \) and \( a_s \) were the weights of RT and ST respectively.

- **Dimensionless data processing**

  Considering the units of RT and ST measured in this paper were different, min-max normalization method was used to remove the dimension. The method was

\[ NRT_i = \frac{RT_i - \min_{j\in J} \{RT_j\}}{\max_{j\in J} \{RT_j\} - \min_{j\in J} \{RT_j\}} \]  

\[ NST_i = \frac{ST_i - \min_{j\in J} \{ST_j\}}{\max_{j\in J} \{ST_j\} - \min_{j\in J} \{ST_j\}} \]

Where: \( NRT_i \) and \( NST_i \) were the values that had been dimensionlessly processed.

- **Final construction of VI**

\[ VI = 1 - a_r \cdot NRT_i - a_s \cdot NST_i \]

When the RT value or ST value became larger, VI decreased as well as driver vigilance.

2.4.2. The optimal scale regression method

The principle of optimal scale regression is to digitize the original variables through repeated iterations, and then use the linear regression method to obtain the optimal regression equation. The specific process of variable numericalization is shown in equations (7) and (8).

The purpose of iteration is to minimize the objective function (7).

\[ \sigma(y_r; b; y) = (G_r y_r - \sum_{j\in J} b_j G_j y_j) W (G_r y_r - \sum_{j\in J} b_j G_j y_j) \]  

Where: \( y_j \) and \( y_r \) represent the digitized order vector of the independent variable and the dependent variable; \( J_p \) represents the indicator set of the independent variable; \( G_j \) and \( G_r \) represent the indicator matrix of the independent variable and dependent variable; \( b \) represents the regression coefficient of the independent variable; \( W \) represents the weight matrix.

The constraints of the objective function is

\[ y_r ^T D y_r = n_w \]  

Where: \( D_r \) is a matrix containing dependent variable information and weight information; \( n_w \) is the sum of the weights.

Traditional linear regression cannot fully consider the impact of the distance between categorical variables on the regression results. According to the principle of the optimal scale regression method, this method is good at quantifying categorical variables. It can better solve the limitations brought by categorical independent variables in linear regression and improve the processing capacity of categorical variables.

The independent variables selected in this paper were all categorical variables, so it was more appropriate to choose the method of optimal scale regression as the main analysis method.
### 3. Results and discussion

#### 3.1. Analysis of factors affecting driver vigilance

The factors influencing driver vigilance were mainly divided into external factors and individual driver factors. The former mainly included the experimental time period (8:00~12:00 and 13:30~18:00), the experimental location (3500m and 4100m) and the experimental phase (start and end); the latter mainly considered the age of the drivers (≤ 40 years old and > 40 years old). The data was imported into SPSS 19.0. The results of the optimal scale regression are shown in Table 1.

| Variables          | Standard coefficient | F     | P     |
|--------------------|----------------------|-------|-------|
| Experimental phase | -0.34                | 4.86  | 0.04  |
| Age                | -0.50                | 9.89  | 0.01  |
| Experimental period| -0.05                | 0.19  | 0.67  |
| Experimental location | 0.21                | 1.61  | 0.22  |

It can be seen from Table 1 that the P value of the experimental time period and experimental location in the optimal scale regression analysis were greater than 0.05, which were not statistically significant. The experimental time period and experimental location were excluded from the model.

Only experimental phase and age factors were considered in the finally regression model. The adjusted R² of the model was 0.314, P = 0.007 <0.01, and the P values of the independent variables were both less than 0.05, so the model was statistically significant.

The changes of driver vigilance indicator under the influence of different experimental phases and age factors as shown in Figure 1 and Figure 2.

Figure 1 shows that the driver's vigilance decreased at the end of the experiment compared to the beginning of the experiment. This may be because the driver was already in a certain degree of fatigue after completing the one-hour driving task.

Figure 2 shows that older drivers above 40 were less alert than young drivers aged 40 and below. This may be due to the drivers’ reduced energy and physical strength when they were getting older.

Optimal scale regression can quantify the impact of two factors on vigilance, as shown in Figure 3 and Figure 4. The quantitative score change of VI from the beginning to the end of the experiment was -0.34×(1-(-1))=-0.68; the quantitative score difference of VI between the drivers over 40 years old and the drivers below 40 was -0.50×(0.58-(-1.73))=-1.155. It could be inferred that the driver's age had a greater influence on the driver's vigilance than the experimental phase, and the former has an influence on the driver's vigilance about 1.699 times that of the latter.
3.2. Driver vigilance analysis under different influencing factors

From the above analysis, it could be seen that the experimental phase and the driver's age were two major factors that affect the driver's vigilance, so this paper divided the influencing factors into four levels according to the experimental phase and the driver's age. RT, ST and VI changes among the four influencing factor levels are shown in Table 2.

Table 2. Changes in response time, attention and vigilance indicators at different levels of the influencing factors.

| Indicators | RT/ms       | ST/s       | VI         |
|------------|-------------|------------|------------|
| Start/≤40  | 479.56 ± 74.52 | 25.49 ± 5.64 | 0.79 ± 0.22 |
| End/≤40    | 519.22 ± 32.39 | 25.56 ± 4.00 | 0.71 ± 0.11 |
| Start/>40  | 537.04 ± 54.46 | 30.47 ± 3.95 | 0.60 ± 0.11 |
| End/>40    | 596.15 ± 86.51 | 33.96 ± 6.96 | 0.43 ± 0.21 |

As shown in Figure 5, the optimal scale regression method was used to quantify the above four levels of VI. The quantified scores of the four levels of VI gradually decreased. The differences between adjacent levels are 0.684, 0.487 and 0.684, respectively. It can be deduced that the degree of vigilance for all the drivers decreased at similarly speed during the experiment. However, the vigilance of drivers aged 40 and older at the beginning of the experiment was already lower than that of the drivers aged 40 and younger at the end.

Figure 5. Changes in vigilance quantification scores between different levels.

4. Conclusions

In order to improve the traffic safety level along the Qinghai-Tibet Highway, this paper collected the RT and ST values of 12 drivers. Driver vigilance indicator VI was constructed based on RT and ST.
The optimal scale regression was used to analyse the influencing factors of VI. The research conclusion were as follows:

- Experimental phase had an impact on driver vigilance, which may be because the drivers had signs of fatigue after an hour’s driving.
- Driver age also affected driver vigilance, younger drivers were more alert.
- The impact of driver age on driver vigilance was about 1.6 times that of the experimental phase.

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