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Driver Adaptability When Traffic Side Is Switched from Left to Right and Vice Versa: A Driving Simulator Study with Chinese and Pakistani Drivers

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Abstract: Driving simulators serve as valuable instruments for traffic safety research because they enable the creation of various scenarios that are hard to replicate in the real world. Eye tracker devices have proven to be immensely beneficial in studying eye movements. In this particular study, the objective was to examine potential variations in the adaptability of young male Chinese and Pakistani student drivers to left-hand traffic (LHT) and right-hand traffic (RHT) infrastructures when navigating under unfamiliar driving rules and environments. To achieve this, twenty-one Pakistani and twenty Chinese young male drivers were recruited to participate in different simulated driving scenarios (LHT and RHT). The factors tested were: (1) hazard perception; (2) time to collision (TTC); and (3) intersectional and lane-changing behavior. Using data collected from the driving simulator and eye tracker, differences in adaptability between both pools of drivers were compared using the ANOVA technique. The results showed that young male Chinese drivers were more vigilant and had a higher adaptability to unfamiliar infrastructure (3), they also had a better hazard perception (1) and time to collision (1 and 2). Young male Pakistani drivers had poorer hazard perception (2) and consequently had the shortest brake response time in the RHT scenario (2).

Keywords: adaptability; left-hand traffic (LHT); right-hand traffic (RHT); hazard perception; time to collision (TTC)

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1. Introduction

Annually, around 1.3 million individuals lose their lives due to road traffic accidents, while an additional 20 to 50 million people endure non-fatal injuries, with a significant number experiencing disability as a consequence of these injuries [1]. Approximately 65% of the world's population drives on the right-hand side (RHT) of the road, while about 35% drives on the left-hand side (LHT) [2]. Countries which were colonized by British Empire opted the LHT and constitute more than 35% of the world's population, while the countries which were colonized or follow French or American driving systems use RHT and constitute about 65% of the world's population. The majority of road traffic accidents can be directly linked to human factors, either as the primary cause or as a contributing element [3]. Human factors in driving can be viewed as comprising two distinct elements: driving skills and driving style, which can be referred to as driver performance and behavior, respectively [4,5]. Driving skills encompass information processing and motor skills, which are enhanced through practice and training, specifically with increased driving experience. On the other hand, driving style pertains to the manner in which drivers choose to operate their vehicles or their habitual driving behaviors, such as preferred driving speed, level of overall attentiveness, and tolerance for accepting gaps in traffic [6].

Historically, for 233 years, Sweden had opted for left-hand traffic, but owing to global trade and Swedish consumer preferences, vehicles in Sweden were commonly manufactured with left-sided steering wheels. This led to a significant number of accidents, particularly on narrow roads. On 3 September 1967, Sweden underwent a momentous change known as the "Högertrafikomläggningen," transitioning from left-hand traffic to right-hand traffic to normalize with the continental European standard. While still using left-hand drive vehicles. This change in traffic direction represented a significant and distinctive shift in standards [7].

In another study in Japan, when drivers accustomed to driving on one side of the road transition to the opposite side, they often experience an elevated mental burden resulting from their unfamiliarity with the altered driving regulations, the repositioning of the driver's seat, the change in driving directions, and the various divergent elements compared to their native driving customs. One approach to mitigate this situation involves ensuring that the guidance provided by in-vehicle route information (RGI) remains clear and uncomplicated, thereby helping drivers enhance their safety. Consequently, the objective of this research was to enhance the mobility and safety of drivers accustomed to right-sided driving who temporarily need to adapt to left-sided traffic [8].

Canadian researchers conducted a study that highlights the increased difficulty and danger associated with making left-hand turns in countries where traffic moves on the right-hand side. Data from insurance and crash statistics indicate that left-hand turns at busy intersections are the primary locations for severe accidents. In contrast, when driving on the left-hand side of the road, executing a left-hand turn is considerably simpler, as the driver is already positioned on the left-hand side of the road and merely needs to complete the turn, without the need to carefully assess traffic and time the maneuver precisely [9].

1.1. Cultural Differences

Cultural changes have been extensively examined in numerous studies as a significant factor affecting a driver's behavior behind the wheel. According to the "social accident" model, drivers from diverse social groups may interpret a given situation differently, potentially leading to accidents [10]. In many low- and middle-income countries (LMICs), there is a lack of formal traffic regulations, causing drivers to develop informal methods of communication and interaction with one another [11,12]. It has been proposed that cultural differences could provide an explanation for the variations observed in traffic violations and crash rates [13]. Consequently, the road safety values prevalent within a society or country would be anticipated to have a substantial impact on driving behavior. The concept of traffic culture encompasses certain elements, including the drivers' skills, attitudes, and behaviors, as well as vehicles and infrastructure, that collectively and directly or indirectly impact the overall level of traffic safety within a country [14]. According to Iversen, attitudes towards rule-breaking and risk-taking behavior can be influenced by societal norms and the pressures imposed by society [15].

1.2. The Road Environment

According to international accident reports, the leading factor responsible for road accidents is linked to drivers' insufficient recognition of fellow road users and various elements like pedestrians, vehicles, traffic signs, and road markings. Research findings indicate that mistakes made by humans, such as driver distraction or cognitive overload, lead to an inaccurate understanding of the surrounding environment, leading to traffic disruptions and accidents [16–18]. Driving behavior and safety are influenced by the road environment, which encompasses the vehicle, road infrastructure, and traffic regulations [19]. In the scope of this paper, the term "environment" pertains to the outside conditions surrounding the vehicle, primarily focusing on the road and its attendant infrastructure. The road environment, and factors such as traffic layout and safety, play a crucial role in ensuring road user safety. According to Rospa, approximately 2–3% of crashes can be directly attributed to environmental factors, particularly the road environment, while these factors contribute to approximately 18% of all road crashes [20]. Understanding the driver-related issue is relatively straightforward and has received some acknowledgment in the literature. Although no specific studies were found addressing the safety of right-hand drive (RHD) vehicles in a left-hand drive (LHD) environment, a few studies have examined the issue of driver unfamiliarity with local road travel conventions. Dobson discovered that drivers born outside Australia (where the left-side driving convention applies) did not exhibit a higher risk compared to native-born drivers in the country, but immigrant pedestrians did demonstrate an increased risk [21].

1.3. Hazard Perception

Models of health behavior argued that risk perception may influence risky behavior [22,23]. Risk perception, also known as perceived risk, involves the personal evaluation of the likelihood of an undesirable event occurring and the assessment of the potential severity of its consequences [15,24]. Empirical evidence has indicated that individuals are more inclined to exhibit cautious behavior whenever they perceive themselves to be vulnerable to risks [24,25]. The World Bank report suggests that cultural factors may have a greater impact on the high rates of traffic fatalities in low- and middle-income countries, where limited resources and insufficient training for law enforcement hinder the enforcement of traffic regulations [26]. The prevalence of road traffic crashes in these countries can be due to various factors, including unsafe vehicles, inadequate road design and maintenance, lack of driver education, and poor enforcement of traffic safety laws [27]. Atchley conducted a comparative study on traffic safety culture in China, Japan, and the United States, highlighting national differences [28]. Although they did not explicitly address driving styles, they concluded that the varying records of crash risk in the three countries were associated with distinct cultural values concerning risk perception and compliance with traffic rules and regulations.

