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Research Article

Exploration of the Relationships between Hazard Perception and Eye Movement for Young Drivers

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Aiming at young drivers' hazard perception (HP) and eye movement, a cross-sectional study was conducted in the city of Xi'an, China. 46 participants were recruited, and 35 traffic scenes were used to test drivers' hazard perception and eye movement. The difference analysis and correlation analysis were carried out for the acquired data. The results suggest that some indices of hazard perception and eye movement are significantly correlated. A higher saccade speed is in the direction of higher hazardous scenes. Higher complex scenes result in smaller saccade angle. The number of hazards unidentified is negatively influenced by complexity degree and hazardous degree of traffic scenes, and similar associations are found between hazard identification time, complexity degree, and hazardous degree. The hazard identification time and the number of hazards slowly identified are positively affected by the number of fixations and the number of saccades. Meanwhile, differences in the hazardous degree evaluation, hazard identification time, number of hazards unidentified, number of fixations, and number of saccades are found in different types of traffic scenes. The results help us to improve the design of road and vehicle devices, as well as the assessment and enhancement of young drivers' hazard perception skills.

1. Introduction

Young drivers are getting a lot of attention because they are involved in more road traffic accidents. Young male drivers have lower hazard perception (HP) skills than older and more experienced drivers, but there is a tendency for them to overestimate their driving skills in hazardous situations, and both factors contribute to an overrepresentation in traffic accidents [1]. Hazard perception is usually considered as the ability to "read the road" or the awareness of hazardous situations [2]. It is the process of detecting, evaluating, and responding to dangerous events on the road that have a high likelihood of leading to a collision [3, 4]. Young experienced drivers reacted to covert hazards and overt hazards faster than young novice drivers [5]. Young drivers' objective and subjective HP skills were consistent, although only for visible hazards. Also, drivers who responded in time had significantly higher subjectively assessed hazard perception and driving skills than drivers who did not respond to the hazards [1, 6]. Meanwhile, eye movement dynamics and change in pupil diameter can provide good measures of the drivers' hazard perception and prediction [7]. Differences in eye movement patterns are often found when comparing passive viewing paradigms to actively engage in everyday tasks. Arguably, investigations into visuomotor control should therefore be most useful when conducted in settings that incorporate the intrinsic link between vision and action. The interactivity of simulated driving increases the demands on visual and attention than simply viewing driving movies [8]. Subtasks (e.g., letter search) can interfere with hazard identification and the allocation of attention [9, 10].

The information relevant to driving is predominantly visual [11]. The introduction of eye tracking technology provides a measure to record the location of eye fixation and saccade duration as well as visual search strategies [12, 13]. Many studies based on eye movement have revealed some interesting and instructive findings. For example, some hazards (e.g., behavioral prediction hazards, environmental prediction hazards, and dividing and focusing attention hazards) are more attractive than others to be easily fixated on [13], and novice or inexperienced drivers do not have the optimum visual search strategies compared to experienced drivers [3, 14–20]. It is worth noting that most works on drivers' eye movements are focused on the visual characteristics in specific traffic environments or situations [4, 21–23]. However, what we can read from the performance of eye movements is not attached more attention, although relevant research studies are in the direction of drivers' intent inference via eye behavior analysis [24]. In fact, drivers' eye movement can possibly tell us more information, such as the situation they are facing, the level of mental load, visual behaviors for the traffic scenes, necessary information for a decision, and so on. To accomplish the task, it is necessary for us to discover the corresponding relationship between indices of eye movements and hazard perception.

Hazard perception tests are being used with greater frequency for driver training, assessment, and licensure [10], and they have become part of the graduated driver licensing (GDL) systems in countries, such as Australia, the UK, and the Netherlands [25]. In research studies related to hazard perception, four key methodologies (video, static image, simulator, and real-world test) were used for testing either singularly or in conjunction with other methods. The most used methodology was video, and the majority were filmed from the perspective of road users [26–30]. Static image tests were less commonly used and only studied for car drivers [31–33]. Static image tests may not be representative of the dynamic nature of real-world driving. However, both methodologies were correlated with self-reported driver errors and were able to discriminate between drivers based on age and experience [15, 16]. Also, there was no correlation between static image and video tests, suggesting that these methodologies may be tapping into different aspects of hazard perception [14]. Static image tests can reduce testing time and allow a larger variety of hazardous scenarios to be tested. They also have the benefit of explicit response time that can be calculated from stimulus onset while videos contain subjectively predetermined hazard windows that may fail to capture early responses [16]. In still images, it is often easier to select the moment of onset of one unambiguous hazard because hazard onset is synchronous with image onset in a static image, whereas an extended dynamic scene may create problematic response variability. For dynamic scenes, there is no uncertainty about determining the onset of a hazard, which is a factor that can complicate the calculation of response latency [8, 9, 33]. Although simulators may more accurately reflect the greater cognitive load experienced while driving [8] and can better emulate the on-road situations [13, 34, 35], the use of simulators is largely restricted to the costs associated with the setup. Real-world test is the most naturalistic method, but it is costly, time-consuming, and poorly controllable for hazards [16].

