THE DESIGN OF DRIVING SIMULATOR PERFORMANCE EVALUATIONS FOR DRIVING WITH VISION IMPAIRMENTS AND VISUAL AIDS

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ABSTRACT
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 used general driving scenarios. We propose that scenarios with different task requirements should be designed specifically to address the condition under investigation. As an example, we describe the design of driving scenarios and tasks that are specific for the evaluation of one type of visual field loss, homonymous hemianopia. Results of pilot studies show that, even with a very 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, provide 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.

INTRODUCTION

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 driving fitness of individuals with various impairments using on-road courses. On-road testing, while 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 using 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 either 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, while 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

In this paper, we describe the development of simulator driving scenarios and analysis tools that 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. While 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). Our 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 below).

Homonymous Hemianopia

Homonymous hemianopia, the loss of half the visual field on one side in both eyes (Fig. 1a), occurs as a result of brain damage from stroke, trauma or tumors. The number of stroke survivors in the United States is estimated to be more than 4 million annually [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; while in many other states, they are discouraged from driving even when the laws do not prohibit 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 when driving and hence improve driving performance and safety.

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^o vertical × 120^o horizontal region of the simulator's visual display. These findings are not surprising, since the subjects (who were driving at 100 km/hr on a narrow road) were most likely staring straight ahead at the center of the simulator display, just as they would do while maintaining 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 (useful field of view shrank) [8], but when the peripheral targets were rear lights on 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 minutes for Szlyk et al. [10, 11] vs. 30 minutes for Coeckelbergh et al. [13]) and the number of "challenges" to drivers with specific types of impairment. One limitation of Szlyk et al.'s methodology 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^o. This eccentricity, while 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 our 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. Coeckelbergh et al., [13] however, found that patients with central visual field loss had 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. Szlyk et al.'s [10-12] lane boundary crossing measure and Coeckelbergh et al's [13] SD of lane position, for example, appear to be a single number representing performance across all segments of the test drive (straight-aways, right and left curved sections, and 90º turns at intersections). However, since the contribution of vision, as opposed to other factors, on performance on each of these roadway segments may be different, it seems appropriate to score them separately. (Note: Coeckelbergh et al. did compute average lane position separately for right and left curves). A more detailed explanation of our reasoning appears in the methods (*outcome measures*) section.

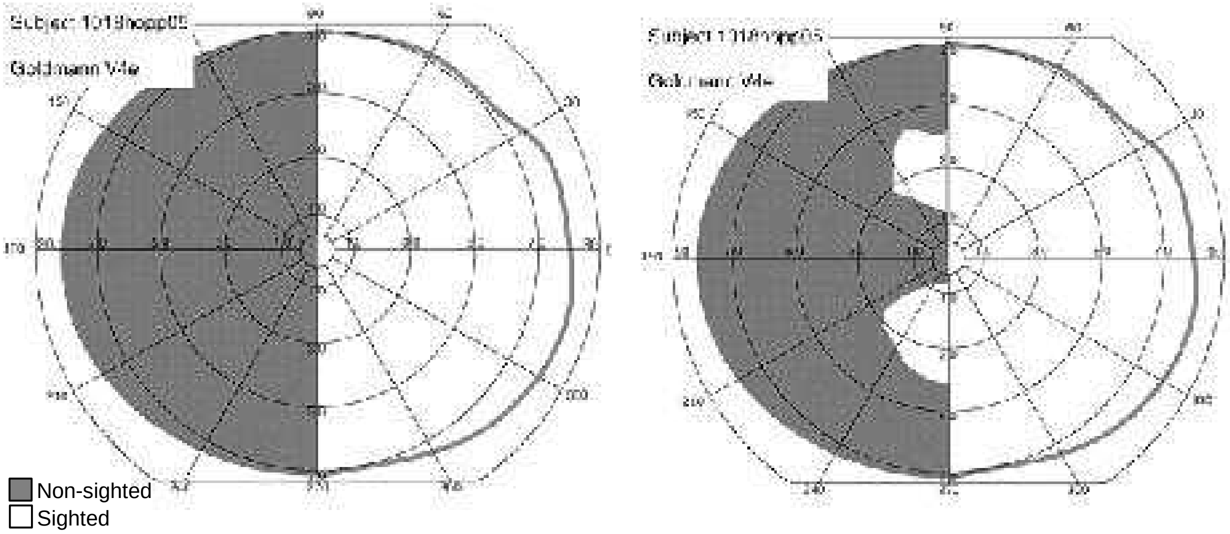
METHODS

a) 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 are 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 (Fig. 1a) and may miss driving-relevant objects on that side. Scenarios were designed to evaluate the detection of pedestrian targets that would suddenly appear to either the right or the left of the road. