Driving Performance under Violations of Traffic Rules: Novice vs. Experienced Drivers

Jiawei Xu, Kun Guo, Poly Z.H. Sun, *Member, IEEE*

***Abstract*—It is of great significance for safe driving to study drivers' eye movement and driving operation behavior when they encounter other road users violating traffic rules. The underlying reason is that most drivers are unable to process the unexpected visual stimulation, which is more likely to lead to driving accidents, especially in a hybrid situation. In this study, a driving simulator is used to design driving scenarios and study the driving performance of drivers with different driving experiences when other road users violate traffic rules. The experimental results show that some novice drivers ignore the position of their own vehicle when they encounter traffic violations which will lead to the collision with other road users. Moreover, some novice drivers can only perform one of the operations between steering and braking to avoid collision in these emergent situations. They cannot reasonably combine braking and steering to complete emergency driving operations like experienced drivers. Finally, when the driving difficulty increases, experienced drivers spend less time looking and more time scanning their surroundings to ensure that they can cope with the more complex driving environment while novice drivers do the opposite. This study reveals the difference between novices and experienced drivers, which paves a useful reference for the future advanced driving assistance system.**

***Index Terms*—Human Factors in Driving; Driving Ergonomics; Violation of Traffic Rules; Novice vs. Experienced Drivers.**

I. INTRODUCTION

DRIVING is a highly visual task [1]. About 80-90% of the perceptual information of drivers during driving depends on vision. A considerable part of road traffic accidents is caused by problems with visual attention [2-3]. Therefore, it is of great significance to analyze eye movement while driving [4]. In addition, according to the statistics on traffic accidents [5], most accidents are also caused by drivers' improper control. Even if in the same scenario, different drivers may operate otherwise due to their age, mentality, experience, cognition, and so on. To ensure safety as much as possible, drivers always conduct frequent visual searches while driving. In general, different drivers have different strategies to acquire visual information [6]. A study in [7] showed that the search and scan pattern of novice drivers differs from those of experienced drivers. They explained that the visual patterns of experienced drivers have the following three characteristics: 1) horizontal scanning in a wide range; 2) gaze far ahead; 3) multi-mirror gaze. These characteristics indicate that experienced drivers are actively seeking a large amount of information. Besides, in highway driving, novice drivers sample lane signs at a high frequency while experienced drivers see far ahead of the vehicle. This means that experienced drivers apparently use peripheral vision to monitor lane position while novice drivers use fovea vision. From these points of view, the performance of different drivers varies in many ways.

Manuscript received XX. XX, 2021; revised XX. XX, 2022; accepted XX. XX, 2022.

J. Xu is with Human Factors in Driving Research Lab, Huawei Technologies, Co. Ltd, Shenzhen, China, He is also with College of Computer Science and Artificial Intelligence, Wenzhou University, China (e-mail: jxulincoln@gmail.com)

K. Guo is with the School of Psychology, University of Lincoln, Lincoln, LN6 7TJ, United Kingdom (e-mail: kguo@lincoln.ac.uk)

Poly Z.H. Sun is with the Department of Industrial Engineering, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China, and with the Department of Automation, Shanghai Jiao Tong University, Shanghai 200240, China (e-mail: zh.sun@sjtu.edu.cn)

As we all know, visual stimuli are essential to driving. When the visual stimuli are more complex and urgent, the possibility of breaking traffic rules increases. In this situation, drivers need to detect key visual stimuli more quickly, otherwise, safety problems can easily occur [8].

Up to now, only a few works have been devoted to the combination situation of eye movements and controls when encountering violations of traffic rules. There are many existing challenges in this situation. It can be concluded as following three aspects.

1) The emergency conditions require a higher workload than the normal driving conditions due to the combination of multiple visual stimuli sources.

2) It is challenging to reproduce these driving conditions in the naturalistic driving task.

3) The experiment for the naturalistic driving task is highly cost since it brings fatal harmfulness or mortality.

Considering the above challenges, the high traffic accident rate, and the severity of the consequences under the complex situation in real life, this study attempts to analyze the combination of eye movement and control behavior of drivers at **straight**, **bend**, and **intersection** on city roads by taking driving simulators as the experimental environment.

Specifically, this study addresses three questions when drivers encounter traffic violations by other road users.

a) What types of errors are drivers prone to make?

b) The difference in eye movement and behavior between experienced and novice drivers under driving tasks.

c) Which manipulations of novice drivers cause traffic accidents?

The rest of this paper is organized as follows. Section II briefly reviews recent studies on driver performance on challenging driving tasks. Section III details the proposed methodology. Section IV provides insights into human factors in driving. Finally, the summary is concluded in Section V.

II. Related Work

While most of the existing research literature on emergency driving has focused on driving operations in dangerous situations, there has been little analysis on eye movement and control of driving in complex emergencies. In [9], Fajen *et al.* studied the visual control of braking between different cohorts, i.e., gender, age, and other human factors [10]. Adams *et al.* [11] studied the braking operation of drivers in emergencies. Banks *et al.* [12] investigated driver behavior in emergencies via verbal protocol analysis.

To simulate the challenging situation that the natural driving tasks cannot cover, several attempts have been conducted a study on emergencies in a driving simulator. For example, Yoshida *et al.* [13] showed in the study of a simulated environment that there is a significant difference between drivers' braking behavior in emergency and general conditions. Loeb *et al.* [14] studied the emergency braking response of the driver in sudden driving events via simulation. They found there is a significant difference between experienced adults and novice teenagers in applying brake pressure. Warshawsky-Livne *et al.* [15] found that vehicle models have no influence on drivers' perceptual reaction time and braking action time, and the perceptual reaction time is directly proportional to the driving complexity and driver's age. In [16], the authors demonstrated the response time and steering duration of novice drivers are significantly longer than those of experienced drivers. Fujita *et al.* [17] studied pedal operation during emergency braking. This work reported even though the elderly driver could take a similar period from receiving the visual stimulus to releasing the accelerator pedal as the younger driver, they should take a longer time to switch the accelerator pedal to the brake pedal.