1.4. Eye Tracker

The use of eye trackers has become increasingly valuable in studying the eye movements of individuals while driving. In recent years, there has been a rise in research focused on oculometry and its implications for road safety, indicating a growing interest among researchers [29]. However, many studies have primarily utilized eye trackers in simulated driving scenarios rather than real-life road conditions [30,31]. Distraction during driving has been identified as a major contributor to road accidents according to numerous studies [32]. Modern urban infrastructure aims to facilitate the coexistence of different road users and promote sustainable modes of transportation. However, this amalgamation of road users also increases the vulnerability of individuals who are not in motorized vehicles. Furthermore, the design of road infrastructure sometimes inadvertently creates situations that lead to driver inattention [33].

1.5. Simulator Studies

Numerous studies have explored the impact of cultural differences on driver behavior, with some focusing on analyzing aggressive driving across different countries [34], while others have investigated the relationship among factors of the Driver Behavior Questionnaire (DBQ) and social context [35]. However, there is a limited amount of literature available on the influence of cultural change on drivers' behavior within an experimental setting. Driving simulators offer several benefits for researching driver behavior, as they allow for the creation of scenarios involving traffic conflicts as needed, while ensuring the safety and well-being of participants during the experiments.

1.6. Current Study

Sustainability in traffic engineering refers to the practice of planning, designing, and managing transportation systems in a way that minimizes negative impacts on the environment, society, and the economy, while promoting long-term viability and efficiency. Sustainable traffic engineering aims to strike a balance between meeting current transportation needs and ensuring the well-being of future generations. Investigating the effectiveness of policies and regulations aimed at promoting sustainable transportation is crucial. Integrating transportation planning with urban development is a key area of research. Areas of sustainability in traffic engineering that we aimed to include in this research are:

- Social equity;
- Economic viability;
- Safety;
- Transportation improvements;
- Urban planning for sustainability.

Social equity ensures that transportation systems are accessible to all members of society. This involves designing infrastructure that supports pedestrians, cyclists, and public transport, and considering the needs of all populations from different cultural and infrastructural backgrounds; creating transportation systems that contribute to economic development while being cost-effective and financially sustainable. A similar kind of infrastructure and same side driving vehicles could prove to be a huge milestone towards economic sustainability; prioritizing the safety of all road users, including pedestrians, cyclists, and motorists across borders globally. Sustainable traffic engineering =can implement measures to reduce accidents and improving overall road safety. This research can also help in transportation infrastructural and policy improvements that can be implemented in future to reduce risks for drivers once the infrastructure and driving side are changed and can help in urban planning for a more sustainable and safer transportation network.

Driver confidence and behavior and resistance to change play vital roles in adapting to change and hazard perception. In this study, we set the cultural difference and the infrastructural difference as the variables. Drivers were recruited from two different cultural and infrastructural backgrounds. Chinese drivers have a left-handed traffic, infrastructure, and driving experience, while Pakistani drivers have a right-handed traffic, infrastructure, and driving experience. Two scenarios, one left-handed and one right-handed, were made with a pedestrian (hazard) crossing the road suddenly after a roundabout, and both groups were asked to drive through the scenario. Their hazard perception, lane violations, availing of free turns (FRT in RHT and FLT in LHT), stopping turns (RT in LHT and LT in RHT), and time to collision (TTC) were compared using the ANOVA technique from the data collected from the driving simulator and eye-tracking device, both within each group and between the Chinese and Pakistani drivers. Several hypotheses were commenced based on our experimentation which were further verified, and a comparison was made through the analytical analysis and previous case studies.

Hypothesis 1. *Time to collision (TTC) of Pakistani drivers is significantly low (Mean = 1.2 s) in RHT.*

Hypothesis 2. *Pakistani drivers lose focus significantly (making more mistakes) after the infrastructure changes from LHT to RHT and they drive more casually.*

Hypothesis 3. *Chinese drivers' pupils are more dilated when driving in the infrastructure they hold a license in (RHT).*

2. Method

2.1. Participants

The reason only young male drivers were chosen is to make the pools of drivers comparable. As we know, gender and age are significant factors to be considered when judging a driver's driving skill; therefore, to minimize this, only people from one age group and one gender were recruited and tested. As we know, young drivers can be compared with other young drivers, middle-aged with middle-aged and old drivers with old drivers. Since the experiments took place in Shanghai, foreign middle-aged and old drivers were not available to be recruited and tested. Two groups of similar drivers comprising forty-one drivers (20 Chinese and 21 Pakistanis) were recruited from both China and Pakistan. We selected drivers who were young (aged 22–35), male, well-educated (students enrolled in university), and possessed a minimum of one year of driving experience in their respective countries. The Chinese drivers had a mean age of 25.5 years and the Pakistani drivers had a mean age of 27.85 years. Both had been issued licenses in their countries of origin with similar total kilometers driven. All participants were in good health with no physical or mental disabilities. We had to recruit all participants in Shanghai. Thus, the Pakistani drivers were required to meet an additional criterion: they should not have a Chinese license and should never have driven in China before. We proposed this criterion to preserve the originality of differences in road structures and to ensure that the Pakistani participants had not been influenced by left-handed road infrastructure or the driving culture in China. All the drivers had basic knowledge of both the left-hand and right-hand infrastructure and all the drivers had performed experiments on a simulator before. The few drivers who did not have prior driving experience on a simulator were allowed to use it until they felt comfortable driving.

2.2. Equipment

For the experiment, a driving simulator, located within the Department of Transportation Engineering at Tongji University, was acquired. The simulator, depicted in Figure 1, consists of various hardware components, including a movable seat, Logitech G27 Driving Force GT steering wheel with force feedback, a brake pedal, and a throttle pedal. The driving scenarios were screened on three 50-inch television screens, each having a resolution of 1920 × 1080 pixels. Two scenarios in the simulation software SCANER STUDIO^{TM}1.6 were made, one with right-handed infrastructure and traffic rules, and the other with left-handed infrastructure and traffic rules.

Figure 1. The driving simulator at Tongji University.

7 Invensuns ASEE STUDIO eye-tracking software and the ASEE pro glasses device shown in Figure 2, were used to collect gaze tracking data and pupil data. The scenarios were run on a simulator with three projectors along with the driving assembly and pedals.

Figure 2. Asee Pro Glasses with scanned Pupils.

2.3. Scenario & Experiment Design

Both the scenarios were designed according to the LHT and RHT rules and lane positions of similar length and similar driving time. Both scenarios had one free turn, one stopping turn, and a roundabout shown in Figure 3. The drivers were asked to stay within the speed limit of 70 kms/hour. A hazard in the form of a pedestrian was designed to be triggered once the driver exits the roundabout. The drivers' response was noted and the time taken to respond was calculated. The mistakes made by drivers during the adaptation to the lane-changing behavior and at turns/intersections were collected manually through their simulation videos.

