Exploring Physical and Gaze Behavior Factors Affecting Drivers' Responses in Intersection Collisions

Yuqing Zhao, Kotaro Sugiura, Yuki Nitta, Koji Mizuno

I. INTRODUCTION

The driver's visual abilities, such as the useful field of view and peripheral vision, are closely related to their responses in collisions [1-2]. Additionally, decreased physical abilities, such as neck flexibility and head and eye movement capabilities, may lead to a reduction in scan frequency and range, thereby increasing the likelihood of missing hazards [3-4]. However, comprehensive studies on the relationship between physical factors, gaze behavior, and collision risk from hazards remain limited. This study aims to identify the hierarchical structure of physical and gaze-related factors that affect drivers' response mechanisms to hazards in collisions. To achieve this, we conducted an integrated analysis using a decision tree model, combining (1) driving aptitude tests and (2) driving simulator experiments that collect eye tracking data to analyze gaze behavior.

II. METHODS

Driving aptitude tests

First, participants underwent driving aptitude tests conducted by the National Agency for Automotive Safety and Victims' Aid (NASVA) to evaluate psychological and physical factors. Using computer software, the aptitude tests primarily assessed the following: 1) performance accuracy: action accuracy and timing of judgment and actions; 2) attention distribution; 3) visual functions: dynamic visual acuity, eye movements, peripheral vision, and night vision; and 4) driving attitude: safety attitude and danger sensitivity. Each item was evaluated with a score: visual item scores ranged from 0 to 10, while all other items were scored from 0 to 100.

Driving simulator experiments

A driving simulator experiment equipped with an eye-tracking system was conducted at Nagoya University (Fig. 1). The driving scenario was simulated using UC-win/Road Ver.15 and included a bidirectional two-lane road with a total length of 2.5 km and 9 intersections. A hazardous event was introduced at the final intersection, where a bicycle unexpectedly appeared from the right side (far side) with a time-to-collision (TTC) of 2.5 s. Drivers were instructed to maintain a speed of 50 km/h and drive as they normally would.

Eye-tracking data were collected using the Smart Eye Pro DX. The driver's gaze behavior was identified using the Glance Algorithm to automatically detect scans [5]. The following gaze characteristics (composed of eye and head data) were examined: total number of scans, scan time, fixation time for object recognition, scan angle (maximum gaze deviation), and scan speed (maximum scan angle divided by the time taken to reach it) (Fig. 2).

Fig. 1 Driving simulator with an eye tracking system.

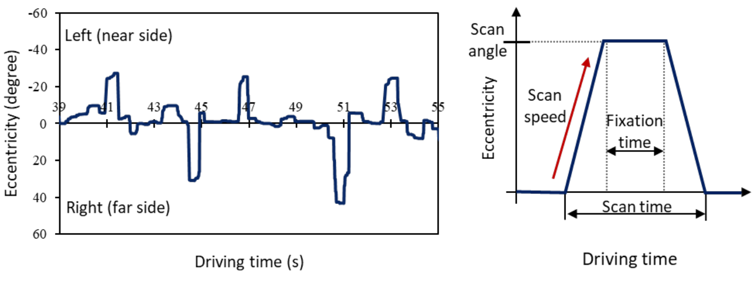

Fig. 2 Example of scan behavior (horizontal eccentricity) and the definition of a scan.

Participants

9 younger participants (5 males and 4 females; mean age = 34.8 years) and 16 older participants (9 males and 7 females; mean age = 71.4 years) without eye diseases were recruited to participate in this study. All participants held a valid driving license and drove weekly. Due to motion sickness induced by the driving simulator and

Y. Zhao is an Assistant Professor (+81 52 788 6233, yuqing.zhao@mae.nagoya-u.ac.jp), K. Sugiura is a BEng student, Y. Nitta is a MEng student, K. Mizuno is a Professor in the Department of Mechanical Systems Engineering at Nagoya University in Japan.

excessive noise in the gaze data, the final analysis included 14 older participants (7 males and 7 females) and 9 young participants. This study was approved by the Ethics Committee of Nagoya University (24-13).