III. Methodology

This section elaborates on the experiments of the driving behavior in terms of eye movement and controls, with a particular design when encountering violations of traffic rules.

A. Participants

The Human Factors in Driving Research Lab, Huawei Technologies, Co. Ltd, approved this research. In this study, a total of 24 participants were recruited for the driving test including 16 males and 8 females.

The age, driving age, and driving mileage of the participants are depicted in Table I. All participants with ages ranging from 18 to 36 years old with a mean of 24.1 ± 4.2 (mean ± SEM) volunteered to participate in this research. All the participants have normal or corrected normal vision and normal color vision and they are responsible for the authenticity of their messages. A fair classification between the experimental group (EG) with 12 subjects and the control group (CG) with 12 subjects is conducted for a further comparison test. We classify drivers whose mileage is more than 50,000 km with no traffic accident history as expert (experienced) drivers and the rest as novice (inexperienced) drivers. After completing the experiment, one of the men (No. 13) has dizziness during the conditioning feedback. Therefore, the subsequent data statistics of participants will not include his data.

B. Apparatus

Carla [18], an open-source urban driving simulator, was adopted in this study. Specifically, Carla version 0.9.12 was used. It can support flexible settings of sensor suites and environmental conditions. The content is created from scratch by a dedicated team of digital artists, which includes the city layout, plenty of vehicle models, buildings, pedestrians, street signs, etc. It also provides signals that can be used for driving strategy training. Carla is designed for flexibility and realism in rendering and physics simulation, which is implemented as an open-source layer over Unreal Engine 4 (UE4) [19].

We built UE4 and Carla (Version 0.9.12) on a Windows 10 host with an i9 10850k 3.6 GHz processor, 32G memory, and GTX3080 GPU. A 21-inch monitor with a resolution of 1600*900 is used as the experimental monitor for participants, and a 27-inch monitor HKC G27 with a resolution of 1600*1050 is used as the monitoring monitor for the experimental researchers.

Carla supports an external device named Logitech G29 in terms of driving control. By connecting Logitech G29 with the force feedback steering wheel and pedals, participants can control the driving simulator. We set the rotation amplitude of the steering wheel at 900 degrees (450 degrees on the left and 450 degrees on the right), the central elasticity at 20 degrees (0-100), and the sensitivity at 50 (0-100). After the appraisal of several experienced drivers, the above settings are most close to the real driving feeling. The transfer between the data is fused through the Logitech G29 calling code supported by Carla.

Finally, Gazepoint GP3 HD [1], a research-grade eye tracker, was used to track participants' eye movements. Parameters of Gazepoint GP3 HD are shown in Table II. This study used a nine-point calibration method and a 60Hz sampling rate.

C. Design of Driving Scenario

To study the general driving performance of novice and experienced drivers when encountering other road users who do not obey the traffic rules, the typical and common straight, bend, and intersection of city road scenarios are studied. In this study, visual stimuli include pedestrians, non-motor vehicles (bicycles), vehicles, buildings, traffic signs, etc.

Carla provides multiple choices of OpenScenario. To obtain a comparable performance, it is required for experiments to ensure the same traffic events for all participants. Therefore, it is needed to strictly set the same condition for all participants on the OpenScenario platform. In particular, to avoid the influence of altering environmental conditions and changing lighting levels like driving at dusk and noon, Carla's Sunny Day weather is adopted uniformly in 12 experimental scenarios. The generated 12 experimental scenarios are shown in Fig. 1. It can be seen all experimental scenarios are relatively bright, which could provide a uniform and well-lit simulation environment.

The speed of the vehicle will affect the driver's performance. To reduce the influence of the speed on the driver's

[1]www.gazept.com/product/gp3-hd-professional-bundle-eye-tracking-research/

TABLE I
PERSONAL INFORMATION OF PARTICIPANTS

Experimental Group (EG)				Control Group (CG)			
Number	Gender	Age	Mileage (km)	Number	Gender	Age	Mileage (km)
1	male	18	few	13	male	23	55000
2	male	19	few	14	female	24	71000
3	male	24	2000	15	female	24	83000
4	male	23	few	16	male	26	50000
5	female	25	few	17	male	25	65000
6	male	23	few	18	male	23	42000
7	female	23	few	19	male	23	64000
8	female	26	1200	20	female	32	65000
9	male	21	few	21	male	21	82000
10	female	18	few	22	male	22	70000
11	female	27	14000	23	male	36	>100000
12	male	24	few	24	male	28	>100000

TABLE II
PARAMETERS OF EYE TRACKING DEVICE

Content	Configuration
Visual Accuracy	0.5-1.0 degree
Sampling Rate	60 Hz / 150 Hz
Calibration	5/9 points calibration
API	Open Standard API
Moving range	Horizontal * vertical (35cm*22cm)
Size	235*45*47(mm)
Weight	125g
Compatible Monitor Size	<=24 inches

performance, the vehicle in our experiments is limited to under 60km/h. Also, warning signs have been inserted into the virtual driving task to make the participants aware before experiments.

Fig. 1. Snapshots of video clips in the 12 scenarios.

There are four experimental scenarios (three columns from left to right in Fig. 1) in the straight, bend, and intersection. In the experimental scenarios, there are two motor vehicle lanes plus one non-motor vehicle lane.

Straight:

Scenario 1: About 100m ahead, a pedestrian jaywalks at a speed of 2.5m/s.

Scenario 2: Based on scenario 1, there is a cyclist illegally driving about 80m ahead.

Scenario 3: Based on scenario 2, there is a vehicle in the left lane moving forward at 80km/h.

Scenario 4: Based on scenario 3, there is a vehicle running at about 60km/h in the opposite direction.

