Design for Simulator Performance Evaluations of Driving with Vision Impairments and Visual Aids

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Driving simulator technology provides a safe method for evaluating the impact of vision loss on different components of the driving task and the potential efficacy of visual aids intended to compensate for a particular type of vision loss. Most previous investigations have used general driving scenarios. It is proposed here that scenarios with different task requirements be designed specifically to address the condition under investigation. As an example, the design of driving scenarios and tasks that are specific for the evaluation of one type of visual field loss, homonymous hemianopia, is described. Results of pilot studies show that even with a small sample size, the design is sufficiently sensitive to differentiate individuals with hemianopic visual field loss from control drivers. These results suggest that careful design of test situations, measurements, and analyses provides a strong basis for investigations of driving performance of individuals with specific types of vision impairment and could be used to evaluate the efficacy of low-vision driving aids.

The aging of the population will result in an increasing number of drivers with declining visual abilities due to age-related eye disorders (e.g., macular degeneration, glaucoma, and cataracts) or vision loss from other systemic disease (e.g., stroke and diabetes). Vision and driver rehabilitation specialists need testing strategies to evaluate driving abilities of people with various types of vision loss driving with and without visual aids.

Driving instructors commonly evaluate the driving fitness of individuals who have various impairments by using on-road courses. On-road testing, although clearly important as a final step before certifying someone as fit to drive, is constrained by safety and thus may not be sufficiently sensitive to evaluate the efficacy of visual aids (devices). However, safety considerations do not constrain the design or difficulty of test protocols that use driving simulators. Rather, driving scenarios can be tailored (*a*) to test particular situations that are expected to be difficult for individuals with specific types of visual loss and (*b*) to evaluate the effect of a device on performance in these situations.

Eye diseases produce a loss in the central visual field, the peripheral visual field, or both; devices are designed to compensate for a particular type of visual loss. With central field loss, such as that resulting from macular degeneration, resolution is reduced, whereas the peripheral visual field remains unaffected. With peripheral visual field loss, the high-resolution central visual field remains intact, but awareness of objects in the blind area of the peripheral field is reduced. For such individuals, a device that compensates for missing portions of the field might be helpful. This field expansion can be achieved either by minification (*1*) or by field enhancement at normal magnification (*2*).

PURPOSE

The development of simulator driving scenarios and analysis tools is described; these scenarios and tools are designed to measure the effectiveness of a novel field-expanding device [peripheral prism spectacles (*2*)] for individuals with one type of peripheral field loss, homonymous hemianopia. Although the field expansion device may improve one function (i.e., detection of objects in the areas of field loss), it may impair another (e.g., steering stability). These scenario designs and data analysis methodologies aim to address such questions directly and specifically rather then testing subjects on generic test drives with generic analysis tools, as has been the case in previous studies (see literature review section).

HOMONYMOUS HEMIANOPIA

Homonymous hemianopia, the loss of half the visual field on one side in both eyes (Figure 1*a*), occurs as a result of brain damage from stroke, trauma, or tumors. In the United States there were almost 5 million stroke survivors in 2002 (*3*), and as many as one-third in rehabilitation have either homonymous hemianopia or hemi-neglect (*4*).

In 22 states (*5*), driving is prohibited for people with hemianopia; in many other states, they are discouraged from driving even when the laws do not prohibit them from driving. A driving ban imposes significant restrictions on lifestyle, mobility, and independence. Many hemianopes retain good visual acuity equal to or better than that required for licensure; therefore the main challenge facing hemianopes who wish to drive is the hemianopic field defect. With the exception of one pilot study (*6*), little attention has been paid to the question of whether hemianopes could use field-expanding devices to improve object detection on their blind side during driving and hence improve their driving performance and safety.

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Transportation Research Record: Journal of the Transportation Research Board, No. 1937, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 128–135.