(**a**) (**b**)

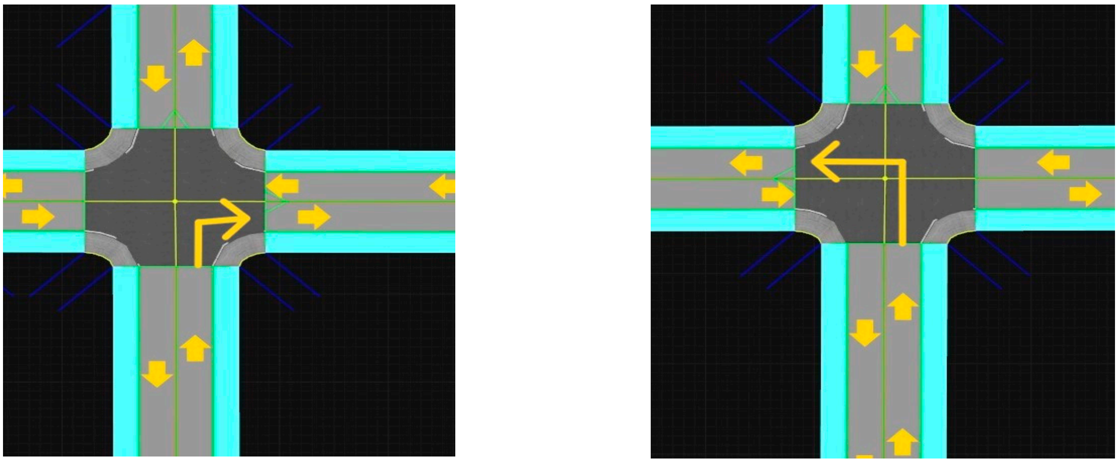
Figure 3. Shows both driving scenarios designed in SCANer Studio with (**a**) a LHT scenario with two intersections and a round-about and (**b**) a RHT scenario with two intersections and a round-about.

2.3.1. Adaptability to Lane-Changing Behavior

Improper lane-changing behavior, as indicated by earlier research [36], can lead to different kinds of collisions, including rear-end collisions, sideswipe collisions, and angle collisions. Not only do these maneuvers contribute to a higher accident rate [37], they also contribute to traffic congestion [38]. Sivak et el. investigated the potential impact of visibility on the risk of merging or lane-changing crashes for vehicle drivers [39]. In driving simulator tests carried out within a simulated Yokohama, Japan, setting, it was noted that Korean drivers, who were not familiar with right-hand driving (RHD), demonstrated lower performance when navigating a left-sided road layout compared to native Japanese drivers. The former group showed an increased frequency of lane position adjustments, decreased visual scanning during turns across traffic lanes, and, in general, experienced twice the mental workload in comparison to the latter group [40].

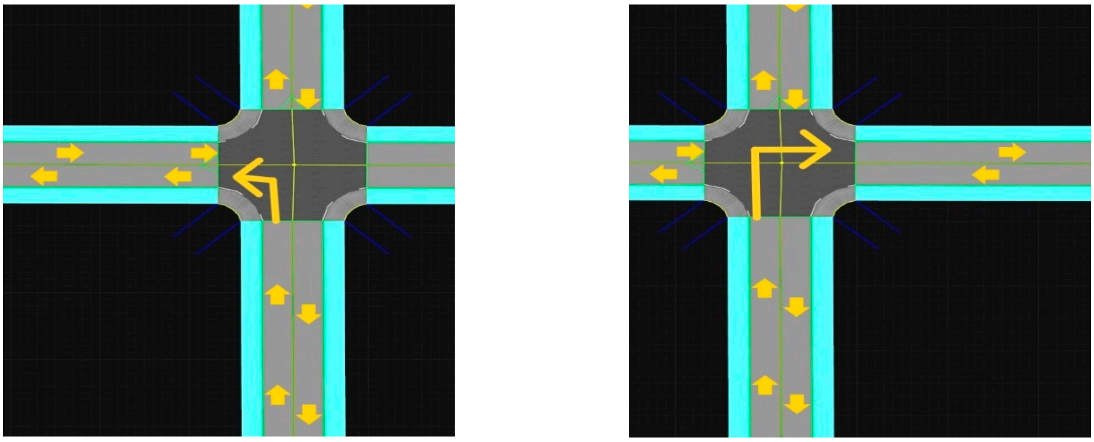
2.3.2. Adaptability at the Intersections

The turns were included specifically as there are different rules for turns in both LHT and RHT infrastructure shown in Figures 4 and 5.



(**a**) (**b**)

Figure 4. Free right turn (**a**) and a stopping left turn (**b**) in RHT infrastructure.



(**a**) (**b**)

Figure 5. Free left turn (**a**) and a stopping right turn (**b**) in LHT Infrastructure.

Previous studies indicate that safety issues at intersections are a widespread concern with similar outcomes worldwide. According to a previous study, approximately 40% of accidents in Norway took place at intersections [41,42] In Singapore, an examination of collision data spanning from 1992 to 2002 demonstrated that more than 33% of accidents took place at intersections [43]. Similarly, in Canada, more than 30% of road fatalities and 40% of severe road accidents were reported at intersections [44].

Intersection accidents constituted 54.2% of all accidents and 20.8% of all fatal accidents in the State of New South Wales, Australia, in 2010 [45]. Furthermore, it was found that over 40% of intersection accidents took place on urban roads in Italy, while rural roads accounted for more than 20% [46]. The drivers were asked to drive through both of the scenarios with different free turns to test whether they could follow the free turn rule or if they would make mistakes at the intersection, as an intersection is a risk zone with a high crash rate, as discussed in previous studies. A driver making a mistake here due to an infrastructure change could be very costly.

2.3.3. Eye Tracking

The ASEE STUDIO eye-tracking software was used for processing the raw pupil data and gaze data. The ASEE PRO GLASSES eye tracker device (Figure 2) was used to collect the gaze tracking data and pupil data. The quality of the recording was set to 30 fps, so the data collected for the shrinkage and dilation of the pupil was corrected to 1/30th of a second.

The gaze pointer helped us to show the vigilance of the driver and told us exactly where the participants were looking at which instance. The gaze pointer (example shown in Figure 6) showed us in which second the drivers looked at and perceived the hazard (pedestrian).

(**a**) (**b**)

Figure 6. Pointer showing that the driver is looking at the hazard (**a**) and looking at the traffic signal (**b**) on an intersection.

2.4. Factors to Be Compared

The following are the metrics that were compared among the Chinese and Pakistani drivers, both between the groups and within each group:

- Hazard perception;
- Time to collision (TTC);
- Pupil size (shrinkage and dilation);
- Lane violations;
- Mistakes made during free turns (FLT and FRT);
- Mistakes made during stopping turns (RT in LHT and LT in RHT).