Bend:

Scenario 5: After entering the turn, a pedestrian jaywalks at a speed of 2.5m/s.

Scenario 6: Based on Scenario 5, a cyclist is driving illegally.

Scenario 7: Based on scenario 6, there is a vehicle going straight ahead at 80km/h in the left lane.

Scenario 8: Based on scenario 7, there is a vehicle running at about 60km/h in the opposite direction.

Intersection:

Scenario 9: The traffic light facing the participant is green and a pedestrian is jaywalking at 2.5m/s.

Scenario 10: Based on Scenario 9, a cyclist is driving illegally.

Scenario 11: Based on scenario 10, a vehicle in the left lane drives to the intersection and turns left.

Scenario 12: Based on scenario 11, there is a vehicle in the opposite lane running a red light and turning left at the intersection (turning right from the participant's perspective).

D. *Experimental Setup*

Before the start of the experiments, participants were taught how to correctly use the pedal and brake, and the clutch is waived off since the participants are driving Citroën C3 [2].

Also, the participants were told that there was no clear driving task which indicates no top-down intervention for a fair comparison between novice and experienced drivers. Before experiments, the exercise continues until participants told the study staff to stop when they get familiar with the manipulation. Several measures were used to avoid the imbalance of driving fatigue caused by a long pre-test. For example, some participants took 20 minutes to complete the pre-test while others took an hour or even two hours. Therefore, the researchers would remind the participants to have a short relax appropriately when the exercise lasts more than half an hour.

[2]https://en.wikipedia.org/wiki/Citro%C3%ABn_C3

The participants were informed to sit on a chair of moderate height, after completing the preparation. A 21-inch monitor with a resolution of 1600*900 in front of the participant is mounted for the display of the driving tasks. Virtual scenarios are presented on the monitor. Gazepoint GP3 HD eye tracker is placed below the monitor. The updating frequency of the virtual scenario is 30 fps, and the sampling rate of the eye tracker is set to 60 Hz. The driving environment of participants is captured in Fig. 2. The Logitech G29 force feedback steering wheel is attached to the desk. The pedal is fixed under the desk. The vertical centers of the screen, eye tracker, and steering wheel remain in the same line. To ignore the interference of vehicle factors, the driving perspective of this study is the RGB camera installed on the windshield of the car. The angle of view is 180 degrees ahead. Each participant will conduct experiments to fully familiarize him/her with the G29 steering wheel and pedals before starting the first formal experiments.

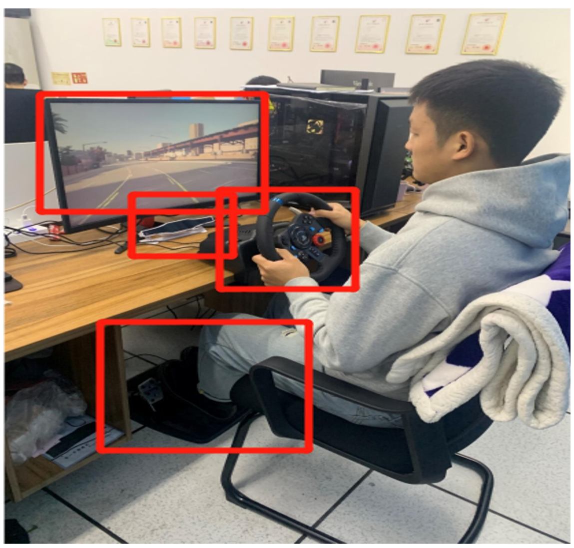


Fig. 2. A snapshot of the driving simulator. The red boxes represent the monitor, eye tracker, and pedals from top to the bottom, respectively. The steering wheel, however, is mounted on the desk, with the closest distance to the participants.

After the completion of the exercise, the participants were informed of the upcoming eye-movement calibration test. After the calibration had been correct, the simulation driving experiment of four straight scenarios was conducted continuously, and the driving task was to reach the bend through the current straight. After completing four straight experiments, the participants were told that they were going to have four simulated driving experiments on a bend. The driving task was to reach the road intersection through the bend. After completing the four bend experiments, the participants were instructed that they were about to conduct the simulation driving experiment at an intersection. The driving task was to pass through the intersection in front of them and go straight ahead at the intersection. After a total of 12 scenarios was completed, participants' personal information and mental status (dizziness or not) were recorded.

After completing the driving tasks, the synchronization of driving data, driving scenario frame, and eye tracker were completed by OpenCV 2.4.9 for the balance of CPU computational timing delay.

E. Data Processing

The subjects were divided into two groups: EG (novice drivers) and CG (experienced drivers). Their eye-movement data, driving data, and frame recording data communicate with recorded CPU time. In this study, ground truth (GT) is defined as eye movement data and driving maneuver data of expert drivers, i.e., experienced drivers. We believe that the driving behaviors of participants in the 12 scenarios are different. We take the errors of driving behavior as the key point and conduct a comparative analysis with GT according to drivers' purposes. For example, a novice driver finally hit a pedestrian while driving on a bend, since he got too close to the pedestrian when he noticed the pedestrian crossing the road. In this case, we complete the analysis and comparison of eye movement data and driving control data by analyzing:

a) data from the first 1000ms before the novice driver noticed the pedestrian to the time of the accident;

b) GT data from the first 1000ms of staring at the pedestrian to safe passage (when the pedestrian disappears).

Specifically, we used synchronized driving video images to look for driving behavior errors (e.g., driving across solid lines, driving across non-motorized lanes, not maintaining a safe distance from other road users, etc.). The synchronized data is then sliced through frame-by-frame video analysis. The leave-one-subject-out (LOSO) cross-validation strategy [20] has been illustrated to be an excellent evaluation strategy. In the subject-independent experiment, we used the LOSO cross-validation strategy to evaluate GT. To analyze human factors in driving, the procedure to process raw data is illustrated in Fig. 3.