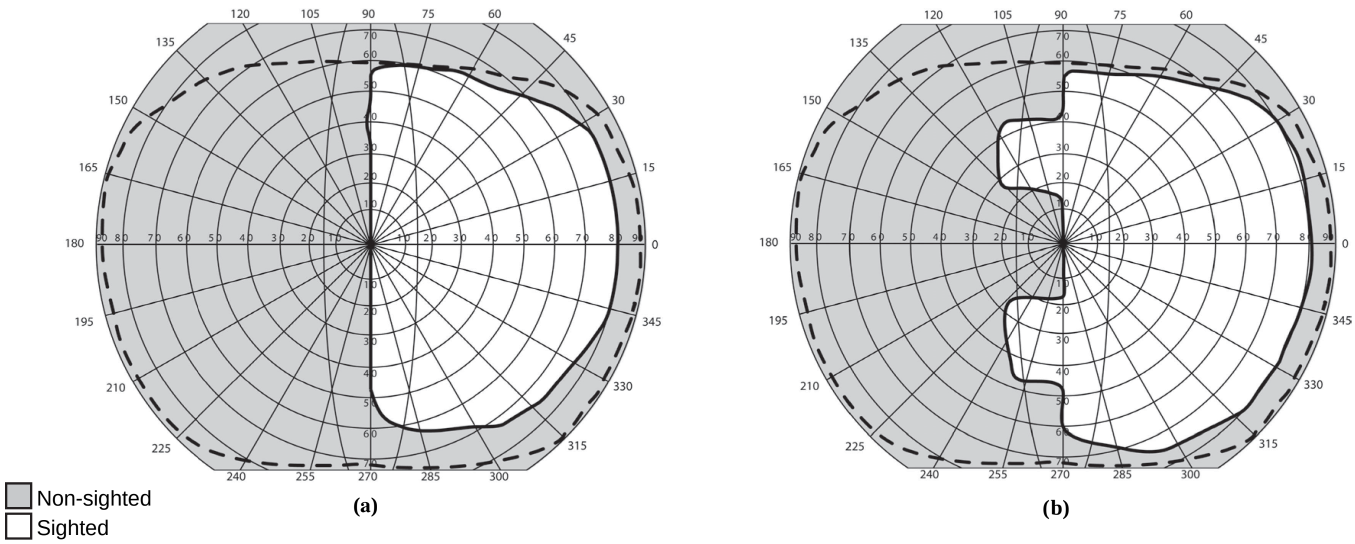


FIGURE 1 Hemianopia (dashed lines represent extent of normal binocular field): (*a*) binocular field of patient with left hemianopia showing complete loss on left (gray shading) and essentially normal field to right of fixation (fovea) when fixating on target at center of field and (*b*) binocular field of same patient with peripheral prisms; two areas of about 20 degrees by 20 degrees of field expansion extending leftward from vertical midline.

LITERATURE REVIEW: SIMULATOR EVALUATIONS OF DRIVING WITH VISUAL FIELD LOSS

One simulator study (*7*) found that peripheral field loss, as defined by perimetric measurements (measurements of the extent of the visual field), impairs the ability to detect and react rapidly to targets presented within the forward 20-degree vertical by 120-degree horizontal region of the simulator's visual display. These findings are not surprising, since the subjects (who were driving at 100 km/h on a narrow road) were most likely staring straight ahead at the center of the simulator display, just as they would do while maintaining their gaze on the central target during perimetry. Furthermore, the targets were fixed on the simulator display in the vehicle coordinates, as they would be if presented in a perimeter. In contrast, during on-road driving, drivers should respond to peripheral targets that appear at different eccentricities and then increase in both size and eccentricity as the driver approaches them. Targets that appear and do not change in size and eccentricity would be perceived as moving with the vehicle, not separately from it.

The importance of using realistic targets is reinforced by the results of recent simulator investigations (*8, 9*) of the useful visual field of normally sighted drivers. Changes to the useful field of view as a function of the state of vigilance of the driver were dependent on the type of peripheral target to be detected: when lights were fixed on the simulator display, tunnel vision resulted (the useful field of view shrank) (*8*), but when the peripheral targets were the rear lights of other vehicles in the traffic flow, detection performance deteriorated equally across all areas of the field as drowsiness increased (*9*).

Investigations of driving simulator performance in individuals with different types and amounts of visual field loss were reported by Szlyk et al. (*10–12*) and Coeckelbergh et al. (*13*). These studies have many features in common, including measurements of mechanical variables that might be affected by vision impairments. However, they also differ in a number of details, such as the length of the simulator test drives [5 min for Szlyk et al. (*10, 11*) versus 30 min for Coeckelbergh et al. (*13*)] and the number of challenges to drivers with specific types of impairment. One limitation of the methodology of Szlyk et al. was that the reaction time measure appears to be based on a single presentation of a stop sign. Furthermore, the stop sign initially appears along a roadway on a curve and at an initial eccentricity of 30 degrees. This eccentricity, although potentially useful for testing patients with peripheral field loss, would not provide as useful a measure for those with central field loss, since their field would be relatively normal at this eccentricity.

To the best of the authors' knowledge, these investigators have used the same driving scenarios to test driving performance in individuals with central and peripheral field loss, which may have led to conflicting results. Szlyk et al. (*12*) reported that individuals with either peripheral or central field defects were equally likely to make lane boundary crossings and that both groups made more errors than normally sighted control subjects did. Coeckelbergh et al. (*13*), however, found that patients with central visual field loss had a more stable lane position and made fewer boundary crossings than those with peripheral field defects. The extent to which such conflicts are due to methodological differences (length of drive, number of challenges presented, and scoring methods) is unclear. The lane boundary crossing measure of Szlyk et al. (*10–12*) and the standard deviation of lane position of Coeckelbergh et al. (*13*), for example, appear to be a single number representing performance across all segments of the test drive (straightaways, right and left curved sections, and 90-degree turns at intersections). However, since the contribution of vision, as opposed to other factors, to performance on each of these roadway segments may be different, it seems appropriate to score them separately. (It should be noted that Coeckelbergh et al. did compute average lane position separately for right and left curves.) A more detailed explanation of this reasoning appears later in the outcome measures subsection.

