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Investigating Effects of Assistance Systems for Visually Impaired Drivers at Preventing Traffic Accidents

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ABSTRACT

Visual field defects (VFDs) are closely associated with driver hazard perception. Drivers with advanced VFD may be exposed to the high risk of road traffic accidents. Therefore, it is expected to establish assistance systems for the patients with advanced VFD. Hence, the purpose of this study is to investigate the effectiveness of three driver assistance systems in reducing traffic accidents in several traffic situations, including automatic braking and two alerts with different times to collision. An experiment under simulated VFD is conducted with a low-fidelity driving simulator. According to the experimental results, alarm systems are very effective in reducing the incidence of accidents. In addition, subjective evaluations indicate that drivers with simulated VFDs are actively engaged in compensatory behaviors.

Keywords: Visual field defect, Driver assistance system, Accident prevention, Driver behavior, Driving safety

INTRODUCTION

The manner in which people act to achieve a goal can be considered information processing, a process in which perception, understanding of a situation, and selection and execution of an action are repeated (Parasuraman et al. 2000). In the perception segment, a driver relies mainly on vision to obtain information. Vision is an important part of driving behavior (Owsley & McGwin, 1999). Since drivers obtain road information mainly through vision, good vision is essential for safe driving (Owsley & McGwin, 1999). However, patients with visual field defects (VFDs) have deficits in the first step. Studies reveal that drivers with visual field impairments are more likely to be involved in accidents than drivers with normal vision (Satou et al. 2014). Furthermore, due to the developmental nature of visual field disorder symptoms, drivers do not immediately recognize the defect in their visual field, causing the incidence of accidents to increase significantly in the advanced stages of the disease. To date, research has focused on accident investigation and driving environment improvement from a human point of view. Investigations on support from the vehicle's assistance system to reduce accident rates are lacking. Therefore, the purpose of this study is to investigate the effectiveness of different types of assistance systems in reducing traffic accidents in several traffic situations.

To investigate the affects of visual field loss on driving, we used extreme scenarios in our experiments (Kunimatsu et al. 2015). Hazardous events were divided into four categories: traffic signals, oncoming right-turning vehicles, objects appearing to the left and right of the driver. We counted the number of traffic accidents for each scenario.

METHOD

Participants

This experiment was completed for the first time in 2019 and in 2022 with an increased number of people under the same conditions. Both the experiments required participants to (i) have a driver's license and drive daily, (ii) have no previous case of eye disease, and (iii) have bare eye vision (corrected vision) of 0.7 or higher. Accordingly, 80 participants were recruited through temporary staffing agencies and on campus at the University of Tsukuba, Japan.

The purpose of the experiment and method of operation were explained to the participants before the experiment began, and the participants' consent to participate was obtained after they were made aware of the need for video recording to investigate driving behavior. This study complied with the ethical regulations of the University of Tsukuba and was approved by the Ethics Review Committee (approval no. 2021R574).

Experimental Equipment

In this experiment, the Honda Safety Navigator (S-Navi for ophthalmology) driving simulator from Honda Motor Co. was used on a 65-inch monitor with a horizontal field of view of 70°, which was specifically set up for an eye hospital. Further, the participants' eye tracking information was acquired at 60 Hz by using ProNano, an eye tracking device manufactured by Tobii. At the same time, an alarm audio support system was generated by a speaker in front of the participant's left side. Fig. 1 depicts the experimental equipment. The simulator contains a movable seat, steering wheel, gas pedal, and brake pedal. The eye tracking equipment is calibrated before the start of the experiment, and participants are asked not to move the seat position after the calibration.