Statistical analysis

The braking reaction time (BRT) in response to the cyclist's appearance was analyzed based on 9 physical factors from the driving aptitude tests and 5 driver gaze behavior parameters. A decision tree model (CART) in R 4.4.2 was employed for hierarchical analysis.

III. INITIAL FINDINGS

Drivers' BRT was the primary factor contributing to collision occurrences in the driving simulator experiments. The decision tree model hierarchically identified the key factors influencing BRT and helped clarify the process by which drivers responded to a cyclist hazard, from initial detection to brake pedal engagement (Fig. 3). As shown in Fig. 3, the root node represents the entire dataset, with an initial mean BRT of 1.7 s. The subsequent splits illustrate how different parameters contribute to BRT variations. The model indicated that the number of scans was the initial screening factor influencing BRT, followed by dynamic visual acuity and physical factors such as danger sensitivity and the timing of actions and judgment.

The first splitting condition was the number of scans: drivers with fewer than 12 scans had the longest BRT of 2.7 s (11%), exceeding the TTC of 2.5 s, indicating an extremely high risk of collisions. The second splitting condition was dynamic visual acuity: when it was lower than 4, the mean BRT was 2.3 s. The number of scans exceeding 52 played an important role again when dynamic visual acuity was greater than 4, resulting in a smaller and safer BRT of 0.9 s (11%) for drivers to achieve a low risk of collisions. If the number of scans was fewer than 52, drivers' danger sensitivity needed to be greater than 90 to contribute to a smaller BRT of 0.8 s (5%). The next splitting condition after danger sensitivity was the timing of judgment and actions.

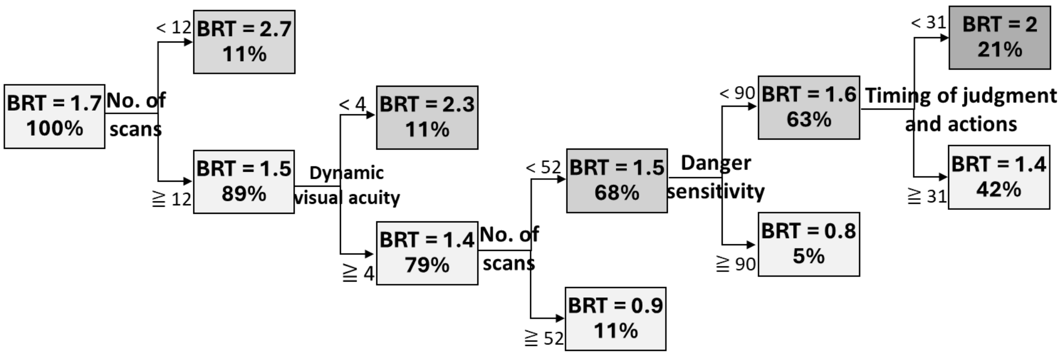

Fig. 3 Factors affecting driver's BRT in the decision tree. The percentage is the proportion of each node.

IV. DISCUSSION

A decision tree model was used to relate driving aptitude test results and scan behavior in a driving simulator to braking reaction time (BRT) in this study. Accordingly, the number of scans (measured in the driving simulator), dynamic visual acuity, danger sensitivity, and timing of judgment and actions (assessed through the aptitude test) are critical parameters for evaluating drivers' abilities to avoid intersection collisions. The decision tree may clarify the response mechanism by identifying the hierarchical contribution of key factors when drivers encounter hazards: drivers tend to increase the number of scans to assess their environment, particularly when approaching intersections, then rely on dynamic vision to detect intruding hazards, followed by an evaluation of potential danger, and ultimately respond (e.g., by pressing the brake pedal) based on the timing of judgment and actions.

In this study, no significant differences in BRT were observed between older and younger drivers, which could be explained by the fact that scan frequency was not significantly different between the two groups. Further research should investigate the relative effects of each contributing factor on BRT using a larger sample size to improve the generalizability of the findings.

V. REFERENCES

[1] Ball, K. et al., Invest. Ophthalmol. Vis. Sci., 1993. [2] Green, M., Transp. Hum. Factors, 2000.
[3] Isler, R. B. et al., Accid. Anal. Prev., 1997. [4] Savage, S. W. et al., Hum. Factors., 2023.
[5] Swan, G. et al., Behav. Res. Methods, 2021.