In the present study, to further search for the correlation hidden in indices of eye movements and hazard perception, we used static images taken from a young driver's perspective to collect data of participants' visual behaviors, subjective feeling/cognition, and objective response while inspecting the traffic scenes. The rest of the study is organized as follows. Section 2 further introduces the experimental method, gives the participant characteristics, materials, and equipment, and reports the content and procedures of the experiment. Section 3 reports the results of the experiment, the correlation analysis of participants' hazard perception, the difference analysis of the participants' eye movements, and the correlation between hazard perception and eye movements. Then, the results are discussed in Section 4. Finally, Section 5 reports the conclusion of the study.

2. Method

2.1. Participants. A total of 46 young drivers participated in this study. All participants held a valid driver license and had normal or corrected-to-normal vision. Every participant had a good willingness to participate. They were invited to fill out a demographic questionnaire, which included age, gender, driving experience, driving mileage, number of collisions involved, and traffic citation in the previous 3 years, as shown in Table 1. Table 1 shows the description and coding of drivers' demographic information.

2.2. Materials and Apparatus. Considering the feasibility and benefits of using static scenes [8, 9, 15, 16, 33], a total of 35 traffic scenes containing hazards were used to test participants, which were taken from a driver's perspective in a car traveling along different road situations. In order to analyze the possible influence of the traffic characteristics on the driver's hazard perception and eye movement, the scenes fell into five categories according to the similarity in traffic environment or hazard instigators. The reference characteristics for dividing traffic scenes are as follows.

Category 1 (vehicle lane-changing or braking on road): the category is characterized by vehicles ahead braking or changing into the lane that the instrumented car was in. This category contains 12 traffic scenes. Category 2 (vehicle turning at junctions or merging at ramps): the scenes show that when the instrumented car is approaching junctions or ramps, other cars are turning or merging and possibly invaded or had invaded the lane of the car. This category involves 5 traffic scenes. Category 3 (cyclist appearing from junction/ramp or traveling on lane/roadside): this category contains 7 traffic scenes. Category 4 (pedestrian crossing the road or waiting to cross): there are 6 traffic scenes in this category. Category 5: there are hazards which were invisible but possible to occur. The category involves 5 traffic scenes. As examples, five typical scenes are shown in Table 2.

A 15.6-inch flat-screen monitor with a resolution of 1280×1024 was used to display traffic scenes. Participants sat directly facing the screen and holding a computer mouse to click relative regions where hazards were in. The click time was recorded with a hazard perception test software developed based on MATLAB GUI and Win10 system. The software was run on a computer with 4 GB RAM and Intel Core i53210M processor. At the same time, Dikablis head-

Table 1: The information of participants.

Drivers' demographic information	Coding	Number	Proportion (%)
Age	1⟶age of 21–25 years	31	67.391
	2⟶age of 26–30 years	15	32.609
Gender	1⟶male	34	73.913
	2⟶female	12	26.087
Driving experience	1⟶less than 1 year	11	23.913
	2⟶1–3 years	19	41.304
	3⟶more than 3 years	16	34.783
Driving mileage	1⟶less than 5,000 km	19	41.304
	2⟶5,000–10,000 km	18	39.130
	3⟶10,000–50,000 km	7	15.217
	4⟶more than 50,000 km	2	4.348
Collisions involved in the previous 3 years	1⟶none	43	93.478
	1⟶no less than 1	3	6.522
Traffic citations in the previous 3 years	1⟶none	37	80.435
	2⟶no less than 1	9	19.565

mounted eye tracker and D-Lab software were used to record eye movement data. The data were recorded by another computer. As shown in Figure 1, Figure 1(a) shows the equipment involved in the eye tracker. After being connected and worn, it constitutes the situation shown in Figure 1(b). Figure 1(c) shows an eye tracker head-mounted device, which has three cameras on it, and the two on the bottom are used to collect eye movement data. The upper front camera is used to capture the front view of the subject, as shown in Figure 1(d).

