The Impacts of Warning Release Time and Speed Limit on Driving Behaviour and Pedestrian-Vehicle Collision Rate on Side-parking Road

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Abstract. As we all know, pedestrian-vehicle collisions would cause serious damage to us, especially those caused by blind spots. This study focused on collisions happen in the side-parking road, using a driving simulator to design scenarios. After finishing the experiment, we selected some variables to describe the driver's driving behaviour, including brake reaction time, warning-to-brake time, and maximum deceleration. To verify the effectiveness of the audio warning system, the collision rate was also discussed. It was found that warning release time has significant effects with all the variables, and gender has significant effects with brake reaction time and warning-to-brake time, while the speed limit only influences maximum deceleration. Collision rate was affected by speed limit and warning release time, which decreased with the increase of speed limit and the late release of warning. It is recommended to set the warning release time to 4s before the collision. On the other hand, it is necessary to select a proper speed limit on the side-parking roads, and it is better to set it under 30km/h to reduce the probability of pedestrian-vehicle collision.

1. Introduction

With the development of the social economy, every country’s car ownership is gradually rising. In the “Global Status Report on Road Safety 2018”[1], WHO pointed out that deaths caused by road traffic continue increasing, which now is 1.35 million a year. Globally, pedestrians and cyclists account for 26 percent of all road traffic deaths, motorcyclists and passengers account for 28 percent of all road traffic deaths.

In China, the Traffic Management Bureau of the Ministry of Public Security reported that the number of deaths from road traffic accidents had a 17.1% decrease, and the number of serious accidents dropped by 10.2% in 2019[2]. Though the traffic accident rate is falling year by year, the number of deaths due to traffic accidents still ranks among the highest in the world. Among all pedestrian-vehicle collisions, accidents caused by side-parking account for a high proportion[3-4], so it is essential to understand the relationship between side-parking and pedestrian-vehicle collisions in order to improve both pedestrians’ and drivers’ safety on the road.

Based on the real-life driving experience, we think that there are two main reasons for traffic accidents caused by side-parking. Firstly, side-parking narrows the driving area of the road, causing drivers to drive closer to the vehicles parked on the street while driving, and there is no enough area for the lateral transition. Another reason is that parked vehicles on the street block the driver's view. Drivers
are unable to get control of the situation on the road to react when pedestrians suddenly rush out, while the reaction time is one of the critical factors in determining whether an accident will occur or not[5-6]. If drivers don’t have such driving experience of the road with side parking and drive as usual, they wouldn’t have enough time and distance to avoid pedestrians.

If drivers do not respond to the surrounding situation in time and adjust their driving conditions, it will cause severe inevitable traffic accidents. Some researches about the relationship between side parking and driving behavior have been done in recent years. Greibe[7] found that side parking and road width significantly affect the crash rates, especially side parking. They considered that drivers wouldn’t adjust their driving speed when there are parked vehicles on the street side. However, it has been found that drivers would choose slower speeds with higher parking densities[8]. This adaptation can be explained from a psychological perspective. Chinn and Elliot[9] made questionnaire research about drivers’ feelings of different road scenes. It was found that on-street parking would make drivers’ feelings of tension stronger and decrease the perceived safe speed. This result is consistent with other researches about driving behavior that slower speed would be chosen when drivers are in dangerous situations, for instance, Fuller’s[10] and Fuller et al.’s[11] Task-Capability Interface Model.

In addition to the psychological aspects, there have been some previous studies on the relationship between side parking and driving behaviors in different aspects. Comparing scenarios with occupied bays and empty bays, Jessica Edquist et al.[12] found that drivers would lower their speed when the bays are occupied with compensating for the higher mental workload in a complex environment. But this compensation can’t be sufficient to reduce the crash risk due to the unexpected pedestrians’ occurrence. Except for the driving speed, drivers’ yielding behavior is also one of the crucial research elements. Yinan Zheng et al.[13] explored pedestrian’s jaywalking behavior and driver’s yielding behavior, it was found that drivers would choose hard yield when they have slow speed and are quite close to the jaywalkers, while drivers with higher speed would decide to soft yield to jaywalkers if they are far away from the collision point. If they are close to the collision point with high speed, they will choose not to yield.

