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How does intersection field of view influence driving safety in an emergent situation?

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ABSTRACT

Restricted intersection field of view (IFOV) can influence drivers' hazard detection abilities and driving safety in an emergent traffic event. However, no field studies or crash-data analyses have been conducted to prove the adequateness of the current intersection sight-distance design standards, which are adopted to ensure that the approaching-intersection drivers have a sufficient field of view to detect traffic hazards and travel safely at intersections. In this study, we conducted a driving simulator experiment to compare drivers' behavioral and eye-movement measures between different IFOV conditions that met the current intersection sight distance design standards. We examined the influencing mechanism of IFOV on the drivers' collision avoidance process being composed of three consequential stages, respectively in terms of search stage, decision stage and action stage. Our experiment results showed that restricted IFOV impacts the three-stage driving performance interlockingly. Enlarging IFOV can significantly improve drivers' performance in detecting a conflicting vehicle more timely, having a longer perception-reaction time in monitoring the hazard, spending more time on observing intersection surroundings, and taking brake actions earlier and more smoothly so that drivers were more likely to successfully avoid colliding with the conflicting vehicle. In addition, we found that compared with female drivers, male drivers were less likely to take brake actions to avoid a potential collision and had a lower deceleration rate in the braking stage of collision avoidance while there was no significant gender difference in crash involvement rates. The findings indicated that male drivers were more skillful in vehicle control than female drivers. Nevertheless, male drivers had less traffic-crash expectation, which degraded their overall crash avoidance effect. Considering the traffic safety that more than five million intersection-related crashes occur in American each year, these experimental findings have implications for public safety and health.

1. Introduction

Traffic hazard reflects a potential risk that may result in drivers' intervening actions to avoid a crash. Because more than 90 percent of the traffic crashes are owing to the problems with the acquisition of visual information (Hills, 1980; Olson et al., 1993; Sivak, 1996), drivers' abilities to anticipate road events and detect hazardous traffic objects are critical for crash avoidance performance (Yan et al., 2016; Zhang et al., 2016; Horswill and McKenna, 2004; Anstey et al., 2012). The abilities are defined as hazard perception (HP) (Shahar et al., 2010) in contrast to other skills specific to the driving context, such as vehicle control (Horswill and McKenna, 2004). HP has been identified to be associated with crash risk in a number of studies (Darby et al., 2009; McKenna and Horswill, 1999; Quimby et al., 1987; Wells et al., 2008). Even, HP was found to be superior to other driving components for predicting accident involvement (Horswill and McKenna, 2004). Earlier hazard detection of drivers affords more sufficient time for appropriately responding to the hazards (Hosking et al., 2010).

Driving across intersections is a complex task for drivers highly relying on HP (Isler et al., 1997; Fildes, 2006). It requires gathering distal and proximal visual information from many different angles, normally received through eye and/or head movements (Isler et al., 1997; Kito et al., 1989). However, when approaching to the intersections, drivers' fields of view (FOV) to the conflicting vehicles in the crossing roadways are frequently restricted by obstacles at the corners of the intersections, such as buildings, trees, advertisement boards, etc. In consequence, drivers have insufficient information to dynamically evaluate the driving situation (Werneke and Vollrath, 2012). Providing the drivers with a wider field of view, which includes more traffic environmental cues that are related to the potentially hazardous situation,

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increases their abilities to detect hazards (Shahar et al., 2010).

Numerous previous studies indicated how a driver's useful field of view (UFOV) plays a significant role in driving safety. It is defined as the area through which one can extract visual information in a single glace without eye or head movement (Sivak, 1996; Robinson et al., 1972; Green, 2002; Houten and Retting, 2001). Drivers with UFOV impairments encounter more difficulties in detecting peripheral targets (Chaparro et al., 2001; Sifrit et al., 2001) and require a larger number of eye movements to identify the location of a target (Scialfa et al., 1994). Essentially, a reduced UFOV is associated with an individual's internal degraded HP. Nevertheless, little previous research focused on the influencing mechanism of the external restricted field of view on drivers' HP and crash-avoidance performance at intersections. A restricted horizontal field of view reduces the amount of available peripheral visual information around the intersections. The crash-data analyses showed that when drivers are less likely to perceive the dangerous objects around them, a typical perceptual error occurs: divers looked but failed to see (Brown, 2005; Cairney and Catchpole, 1996; Herslund and Jørgensen, 2003; Koustanaï et al., 2008; Langham et al., 2002). Therefore, persistently and accurately scanning traffic environments at intersections is critical for drivers to understand other traffic participants' intention and take proper collision-avoidance actions.