2.3. Test Content. The test content consisted of hazard perception and eye movement. We wanted to know participants' subjective feeling/cognition, objective reaction, and corresponding visual behaviors during inspection of the scenes.

Hazard perception is a comprehensive concept [10, 14, 33], and indices of complexity degree evaluation (CDE) and hazardous degree evaluation (HDE) on traffic scenes [14, 33], hazard identification time (HIT) [10], number of hazards slowly identified (NHSI), and number of hazards unidentified (NHU) were brought into the analysis of participants' hazard perception. Complexity degree and hazardous degree were measured by values ranging from 1 to 5, and bigger value indicated higher complexity or hazardous degree. Hazard identification time was the interval between scene onset and the first click on the hazard region. The number of hazards slowly identified was the number of participants whose hazard identification time exceeded definition identification time, which was set as 4 s in the study [9, 33]. The number of hazards unidentified (NHU) indicated the number of participants who did not identify hazard for a traffic scene. The data of HDE, CDE, and HIT were recorded by the hazard perception test software, and the data of NHSI and NHU were processed according to the hazard identification result.

Eye movement indices included horizontal eye activity (HEA), vertical eye activity (VEA), mean fixation duration (MFD), average number of fixations (ANF), mean saccade duration (MSD), mean saccade angle (MSA), and average number of saccades (ANS). Eye movement data were directly recorded by the D-Lab software while participants inspected the traffic scenes, and the related indicators above were analyzed subsequently with the help of the software.

2.4. Procedure. As shown in Figure 2, after recruiting participants, the researchers explained the study in detail and invited them to complete the demographic questionnaire shown in Table 1. Before the actual experimental test, 3 to 6 illustrative scenes (i.e., the scenes not included in the 35 traffic scenes) were used to practice to ensure that participants understood the testing procedure.

The first task for participants was to read 35 traffic scenes displayed in the monitor while wearing the Dikablis head-mounted eye tracker, identify hazards in traffic scenes, and click the hazard region. Participants were fitted with the eye tracking equipment and calibrated to ensure the eye movement data can be collected. Traffic scenes were switched by participants. After finishing the test, participants were asked to evaluate the complexity degree and hazardous degree of each traffic scene with a corresponding value.

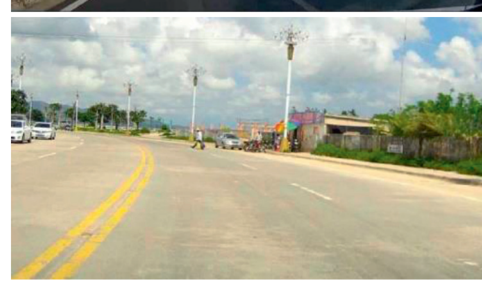
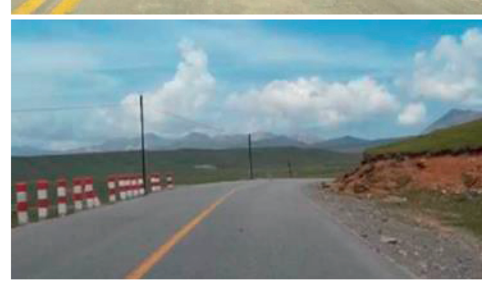
3. Results

3.1. Hazard Perception. The average values of the hazard perception indices are shown in Table 3. It is obvious that the number of hazards unidentified in Category 5 is much more than that in other traffic scenes. The potential hazards with no obvious cue in the scenes are much less likely to be identified.

Analysis of variance (ANOVA) was used to compare the hazard perception indices across the categories of traffic scenes. As shown in Table 4, the hazardous degree evaluation (HDE), hazard identification time (HIT), and number of hazards unidentified (NHU) show significant difference between different categories of traffic scenes, respectively.

Moreover, the post hoc tests (i.e., multiple comparisons) based on Bonferroni indicated that no statistically significant difference was found between any specific two categories of traffic scenes regarding the HDE. The hazard identification

Table 2: Examples of typical traffic scenes.

Categories	Typical scenes
Category 1	
Category 2	
Category 3	
Category 4	
Category 5	

time (HIT) in Category 1 was much less than that in Categories 4 and 5. The number of hazards unidentified (NHU) in Category 5 was much more than that in Categories 1, 2, 3, and 4. Further, to test whether there was correlation between hazard perception indices, Spearman's rank correlation coefficient was used in the analysis.