Among pedestrians of all ages, child safety is the most important concern. Children do not have the ability to judge the condition of the road to decide whether it is suitable to cross the street, and because children are generally shorter, they are more difficult for drivers to detect, especially for novice drivers. Līva Ābele et al.[14] analyzed young drivers’ scanning patterns and driving behaviors towards children and adults passing the street when there has side parking or not. The results showed that the speed of the driver when passing through children and roads with side parking is higher than that of adults and roads without side parking. Another finding is that driver is driving more to the right when passing a road covered by vehicles.

From the literature review, we can conclude that there is already some researches on the impacts of side parking on driving behaviors that have been done. However, in their research contents, the speed limit of the host vehicle is fixed, so the differences in driving behavior of drivers at different driving speeds have not been described yet. Based on the above, our study aims to find whether the driving behavior can be different due to the speed limit when their vision is blocked by side-parking vehicles. Another object is to know whether drivers’ driving behavior can be affected by different warning release time as we designed a warning system to alarm drivers. Due to the danger of pedestrian-vehicle collisions, we chose using the driving simulator for experiments.

2. Methodology

2.1. Participants

In this study, 49 participants were recruited (25 females, 24 males), but only 48 participants completed the whole experiment without sickness. Due to the COVID-19, all the participants are our school’s students, aged between 20-27 years old (M = 23.80, S.D. = 1.47), everybody has a valid driver's license, and the driving experience is more than two years. They were recruited through campus forum advertisements and WeChat posts. The experiment lasted for about two hours as we have to do some
preparation in order to record their EEG and eye movement data for another study, which took about one hour to prepare. Each participant will receive 500RMB if they complete the experiment. All the experiments were conducted by the authors in approved guidelines.

2.2. Apparatus
This experiment used a driving simulator of Beijing Jiaotong University with high performance and high fidelity with a linear motion base capable of operation with 1 degree of freedom, which is shown in figure 1. The BJTU simulator includes five forward views and three rearview mirrors so that the simulated environment would be projected at 300° of horizontal field view and at a resolution of 1400×1050 pixels. It is composed of a full-size vehicle cabin with a real operation interface, environmental noise and shaking simulation system, digital video replay system, and vehicle dynamic simulation system. We use Sim Creator to build the dynamical model and Sim Vista for the driving scenario design and virtual traffic environment simulation. The sampling frequency of the BJTU simulator is up to 60 Hz and can conduct scientific research such as driving behavior, vehicle dynamics, and transportation facility evaluation for analysis.

2.3. Scenario design
Two-way four-lane city road with 3.5m lane width was used as the basic road in this experiment, the total length of the road was 4 kilometers in each scenario with side-parking vehicles in the rightmost lane to build blind spot for drivers so that drivers can’t notice pedestrians in advance, as shown in figure 3, and figure 2 showed a screenshot of a scenario in participant’s view.

Figure 1. The appearance of the driving simulator.  Figure 2. A screenshot of a scenario.

![Figure 1: The appearance of the driving simulator.](image1.jpg)

![Figure 2: A screenshot of a scenario.](image2.jpg)

![Figure 3: Description of the collision block and the velocity changing process.](image3.jpg)
In the experiment, the pedestrian-vehicle collision event is triggered by the TTC (Time to Collision) Sensor. The TTC Sensor is placed at the collision point between the pedestrian and the host vehicle. During the driving process, the TTC Sensor will calculate the time required for the host vehicle to reach the collision point. When the time headway of the host vehicle to the collision point is 4.5s, the pedestrian will be immediately triggered to walk or run to the collision point at one of the three different speeds, including 2m/s, 3m/s and 4m/s. The warning is also triggered by TTC Sensor, but using the time headway between pedestrians and collision points as the basis for judgment. There are five voice warning release times in the sub-scenario, including 2.5s, 3s, 3.5s, 4s and 4.5s. The audio warning message is: Watching out for jaywalkers, please slow down.