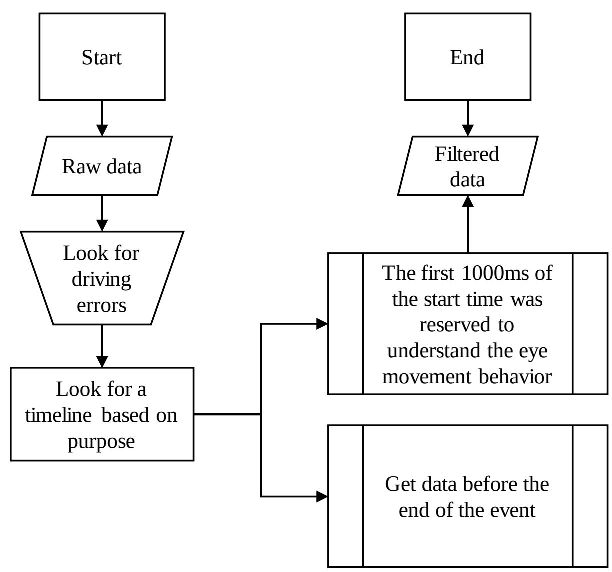


Fig. 3. Data processing for the analysis of human factors in driving for both EG (novice drivers) and CG (expert drivers).

IV. Human Factors in Driving

In this section, three following key questions are discussed in terms of human factors in driving.

a) What types of errors are drivers prone to make?

b) The difference in eye movement and behavior between experienced and novice drivers under driving tasks.

c) Which manipulations of novice drivers cause traffic accidents?

A. What types of errors are drivers prone to make

As is known to all, incorrect driver eye movement does not necessarily lead to errors in driving operations. This study takes driving behavior as the key point. We searched and analyzed driving errors and their causes in experiments by synchronizing the virtual driving scenarios and the driving performance (eye movements and maneuvers).

This study adopts the classification of **Slip**, **Lapse**, **Mistake**, and **Violation** proposed by James Reason [21] as the formal human error in driving. **Slip** and **Lapse** represent attention error and memory error, respectively. Besides, **Mistake** represents a subjective error, **Violation** indicates breaking the rules.

Based on this classification, Table III lists the driving errors in experiments, in which No. 19 was experienced drivers and the rest were novice drivers. Among these 25 driving errors, the most common driving errors were caused by **Lapse**, which we believe is caused by the driver's inexperience and incomplete familiarity with the driving simulator. Besides, **Slip** (attention errors) are the second largest group of driving errors, which confirms that eye movement errors are one of the main causes of driving errors. When drivers encounter other road users who do not obey traffic rules, the most common eye-movement errors are distraction and attention deficit [22] which can be interpreted as the existence of driving expectations. Driving expectation can be understood as the road and traffic conditions of drivers in normal driving. In this situation, drivers are usually not very alert. Therefore, the driver fails to detect and react the first time when other road users do not obey the traffic rules. It is worth noting that drivers have more attention errors in the straight which can be interpreted as the average fixation time of drivers in the straight is longer which makes drivers fail to notice dangers in time.

B. The difference in eye movement and behavior between experienced and novice drivers under driving tasks

Statistical Product and Service Solutions (SPSS) 23.0 was conducted to test whether there exists a significant difference in straight, bend, and intersection. Considering that these differences in visual stimuli could be reflected by fixation time, saccade magnitude (in pixels), or saccade angle (0-360 degrees), the difference in visual stimulus between scenarios could be indicated by a significant difference in either fixation time, saccade magnitude or saccade angle. Therefore, a non-parametric test is further adopted once the fixation time, the saccade magnitude, and the saccade angle do not accord with normal distribution for the straight, bend, and intersection. Besides, the results of the following tests are set at a confidence interval of 0.95.

Table IV and Fig. 4 demonstrate the hypothesis and Mann-Whitney U test for the fixation time between scenarios 1 and 2 on the **straight**. It can be seen that p-value is 0.024. The same test can be conducted on other pairs of scenarios. To avoid repetition, only the results are presented here. p-values of scenarios 2 and 3, scenarios 3 and 4 are 0.239 and 0.026, respectively. Then, a non-parametric test for saccade magnitude for scenarios 2 and 3 on straights is further adopted since it does not accord with normal distribution. The result shows the significance level of the non-parametric test on scenarios 2 and 3 is 0.020. The above results show there are significant differences in different scenarios in the straight.

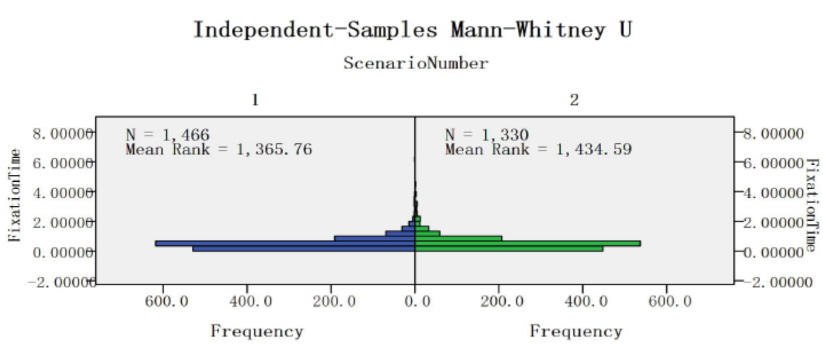
We then compared the data of **Slip** (attention error as the basic error type shown in Table III) with GT to understand the difference between novice drivers and experienced drivers in eye movement and driving behavior caused by attention error. It should be emphasized that the data were compared from the driving behavior of the subjects. For example, novice drivers with a lack of attention result in noticing the pedestrian jaywalk too late while driving in a straight lane. Then, he/she performs an emergency maneuver to change direction and slow down. As a result, he/she fails to keep a safe distance from the pedestrian. The time range of GT data is 1000ms before GT's gaze to the pedestrian and after GT passes safely (the pedestrian disappears). Hypothesis tests numbered 1, 2, and 3 in Table V show the U test in terms of fixation time, saccade magnitude, and saccade angle results between the novice and expert drivers.