2.4.1. Hazard Perception

Hazard perception is the time taken by the driver to see the stimulus after it is triggered. In our experimentation we installed a trigger at the turn, once the driver passed the trigger the stimulus was triggered, and the pedestrian would cross the road. The gaze pointer of the eye-tracking device showed us when the driver actually precepted the hazard.

2.4.2. Time to Collision (TTC)

Time to collision (TTC) is the time taken by the driver to perceive the hazard and react to it (this could be maneuvering, avoiding, or breaking). It was calculated from the time the drivers gaze marker looked at the hazard to the time his brake force turns positive from zero.

2.4.3. Pupil Size

The frame rate of the eye-tracking device was set to 30 fps, so the pupil size data were collected at 30 readings per second, which was then converted into mean data and further processed for comparison. The data were taken from the Asee pro glasses through the Asee studio software and were further analyzed in Excel 2019to see if there was any certain difference in shrinkage and dilation in both groups. The mean data of each driver's pupil were taken and then compared for dilation or shrinkage among groups.

2.4.4. Lane Violations, Mistakes Made during Free Turns (FLT and FRT), Mistakes Made during Stopping Turns (RT in LHT and LT in RHT)

These three metrics were calculated manually for every participant through the video recordings made by the eye-tracker device in Asee studio. The data were further processed and converted into mean values and cumulative mistakes to enable a comparison within the groups and between the groups.

2.5. Problem Statements

The drivers' behavior and adaptability were tested in three situations and in different infrastructural conditions both in their home conditions (where the participants hold a license) and away conditions (where the participants do not have license and have never driven before).

1. To test their adaptability to free left turns (LHT) and stopping right turns (LHT), as well as their adaptability to free right turns (RHT) and stopping left turns (RHT).
2. To test their adaptability to lane-changing behavior.

Finally, to test the hazard perception and the time to collision (TTC) among both the Chinese and Pakistani groups of drivers when a pedestrian crosses the road suddenly in both LHT and RHT scenarios.

The driver's behavior, adaptability, and response to change were observed in both scenarios. A pedestrian crossing the road suddenly from a non-zebra crossing area to where a hazard was to be perceived by the participant, and to which they had to respond accordingly. Hazard perception and time to collision (TTC) were observed at the time of the pedestrian crossing the road, pupil size (shrinkage and dilation) and lane violations were observed throughout the driving scenario, while mistakes made during free turns (FLT and FRT) and mistakes made during stopping turns (RT in LHT and LT in RHT) were observed at the intersections of both the LHT and RHT infrastructure scenarios.

2.6. Dataset and Statistical Analysis

Seven types of data were collected. Gaze data and pupil (dilation and shrinkage) data were collected through the Asee pro glasses with the help of Asee studio software to know where the drivers were looking and how focused they were at a given instance of time, to derive their hazard perception ability and how it affects their pupil (shrinkage or dilation). The speed of the vehicle, braking force, and the time taken by the driver to respond to perceiving the hazard were collected through the simulation data provided by SCANer studio™ and ASee Studio to calculate the time to collision (TTC). Lane violations, free turn and stopping turn data were calculated manually for each driver in both the LHT and RHT scenarios using the eye-tracking device in the simulation recordings. Analysis was performed using comparative analysis between the different groups and within the same group. Analysis of the different groups (Pakistani and Chinese) driving through the same scenario showed us whether their performance is subject to any cultural or social differences, while the analysis of same group showed us variations that are not due to cultural or social difference and are mostly due to infrastructural and rules change (in LHT and RHT), which further helped us in analyzing which groups' performance has the most significant difference and under what conditions. The basic idea behind ANOVA is to partition the total variation observed in a dataset into two components: variation between groups and variation within groups. By comparing the ratio of these two variances, ANOVA determined if the observed differences between the groups are statistically significant. The Tukey test is a post hoc test commonly used after conducting an ANOVA. Its purpose is to find which specific group's means differ from each other when a significant result is found in the ANOVA test. The Tukey test compared all possible pairs of group means and calculated their critical value, known as the minimum significant difference (MSD). It then compared the differences between each pair of means to the MSD. When the difference between two means is larger than the MSD, it indicated that the means are significantly different from each other.

3. Results

3.1. Hazard Perception and Time to Collision

Here we can observe that Chinese drivers outperform Pakistani drivers with a better hazard perception in LHT compared to Pakistani drivers' performance in RHT, consequently they have more time to react and brake, thus having a better time to collision (TTC) in Pakistani driving infrastructure or LHT. A significant difference was observed in the hazard perception and for time to collision between Pakistani and Chinese drivers (Figure 7), with Chinese and Pakistani participants both having a significantly better time to collision in their mother driving infrastructure with (Mean = 2.04 s) for Pakistani drivers and (Mean = 1.9 s) for Chinese drivers, compared to when they switch sides from LHT to RHT, where the Pakistani participants (Mean = 1.20 s) time to collision drops significantly.

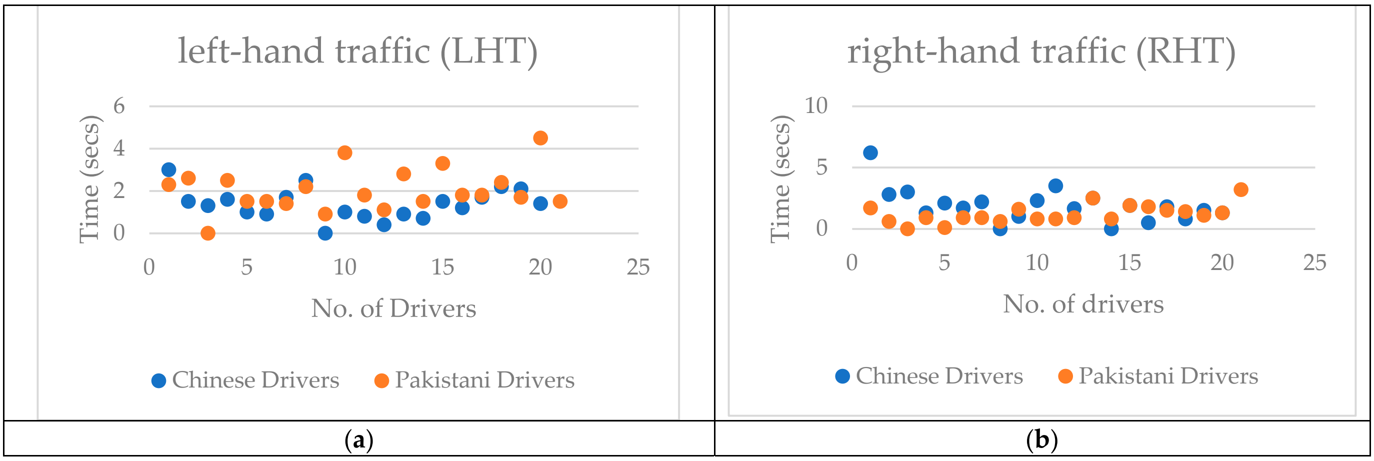


Figure 7. (**a**) Shows TTC in left-hand traffic and (**b**) shows TTC in right-hand traffic, where the orange line shows the time taken in seconds by Pakistani drivers and the blue line shows time taken by Chinese drivers.