TABLE 1 Details of Five Scenario Types

Scenario Type	Posted Speed	Location	Scripted Traffic	Attention Getters	Intersection Pedestrian Targets	Other Features
Low-Speed 1	30 mph	City	No	No	No	
Low-Speed 2	30 mph	City	Yes	Yes	Yes	
Low-Speed 3	30 mph	City	Yes	Yes	Yes	Subject asked to follow a second vehicle.
Low-Speed 4	30 mph	City	Yes	Yes	Yes	Subject had to pass a stationary vehicle parked in the driving lane.
High-Speed	60 mph	Rural	Yes	No	No	Route includes long curves.

METHODS

Development of Scenarios

Overview

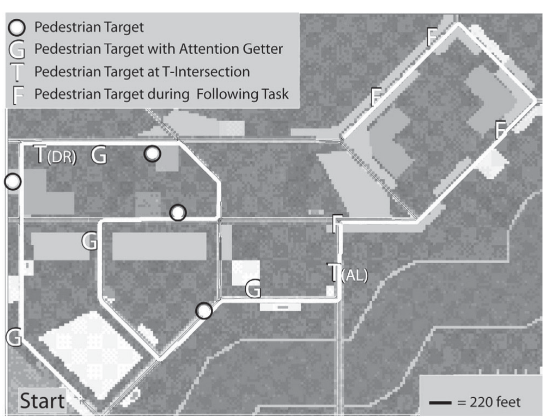
Scenarios were designed in order to better understand and evaluate the impact of hemianopic visual field loss and scanning eye movements on driving, both with and without field-expanding peripheral prism spectacles (*2*). Four test drives were planned for the study: one drive for each of two types of peripheral prism lens designs and two drives without prisms, to control for practice effects. Four versions of each of five scenario types were therefore developed to provide a variety of driving situations.

Drivers with hemianopia have a binocular visual field loss on the right or the left (Figure 1*a*) and may miss driving-relevant objects on that side. Scenarios were designed to evaluate the detection of pedestrian targets who would suddenly appear to either the right or the left of the road. Two different eccentricities (4 and 14 degrees from the driver's presumed line of sight) were included. These two eccentricities permit probing of the effect of the field-expanding prisms (shown in Figure 1*b*) and are similar to the range that would be illuminated by automobile headlamps. A unique aspect of this scenario design was the inclusion of pedestrian targets placed at certain locations near intersections to present specific challenges to hemianopic drivers.

Scenario Specifics

A scenario consisted of a drive along a predetermined route within the virtual environment with scripted events that occurred contingent on the position of the subject's car along the route. Five scenario types (Table 1) were designed to provide a range of driving situations and driving difficulty: four at low speed [30 mph (48 km/h)] on city streets and one at high speed [60 mph (96 km/h)] on curved rural roads. All but one scenario type (Low-Speed 1) included other scripted traffic. The traffic density was approximately one vehicle every 30 s, with vehicles programmed to proceed when the participant's car reached a predetermined location. Scenario lengths—15,000 ft (4,570 m) for low speed and 30,000 ft (9,100 m) for high speed—were chosen so that each route would take approximately 6 min. Each version of each scenario type followed a different route (Figure 2*a*). Scenarios contained an approximately equal number of left and right turns as well as left and right curves.

Scenarios were scripted by using an authoring tool, the Scenario Toolbox (Version 1.3), and implemented on a PP-1000-X5 driving simulator (FAAC, Inc., Ann Arbor, Michigan). The authoring software



(a)

(b)

FIGURE 2 Scenario details: (*a*) typical route for city-driving scenario (view from above as provided by development tool) with locations of pedestrian targets marked (white circle, G, T, F); intersection pedestrians at D_R and A_L (as defined in Figure 3); and (*b*) example of AG setup as previewed from driver's perspective with scenario development toolkit software.

was used to add the necessary objects (e.g., pedestrians, other moving vehicles, special-purpose signs and barriers) and auditory cues, which provided the driver with instructions (e.g., "Turn right at next intersection"). Scenarios were scripted within a general-purpose world provided with the simulator that contained a mix of urban, suburban, and rural (high-speed) roadways, along with buildings, other static objects, and vegetation. The world was 50 mi^2 (130 km^2), with the urban region covering 4.4 mi^2 (11.4 km^2).