2.4. Experimental procedure
When the participants arrived at the laboratory, the requirements of the experiment were explained to everyone first, and then they were asked to read and sign the informed consent forms. Before the formal experiment, each participant needs to perform a practice drive of at least 5 minutes just as they usually drive in real situations, in order to get familiar with the driving simulator. The participants experienced manoeuvres, including straight driving, left and right turn, acceleration, deceleration and other basic operations in the practice drive. If the participants feel sick or any other discomfort in the practice session or formal experiments, they could quit immediately.

During the experiment, each participant was arranged to drive in six scenarios at three different speed limits, including 30km/h, 40km/h and 50km/h. Five audio warning release times are randomly matched with three pedestrian speeds and three sub-scenarios, which do not include voice warning. Those 18 sub-scenarios were divided into two parts and randomly distributed into 2 scenarios. So drivers were asked to drive at the same speed for two scenarios then change to another speed. Every participant drives the six scenarios in a random order to avoid the order effect. In each test scenario, the pedestrian’s type, clothing color and speed-change profile were the same to exclude the effects due to such factors. In real-life situations, pedestrian-vehicle collision situations as designed in the scenarios wouldn’t frequently happen in such a short time, so some measures were taken to reduce learning effects and the possibility of the participants speculating on the purpose of the experiment. Firstly, each participant took a rest of 10 minutes before starting the next scenario. Secondly, before the next pedestrian crossing the street, participants drove through roads of different lengths to increase their driving experience. Thirdly, some ambient pedestrians were arranged to walk on the side of the road.

2.5. Variables
Each driver experienced 54 collision blocks in three speed limits, after getting rid of the invalid block due to incomplete experiment and abnormal driving, there are 2538 effective blocks’ data used in the analysis. This study uses brake reaction time, warning-to-brake time, maximum deceleration and collision rate to describe the changes in driving behavior. Taking the time of triggering the pedestrian and decelerating to the minimum velocity in the current block as the start point and stop point, the velocity changing process has been shown in figure 3, which can help to define the variables talked above and their specific definition are explained as follows.

Brake reaction time: the time is measured from the time when the pedestrian being triggered, to the driver’s first brake time.

Warning-to-brake time: the time is measured from the time when the warning being released, to the driver’s first brake time.

Maximum deceleration: the maximum deceleration in the start of braking to minimum velocity process.

Mixed effect model was used to see the significance between factors and variables introduced above. The level of significance is p < 0.05. Logistic regression is used to evaluate statistically significant differences for different warning release times and speed limits correlated to the collision rate.
3. Results

3.1. Brake reaction time

Driving performance with different factors is listed in table 1, including brake reaction time, warning-to-brake time, maximum deceleration and collision rate.

Table 1. Mean driving performance within different categories of factors.

| Condition          | Brake reaction time (s) | Warning-to-brake time (s) | Maximum deceleration (m/s/s) | Collision rate (%) |
|--------------------|-------------------------|---------------------------|------------------------------|--------------------|
| Gender             |                         |                           |                              |                    |
| Male               | 2.93±2.21               | 1.37±1.29                 | -4.50±3.84                   | 26.47              |
| Female             | 2.81±2.08               | 1.29±1.18                 | -4.44±3.86                   | 28.16              |
| Speed limit (km/h) |                         |                           |                              |                    |
| 30                 | 2.82±2.01               | 1.35±1.27                 | -4.47±3.82                   | 19.76              |
| 40                 | 2.90±2.16               | 1.28±1.17                 | -4.45±3.84                   | 28.36              |
| 50                 | 2.92±1.95               | 1.39±1.28                 | -4.46±3.88                   | 34.50              |
| Warning release time (s) |                 |                           |                              |                    |
| NA                 | 3.05±2.01               |                            | -4.44±3.86                   | 69.91              |
| 2.5                | 3.01±1.42               | 1.12±1.01                 | -4.51±3.83                   | 42.60              |
| 3                  | 3.31±1.42               | 1.41±1.27                 | -4.79±3.55                   | 27.55              |
| 3.5                | 2.46±1.26               | 1.27±1.19                 | -5.05±3.20                   | 8.56               |
| 4                  | 2.18±1.02               | 1.17±1.08                 | -4.73±3.50                   | 6.25               |
| 4.5                | 1.89±1.15               | 1.50±1.12                 | -5.11±3.14                   | 9.03               |