We took four groups for comparison of TTC among them:

A: Pakistani drivers TTC in LHT.
B: Pakistani drivers TTC in RHT.
C: Chinese drivers TTC in LHT.
D: Chinese drivers TTC in RHT.

Although the Chinese driver's time to collision (TTC) is slightly less than Pakistani drivers in their own driving infrastructure (mean for Chinese = 1.9, mean for Pakistanis = 2.0 s), but when they drive in the left-handed infrastructure, they outperform Pakistani drivers driving in right-handed infrastructure. If we compare the Pakistani driver's performance in both LHT and RHT, there is a significance difference between the time to collision (TTC). To further examine this difference, we performed the ANOVA and Tukey tests. A one-way ANOVA with a significance level alpha 0.5 was conducted with a null hypothesis assumption (H_o = there is no variation in the TTC among all groups) was performed.

Descriptive statistic and Shapiro–Wilk tests were conducted to check whether the data are normally distributed or not. The results in Tables 1 and 2 show that the data have a normal distribution and ANOVA analysis was performed to check variance among the groups in Table 3.

Table 1. Descriptive statistics.

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
A	21	0	2.04286	1.00676	0.21969
B	21	0	1.20476	0.75198	0.1641
C	20	1	1.37	0.71826	0.16061
D	20	1	1.8825	1.31041	0.29302

Table 2. Shapiro–Wilk test to check the normality of the data.

	DF	Statistic	*p*-Value	Decision at Level (5%)
A	21	0.95477	0.4177	Data are normally distributed
B	21	0.93567	0.17874	Data are normally distributed
C	20	0.98197	0.9569	Data are normally distributed
D	20	0.91374	0.07511	Data are normally distributed

A–D: At the 0.05 significance level, the data originated from a population with a normal distribution.

Table 3. ANOVA analysis on the time to collision (TTC) among both groups.

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
A	21	0	2.02	1.006	0.216
B	21	0	1.20	0.751	0.164
C	20	1	1.37	0.718	0.160
D	20	1	1.90	1.374	0.307
	DF	**Sum of Squares**	**Mean Square**	**F Value**	**Prob > F**
Model	3	10.21	3.40	3.43	0.0208
Error	78	77.29	0.99		
Total	81	87.50			

ANOVA, at the 0.05 level, the population means are significantly different.

Once we look at the F distribution table, we can find out the value of p through our F value, which is 0.0208. Since this value is less than our $\alpha = 0.05$, the null hypothesis is rejected and the alternative hypothesis is accepted and a significant difference exists.

A significant difference was observed in hazard perception, so the null hypothesis was rejected for time to collision (TTC) between Pakistani and Chinese drivers, with Chinese and Pakistani participants both having a significantly better time to collision (TTC) in their mother driving infrastructure with (mean = 2.04 s) for the Pakistani drivers and (mean = 1.9 s) for the Chinese drivers, compared to when they switch from LHT to RHT, where the Pakistani participants (mean = 1.20 s) time to collision (TTC) drops significantly. Similarly, a significant change was found in Chinese drivers after they change from RHT to LHT, their time to collision (TTC) (mean= 1.37 s) also drops considerably (shown in Table 3). To further examine the significance level between the drivers, a Tukey test was conducted in Table 4.

$$\text{Tukey's Critical Value T} = \text{q}\sqrt{\text{MSE}/\text{n}} \tag{1}$$

$$\text{Studentized range distribution} = \text{q} = \text{k}/\text{DF}_{\text{E}} = 4/78 = 3.713\text{, from (q) chart}$$

$$\text{MSE} = 0.99 \ \text{n} = 21$$

$$\text{Tukey's Critical Value} = 0.805\text{, putting values in (1)} \tag{2}$$

Table 4. Tukey test showing mean comparisons in TTC among all groups.

	Mean Diff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
BA	−0.838	0.307	3.83	0.03	0.05	1	−1.64	−0.03
CA	−0.672	0.311	3.05	0.14	0.05	0	−1.48	0.14
CB	0.165	0.311	0.75	0.95	0.05	0	−0.65	0.98
DA	−0.140	0.311	0.63	0.96	0.05	0	−0.95	0.67
DB	0.697	0.311	3.17	0.12	0.05	0	−0.11	1.51
DC	0.532	0.314	2.39	0.33	0.05	0	−0.29	1.35

Sig equals 1: indicates that the difference in means is significant at the 0.05 level. Sig equals 0: indicates that the difference in means is not significant at the 0.05 level.

The minimum mean difference must be more than 0.805 to have honestly significant difference or HSD within groups.

Here we can observe that B and A have a significant difference with a value of 0.838 > 0.805. A being the Pakistani drivers driving in left-handed infrastructure with a time to collision (TTC) (mean = 2.04 s), while B being Pakistani drivers driving in Chinese infrastructure with the lowest time to collision (TTC) among the groups (mean = 1.2 s) only.

3.2. Comparison of Pupil Size between Pakistani and Chinese Drivers in LHT and RHT

If we look at Figure 8, we can clearly see that Pakistani drivers' pupil size was found to be smaller than the Chinese drivers pupil size when the data were analyzed. Chinese driver's pupil size looks more dilated while the pupil size of Pakistani drivers is constricted.

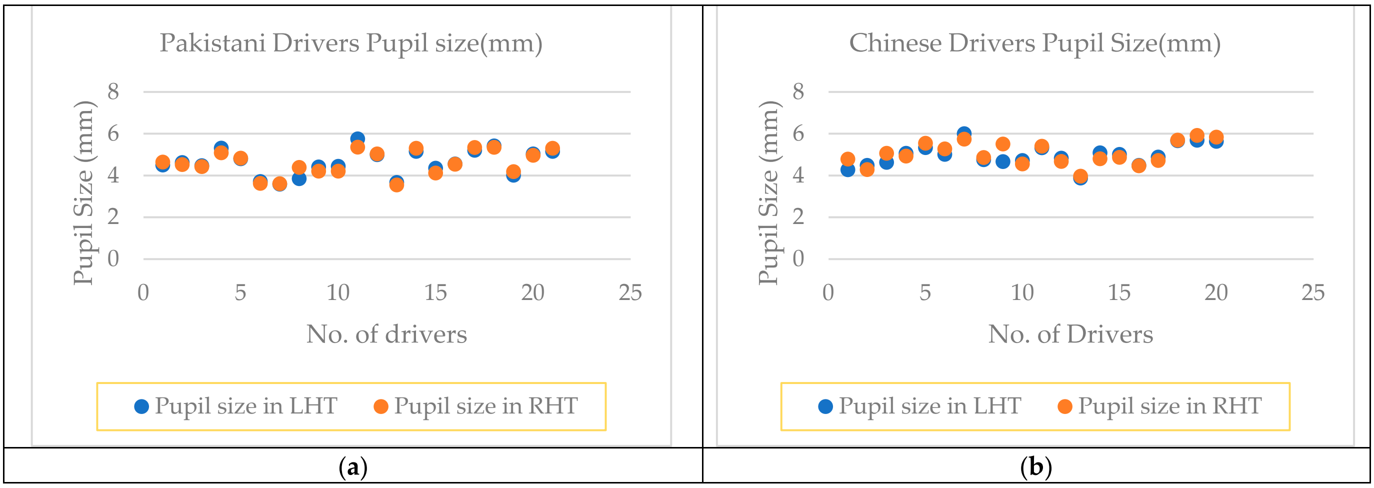


Figure 8. (**a**) Shows the pupil size of Pakistani drivers while driving in the LHT and RHT scenarios and (**b**) Shows the pupil size of Chinese drivers while driving in the LHT and RHT scenarios.