Visual Field Defects Simulation System

In this experiment, to simulate a high degree of VFDs in a driver, we designed and employed a simulation mask system. The mask pattern simulated the typical pattern of defects in patients with retinitis pigmentosa, and it was designed such that when it was displayed on the screen, the left and

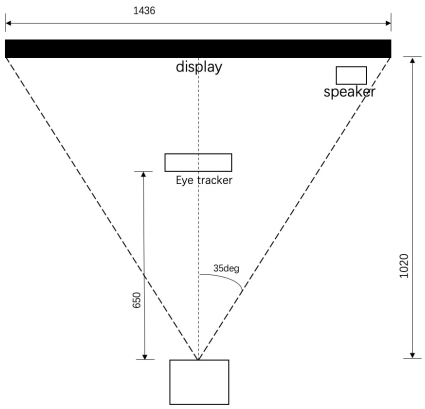

Figure 1: Sketch of the experimental equipment.

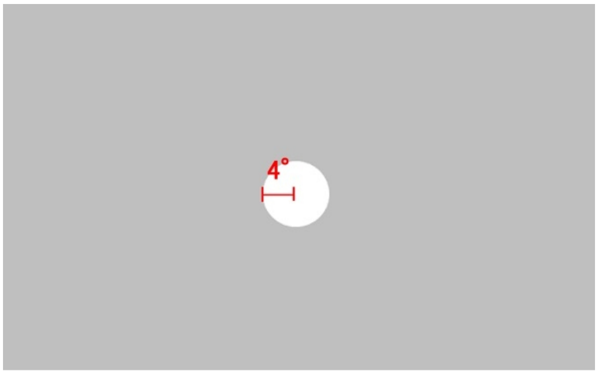

Figure 2: Simulation mask system.

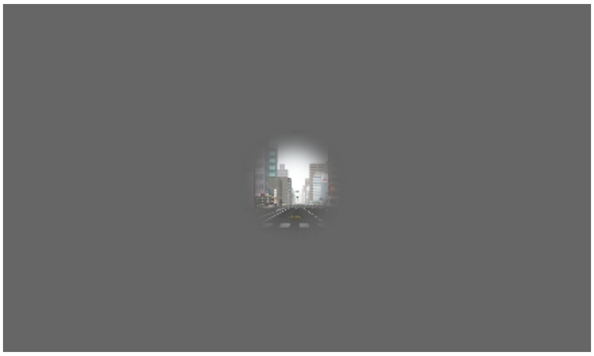

Figure 3: Simulation of the driving screen in the case of virtual field defects.

right horizontal fields of view were 4° each, forming a total of 8°. At the beginning of the experiment, the central 8° visual field of view moved with the participant's line of vision (Fig. 2). Fig. 3 depicts a specific driving screen.

Table 1. Examples of hazardous events.

Traffic signals	Stop signs	Oncoming right-turning car
		
Trucks that appear from the driver's right	Cars that appear from the driver's left	Senior cars crossing from the right outside road
		

Table 2. Wording of the audio guide.

Categories	Alert message
Traffic signals (traffic signals and stop signs)	Please stop at the traffic light Please stop at the stop sign
Oncoming right-turning cars	Please be aware of oncoming traffic
Objects that appear from the driver's right side	Please note the right direction
Objects that appear from the driver's left side	Please note the left direction

Experimental Conditions

To investigate the effects of different driving support systems, this study designed a VFD condition (mask only) and three assistance systems based on the time to collision (TTC) in hazardous events: automatic braking (AB; TTC = 0.8 s) and providing audio guidance on driver behavior to cope with encountering situations. Further, two guidance systems were presented in different alert timings (VGEarly: TTC = 4 s, VGLate: mean TTC = 2.81 s). We classified hazardous events (Table 1) into four categories: traffic signals (traffic signals and stop signs), oncoming right-turning cars, objects that appear from the driver's right and left sides. Finally, participants completed two experimental trials that included 29 hazardous events.

The automatic braking system has a TTC setting of 0.8s except for the two scenarios of pedestrians coming from the left and right directions and temporary stop (TTC = 0.75s). Further, the deceleration of automatic braking was 0.7s. Table 2 depicts the wording of the audio guide.

