Experimental Investigation on the Uncertainty of Driver's Perception Response Time in Safety-critical Scenarios

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I. INTRODUCTION

The timing of hazard perception and collision-avoidance decision-making taken by human drivers in safety-critical scenarios significantly affects vehicle dynamics and the resultant collision risk [1]. For human-driven vehicles, the perception response time (PRT) is the time from the hazard appearance in the scenario to the collision-avoidance action initiated by the driver. PRT is essential for the safety design of roads (e.g. traffic lights) and vehicles. Current Advanced Driver Assistance Systems (ADAS) are designed to provide additional support to human drivers. They have not, however, incorporated a precise inference of PRT and therefore lacked an individualised design of the collision-avoidance algorithms [2]. PRT exhibits a high level of inherent uncertainty at individual and population levels because it depends both on the driver and the scenario's urgency level [3]. However, how drivers perceive information and use it to avoid collisions in safety-critical scenarios remains unclear. As a preliminary investigation, this study analysed the uncertainty and individual differences of drivers' PRT using experimental data in simulated, representative safety-critical scenarios.

II. METHODS

We used the previously reported experiments [4] to quantify PRT and to analyse its characteristics in safety-critical scenarios. In total, 864 experimental cases capturing the pre-crash active behaviour were performed via a driving simulator. This involved 24 experienced drivers (denoted as Subject i, i = 1, …, 24; 37.6 ± 6.0 years, 13.1 ± 5.3 driving years) participating in car-following scenarios on the freeway. The experiment matrix included three independent variables: designed headway time (THW); leading vehicle brake lights (LVB); and the deceleration of the leading vehicle (DLV)); among which designed THW and DLV define the urgency level of each scenario. Driver's visual looming (VL) is produced during the change in relative distance between the ego vehicle and the leading vehicle. Thus, VL is represented by parameters related to the driver's visual angle α (Fig. 1).

$$\alpha(t) = 2arctan\left(\frac{W}{2D(t)}\right) \tag{1}$$

$$\dot{\alpha}(t) = \frac{-W \cdot v(t)}{D^2(t) + W^2/4} \tag{2}$$

where optical expansion rate $\dot{\alpha}$ is the derivative of the visual angle of the leading vehicle (α) with respect to time, i.e., α describes the relative distance, and $\dot{\alpha}$ represents how fast the leading vehicle is approaching; W is the width of the leading vehicle, D is the distance from the driver's eyes to the rear of the leading vehicle, v is the relative velocity between the ego vehicle and the leading vehicle.

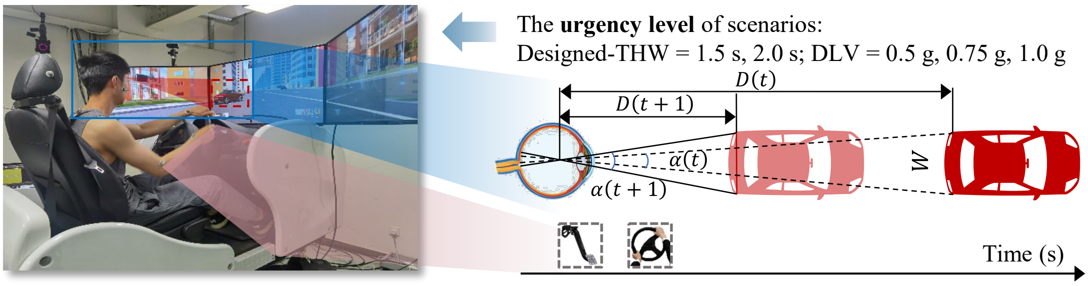

Fig. 1. Experimental design and parameters definition on the driving simulator.

During experiments, PRT was output as the time interval from the leading vehicle braking to the collision-avoidance action taken by the driver (subject) (i.e. braking or steering). Kinematics parameters of the leading and ego vehicles (e.g. velocity, coordinates) were used to calculate the time-varying THW during car-following. In addition, visual angle change (VAC) was defined as the integral of the optical expansion rate from the hazard appearance to the collision-avoidance action, to indicate the perceived signals by drivers.

III. INITIAL FINDINGS

In the car-following safety-critical scenarios, drivers generally tend to brake first (1.13 ± 0.33 s), then steer (2.60 ± 0.65 s). When detecting the approaching vehicle, a typical driver first brakes to reduce the velocity and then

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steers when the collision is imminent, or even after it has occurred. VAC exhibits concentrated distribution and is positively correlated with PRT, although the distribution of PRT is wider. This means that the driver has a stable decision threshold in different scenarios. When the brake lights turn on, PRT decreases, and the distribution of VAC becomes more concentrated in low-value (Fig. 2(a) ①⑨).