To further analyze how the drivers' pupil size is affected during driving in both scenarios, the data with 30 fps were compared in both LHT and RHT between the following groups:

A: Pakistani drivers' pupil size in LHT;
B: Pakistani drivers' pupil size in RHT;
C: Chinese drivers' pupil size in LHT;
D: Chinese drivers' pupil size in RHT.

Descriptive statistical and Shapiro–Wilk tests were performed to check whether the data were normally distributed or not. The results in Tables 5 and 6 show that the data have a normal distribution and ANOVA analysis can be performed to check variance among the groups.

Table 5. Descriptive Statistics.

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
A	21	0	4.61472	0.61695	0.13463
B	21	0	4.59512	0.59769	0.13043
C	20	1	4.96666	0.52617	0.11766
D	20	1	5.04	0.54809	0.12256

Table 6. Shapiro–Wilk test to check the normality of the data.

	DF	Statistic	*p*-Value	Decision at Level (5%)
A	21	0.96169	0.55088	Data are normally distributed
B	21	0.92134	0.0923	Data are normally distributed
C	20	0.98178	0.9549	Data are normally distributed
D	20	0.96343	0.6145	Data are normally distributed

A–D: At the 0.05 significance level, the data originated from a population with a normal distribution.

To check the variance in the pupil size, a one-way ANOVA with an alpha level of 0.05 was conducted with a null hypothesis (H_o = pupil size of all groups has no variation) to compare the difference between the pupil size of the all groups. Table 7 summarized the results through ANOVA.

Table 7. ANOVA test showing the variance of pupil size among all groups.

	N Analysis	N Missing	Mean	Standard Deviation	SE of Mean
A	20	0	4.58	0.62	0.138
B	20	0	4.55	0.59	0.131
C	20	0	4.96	0.52	0.117
D	20	0	5.04	0.54	0.122
	DF	**Sum of Squares**	**Mean Square**	**F Value**	**Prob > F**
Model	3	3.75	1.25	3.81	0.0132
Error	76	24.89	0.32		
Total	79	28.64			

ANOVA, at the 0.05 level, the data means were significantly different.

If we look at the F distribution table, we can find out the value of p through our F value, which is 0.0132. Since this value is less than our $\alpha = 0.05$, the null hypothesis is rejected and the alternative hypothesis is accepted and a significant difference exists.

A significant difference was observed in the ANOVA test results since the p value is less than 0.05 so the null hypothesis was rejected. The Tukey test in Table 8, was performed to see the difference among the groups.

$$\text{Tukey's Critical Value T} = \text{q}\sqrt{\text{MSE}/\text{n}} \tag{3}$$

$$\text{Studentized range distribution} = \text{q} = \text{k}/\text{DF}_\text{E} = 4/76 = 3.715\text{, from (q) chart}$$

$$\text{MSE} = 0.327\ \text{n} = 20$$

$$\text{Tukey's Critical Value} = 0.475\text{, putting values in (3)} \tag{4}$$

Table 8. Tukey test showing means comparisons in pupil size among all groups.

	Mean Diff	SEM	q Value	Prob	Alpha	Sig	LCL	UCL
BA	−0.028	0.181	0.22	0.99	0.05	0	−0.503	0.44
CA	0.037	0.181	2.95	0.16	0.05	0	−0.096	0.85
CB	0.406	0.181	3.17	0.11	0.05	0	−0.068	0.88
DA	0.452	0.181	3.53	0.06	0.05	0	−0.023	0.92
DB	0.480	0.181	3.75	0.04	0.05	1	0.004	0.95
DC	0.073	0.181	0.57	0.97	0.05	0	−0.402	0.54

Sig equals 1: At the 0.05 level the difference in means is significant. Sig equals 0: At the 0.05 level the difference in means is not significant.

The minimum mean difference must be more than 0.475 to have honestly significant difference or HSD within groups.

It was evident from the test that DB have a significant difference with a value of 0.480. When we look at the mean data, we can that see D (mean = 5.04) is significantly different. We can say that the pupil size of Chinese drivers, when driving in their mother infrastructure, is the most dilated while they drive in the RHT, and that Pakistani drivers driving in both the scenarios have no significant difference.

3.3. Lane Violations and Mistakes on Free Turns and Stopping Turns

3.3.1. Lane Violations

In case of lane violations, when Chinese drivers were compared to Pakistani drivers, both driving in the opposite driving infrastructure (opposite to the one they hold a license in), the Chinese drivers showed better adaptability and made fewer cumulative mistakes and showed greater vigilance after the switch as shown in Figure 9. Pakistani drivers had a higher cumulative score with almost every driver making more than one mistake in lane switching (Mean = 1.28), compared to the Chinese drivers (Mean = 1.15) performing slightly better than the Pakistani drivers.