Driving Tasks and Scenarios

This experiment was divided into three sections: a wide two-lane road, single-lane road, and residential road, corresponding to maximum speeds of 50, 40, and 30 km/h (Kunimatsu et al. 2015), respectively. Since this experiment did not involve turning and other operations, participants had to operate only the brakes and throttle. The experiment was set to automatically accelerate to the maximum speed of the corresponding road section by stepping on the gas pedal only once. When the participants judged the presence of danger and wanted to apply brakes or slow down, they had to apply the brake. Further, if the brakes were released before the speed became 0, the vehicle would automatically accelerate to the maximum speed.

In this study, two experimental trials were conducted with the same hazard scenario settings, following the adjustment of the order and number of occurrences. Trial 1 had 15 scenarios: H1 to H7 was a 50-km/h section, H8 to H9 was a 40-km/h section, and H10 to H15 was a 30-km/h section. Trial 2 had 14 scenarios: H1 to H6 was a 50-km/h section, H7 to H8 was a 40-km/h section, and H9 to H14 was a 30-km/h section.

Experiment Procedure

Upon arrival, participants were given a summary description of the experiment and a consent form. After the participants signed the form, we explained the driving behaviors to be exhibited by the participants; then, the participants performed a two-minute practice to familiarize themselves with the driving simulator. Subsequently, we adjusted each participant's position and calibrated the eye tracking equipment. Once everything was in order, two experiments were conducted, interspersed with a five-minute break. The entire experiment lasted for approximately 40 minutes.

RESULTS

Number of Accidents

For this analysis, we used 2018 data (same scenario, no mask) as the baseline (BL). Tables 3 and 4 depict the number of incidents/violations in the BL group and VFD group for three different assistance systems. Excluding the reasons due to the state of the participants and equipment trouble, Trial1: 10, 18, 19, 18, and 19, Tria2: 30, 18, 19, 18, and 19 individuals participated in the BL VFD, VGLate, VGEarly, and AB groups, respectively.

Time to Find the Obstacles

A survival analysis was performed using the Kaplan–Meier method. Accordingly, we analyzed the situation where a red car appeared from the right and another car came from the opposite side.

Kaplan–Meier survival analysis estimates the proportion of drivers finding obstacles under a condition.

1) The red car that appeared from the right

An overall comparison of survival curves using the log-rank test showed that the effect of the experimental conditions was significant ($p<0.001$). Further, results revealed that drivers had a fast response at BL, and the estimated survival proportion was 1. None of the AB group survived the scenario.

Table 3. Number of accidents in Trial 1.

Group / Categories	BL	VFD	VGLate	VGEarly*	AB
Traffic signals	0/50 (0%)	6/90* (6.7%)	0/90* (0%)	0/90* (0%)	0/95 (0%)
Oncoming right-turning cars	0/20 (0%)	20/36* (55.6%)	16/36* (44.4%)	11/36* (30.6%)	22/38 (57.9%)
Objects that appear from the driver's right side	0/30 (0%)	38/54* (70.4%)	16/54* (29.7%)	11/54* (20.4%)	0/57 (0%)
Objects that appear from the driver's left side	4/49 (8.2%)	64/90* (71.1%)	46/90* (51.1%)	33/90* (36.7%)	51/95 (53.7%)

*Cases of equipment trouble and participant status; date were excluded from the tally.

Table 4. Number of accidents in Trial 2.

Group / Categories	BL	VFD	VGLate	VGEarly	AB
Traffic signals	5/174 (2.9%)	8/108* (7.4%)	0/114 (0%)	0/108* (0%)	1/114 (0.8%)
Oncoming right-turning cars	1/58 (1.7%)	12/36* (33.3%)	10/38 (26.3%)	7/36* (19.4%)	15/38 (39.4%)
Objects that appear from the driver's right side	0/87 (0%)	43/54* (79.6%)	18/57 (31.6%)	9/54* (16.7%)	0/57 (0%)
Objects that appear from the driver's left side	1/87 (8.2%)	28/54* (46.3%)	14/57 (24.6%)	5/54* (9.26%)	14/57 (24.6%)

*Cases of equipment trouble and participant status, date were excluded from the tally.