The pedestrian target used throughout the study was a static model of a man in a white shirt and blue pants (Figure 2*b, white oval*). The time between successive pedestrian appearances was varied pseudorandomly and ranged from 10 s to 50 s. There were 12 regular pedestrian targets in each of the five scenario types, balanced left and right, with three targets appearing at each eccentricity (4 degrees and 14 degrees). The target pedestrians were scripted to appear suddenly when the subject was at 220 ft or 440 ft (for low- and high-speed scenarios, respectively) from the appearance location and to disappear once the car had passed that location. The driving maneuver of the bus around obstacles in the road should attract the subject's gaze at the time of pedestrian appearance. The pedestrian in Figure 2*b* appears about 14 degrees to the right of the space between the bus and barrel.

In addition, there were five intersection pedestrian targets per scenario set, which were only included in the three low-speed scenarios with traffic. Four placement locations were used (Figure 3), one of which was used twice—once for a left turn and once for a right turn. These pedestrians were programmed to appear when the car was 17.5 ft (5.3 m) from the white stop line. The four locations represent areas that could provide critical information about potential road hazards (Figure 3). To encourage subjects to look both ways, these intersections were scripted to have clearly visible cross traffic as the subject approached the stop sign.

In Figure 3, the two diagonal straight thin lines represent directions of gaze that a driver may take before making a right or left turn. Objects at Location A (on the left) might be expected to be missed by a left hemianope (but would be seen by a right hemianope) when making a left turn (A_L) and a right turn (A_G); objects at Locations B_L and C_L might be missed by both left and right hemianopes when making a left turn; objects at Location D_B might be missed by a right hemianope (but would be seen by a left hemianope) making a right turn. Objects in the direction of A and D are a threat to a right-turning vehicle. Objects at A, C, and B are a threat to a left-turning vehicle.

Determining Eccentricity of Pedestrian Target

In most cases, eccentricity was calculated relative to the car's heading, since this was assumed to be the predominant direction of the driver's gaze. Although this assumption might be reasonable when one is driving straight down a narrow road at high speed (*7*), it may not be reasonable when driving under slower, less demanding conditions. If fixation is constrained to a specific place, the results of the detection evaluation should not be significantly different from the results of simple perimetry, as reported by Lovsund et al. (*7*).

The point of gaze at any time during a low-speed city drive is not known with high confidence and frequently would not be straight down the road. Nonetheless, most pedestrian targets (44 out of 65 in every scenario set) were placed at eccentricities relative to the vehicle's heading. Scanning eye movements may enable hemianopes to detect targets on the affected side in such a scenario, but one would expect even better performance with the prism devices if they expand the field effectively. To better determine if detection of targets is due to scanning behavior or due to the field-expanding peripheral prisms, objects were introduced in each set of test drives (with traffic at low speed) that were designed to attract the driver's attention, for example, a police car with flashing lights or an unusual maneuver of a vehicle ahead (Figure 2*b*, bus driving around obstacles in the road). It was assumed that the driver would fixate on these attention-getters (AGs) when they appeared, thereby enabling assessment of the effect of the hemianopia and the prisms on pedestrian detection with more confidence. In these cases, pedestrian eccentricities were computed relative to the line of sight to the location of the AGs, which were programmed to appear 1 to 2 s before the pedestrian appeared. Sixteen of the 65 pedestrian locations in each scenario set were positioned relative to these AGs.

Fixation location can also be anticipated with reasonable probability on curved road segments, since drivers usually fixate on the tangent to the curve of the inside driving lane boundary (*14, 15*). Pedestrian appearance placements and eccentricities were therefore calculated with respect to this presumed fixation point on the curved sections of the high-speed scenarios (four pedestrians per scenario, one at each combination of side and eccentricity).

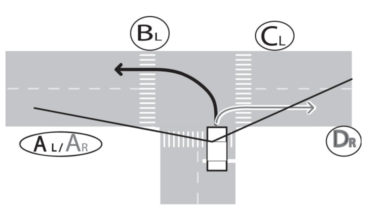


FIGURE 3 Pedestrian placements (A to D) at intersections to assess effect of hemianopia on detection of traffic-relevant objects while driver is planning right (R) or left (L) turn.

Pilot Testing of Scenarios

To evaluate the scenarios, two pilot studies were conducted during the development phase. The purpose of these studies was to determine whether the outcome measures were sensitive to differences in detection performance on the blind side and the seeing side. Unless such differences could be demonstrated, the scenarios could not measure a positive (or negative) effect of the visual aid (namely, the peripheral prism spectacles). The first pilot study was performed in the early stages of the development process with a preliminary set of four scenarios. These early scenarios contained only 10 pedestrians each, no intersection pedestrian targets, and an unbalanced distribution of right and left targets at near and far eccentricities. A second pilot study was subsequently carried out with sets of five scenarios that conformed in every respect to the final design criteria described earlier. These two initial pilot studies were conducted with subjects driving without the peripheral prism spectacles.