As shown in Table 5, a significant positive correlation ($p < 0.01$) is found between the complexity degree evaluation (CDE) and hazardous degree evaluation (HDE). The hazard identification time (HIT) is positively related to the number of hazards slowly identified (NHSI) ($p < 0.01$) and is negatively affected by CDE ($p < 0.05$) and HDE ($p < 0.01$). The number of hazards unidentified (NHU) is negatively influenced by CDE ($p < 0.05$) and HDE ($p < 0.01$) and positively related to HIT ($p < 0.05$) and NHSI ($p < 0.05$).

At the same time, the correlation between driver characteristics and the above five indicators was also analyzed. With the help of ANOVA, the results suggested that the young driver characteristics in Table 1 have no significant impact on these indicators.

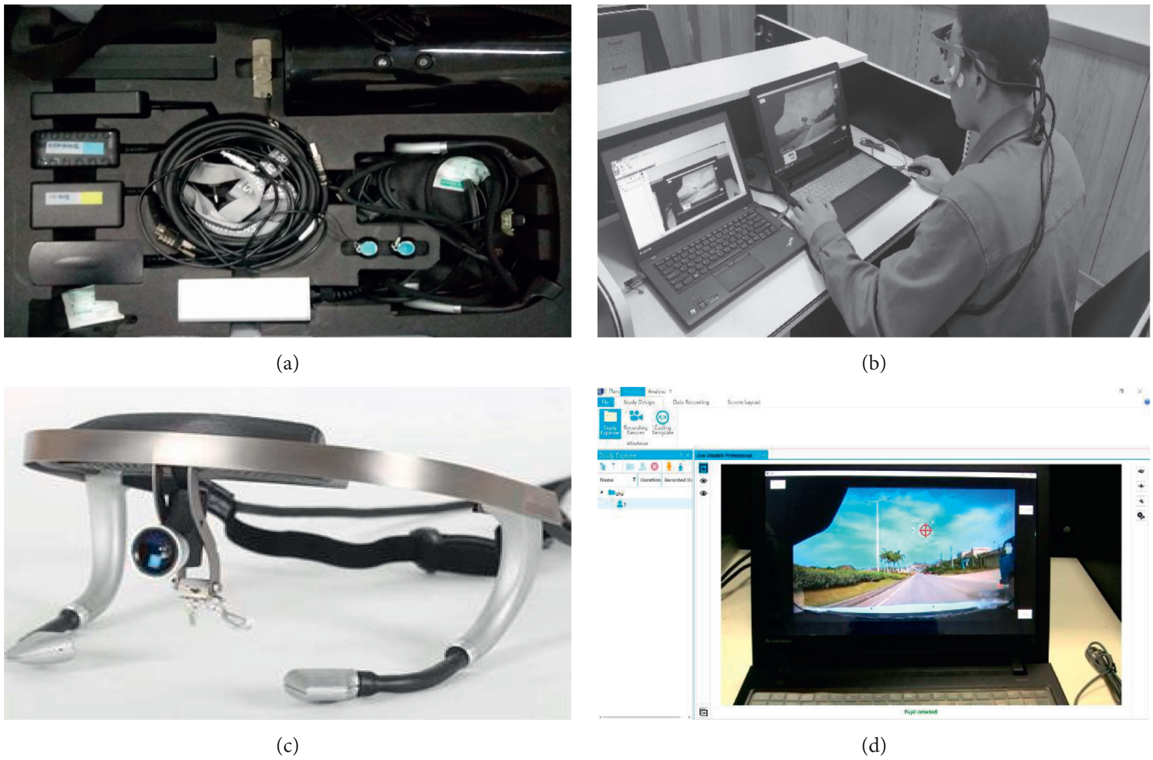


Figure 1: Schematic diagram of test equipment. (a) Eye tracker equipment. (b) Schematic of the test site. (c) Eye tracker headset. (d) Schematic of the scene display.

