

Effects of Dark Conditions on Pedestrian Crossing Decisions

Wataru Nakashima ¹⁾ Taiki Yoshikawa ²⁾ Kazusa Fukawa ²⁾
Takeshi Waragaya ¹⁾ Tatsuru Daimon ³⁾

1) Stanley Electric Co., Ltd.

242 Soya, Hadano, Kanagawa, 257-8577, Japan

(E-mail: wataru_nakashima@stanley-electric.com)

2) Keio University, Graduate School of Science and Technology

3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa, 223-8522, Japan

3) Keio University, Faculty of Science and Technology

3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa, 223-8522, Japan

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As Level 4 automated driving systems are increasingly expected to operate in public road environments, pedestrians may encounter automated vehicles without implicit communication from a human driver. In such situations, conventional implicit communication through eye contact, gestures, and vehicle behavior may be reduced or lost. External human-machine interfaces (eHMIs) have therefore attracted attention as a means of communicating vehicle intent to pedestrians. However, many previous studies have been conducted in controlled environments, such as virtual reality or video-based experiments, and the effects of dark conditions in real-world environments on pedestrian crossing decisions remain insufficiently understood.

This study aims to clarify how dark conditions affect pedestrians' crossing decisions when an automated vehicle yields to a pedestrian at an unsignalized crosswalk. Pedestrian crossing decisions were evaluated from two perspectives: yielding recognition, defined as recognizing that the approaching vehicle intends to yield, and safe crossing judgment, defined as judging that it is safe to cross the road.

Real-world vehicle experiments were conducted on an outdoor straight test track with a simulated stop line and crosswalk. The experiment encompassed both daytime and dark conditions. In the dark condition, surrounding lighting and streetlights were not used, and the ambient illuminance was below 0.2 lx, except for the vehicle headlamps. Twenty-three vehicle behavior conditions were tested by combining vehicle speed, deceleration start position, and stopping position. Participants stood near the crosswalk and pressed a handheld switch when they recognized that the vehicle had yielded and when they judged that it was safe to cross. Data from 19 participants in the daytime condition and 11 participants in the dark condition were analyzed using generalized linear mixed models.

Overall comparisons revealed no significant difference between daytime and dark conditions in either yielding recognition or safe crossing judgment. However, the GLMM analysis showed that vehicle speed and residual deceleration significantly affected yielding recognition. Residual deceleration had a stronger influence than vehicle speed, suggesting that pedestrians used deceleration behavior beyond that predicted from speed and deceleration start position as a cue for recognizing yielding intent. Under dark conditions, the effect of residual deceleration was attenuated, indicating that pedestrians may have difficulty perceiving vehicle deceleration at night.

For safe crossing judgment, stopping position was the dominant factor. When the vehicle stopped beyond the stop line, pedestrians were more likely to judge that it was safe to cross under dark conditions than under daytime conditions. Since approximately 80% of safe crossing judgments were made before the vehicle came to a complete stop, pedestrians likely predicted the final stopping position from the approaching vehicle's kinematics. Under dark conditions, reduced visibility of the vehicle body, distance, and relative position may have decreased the accuracy of this prediction.

These findings suggest that yielding recognition and safe crossing judgment are based on different cognitive processes. Dark conditions may impair both the perception of vehicle deceleration and the prediction of stopping position. Therefore, eHMI systems for dark environments should not only communicate yielding intent but also help pedestrians understand the vehicle's deceleration state and its intention to stop.

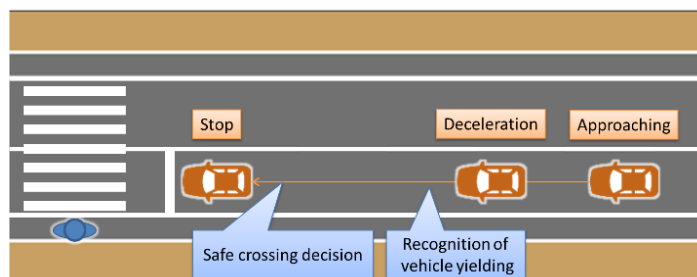


Fig. 1 Overview of the Experimental Procedure