Table VI shows the normality test of the **eye movement** (i.e., fixation time, saccade magnitude, and saccade angle) between novice drivers whose error type is **Slip** in the straight and expert drivers. Moreover, a non-parametric test is adopted for the reason of fixation time, saccade magnitude and saccade angle do not accord with normal distribution. The results illustrate that the fixation times for different subjects (novice or expert drivers) are different since the significance level $\alpha = 0.013$ which is less than 0.05. Therefore, it can be considered that there is no significant difference in saccade magnitude and saccade angle between novice drivers and expert drivers for this situation.

Similarly, a normality test was also conducted on the **manipulation**, as shown in Table VII. The hypothesis tests numbered 4, 5, and 6 in Table V have been conducted as a U test in terms of throttle, brake, and steer results between novices and expert drivers. It can be seen in Table VII Sigs of the K-S test and S-W test are all less than 0.001. Finally, a U test was adopted to detect whether there was a significant difference in the control of the novice and expert drivers. When the significance level is 0.05, the test results show that there are significant differences in throttle, brake, and steering control between novices and experienced drivers. From the mean value of control, the acceleration change (the mean value of accelerator-brake) of novice drivers is 0.53, while that of experienced drivers is 0.35, indicating that the acceleration and deceleration change of novice drivers is more severe than that

TABLE III
SUMMARY OF DRIVING ERRORS FOR BOTH EG (NOVICE DRIVERS) AND CG (EXPERT DRIVERS)

Behavior	Scenario	Number	Base Error Type	Reason
Cross the left-solid lane	Straight	2	Slip	Not find the child crossing the road in time, the remedy is to swerve
		7	Lapse	Turning the steering wheel too much when changing lanes
		10	Lapse	Turning the steering wheel too much when changing lanes
		11	Lapse	Turning the steering wheel too much to avoid the bike
	Bend	5	Lapse	Turning and changing lanes, turning the steering wheel too much
		7	Lapse	Turning the steering wheel too much
		8	Lapse	Turning the steering wheel too much
		3	Lapse	Turning and changing lanes, turning the steering wheel too much
		1	Lapse	Turning the steering wheel too much
		4	Lapse	Turning the steering wheel too much
		9	Lapse	Turning the steering wheel too much
		6	Lapse	Turning and changing lanes, turning the steering wheel too much
Crossing non-motorized lane	Intersection	10	Violation	Not aware of any violations
		19	Violation	Commit a wrongful act even when you know it's against the rules
Not keeping a safe distance	Straight	7	Slip	Attention deficit
		8	Slip	Attention deficit
		12	Slip	Loss of concentration, emergency braking in case of danger
		11	Slip	Distractions
		3	Slip	Attention deficit
	Bend	9	Slip	Attention deficit
	Intersection	4	Lapse	Wrong distance estimation
		7	Mistake	Overconfidence
		3	Lapse	Wrong distance estimation
Crash	Straight	2	Slip	Failing to detect the child crossing the road in time
	Bend	7	Mistake	It should have stopped, but the driver didn't



Total N	2,796
Mann-Whitney U	1,022,885.500
Wilcoxon W	1,908,000.500
Test Statistic	1,022,885.500
Standard Error	21,318.005
Standardized Test Statistic	2.251
Asymptotic Sig. (2-sided test)	.024

Fig. 4. Details of the Mann-Whitney U test between scenarios 1 and 2 for fixation time on the straight.

TABLE IV
HYPOTHESIS TEST BETWEEN SCENARIOS 1 AND 2 FOR FIXATION TIME ON THE STRAIGHT

Hypothesis Test Summary				
ID	Null Hypothesis	Test	Sig.	Decision
1	The distribution of fixation time is the same across categories of scenario number.	Independent-Samples Mann-Whitney U Test	0.024	Reject the null hypothesis.
Asymptotic significance is displayed. The significance level is 0.05.				

TABLE V
SIGNIFICANCE OF ALL HYPOTHESIS TEST

ID	Null Assumption	Test	Significance	Decision
1	Within the categories of types, fixation time has the same distribution.	U test	0.013	Reject null hypothesis
2	Within the categories of types, saccade magnitude has the same distribution.	U test	0.098	Reserve null hypothesis
3	Within the categories of types, saccade angle has the same distribution.	U test	0.371	Reserve null hypothesis
4	Within the categories of types, throttle has the same distribution	U test	0.000	Reject null hypothesis
5	Within the categories of types, brake has the same distribution	U test	0.000	Reject null hypothesis
6	Within the categories of types, steer has the same distribution	U test	0.003	Reject null hypothesis

TABLE VI
NORMALITY TEST OF EYE MOVEMENTS

Eye movement data	Driver Types	KS^a			SW		
		Statistics	DOF	Sig	Statistics	DOF	Sig
Fixation Time	Novice	0.289	63	0.000	0.448	63	0.000
	Experienced	0.172	15	0.200	0.911	15	0.142
Saccade Magnitude	Novice	0.132	63	0.008	0.920	63	0.001
	Experienced	0.245	15	0.015	0.791	15	0.003
Saccade Angle	Novice	0.119	63	0.027	0.916	63	0.000
	Experienced	0.201	15	0.105	0.879	15	0.046

* The superscript a of KS represents Lilliefors significant correction (see https://en.wikipedia.org/wiki/Lilliefors_test).

of experienced drivers. Besides, the mean steering change of novice drivers is -0.02 (less than 0 means turning left, larger than 0 means turning right) and the standard deviation is 0.014 while the mean steering change of experienced drivers is 0.001 and the standard deviation is 0.008. The above data indicate that novice drivers also have more drastic changes in steering than experienced drivers. Therefore, it is illustrated that novice drivers are not as steady as experienced drivers when they encounter other road users who do not obey traffic rules.