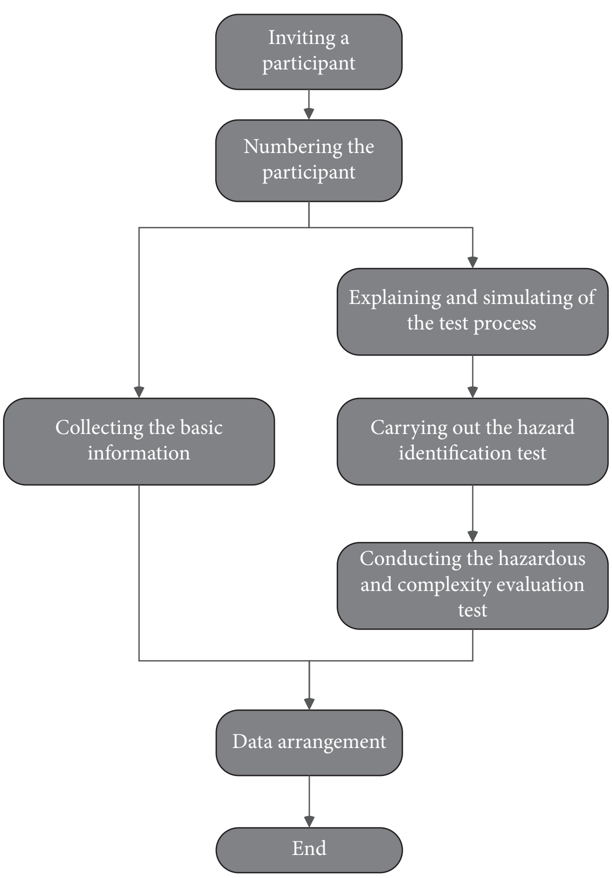


Figure 2: Schematic diagram of the test process.

Table 3: The average value of hazard perception indices.

Indices		CDE	HDE	HIT/s	NHSI	NHU
Category of traffic scenes	1	2.741	2.348	2.052	2.833	4.333
	2	2.247	1.884	2.442	3.000	5.200
	3	1.790	1.418	2.326	3.857	6.000
	4	2.865	2.349	2.550	6.333	5.000
	5	1.877	1.223	2.626	5.800	17.200

Note. CDE = complexity degree evaluation; HDE = hazardous degree evaluation; HIT = hazard identification time; NHSI = number of hazards slowly identified; NHU = number of hazards unidentified.

3.2. Eye Movement. Table 6 shows the average value of participants' eye movement data in different categories of traffic scenes. Furthermore, as shown in Table 7, ANOVA results of participants' eye movement indicate that no statistically significant difference is found between different categories of traffic scenes regarding indices of the horizontal eye activity (HEA), vertical eye activity (VEA), mean fixation duration (MFD), mean saccade duration (MSD), and mean saccade angle (MSA), but the average number of fixations (ANF) and the average number of saccades (ANS) represent significant difference between groups of traffic scenes ($p < 0.05$). In addition, the post hoc tests based on Bonferroni indicated that the average number of fixations (ANF) in Category 4 was significantly more than that in Category 1. No significant difference was found between any specific two categories of traffic scenes regarding the ANS.

Table 4: ANOVA of participants' hazard perception indices.

Indices		Sum of squares	df	Mean square	F	Sig.
CDE	Between groups	6.768	4	1.692	2.242	0.088
	Within groups	22.636	30	0.755		
	Total	29.404	34			
HDE	Between groups	7.487	4	1.872	2.749	0.046
	Within groups	20.423	30	0.681		
	Total	27.910	34			
HIT	Between groups	1.719	4	0.430	7.161	0.000
	Within groups	1.801	30	0.060		
	Total	3.520	34			
NHSI	Between groups	70.086	4	17.521	1.873	0.141
	Within groups	280.657	30	9.355		
	Total	350.743	34			
NHU	Between groups	650.419	4	162.605	7.388	0.000
	Within groups	660.267	30	22.009		
	Total	1310.686	34			

Note. CDE = complexity degree evaluation; HDE = hazardous degree evaluation; HIT = hazard identification time; NHSI = number of hazards slowly identified; NHU = number of hazards unidentified.

Table 5: Correlations between the indices of hazard perception.

Indices		CDE	HDE	HIT	NHSI	NHU
CDE	Correlation coefficient	1.000				
	Sig. (2-tailed)	—				
HDE	Correlation coefficient	0.933	1.000			
	Sig. (2-tailed)	0.000	—			
HIT	Correlation coefficient	−0.363	−0.428	1.000		
	Sig. (2-tailed)	0.032	0.001	—		
NHSI	Correlation coefficient	−0.156	−0.208	0.605	1.000	
	Sig. (2-tailed)	0.369	0.230	0.000	—	
NHU	Correlation coefficient	−0.484	−0.625	0.424	0.488	1.000
	Sig. (2-tailed)	0.003	0.000	0.011	0.003	—

Note. CDE = complexity degree evaluation; HDE = hazardous degree evaluation; HIT = hazard identification time; NHSI = number of hazards slowly identified; NHU = number of hazards unidentified.