Pilot Subjects

In the first pilot study, two experienced drivers with left hemianopia (both had visual fields similar to those in Figure 1*a*) and three normally sighted drivers were tested. In the second pilot study, one individual (currently driving) with a lower-left partial quadranopia (Figure 4) and

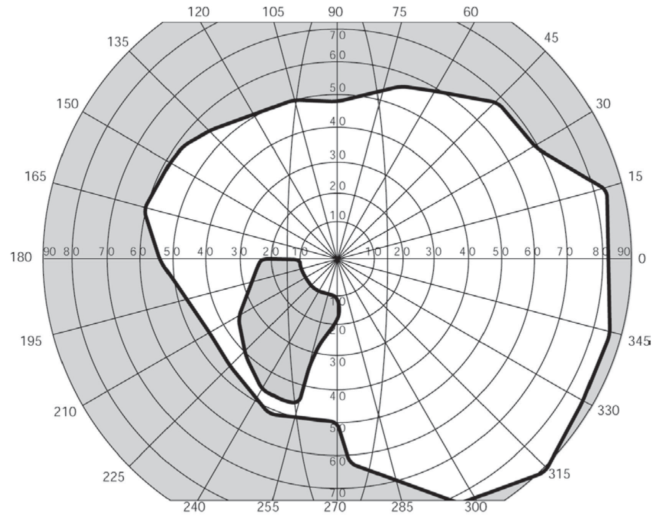


FIGURE 4 Binocular visual field plot for subject with lower-left partial quadranopia resulting from surgical procedure.

two normally sighted drivers participated. Institutional review boards at all of the participating institutions approved the study protocol, and informed consent was obtained from all subjects.

Simulator

The PP-1000-X5 simulator's driving console consists of a seat mounted on a motion platform with 3 degrees of freedom, a force-feedback steering wheel, automatic transmission, and a generic panel of working analog and digital gauges. The simulator recorded input from hardware (e.g., the horn button or brake pedal) and software (e.g., coordinates of the driver or target stimulus) at 30 Hz. Five 29-in. (73-cm) diagonal XGA resolution (1024×768) monitors, refreshing at 60 Hz, provided a 225-degree horizontal by 32-degree vertical field of the virtual environment with the driver sitting approximately 29 in. from the central monitor. The simulator also provided inset displays for the rearview and side view mirrors and a head-up display at the bottom of the center screen that showed vehicle speed.

Procedures

Before beginning the test drive, subjects were acclimated to the simulator by driving in successive situations that increasingly approached the setup of the actual experiment. Once the participant decided that he or she was both comfortable in the virtual environment and capable of controlling the vehicle in that environment, he or she was introduced to the actual experimental task (i.e., the detection of pedestrian targets) through the use of a scripted introductory drive that included example target stimuli presented in a manner identical to the actual task, as well as presentation of audio cues to direct the subject's navigation through the virtual environment. The acclimatization to the driving simulator and the introductory drive took between 15 and 30 min to complete and were not included in data analyses. After completing the introductory drive, subjects then drove through each of the test scenarios in random order.

Outcome Measures

The primary outcome measures for the pedestrian target detection task were percentage of targets seen and reaction time, calculated from a horn-press as soon as a target was detected. A pedestrian was counted as not seen if a horn-press was not detected within a window of 10 s after the time of appearance.

Two measures of steering stability—mean and variability (standard deviation) of vehicle lateral offset from the center of the driving lane—were included as secondary measures of driving performance. Although the impact of certain drugs on steering ability and stability is well known (*16*), the impact of different types of vision loss on steering is not. The steering of various simulators may be quite different from the steering of a car. Even with a force-feedback steering system, most drivers would initially face significant difficulty, particularly on right turns but also on left turns. Though performance improves with training, it remains impaired. These mechanical control issues, unique to the simulator, might have a larger impact on steering in turns than any visual impairment. Nevertheless, vision impairment and field loss in particular might have a further effect on steering behavior. Further, visual aids that improve some function could potentially interfere with steering performance. Therefore, the analysis of steering was evaluated separately for straight road segments, curved road segments, right turns, and left turns.

RESULTS OF PILOT STUDIES

The results of the pilot studies shown here are not meant to represent the performance of the hemianopic population but rather to illustrate the sensitivity afforded by the scenarios and analysis method under development for the planned study of hemianopic driving with and without the peripheral prism spectacles.