C. Which manipulations and eye movement of novice drivers cause collision accidents

We conducted a detailed comparative analysis of the traffic crash scenario to explore eye movement and driving behavior before and after the fatal error. Fig. 5(a) shows the fixation diagram of EG from 1000ms before they gaze at the pedestrian straight to the moment of collision. Figs. 6(a) and 6(b) show the acceleration and steering comparison plots of EG and CG. It should be explained that: 1) the data in EG is the data of subjects in a collision accident, and that in CG is the data of GT; 2) the yellow line in Fig. 6 is the time point when the event occurs (when pedestrians are observed); 3) the acceleration in the acceleration diagram is defined as throttle-brake, and the values of throttle and brake are between [0,1]. If the acceleration is greater than 0, it means the vehicle is accelerating. On the contrary, if the acceleration is less than 0, it means the vehicle is braking; 4) the value of the steer is between [-1,1], and if the value is less than 0, it means the driver turns to the left. On the contrary, If the value is greater than 0, it means the driver turns to the right.

Combined with Figs. 5(a) and 6(a), the following situation can be judged. The 46-th fixation point in Fig. 5(a) indicates that when a child crosses the road, the driver from EG drives faster and the distance between the driver and the child was relatively close.

Fig. 6(a) shows that the driver from EG gradually releases the throttle after about 200ms. However, due to the speed of the vehicle and the distance between the vehicle and the pedestrian, a slow right turn of the steering wheel and gradual release of the gas pedal was not enough for the pedestrian crossing the road. Different from the driver from EG, the driver from CG which is used as GT has a very long timeline of the event. It is illustrated the driver noticed pedestrians very early so that the turning can be much smoother than that of EG. Therefore, our study believes that the driver from EG is unable to timely find the child crossing the road, which leads to the accident. Also, the subsequent emergency response of the driver from EG proves that novice drivers are more likely to have poor **situational awareness**.

Fig. 6(b) shows that the driver from EG had almost no emergency change in steering, and still slowly turned the steering wheel to the right as before seeing the child. Fig. 5(b) shows the fixation diagram of the driver in EG from 1000ms before the pedestrian is observed in the curve to the moment of collision. Figs. 6(c) and 6(d) show the comparison of acceleration and steering of the drivers from EG and CG, respectively. Combined with Figs. 5(b), 6(a), and 6(b), we can

TABLE VII
NORMALITY TEST OF MANIPULATIONS

Driving Maneuver	Driver Types	KS^{a}			SW		
		Statistics	DOF	Sig	Statistics	DOF	Sig
Throttle	Novice	0.275	940	0.000	0.756	940	0.000
	Expert	0.199	329	0.000	0.839	329	0.000
Brake	Novice	0.510	940	0.000	0.382	940	0.000
	Expert	0.341	329	0.000	0.595	329	0.000
Steer	Novice	0.199	940	0.000	0.793	940	0.000
	Expert	0.152	329	0.000	0.945	329	0.000

* The superscript a of KS represents Lilliefors significant correction (see https://en.wikipedia.org/wiki/Lilliefors_test).

(a) on the straight

(b) on the bend

Fig. 5. Fixation map of collision accident on the straight and bend.

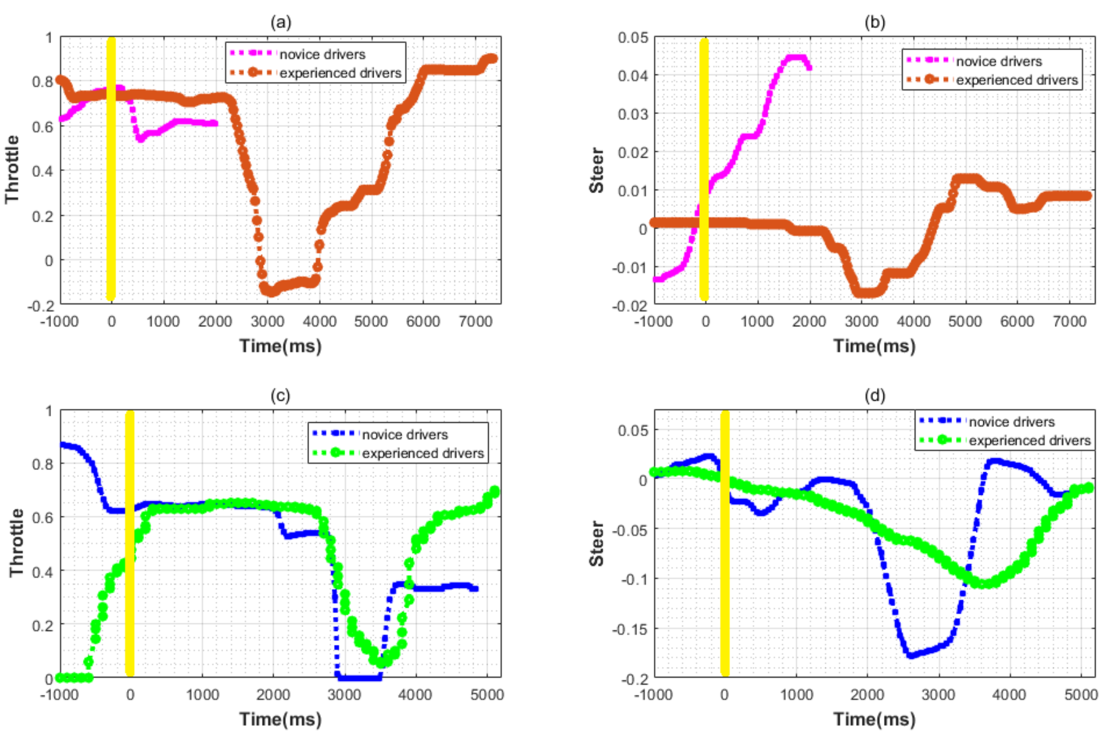


Fig. 6. Throttle and steering control contrast between CG and EG.