In addition, the correlation between driver characteristics and the above eye movement indicators has been analyzed. The ANOVA results show that the mean saccade duration (MSD) of young drivers in different age groups is different, and the older the age, the shorter the saccade time ($p < 0.05$). At the same time, there are differences in the horizontal eye activity (HEA) of young drivers in different driving mileage groups ($p < 0.01$). The post hoc tests based on Bonferroni further suggested that the greater the driving distance, the greater the horizontal eye activity.

3.3. Correlation between Hazard Perception and Eye Movement. To test whether there was inherent correlation between participants' hazard perception and eye movement, we used the Spearman statistical method to analyze the data. The correlation analysis results shown in Table 8 indicate that the mean fixation duration (MFD) and mean saccade angle (MSA) are negatively related to the complexity degree evaluation (CDE) ($p < 0.05$). Higher complex traffic scenes have a shorter mean fixation duration and a narrower mean saccade angle. The mean saccade duration is significantly shorter in higher hazardous traffic scenes ($p < 0.05$), and participants show higher saccade speed. The average number of fixations (ANF) and the average number of saccades (ANS) are positively related to the hazard identification time (HIT) ($p < 0.01$) and number of hazards slowly identified ($p < 0.01$). To a certain extent, the number of fixations and saccades reflects the efficiency of hazard identification.

4. Discussion

The study sought to investigate the correlations between hazard perception (HP) and eye movement, that is, to investigate the young drivers' subjective feeling/cognition, objective response, and eye movement in specific traffic scenes and the mutual correlation between the three factors. The traffic scenes in the form of static images were taken from young drivers' perspective. The static image-based approach can rule out factors of road users' speed and sound (e.g., background noise and traffic sound), which possibly can affect participants' eye movement. Previous research studies have investigated different groups of young drivers' eye movement or hazard detection in different traffic scenes [8, 26, 27, 31, 36]. The objective and subjective HP skills of young drivers are consistent [1, 5–7], which is also proven in this experiment. However, the relationship between hazard perception and specific indicators of eye movement has not yet been distinguished. Our research is to seek the influencing relationship and possible causes. According to the above findings from Tables 5 and 8, all significant correlations between indices of hazard perception and eye movement are shown in Figure 3.

Different categories of traffic scenes resulted in different hazardous degrees, hazard identification times, and number of hazards unidentified ($p < 0.05$). The result was ascribed to characteristics which vary between traffic scenes. Participants detected hazards more quickly in traffic scenes of vehicles lane-changing or braking (Category 1) than in traffic scenes of pedestrian crossing the road or waiting to cross (Category 4) and traffic scenes containing hazards which are invisible but possible to occur (Category 5) ($p < 0.01$). Previous studies have shown that cues are an important factor for drivers to identify hazards [10, 37, 38]. Therefore, the results show that the hazards in Category 1 may have more obvious cues than the other two categories and are easier to be identified for young drivers. For these scenes that may be encountered in a

Table 6: The average value of participants' eye movement indices.

Indices		HEA/pixel	VEA/pixel	MFD/ms	ANF	MSD/ms	MSA/degree	ANS
Category of traffic scenes	1	514.505	152.898	733.865	3.938	31.691	4.660	3.204
	2	593.855	209.921	714.738	4.747	62.077	4.764	3.859
	3	604.934	170.185	740.101	4.652	57.809	4.776	3.499
	4	751.174	216.770	794.491	5.885	38.141	4.705	4.596
	5	1259.756	472.827	723.132	5.948	57.389	4.502	4.708

Note. HEA = horizontal eye activity; VEA = vertical eye activity; MFD = mean fixation duration; ANF = average number of fixations; MSD = mean saccade duration; MSA = mean saccade angle; ANS = average number of saccades.

Table 7: ANOVA results of participants' eye movement indices.