First Pilot Study

Pedestrian target detection and reaction times were analyzed for the four scenarios (all at low speed) included in the first pilot study. For targets on the left, there were 13 to 16 presentations for controls, 20 for Left Hemianope 1 and 18 for Left Hemianope 2. For targets on the right, there were 16 to 23 presentations for controls, 20 for Left Hemianope 1 and 21 for Left Hemianope 2.

There were clear differences in detection performance between subjects with hemianopia and the normally sighted controls (Figure 5). Subjects with hemianopia saw only about 40% of targets on their left (blind) side, whereas control drivers saw all targets (comparison of two proportions; null hypothesis proportions are identical; $z = -5.9$, $p < 0.001$; Figure 5*a*). There was also a small but statistically significant difference in the proportion of targets seen on the right: hemianopic subjects saw on average 93% of targets, whereas controls saw all targets ($z = -2.11$, $p = 0.02$). One of the two hemianopic subjects missed three of 21 pedestrians on the right. Although this latter difference may be a chance occurrence, it may also represent a real effect, resulting perhaps from this person's efforts to compensate for the visual loss on the left.

A two-factor ANOVA was used to investigate the effect of visual field loss (control versus hemianope) and target side (left versus right) on reaction times. Both factors had highly significant effects (Figure 5*b*). Subjects with hemianopia, on average, had longer mean reaction times [$F(1, 155) = 41.3$, $p = 0.001$] and their reaction times were longer for targets presented on the left (blind) side than on the

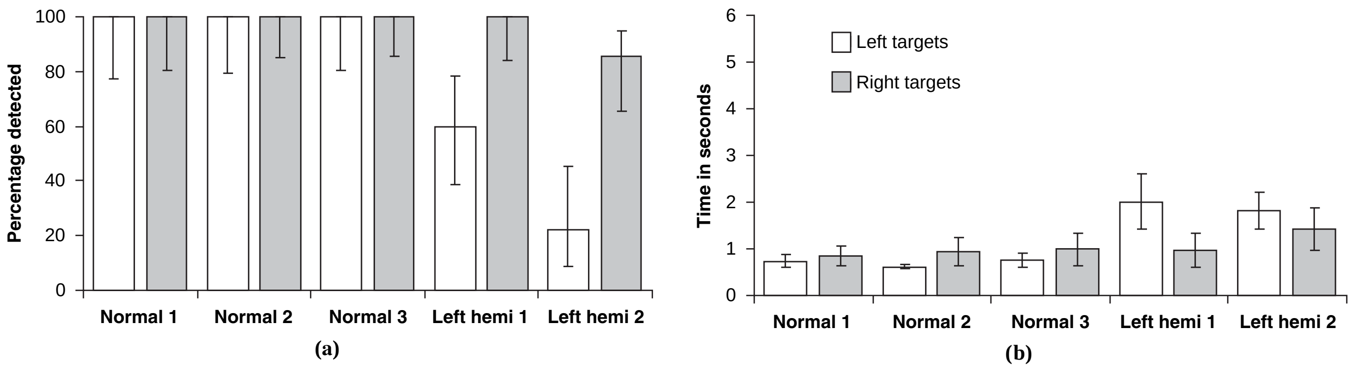


FIGURE 5 First pilot study results by subject and target side: (a) detection performance (percentage of targets seen) and (b) mean reaction times. (Error bars represent 95% confidence limits.)

right side [F (1, 155) = 8.1, p = 0.005]. In addition, there was a significant interaction between field loss and target side [F (1, 155) = 21.1, p = 0.001], with the difference between reaction times to targets on the left versus right sides significantly greater for the drivers with hemianopia. Overall, these results for the first pilot study confirmed that even with a small sample size, the scenarios and simulator task were sensitive enough to distinguish individuals with left hemianopia from control subjects.

Second Pilot Study

The second pilot study included four low-speed scenarios and one high-speed scenario. For the low-speed scenarios there were a total of 23 to 25 target presentations on the left and on the right. For the high-speed scenarios there were 5 to 7 presentations on the left and on the right.

In the low-speed scenarios, all three subjects (including the subject with left quadranopia) correctly detected all pedestrians on both the left and the right. However, in the high-speed scenario, there was a significant difference in detection performance between the quadranopic driver and controls. Specifically, the person with left quadranopia saw only 64% of all targets, whereas the controls saw 95% of all targets (z = –2.25, p = 0.01). The difference in the percentage of targets seen on the left side was significant (50% versus 100%, z = –2.42, p = 0.008), but there was no difference in the percentage of targets seen on the right side (71% versus 90%, z = –1.01, p = 0.16).