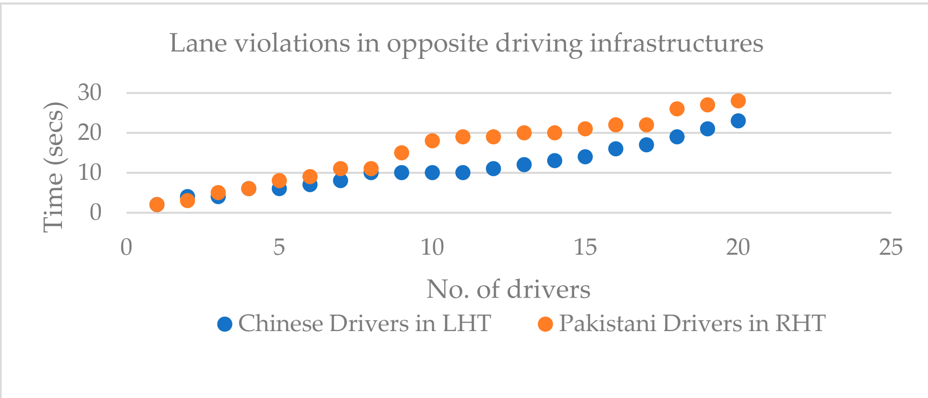
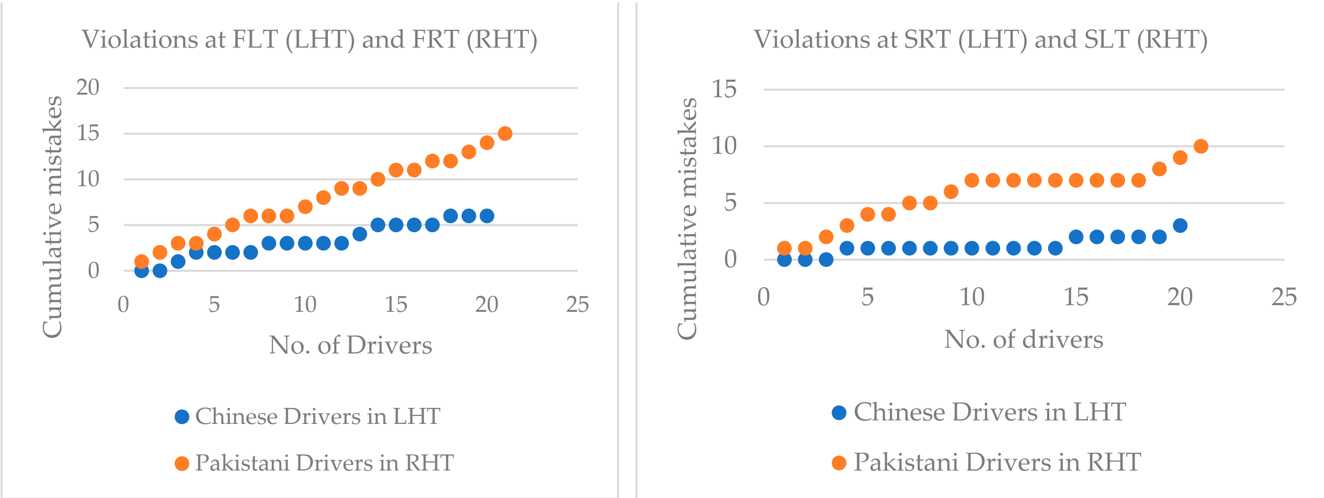


Figure 9. Chinese drivers' lane violations in LHT vs. Pakistani drivers lane violations in RHT.

We can say that Pakistani drivers are more casual and have violated lane rules more often when driving in a non-familiar driving scenario (right-handed traffic infrastructure).

3.3.2. Mistakes during Free Turns and Stopping Turns

In order to examine the difference in the variable values of mistakes made during a free right turn in right-hand traffic infrastructure and a free left turn in left-hand infrastructure, along with not stopping on the right and left turns, alternatively, in both left-hand and right-hand infrastructures. A comparison was made and results are shown in Figure 10.



(**a**) (**b**)

Figure 10. (**a**) Violations during free turns in LHT and RHT. (**b**) Violations at stopping turns in LHT and RHT.

In order to examine the difference in the variable values of mistakes made during a free right turn in right-hand traffic infrastructure and a free left turn in left-hand infrastructure, along with not stopping on the right and left turns, alternatively, in both left-hand and right-hand infrastructures, a Kruskal–Walis ANOVA (see Tables 9 and 10) was performed with an alpha level of 0.05, since the data were not normally distributed with:

A: Chinese drivers making mistakes during FLT in LHT;
B: Chinese drivers making mistakes during SRT in LHT;
C: Pakistani drivers making mistakes during FRT in RHT;
D: Pakistani drivers making mistakes during SLT in RHT.

Table 9. Kruskal–Walis ANOVA test to check the variance between groups.

	N	Min	Q1	Median	Q3	Max
A	20	0	2	3	5	6
B	20	0	1	1	2	3
C	21	1	4.5	8	11.5	15
D	21	1	4	7	7	10

Table 10. Ranks.

	N	Mean Rank	Sum Rank
A	20	35.125	702.5
B	20	15.9	318
C	21	60.52381	1271
D	21	52.92857	1111.5

A significant difference was observed between Pakistani and Chinese participants and can be seen in Table 11, with Chinese participants having a significantly better vigilance in left-hand traffic where they were more vigilant during FLTs (mean rank = 35.12), while Pakistani drivers did not avail the FRT (mean rank = 60.5) in right-handed infrastructure, showing that almost every driver made a mistake and stopped on the free right turn. Similarly, Chinese drivers performed better when it comes to stopping on the stopping right turn in left-handed infrastructure (mean rank = 15.9) and almost no one broke the signal, but Pakistani drivers had the same casual pattern and almost no one stopped on the stopping left turn (mean rank = 52.9) in the right-handed infrastructure.

Table 11. Test Statistics.

Chi-Square	DF	Prob > Chi-Square
43.35238	3	2.07×10^{-9}

At the 0.05 level, the populations were significantly different.

The test in Table 12 shows that AC, BC, and BD are significantly different. If we look at the data we can see there is a considerable difference between (A,B) and (C,D) and since group B is the Chinese drivers' performance during right turns in the left-handed traffic infrastructure and almost none of them made mistakes during right turns (mean rank = 15.9) only. Alternatively, we can say that Pakistani drivers have the lowest vigilance level with mistakes (mean rank = 60.5) during the FRT in right-handed infrastructure, and they follow their instinct even after the driving infrastructure has been changed.

Table 12. Dunn's test to check the variance among groups.

	Mean Rank Diff	Z	Prob	Sig
AB	19.225	2.56981	0.06105	0
AC	−25.3988	−3.43622	0.00354	1
AD	−17.8036	−2.40866	0.09607	0
BC	−44.6238	−6.03719	9.41×10^{-9}	1
BD	−37.0286	−5.00962	3.27×10^{-6}	1
CD	7.59524	1.04033	1	0

Sig equals 1: At the 0.05 level the difference in means is significant. Sig equals 0: At the 0.05 level the difference in means is not significant.

4. Discussion

In this study, we explored the influence of infrastructure and traffic safety culture on hazard perception and time to collision (TTC), in addition to the psychological effect on the drivers and how the infrastructure affects their on-road experience and vigilance. The findings indicated that cultural backgrounds and infrastructure variations had a considerable impact on hazard perception and time to collision (TTC) in our study. We found compelling evidence suggesting that both of these aspects were affected by changes in the infrastructure and the drivers' cultural backgrounds. In the subsequent sections, we aim to explore these results and provide an explanation on how these are related to culture, infrastructure, and traffic regulations. Let us try to explain and verify our hypotheses on the basis of previous research conducted and the results of our experimentation.