Figure 4. Mean brake reaction time under different gender and warning conditions.

According to the mixed effect model, gender (F = 41.019, P < 0.001) and warning release time (F = 1382.816, P < 0.001) showed great impacts on brake reaction time, while speed limit (F = 1.997, P = 0.136) had no significance with it. Mean brake reaction time under different gender and warning release time was presented in figure 4. Comparing with the warning released conditions, brake reaction time is much longer under no warning released condition, which means that the warning system did a great favor to drivers so that they could take actions earlier to avoid collisions. Besides the reference condition, it could be concluded that the earlier the warning released, the shorter the time for drivers to start braking, so it is better to release the warning earlier for providing enough time for drivers to make the right decision. Taking gender as a dependent variable, it was found that female’s brake reaction time was longer than the male’s under every warning release time.
3.2. Warning-to-brake time

Due to the late warning release time, there are some blocks in which drivers made decisions before the warning was released, so those blocks were deleted when analyzing the relationship between warning-to-brake time and factors talked above. From table 1, it could be found that all the warning-to-brake time is around 1.4s, which is closer to Paul’s result[15]. Mixed effect model was also done to find the connection of warning-to-brake time and factors, which showed that gender (F =50.167, P < 0.001), warning release time (F = 6.622, P < 0.001) and the interaction of speed limit and warning release time (F = 4.79, P < 0.001) had significance with warning-to-brake time. As similar to the brake reaction time, the female takes more time to make decisions as shown in the figure 5. Figure 6 illustrates mean warning-to-brake time for situations of different combinations of speed limit and warning release time. The pattern of warning-to-brake time under warning release time was not very clear in this experiment.

3.3. Maximum deceleration rate

The results of the mixed effect model showed that speed limit (F =22.971, P < 0.001) and warning release time (F = 49.164, P < 0.001) had significant influence in deceleration, however, gender (F = 0.458, P = 0.499) didn’t have significant impact on deceleration rate. From figure 7, it could be concluded that the decelerations under different warning release time groups were much higher than the control group. This means that drivers would choose hard braking more if they were alarmed, while they needed more time to detect risks and make decisions without warning, so the deceleration rate was lower than some of the warning release time groups, especially when their view was blocked. Except for the
control group, it was found that later warning release time groups’ (2.5s to 3.5s) deceleration were higher than earlier warning release time groups’ (4s to 4.5s), which means that drivers would choose soft braking when the warning release time is early. Considering with speed limit, the deceleration rate increased as the speed limit increased under warning release time groups, while the lowest deceleration was found when the speed limit was 50 km/h in the control group. It could be explained that when the driving velocity was high under no warning condition, drivers can’t observe the pedestrian in time resulted in a lower deceleration rate.

Figure 7. Mean deceleration under different warning release times and speed limits.

3.4. Collision rate
Changes in the collision rate are the most effective way to see whether the warning system can improve road safety or not. Figure 8 presented the collision rate under different warning conditions, it could be concluded that the collision rate of the control group is much higher than those groups with the warning released, which verified the effectiveness of the warning system. The collision rate also varies according to different levels of warning release time. The collision rate reduces with the time of warning released earlier, especially from 2.5s to 3s, which had a strong decrease in collision rate. However, there was a little bit of rebound when the warning released 4.5s before the collision. This is because the warning was released too early, giving the driver too much search time, which caused the driver to fail to make a correct decision.