2) Oncoming right-turning cars

An overall comparison of survival curves using the log rank test revealed that the effect of the experimental conditions was significant (p<0.05). Further, results showed that drivers had a fast response at BL, and the estimated survival proportion was 1.

DISCUSSION

The main objective of this study was to investigate the effectiveness of different types of assistance systems. We simulated VFDs so that participants were not limited to individuals with true visual field impairment. Further, to investigate the effects of different driving support systems, we established three conditions: VGEarly, VGLate, and AB. Control with the group without any support (VFD). Compared these designs with driving devices without vision defects (BL). We counted the incidence of accidents under different conditions. We found that both audio guidance and automatic braking effectively reduce the number of accidents. In front of the driving field of vision,

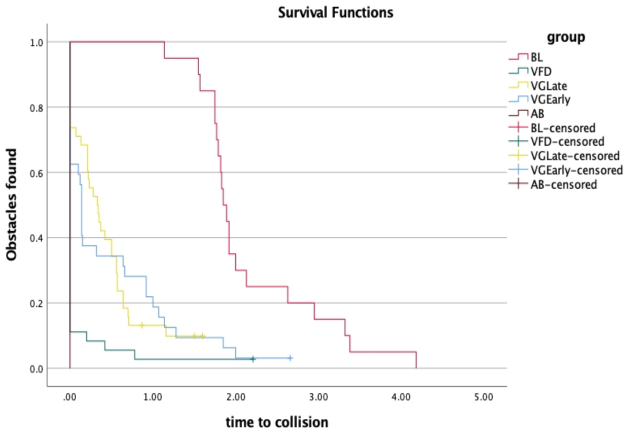

Figure 4: Estimation using Kaplan–Meier survival analysis of the proportion of drivers who found obstacles.

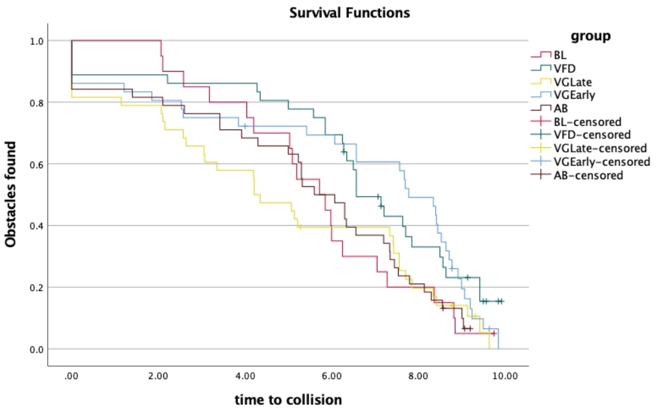

Figure 5: Estimation using Kaplan–Meier survival analysis of the proportion of drivers who found obstacles.

accidents are less likely to occur, even with advanced VFD can be timely detection of red lights, traffic signs, and other signals. In both Trial 1 and Trial 2 (Tables 3 and 4), the VGEarly group showed the lowest accident rates. This may indicate that early alerts can help avoid accidents in patients with VFD. Interestingly, we found that drivers with VFD could not respond immediately even after hearing an audio alert. There is usually a delay of approximately 2 s between hearing the alert and responding to it. For example, in Fig. 4, for the VGEarly group, the TTC when the group first finds the obstacle is approximately 2 s; however, the audio alert TTC is 4 s. If the audio alert is too late, the driver will not be able to react in time; in this case, even if the obstacle is confirmed, there is no chance of avoiding a crash, which can be derived from the slope of VGEarly and VGEarly groups in Fig. 4 and Tables 3 and 4.

The current study has some limitations. First, it only analyzed accident rates; future studies should consider more diverse aspects, such as assistance systems and drivers' traffic cognizance. Second, to study the situation in special scenarios, this study does not fit real life, and future research should invest more effort in system development.

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