Indices		Sum of squares	df	Mean square	F	Sig.
HEA	Between groups	2111986.140	4	527996.535	0.681	0.611
	Within groups	23273379.402	30	775779.313		
	Total	25385365.542	34			
VEA	Between groups	391533.844	4	97883.461	1.158	0.349
	Within groups	2534888.939	30	84496.298		
	Total	2926422.782	34			
MFD	Between groups	22827.252	4	5706.813	0.135	0.968
	Within groups	1270993.702	30	42366.457		
	Total	1293820.954	34			
ANF	Between groups	22.722	4	5.680	3.587	0.017
	Within groups	47.509	30	1.584		
	Total	70.231	34			
MSD	Between groups	5744.399	4	1436.100	2.583	0.057
	Within groups	16681.101	30	556.037		
	Total	22425.500	34			
MSA	Between groups	.267	4	0.067	0.631	0.644
	Within groups	3.176	30	0.106		
	Total	3.443	34			
ANS	Between groups	12.831	4	3.208	2.919	0.038
	Within groups	32.969	30	1.099		
	Total	45.801	34			

Note. HEA = horizontal eye activity; VEA = vertical eye activity; MFD = mean fixation duration; ANF = average number of fixations; MSD = mean saccade duration; MSA = mean saccade angle; ANS = average number of saccades.

driving task, auxiliary guidance message can be considered. Whether these messages come from the car or the road, it is beneficial to the safety of young drivers. The result also shows that potential hazards are difficult to be detected ($p < 0.01$) as shown in the previous study [3, 7, 38]. Maybe participants did not think potential hazard as a hazard before the latent threat materialized, and inadequate evolution information of traffic scenes deteriorated the judgment. Meanwhile, the complexity degree of traffic scenes positively affected participants' hazardous degree evaluation on traffic scenes ($p < 0.01$), the number of hazards unidentified was negatively influenced by complexity degree evaluation ($p < 0.05$) and hazardous degree evaluation ($p < 0.01$) on traffic scenes, and statistically significant correlations were also found between hazard identification time and complexity or hazardous degree evaluation of traffic scenes ($p < 0.01$). The results are close to the findings of Scialfa et al. [33], and higher complex traffic scenes or more hazardous traffic scenes could capture more attention of young drivers. This is largely related to the clue characteristics in a scene. Furthermore, there was a significant positive correlation between the hazard identification time and number of hazards slowly identified ($p < 0.05$). This is consistent with the common sense that the faster the recognition is, the less it will be included in the slow identification.

There is no significant difference in the horizontal and vertical eye movements between different traffic scene groups ($p > 0.05$), which may be related to the limitation of the visual search range due to the traffic scene being presented on the same computer screen. The average number of fixations and saccades represented significant difference between different categories of traffic scenes ($p < 0.05$). The average number of fixations in traffic scenes of pedestrian crossing the road or waiting to cross was significantly more than that in traffic scenes of vehicles lane-changing or braking. More fixations on pedestrians possibly indicated that participants needed more time of fixation to ascertain hazard. This phenomenon may also be affected by the characteristics of clues from the traffic scene. It is noteworthy that no significant findings were in the direction of the mean fixation duration and mean saccade duration across traffic scene categories. The result was likely ascribed to traffic scenes presented as static images.

The above results and analyses reflect the possible correlations between young drivers' hazard perception and eye movements, and the correlations seem to be related to the traffic scenes. This possibility has also been verified. Specifically, higher complex traffic scenes resulted in smaller saccade angle ($p < 0.05$). Participants paid more attention on microregions in front of instrumented vehicle, and the fixation time is less ($p < 0.05$). Higher hazardous traffic scenes were with shorter saccade duration ($p < 0.05$). This indicated that a higher saccade speed was in the direction of higher hazardous traffic scenes. The hazard identification time and the number of hazards slowly identified were positively related to the average number of fixations and

Table 8: Correlations between the indices of hazard perception and eye movement.

	Indices	HEA	VEA	MFD	ANF	MSD	MSA	ANS
CDE	Correlation coefficient	0.220	0.259	−0.337	−0.022	−0.309	−0.410	−0.055
	Sig. (2-tailed)	0.203	0.133	0.048	0.901	0.071	0.014	0.753
HDE	Correlation coefficient	0.176	0.194	−0.304	−0.128	−0.388	−0.144	−0.128
	Sig. (2-tailed)	0.313	0.264	0.076	0.464	0.021	0.409	0.464
HIT	Correlation coefficient	0.006	−0.022	0.205	0.650	0.138	0.167	0.702
	Sig. (2-tailed)	0.972	0.900	0.238	0.000	0.431	0.339	0.000
NHSI	Correlation coefficient	0.268	0.280	0.069	0.705	−0.140	−0.027	0.751
	Sig. (2-tailed)	0.120	0.104	0.696	0.000	0.424	0.877	0.000
NHU	Correlation coefficient	0.043	0.067	0.276	0.269	0.120	−0.225	0.299
	Sig. (2-tailed)	0.805	0.701	0.109	0.118	0.491	0.194	0.081

Note. HEA = horizontal eye activity; VEA = vertical eye activity; MFD = mean fixation duration; ANF = average number of fixations; MSD = mean saccade duration; MSA = mean saccade angle; ANS = average number of saccades; CDE = complexity degree evaluation; HDE = hazardous degree evaluation; HIT = hazard identification time; NHSI = number of hazards slowly identified; NHU = number of hazards unidentified.

