

Analysis of Cyclist Avoidance Behavior in Emergencies Using VR Simulation

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According to Japanese traffic statistics, bicycles account for a substantial share of road casualties, and half of cyclist casualties occur in intersection-crossing crashes. In particular, at unsignalized intersections, automated emergency braking on the vehicle alone may not prevent every crossing collision; consequently, the avoidance behavior of cyclists plays a critical role in crash avoidance. To understand cyclist behavior, this study constructed a VR bicycle simulator using a bicycle, a smart trainer, a steering unit, and a VR head-mounted display (HMD) to explore cycling behaviors, including speed, gaze allocation, and collision-avoidance maneuvers.

The experimental scenario was developed using Unity, reproducing a 550 m residential road with 9 unsignalized intersections. At the 6th intersection, a car crossed from left to right at 30 km/h when the cyclist was 7 m before the intersection. Cycling speed, steering, braking, position, and gaze were recorded synchronously at 50 Hz. Recognition time was defined from vehicle appearance to the leftward gaze response, braking response time from appearance to brake onset, and operation time from recognition to brake onset. Cycling behaviors were compared between the avoidance and collision groups using independent samples t-tests.

Forty (40) participants aged 18–24 were recruited and participated in the experiment. Among them, 21 participants successfully avoided the crossing car and 19 collided with it. Avoidance success did not differ by gender ($p = 0.210$), although male participants exhibited a higher speed trend compared to female participants (male vs. female average speed: 13.0 vs. 11.6 km/h). In the collision group, failure to recognize the car (8 participants) and failure to initiate braking (13 participants) were primary factors, showing that recognition and braking were strongly associated with collision avoidance. The average speeds in the avoidance and collision groups were 11.3 km/h and 13.5 km/h, respectively, with the collision group exhibiting a significantly higher speed across the entire route.

Recognition time among all participants was shorter in the avoidance group (0.52 vs. 1.54 s, $p < 0.001$). Among participants who braked, BRT was also shorter (0.72 vs. 1.22 s, $p = 0.003$), whereas operation time after recognition did not differ significantly (0.21 vs. 0.09 s, $p = 0.393$). Both gaze distributions centered near the travel direction, but the avoidance group looked farther toward the left or near side. Its horizontal gaze median was more leftward (-1.27° vs. -0.07° , $p = 0.005$), while vertical gaze did not differ.

The findings indicate that successful collision avoidance reflects the combined effects of lower cycling speed, earlier recognition of the intruding car, and earlier braking. The absence of a significant group difference in operation time suggests that the difference in braking response time was driven primarily by the recognition phase rather than the subsequent motor execution phase. As a critical factor in car recognition, the gaze distribution of the avoidance group was more dispersed and shifted closer to the near side. However, whether the avoidance group can still successfully prevent collisions if the target vehicle intrudes from the far side warrants further investigation. Additionally, future work should incorporate auditory information and subjective reports to validate the underlying recognition mechanisms. Overall, this study provides insights into cyclist behavioral characteristics and offers theoretical support for improving road traffic safety.

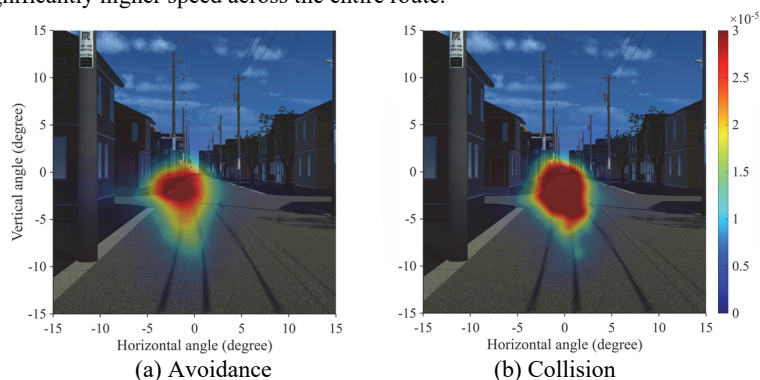


Fig.1 Gaze distributions in the avoidance and collision groups

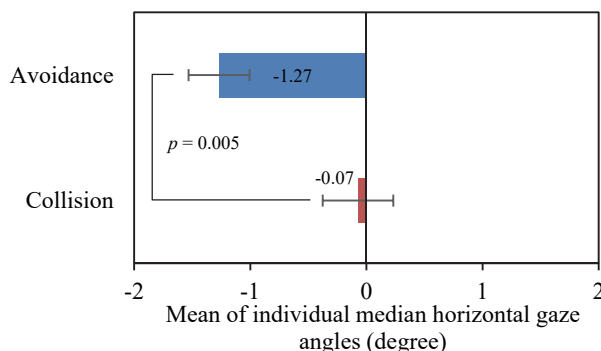


Fig.2 Mean of individual median horizontal gaze angles by collision outcome