4.1. Hypothesis 1

Based on these hypotheses, the results of the analysis of variance showed that Pakistani participants showed that they have more aggressive behavior in right-handed driving infrastructure with the lowest time to collision (TTC) (mean = 1.2 s). Meanwhile, Chinese drivers showed vigilance and their time to collision (TTC) in both LHT and RHT was not greatly affected, although their PRT in LHT lowered by almost 0.5 s with (mean = 1.37), which proves that Pakistani drivers performed less vigilantly under a more dangerous situation and their hazard perception is poor in RHT where the difference is large (their time to collision (TTC) dropped from mean = 2.04 to mean = 1.20 s), which is a large change when so much can happen in the blink of an eye. So, in some cases, they may not have sufficient time to brake resulting in the risk of a crash. Furthermore, during the experimentation, two Pakistanis and one Chinese driver avoided the hazard (pedestrian) after perceiving it, and their TTC is calculated as time to avoid. Similarly, one Pakistani and one Chinese driver crashed into the pedestrian and their TTC is zero as they did not perceive the hazard and did not apply the brakes. Two Chinese drivers and one Pakistani driver performed worse in their mother traffic infrastructure or the infrastructure they held a license in. One possible explanation for this finding is optimism bias. Previously, it has been observed in risk assessments of individuals in Western societies, but it was not as prominent among Ghanaians [47,48]. This may not be as relevant to individuals who experience a higher risk exposure. Optimism bias, as defined by researchers, refers to the consistent tendency of individuals to hold misconceptions about positive outcomes that are more favorable for themselves compared to the general population. In other words, individuals may perceive that they have a higher likelihood of experiencing positive events and a lower likelihood of experiencing negative events than the average person [49]. In support of this concept, studies have shown that people tend to observe higher levels of risk for others when compared to themselves [15]. So, it is a possibility that optimism caused the poor performance of the drivers and they could not step out of their comfort zones while driving in the infrastructure they were familiar with, licensed to drive in, and had experienced.

4.2. Hypothesis 2

Lane-changing behavior was quite significant in our experiments, with Pakistani drivers making more mistakes during FRTs (mean rank = 60.52) and during SLTs (mean rank = 52.92) while driving in RHT. While Chinese drivers performed significantly better (mean rank = 15.9) at SRTs, but they still had a high mistake ratio during FLTs (mean rank = 35.12), and previous studies have shown that most accidents at intersections involve a left-hand turn. As per the National Highway Traffic Safety Administration (NHTSA) in 2010, around 22% of traffic accidents in the United States result from left-turning vehicles colliding with oncoming traffic at intersections. These incidents often involve frontal or side-impact collisions, leading to significant impacts to the driver's well-being [50]. Similarly, in Canada, around 30% of road fatalities and almost 40% of severe road accidents were reported at intersections [44]. Sivak et el. investigated the potential impact of visibility on the risk of merging or lane-changing crashes for vehicle drivers [39]. And we have also seen that Japanese drivers perform better in lane-changing than Korean drivers in a simulator study performed in Japanese driving infrastructure by [40]. Based on the previous research and our experimental findings, we can say that Pakistani drivers, when driving in a non-familiar (RHT) environment, are prone to more mistakes and have a higher risk of collision, since they have poor lane-changing and turning behavior at the intersections in right-handed infrastructure.

4.3. Hypothesis 3

According to the findings from the data collected in our experiments, it can be seen that Chinese drivers have a significantly dilated pupil size in both LHT and RHT scenarios. After the ANOVA variance test and Tukey test, it was further made clear that group D of the drivers have a significant difference (mean = 5.04 mm). The experiments were conducted in a lab under constant light conditions so that pupil size cannot be affected by changes in atmospheric light. Previous studies have shown that pupil size reacts and changes under three kinds of stimulus: they shrink as a response to brightness (light response), they constrict/shrink when there is a near fixation (near response), and dilate/expand as a response to an increase in activity, mental effort and arousal, either triggered by an outside stimulus or spontaneously. Multiple studies have already been conducted on the topic of pupil dilation and its connection with cognitive processes [51–53], such as attention [54], memory [55], and mental load [56,57]. Based on the previous studies and our experimental analysis, a possible explanation for Chinese drivers' having a dilated pupil could be that they are more attentive during driving and that they have a higher mental load, and they are more focused, with the most attentive and vigilant behavior in right-handed infrastructure; thus, resulting in a higher mental load and memory usage with a significantly dilated pupil size in both LHT (mean = 4.96) and RHT (mean = 5.04).

5. Conclusions

Based on the previous research and our experimentations, we can conclude that our hypotheses are true, under certain conditions and limitations. When trialed and tested, Chinese drivers performed better in left-handed traffic infrastructure than Pakistani drivers' in right-handed traffic infrastructure. Our experiments have shown that Pakistani drivers' hazard perception and time to collision (TTC) decreases significantly when the environment changes from LHT to RHT. They also perform ordinarily at intersections and in lane-changing behavior, when the side is switched. Chinese drivers, on the other hand, have better driving behavior when compared to Pakistani drivers but they also have a significant change in their driving behavior when the side is switched from right-handed traffic to left-handed traffic. In addition, Chinese drivers have a higher workload, mental load, and focus while driving compared to Pakistani drivers, thus their pupil size is significantly dilated. However, based on our experimentation and the evidence gathered in our study, we can not specify or generalize that all Chinese drivers as a group may perform better than all Pakistani drivers as a group and this may vary from driver to driver under different conditions. Our study cannot make statements about the differences between Pakistani and Chinese drivers as a group and does not provide sufficient confirmation regarding the influence of traffic infrastructure across all groups of drivers. The data gathered and the experimentation showed us what happened to drivers from one culture as they drive under the conditions of another culture in unfamiliar infrastructure and how it influenced Pakistani drivers.

Hazard-perception and time to collision (TTC) are dependent variables which depend on many factors. So, there are certain limitations to our study. Green provided a comprehensive examination of reaction times for braking across various scenarios, delving into the factors influencing this parameter. These factors include age and gender, cognitive burden, and the level of urgency, all of which are partially explored in the referenced study [58,59]. The sample size and the cultural background, along with age and gender, of the participants also have an influence on their hazard perception and time to collision (TTC) [58]. Under different situations, drivers may react differently or show a similar pattern.

Firstly, it would be beneficial to expand the participant pool for a more comprehensive sampling. By including a wider range of individuals, factors such as gender, age, cultural background, and driving experience could be examined to determine their combined influence. Secondly, additional conflict scenarios, which are commonly encountered or relevant to the design of left-hand traffic (LHT) and right-hand traffic (RHT), should be devised for the driving simulator. In our study, we primarily focused on scenarios that emphasized hazard perception, time to collision (TTC), and the drivers' actions on the brake pedals. However, future studies can incorporate more extensive data collected from participants, vehicles, and the environment. Regarding participant data, it would be valuable to include information on manipulation actions, physical movements, and fixation points of the eyes, among other relevant factors. As for vehicle data, dynamic parameters such as speed, acceleration, and deceleration should be considered. In summary, future studies should conduct driving simulator-based experiments with a broader range of participants and encompassing a greater variety of conflict scenarios. Moreover, a wider range of data should be employed as dependent variables.

Furthermore, it is important to acknowledge that drivers may behave differently in simulated driving compared to real-world driving. Therefore, experiments involving on-road driving are also necessary to complement findings from driving simulators.

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visualization, S.H.H.; supervision, F.C.; project administration, F.C.; funding acquisition, S.D. All authors have read and agreed to the published version of the manuscript.

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