Reaction time results (Figure 6) were analyzed by using a three-factor ANOVA: visual field loss (control versus hemianope), target side (left versus right), and speed (low versus high). The effects of visual field loss [F (1, 166) = 53.8, p = 0.0001], target side [F (1, 166) = 11.2, p = 0.001], and speed [F (1, 166) = 4.9, p = 0.029] were all significant. Overall, the individual with left quadranopia took longer to respond than did the controls, and response times were somewhat longer to targets presented on the left and in the high-speed scenario. The interaction of visual field with side was also significant [F (1, 166) = 9.0, p = 0.003], indicating that the subject with left quadranopia took longer to react to targets on the left side. None of the remaining interactions were significant.

Intersection pedestrian targets were added to the scenarios used in the second pilot experiment. One control driver detected all five of these pedestrians, and the other control detected all but one. The left quadranopic driver missed two of the pedestrians at locations predicted to be difficult for a person with left-side field loss (see Table 2 and Figure 3). These results are for a single presentation of each pedestrian and the individual with field loss had only a mild defect, so conclusions cannot be drawn until further pilot testing is conducted using people with complete hemianopic field loss.

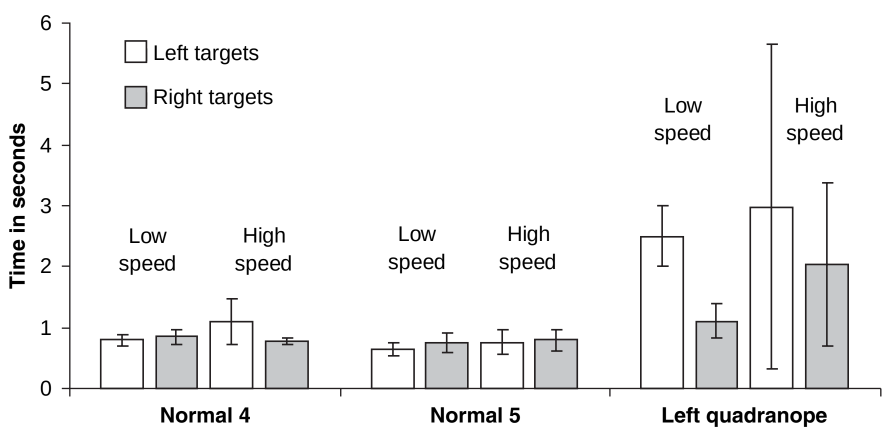


FIGURE 6 Mean reaction times obtained in four low-speed scenarios and one high-speed scenario for second pilot study. (Error bars represent 95% confidence limits.)

TABLE 2 Detection of Intersection Pedestrian Targets Compared with Predictions

	Pedestrian Location (as defined in Fig. 3)				
	A_R Right Turn	A_L Left Turn	B_L Left Turn	C_L Left Turn	D_R Right Turn
Control 4	Missed	Detected	Detected	Detected	Detected
Control 5	Detected	Detected	Detected	Detected	Detected
Left quadranope	Detected	Missed	Missed	Detected	Detected
Prediction Pedestrian missed by	Left hemianope	Left hemianope	Left & right hemianope	Left & right hemianope	Right hemianope

In the second pilot experiment, secondary measures of vehicle steering—mean lane offset and mean lane offset variability—were examined. There were 11 samples per subject for straight segments and 6 to 8 per subject for turns.

Figure 7*a* and *b* show the three subjects' performance on straight roadway segments and on segments requiring 90-degree turns both to the left and to the right. For mean lane offset, effects of segment type [F (2,65) = 16.1, p < 0.0005] and subject [F (2,65) = 8.7, p < 0.0005] were significant. From Figure 7*a*, it is clear that there were considerable individual differences, even among the control subjects. As expected, mean lane offset depended on road segment type, with greater offsets on turns. The roadway segment type by subject interaction was significant [F (4,65) = 2.77, p = 0.034]. For lane offset variability (Figure 7*b*), the effect of roadway segment type was significant [F (2,65) = 13.5, p < 0.0005]; variability in lane offset was greater for turns than for straight segments for all subjects. The effects of subject [F (2,65) = 0.013, p = 0.99] and the subject by roadway type interaction [F (4,65) = 0.48, p = 0.75] were not significant.

DISCUSSION OF RESULTS

Designing and deploying customized simulator scenarios for testing driver functionality is a lengthy and expensive process. The authors estimate that they have invested at least 4 person-years in this project so far. Considering these high development costs, it would be desirable to have a universal test scenario that could assess fitness to drive for any condition. Such an ideal test would make it possible to determine an individual's fitness to drive with any vision or other physical disability, mild cognitive impairment, or disorder requiring the use of possibly function-impairing medications. Such a test would also be useful in assessing the effect of in-vehicle information systems on driving performance and in answering many other questions about driving and driving safety. However, to date no such test scenario (and accompanying data analysis system) has been developed or even proposed. In fact, much effort has been invested recently by the European Community just in the design of methodological guidelines for the development of simulator scenarios for the assessment of in-vehicle information systems (*17*). Similarly, the authors believe that assessment of driving difficulties for people with visual impairments and effects of visual aids on driving performance must be tested in scenarios specifically designed to measure relevant effects. Describing their first effort in designing such a study is the purpose of this paper.