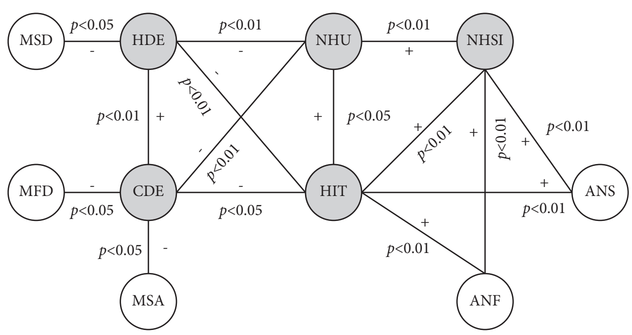


Figure 3: Correlation between indices of hazard perception and eye movement. Note: MFD = mean fixation duration; ANF = average number of fixations; MSD = mean saccade duration; MSA = mean saccade angle; ANS = average number of saccades; CDE = complexity degree evaluation; HDE = hazardous degree evaluation; HIT = hazard identification time; NHSI = number of hazards slowly identified; NHU = number of hazards unidentified.

average number of saccades ($p < 0.01$). Higher efficient hazard identification indicated that participants only needed as fewer numbers of fixations and saccades as possible to ensure they recognized hazards.

In addition, the results in Figure 3 show the correlation between the subjective and objective indicators of young drivers. We can speculate the subjective cognition of them through objective measurement indicators, and vice versa. For example, for the relevance of hazardous degree evaluation to hazard identification time, we can predict the driver's subjective perception of a certain traffic scene (e.g., self-perception of the hazardous degree) through the driver's hazard identification efficiency. At the same time, in terms of driver characteristics, for drivers with more driving mileage, the range of their horizontal eye activity is greater, which means that the more experience the drivers had, the wider the scope of their attention is and the stronger their awareness of hazard search is. The relatively shorter saccade time of older young drivers may also be due to the influence of driving experience [15, 18].

It should be noted that the test conditions in laboratory are not consistent with the real-world environment, which possibly resulted in different psychological feeling and visual behaviors of participants, but we can achieve the same controlled condition for all participants [38], and it is helpful to discover the inherent correlation between hazard perception and eye movement. In fact, we indeed have demonstrated some obvious findings in the study. In terms of future research directions, it is important to determine whether these findings are replicated in on-road testing. Future research should also examine correlations between the evolution procedures of traffic scenes, awareness, and eye movement, especially whether the fixations coincide with the possible traffic conflicts and its characteristics. According to drivers' eye movement when driving in a real-world environment, maybe we can know more information about drivers with the development of further research on the correlations between eye movements, hazard perception, and traffic scenes.

5. Conclusion

In order to analyze the correlation between drivers' hazard perception and eye movement, the study regarded young drivers as the object and implemented a static image-based hazard perception test with the help of different scenes and eye movement data collection equipment. At the same time, the difference analysis and correlation analysis were carried out based on the collected data. The obtained results suggest that in different traffic scenes, some indicators of driver's hazard perception and eye movement reflect significant differences. Also, some indicators of hazard perception and visual behavior are closely related.

The research on hazard perception and eye movement can guide road design, traffic management, driver training, and the test of driver's hazard perception ability. In order to avoid traffic accidents as much as possible, we can add auxiliary massages on the road or in the car for hazardous scenes that are easily overlooked. To reduce risky driving behaviors and the phenomenon of non-motor vehicles or pedestrians appearing on motor vehicle lanes, strengthening traffic management and creating a sound traffic safety climate are recommended. Some typical scenes can also be used to observe, analyze, and improve drivers' hazard perception skill. The results of this paper are based on the analyses of the acquired data. The next step of the research can use more abundant samples, indicators, traffic scenes, and test methods to further analyze the correlation between drivers' hazard perception and eye movement.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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