In this study, we aim to explore the mechanism about how IFOV influences drivers' HP abilities and collision-avoidance performance when encountering an emerging conflicting vehicle at intersections, based on drivers' eye-movement data and driving-performance data. In order to develop the technologies of intelligent collision avoidance systems (CAS), Brännström et al. (2013) proposed a conceptual three-step model for the CAS algorithm. Step 1 is named as Sensor fusion, which is used to estimate the states of vehicles, potential hazardous objects, road conditions and drivers before the traffic conflict occurs; Step 2 is named as Decision-Making, which is used to assess the threat and whether drivers judge the situation as a critical event; Step 3 is named as Actuators (vehicle control), which is used to assign the automatic algorithm into the vehicle control strategy. However, the study only focused on the step of decision-making to measure and predict traffic collision uncertainties from a theoretical aspect, which did not embody the proposed three-step model in details based on empirical driving-performance data. In this study, we particularly propose an analysis framework for intersection collision-avoidance performance as shown in Fig. 1.

In the framework, we divide the drivers' collision avoidance process into three time stages when approaching to an intersection and encountering a traffic conflict event, namely the search stage for scanning hazards before detecting them, the decision stage for perceiving and reacting to the hazards after detecting them, and the action stage for adjusting vehicle speed to avoid collisions. The lengths of three stages durations are individually different under different factors, such as drivers' characteristics, environmental factors, and road conditions. The process may result in drivers' successfully avoiding a collision from the conflicting vehicle or a traffic crash due to an insufficient deceleration rate, improper speed adjustment behavior or improper decision (such as accelerating). The drivers' performance in the upstream stages consequently influences their performance in the downstream stages in a spatial and temporal order. If the drivers' field of view were restricted by obstacles, the whole collision-avoidance process would be interlockingly impacted.

In order to collect data in a well-controlled experiment according to the above analysis framework, we used a high-fidelity driving simulator equipped with an eye tracking system to extract the behavioral and eye-movement measures related to the subjects' collision-avoidance performance under three different levels of IFOV conditions. The IFOV conditions were designed based on the standards of American Association of State Highway and Transportation Officials (AASHTO). Specifically, the lengths of clear sight triangle legs on the minor road for the IFOV1, IFOV2 and IFOV3 conditions were gradually increased while the length of clear sight triangle leg on the major road was constant. We intended testing whether and how increasing IFOV impacts the collision-avoidance performance, such as scanning activities during approaching intersections, timeliness of detecting potential traffic hazards, timeliness of taking a braking action, speed-adjustment performance, etc.

Additionally, gender as a typical driver characteristic is associated with driving performance and crash involvement (Turner and McClure, 2003; Bener, 2013; Obst et al., 2011). It was indicated that male drivers had a higher traffic crash risk than female drivers (Elander et al., 1993; Li et al., 1998).

The female drivers had less risky driving behaviors than male drivers (O¨zkan and Lajunen, 2006; Holland et al., 2010) and male drivers tend to be excessively optimistic on their driving skills and usually behave less cautiously than female drivers (DeJoy, 1992). Some literatures demonstrated the driving-performance differences in visual searching between males and females. It was found that the drivers who looked but failed to see the pedestrian are more likely to be female compared to the looked/responded drivers (White and Caird, 2010). In the HP process, females are more likely to classify a situation as being hazardous, representing a more careful behavior in traffic (Huestegge et al., 2010). Therefore, there could be gender differences in the drivers' eye movements and collision-avoidance performance under different IFOV conditions. To this end, our experiment also explored how the gender factor influences drivers' scanning activities and driving performance in the three different time stages of collision avoidance.

2. Material and methods

2.1. Participants

In this study, we recruited 23 (11 men and 12 women) subjects with a good health condition from the local community. All of the subjects held a valid driver's license, had at least three years of driving experience and drove more than 20,000 km per year. Their ages ranged from 30 to 40, with an average age of 35 years and a standard deviation (S.D.) of 2.99 years. The experiment lasted for about 30 min for each participant, who was compensated with RMB500 (approximately U.S. dollar 80). The experimental procedure was approved by the Institutional Review Boards (IRB) of the Beijing Jiaotong University. The authors conducted the experiment in accordance with the approved guidelines and obtained the informed consent from each subject before the experiment.

2.2. Apparatus

We used the Beijing Jiaotong University (BJTU) driving simulator equipped with eye-tracking glasses (SMI-ETG™) to collect the subjects' behavioral and eye-movement data. The BJTU simulator is a high-performance, high-fidelity driving simulator with a linear motion base capable of operating with one degree of freedom. It comprises a full-size vehicle cabin (Ford Focus) with a real operational interface, environmental noise and shaking simulation system, digital video replay system and vehicle dynamic simulation system. The simulated environment is projected at 300 degrees of a frontal/peripheral field of view and left-middle-right rear view mirrors with a resolution of 1400 * 1050 pixels. The SIM-vista software in the simulator lab allows for driving scenario design, virtual traffic environment simulation and virtual road modeling while the SIM-creator software can be used to run the established virtual driving scenario. The SMI-ETG™ was designed as highly integrated glasses with a natural appearance to wear comfortably and used to collect participants' binocular eye movements without restrictions of cab environment and the range of head motion. The SMI-ETG™ contains three video cameras: one is used to record the frontal views of participants and the other two are used to capture participants' eye movements. The positions of participants' fixation points and the