Yet, there is no significant correlation between the scenario's urgency level and PRT, especially when we focused on the first response time, as evidenced by the THW-PRT scatter plot (Fig. 2(a) ②④). For example, even the PRT of the lowest urgency level with brake lights (1.19$\pm$0.35 s) is shorter than the highest without brake lights (1.35$\pm$0.24 s). Therefore, the driver's cognition on hazard assessment is not purely dependent on scenario-specific parameters in the three-dimensional space (e.g. THW), but also on visual looming-based metrics (e.g. $\alpha, \dot{\alpha}$). In addition, visual cues (e.g. brake lights) also affect driver's hazard perception decisions.

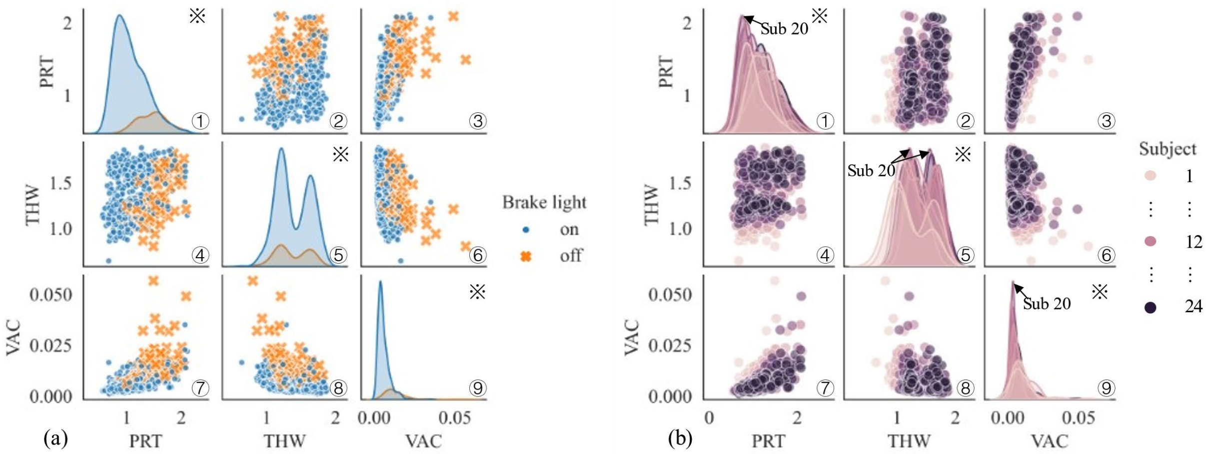

Fig. 2. Variable relationship between subjects and scenarios (graphs with ※ represent the kernel density estimate).

Different drivers (subjects) have similar distribution shapes but various ranges of PRT and VAC (Fig. 2(b) ①⑨), indicating that drivers have a common perceived decision-making process with individual characteristics. For example, the VAC of subject 20 exhibits a narrow range (Fig. 2(b) ⑨), while the PRT is lower and THW shows an apparent bimodal distribution (corresponding to the two designed THW levels) (Fig. 2(b) ①⑤). As VAC can be understood as the evidence accumulation process of $\dot{\alpha}$ before decision-making [5], it reflects the decision threshold accumulated by the drivers based on the optical expansion rate as evidence. This further indicates that drivers with a concentrated distributed VAC have a more deterministic decision threshold. Drivers such as subject 20 have better hazard perception, decision-making and control ability over the vehicle.

IV. DISCUSSION

We analysed the characteristics and individual differences of PRT acquired from experienced drivers in simulated safety-critical scenarios. The results suggest that drivers can infer the urgency level and interaction processes based on visual looming-based metrics and visual cues, which are significant for understanding the underlying perceived decision-making process and then inferring PRT. The inherent uncertainty is from multiple factors of drivers and vehicles, such as how humans understand the visual context with noise. The evidence accumulation process shows that PRT is related to drivers' decision threshold and interaction process. The distribution of VAC shows that drivers have different decision thresholds (i.e. 'expectancy' in [3]), and the accumulation process of optical expansion rate in the time domain reflects the influence of the scenario's urgency level (i.e. 'kinematics-dependence' in [3]). Accurate inference of PRT can describe driver's perceived response characteristics and help advanced safety systems, such as ADAS, to be more individualised and, finally, efficient. Although the present investigation is limited to the given car-following scenario type and simplified cognitive indicators, it presents a framework that can be extended in subsequent studies. An Inference model of PRT, including three-dimensional space parameters and visual looming-based metrics based on the evidence accumulation process, will be constructed for developing collision-avoidance algorithms to mitigate traffic injuries.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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