make the following judgment. Continuous eye movement data showed that the 107-th fixation point in Fig. 5(b) is the time point when the driver from EG saw the pedestrian crossing the road, and there was still a certain distance from the pedestrian. Fig. 6(c) shows that the driver from EG still maintains an acceleration of about 3000ms after gazing at the pedestrian, and then begins to decelerate eagerly. Fig. 6(d) shows that the driver from EG does not show any change in turning direction to avoid the pedestrian for about 2000ms when he/she has overt attention to the pedestrian. Then, between 2000-3500ms, the driver from EG makes a large left turn and turns back to avoid the pedestrian. It should be noted that the driver from EG still keeps accelerating during the first 1000ms or so of the large turn, indicating that the driver does not have excellent hand and foot coordination to deal with emergencies. Therefore, our research believes that in this collision accident, the driver from EG does not break down/ decelerate when he/she should break down/ decelerate, which reflects that the steering control and pedal control cannot be combined effectively some novice drivers. Figs. 7(a) and (b) give the gaze patterns between CG and EG to intuitively compare the difference between novice and experienced Drivers when occurring at the accident scene. It can be inferred that most drivers in CG are aware the crossing pedestrian in an earlier manner but a higher percentage of the drivers in EG cannot process this kind of potential danger.

V. Discussion

This paper aims to reveal the general difference in driving performance of novice and experienced drivers under violations of traffic. Therefore, it is necessary to test the performance of novice and experienced drivers on the most common driving road conditions and the most common driving road traffic violations. For this motivation, the most common driving road conditions and the most common driving road traffic violations should be recognized.

It can be seen from literature that over-speeding, disobeying the traffic rules, crossing the street, and illegally occupying lanes are four typical and most common types of violations [13]-[17]. Besides, through the test subjects studied for the driving test, it is known that straight, bend, and intersection are three typical and most common types of road conditions. Both novice drivers and experienced drivers will encounter the above combination scenarios of violations and road conditions during their driving learning or daily driving activities. Therefore, it is most appropriate to explore the general performance comparison of novice drivers and experienced drivers in the above combination scenarios.

Through our designed experiments, three key contributions can be obtained.

(1) We classify driving behaviors in this study according to the basic error types of James Reason [17].

(2) We performed a detailed statistical analysis of driving data in which the primary error is Slip (attentional error). The results reveal these findings: a) novice drivers are not as smooth as experienced drivers when they encounter other road users who do not obey traffic rules; b) Novice drivers and experienced drivers have different average fixation times when they encounter other road users violating traffic rules.

(3) We analyzed the manipulation control and eye movement of the driver that caused collision accidents in the experiment. The results reveal these findings: a) Some novice drivers have attention deficits, and they may not be able to find dangerous situations in the complex traffic environment for the first time; b) some novice drivers have poor situation simulation ability, and they cannot correctly predict the next driving situation; c) some novice drivers cannot conduct an excellent combination of the steering wheel and pedal during driving, which means that novice drivers are much more likely to have serious traffic accidents in dangerous situations than experienced drivers.

In general, it is illustrated in our research, that novice drivers cannot perform as well as experienced drivers. Therefore, the design of an advanced driving assistance system (ADAS) should take a lesson that the use requirements of ADAS for drivers with different experiences are different. Differentiated assistance service is required to develop and then provide for different (novice or experienced) drivers. For example, for most novice drivers, some important visual stimuli are lost when encountering traffic violations, ADAS should develop warn or alert function to assist the driver to avoid violating traffic rules in an earlier manner. Besides, the combination between pedal and steering is not proper when encountering traffic violations, ADAS is expected to replace humans for safer control of the vehicle. For experienced drivers, developing functions to avoid the potential danger for these experienced cohorts is the key issue for ADAS. For example, No.19 in the experiment, deliberately commits the violations even though he/she knows this violates the traffic rules. For this case, the ADAS should record this behavior and launch an intelligent action, such as brake in advance, to avoid the potential danger.

VI. Conclusion

In this study, a driving simulator is used to design driving scenarios and study the driving performance of drivers with different driving experiences when other road users violate traffic rules. In general, our research illustrates that novice drivers cannot perform as well as experienced drivers when they encounter other road users who do not obey traffic rules in visual attention, manipulation control, and driving situation prediction. For a safer driving environment, therefore, novice drivers are expected to conduct situational simulation and eye movement training in complex scenarios as much as possible in virtual environments to improve their situational awareness. The experienced drivers, particularly those drivers with no accident history, probably could provide constructive guidance for the novice cohorts. Besides, the designer of ADAS may take a lesson from our research that differentiated assistance service is a potential requirement for drivers with different driving experiences.

References

[1] J. Xu, X. Zhang, S. Hyeong Park and K. Guo, "The Alleviation of Perceptual Blindness during Driving in Urban Areas Guided by

(a) CG (b) EG

Fig. 7. Gaze patterns comparison between CG and EG when processing a potential accident.

Saccades Recommendation," *IEEE Trans. Intell. Transp. Syst.*, to be published, doi: 10.1109/TITS.2022.3149994.

[2] Y. Xie, Y. L. Murphey and D. S. Kochhar, "Personalized Driver Workload Estimation Using Deep Neural Network Learning From Physiological and Vehicle Signals," *IEEE T. Intell. Veh.*, vol. 5, no. 3, pp. 439–448, 2020.

[3] B.E. Sabey and H. Taylor, The Known Risks We Run: The Highway (Transport and Road Research Laboratory Supplementary Report 567). Crowthorne, TRRL, UK, 1980.

[4] Z. Wang, R. Zheng, T. Kaizuka and K. Nakano, "Relationship Between Gaze Behavior and Steering Performance for Driver–Automation Shared Control: A Driving Simulator Study," *IEEE T. Intell. Veh.*, vol. 4, no. 1, pp. 154–166, 2019.