Figure 8. Collision rate under different warning conditions.
Table 2. Results of the logistic regression model of collision rate.

| Variables               | B    | S.E.  | Wals  | df | Sig. | Exp(B) |
|-------------------------|------|-------|-------|----|------|--------|
| Speed limit             | 0.053| 0.007 | 66.854| 1  | 0    | 1.055  |
| Warning release time    | -0.805| 0.036 | 494.218| 1  | 0    | 0.447  |
| Constant                | -1.007| 0.272 | 13.678| 1  | 0    | 0.365  |

Logistic regression analysis was done after the descriptive statistics and the result is presented in Table 2. From the result, we can conclude that speed limit and warning release time (P < 0.05) had significant effects on the collision rate, while gender (P = 0.332) do not have significance with the collision rate. Treating warning release time as a continuous variable, increasing one second earlier warning can result in a 55.3% of reduction in the collision involvement rate (Exp (B) = 0.447).

4. Discussion

Based on the driving simulator experiment, this study compared the driving behavior of drivers under different speed limits and warning release time and verified the effectiveness of the audio warning system. As we talked above, some interesting and meaningful results have been found.

First of all, in terms of the brake reaction time, the study found that in the case of warning, the driver's braking reaction time has been significantly reduced compared to the condition without warning, which is as similar as Xuedong Yan et al.'s[16] finding. According to the results, it is better to release warnings earlier to improve drivers' vigilance towards the surrounding environment. As for warning-to-brake time, the result showed that females need more time to react than males while there is no clear pattern of drivers under different warning release time and speed limits. This is due to the driver's conditioned reflex to the audio warning, resulting in a similar reaction whenever he hears the warning.

The maximum deceleration was also affected by warning release time and speed limit. The result indicated that driving at high velocity on the side-parking road is very dangerous. When the driving velocity is fast, the driver cannot carefully observe the roadside situation and react in time, and when jaywalker appears, due to the critical situation, the driver is prone to make wrong reactions. In order to reduce the rate of pedestrian-vehicle collisions due to visual blind areas, it is necessary to reduce the speed limit on road sections with a high incidence of similar accidents. Besides, early warning is still very necessary, which is similar to the conclusions obtained from other related content studies[17-20].

From the result, we can know that the collision rate was influenced by warning release time and speed limit obviously. As discussed above, early warning release time and lower speed limits have significant effects on reducing the collision rate. However, releasing the warning too early is not very good either. According to figure 8, the collision rate with a warning release time of 4.5s has rebounded compared to the 4s. In line with the conclusions we have obtained, the best time to release the warning is 4s, which shows the lowest collision rate in the experiment.

In this study, we used several variables to present the driver’s driving behavior, including brake reaction time, warning-to-brake time and maximum deceleration. Mixed effects model was used to find the significant relationship between those variables and warning release time and speed limit. Logistic regression model was also used to build a collision rate model to show the relationship with warning release time and speed limit more intuitively. Summarized in one sentence, proper warning release time and lower speed limit are effective ways to reduce the incidence of pedestrian-vehicle collisions on the side-parking road section.

5. Conclusion

In conclusion, this study verified the effectiveness of the audio warning system in reducing the collision rate of side-parking road sections and the necessity of reducing the speed limit on the corresponding sections. In the next stage of research, consider combining EEG and eye movements to find more interesting results. Another direction of research is to design a visual warning system and compare it with the audio warning system, as some participants suggested after finishing the experiment. Last but
not least, it is meaningful to find more effective strategies to reduce the pedestrian-vehicle collision rate on side-parking road sections.

Acknowledgments
This work is financially supported by National Key R&D Program of China (2019YFF0301403).

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