The pilot studies reported here were meant to address neither questions concerning the efficacy of the field-expanding prism spectacles for driving with hemianopia nor the safety of driving unaided. The pilot results were only presented to illustrate that scenarios designed in such a way have the advantage of being sensitive to the question at hand and stand a much better chance of answering such critical questions than any universal test scenario. The pilot results indicate that it is possible to design scenarios that, even with relatively small samples, can clearly differentiate subjects with normal and hemianopic visual fields and show differences in detection performance related to the degree of field loss.

In assessing particular effects of specific vision loss, one should not lose sight of all the other components of the driving task. It is impor-

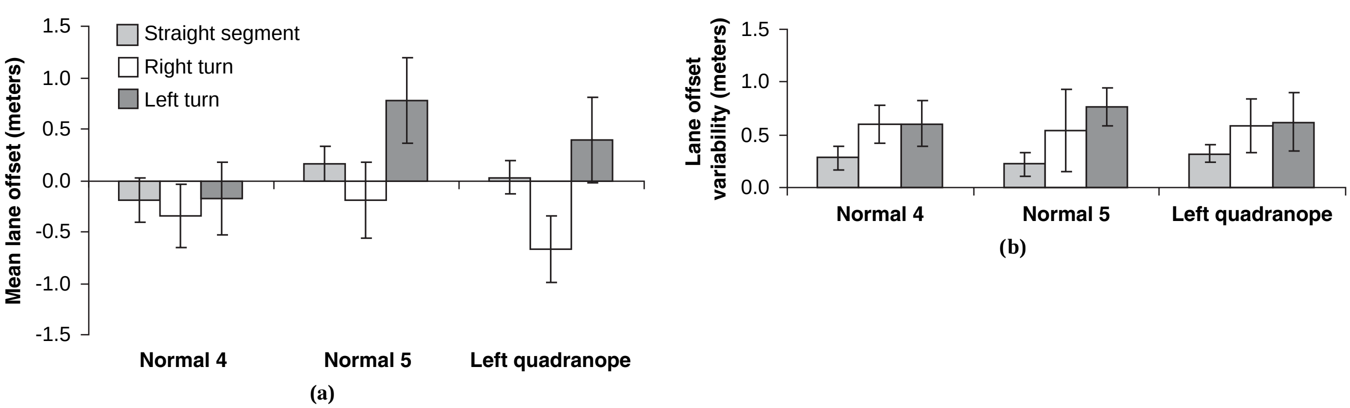


FIGURE 7 Second pilot experiment results by subject and roadway segment type for all scenarios: (*a*) mean lane offset from center of driving lane and (*b*) lane offset variability (standard deviation of lane offset). (Error bars represent 95% confidence limits.)

tant to determine that the subject is performing reasonably on the basic driving task while being tested for the specific effects of his or her impairment or visual aid. Thus, general driving performance measures such as those related to steering stability or maintenance of proper speed and following distance should be incorporated. However, there is room for specific considerations of the condition or devices being evaluated even when these variables are analyzed. Earlier studies of simulator driving by patients with vision loss measured such variables, some of which might be dependent on vision loss, for example, lane boundary crossings and lane position variability (*10, 12, 13*). The authors have suggested, and these pilot results support the idea, that it is important to account for roadway geometry and potential simulator issues (e.g., steering limitations) in the analysis of such measures. In this study, the left quadranope and control subjects showed similar patterns of behavior across roadway segment types, with lane offset variability being largest for turns and smallest for the straight road segments. This finding suggests that analysis of steering control that addresses different maneuvers separately is important.

CONCLUSIONS

The results of these pilot studies demonstrate that scenarios and analysis methods have been designed for simulator driving that are sensitive to differences in performance between subjects with normal and hemianopic visual fields and can be used to address specific questions related to this type of vision impairment. The scenarios will provide functionally relevant tests of the potential of peripheral prism spectacles to be used as driving aids by people with hemianopia.

ACKNOWLEDGMENTS

The research was supported in part by the National Institutes of Health. This project was carried out in collaboration with Joseph Rizzo of the Center for Innovative Visual Rehabilitation at the Boston Veterans Administration Hospital. The authors thank S. Lerner of the Schepens Eye Research Institute and D. Cades and V. Ciaccio of Lighthouse International for technical help.

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The Simulation and Measurement of Vehicle and Operator Performance Committee sponsored publication of this paper.