[5] S. Singh, "Critical reasons for crashes investigated in the national motor vehicle crash causation survey," National Highway Traffic Safety Administration, Washington, D.C., USA, Rep. DOT HS 812 115, 2014.

[6] J. Zell, Driver's Eye Movements as a Function of Driving Experience, Technical Report IE, 16, Engineering Experimental station, Ohio State University, Columbus, 1969.

[7] R. Mourant and T. Rockwell, "Strategies of visual search by novice and experienced drivers," *Hum. Factors*, vol. 14, no. 4, pp. 325–335, 1972.

[8] J. Xu, S. Hyeong Park and X. Zhang, "The Improvement of Road Driving Safety Guided by Visual Perceptual Blindness" *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 6, pp. 4972–4981, 2022.

[9] B.R. Fajen, "Perceptual learning and the visual control of braking," *Percept. Psychophys.*, vol. 70, no. 6, pp. 1117–1129, 2008.

[10] S. Ansari, F. Naghdy and H. Du, "Human-Machine Shared Driving: Challenges and Future Directions," *IEEE T. Intell. Veh.*, to be published, doi: 10.1109/TIV.2022.3154426.

[11] L. D. Adams, "A review of the literature on obstacle avoidance maneuvers: Braking versus steering," Univ. Michigan Transp. Res. Inst., Ann Arbor, MI, Tech. Rep. UMTRI-94-19, 1994.

[12] V. A. Banks, N. A. Stanton and C. Harvey, "What the drivers do and do not tell you: using verbal protocol analysis to investigate driver behaviour in emergency situations," *Ergonomics*, vol. 57, no. 3, pp. 332–342, 2014.

[13] H. Yoshida, J. Kizaki and A. Yamamoto, "Development of A Brake Assist System," Society of Automotive Engineers Paper 980601, 1997.

[14] H. Loeb, V. Kandadai, C. McDonald and F. Winston, "Emergency Braking in Adults versus Novice Teen Drivers: Response to Simulated Sudden Driving Events," *Transp. Res. Record*, vol. 2516, no. 1, pp. 8–14. 2015.

[15] L. Warshawsky-Livne and D. Shinar, "Effects of uncertainty, transmission type, driver age and gender on brake reaction and movement time," *J. Safety Res.*, vol. 33, no. 1, pp. 117–128, Spring 2002.

[16] Z. Yang, Q. Yu, W. Zhang and H. Shen, "A comparison of experienced and novice drivers' rear-end collision avoidance maneuvers under urgent decelerating events," *Transp. Res. Pt. F-Traffic Psychol. Behav.*, vol. 76, pp. 353–368, 2021.

[17] K. Fujita, Y. Kobayashi, M. Sato, H. Hori, R. Sakai, T. Ogawa, T. Sugano, K. Kawabata, and M. Hitosugi, "Kinematic and Electrophysiological Characteristics of Pedal Operation by Elderly Drivers during Emergency Braking," *Healthcare*, vol. 9, no. 7, pp. 1–13, 2021.

[18] A. Dosovitskiy, G. Ros and F. Codevilla, A. Lopez and V. Koltun, "CARLA: An Open Urban Driving Simulator," *Proc. 1st Annu. Conf. Robot Learn.*, 2017, pp. 1–16.

[19] Epic Games: Unreal Engine 4. Accessed: Jul. 02, 2022. [Online]. Available: https://www.unrealengine.com

[20] M. Esterman B. Tamber-Rosenau, Y. Chiu and S. Yantis, "Avoiding non-independence in fMRI data analysis: leave one subject out," *Neuroimage*, vol. 50, no. 2, pp. 572–576, 2010.

[21] J. Reason, Human Error. New York: Cambridge Univ. Press, 1990.

[22] B. Baheti, S. Talbar and S. Gajre, "Towards Computationally Efficient and Realtime Distracted Driver Detection with MobileVGG Network," *IEEE T. Intell. Veh.*, vol. 5, no. 4, pp. 565–574, 2020.

Jiawei Xu is an adjunct consultant in Huawei Technologies specialized in human factors in driving from 2019 and an associate professor in Wenzhou University. He was a postdoc and lecturer in Newcastle University, UK from 2015 to 2019. He received the Ph.D. degree with the topic of Human Factors in Driving, University of Lincoln, UK, supervised by Dr. Kun GUO. His research interests are focused on human factors in aviation (fighter plane, Cessna, A320, etc.) and human factors in intelligent/ automated driving (L2, L3, L4).

Kun Guo received his BSc in Human Physiology from Nanjing University, and Ph.D. in Cognitive Neuroscience from the Chinese Academy of Sciences. Before He came to Lincoln in 2004, he worked as a McDonnell-Pew Research Fellow in the University Laboratory of Physiology, University of Oxford, and a Senior Research Associate in the Department of Psychology, University of Newcastle. He is currently a Professor in Cognitive Neuroscience, School of Psychology, University of Lincoln, United Kingdom.

Poly Z.H. Sun (Member, IEEE) is currently pursuing his Ph.D. degree in Industrial Intelligent System with the Department of Industrial Engineering, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China. Also, he is currently a Research Assistant with the Department of Automation, Shanghai Jiao Tong University, Shanghai, China. He has authored/co-authored over 20 research papers in top-tier refereed international journals and conferences, such as IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS, IEEE TRANSACTIONS ON INTELLIGENT VEHICLES, IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING.

His current research interests include intelligent transportation systems, evolutionary optimization, neuroergonomics, brain and cognitive science, complex network, non-parametric machine learning, operations research, and their applications in industrial or medical problems. He is a member of the IEEE CIS, IEEE SMC, and Association for Computing Machinery. He also has been severing as a reviewer or a session chair for several top-tier international journals and conferences in his research field.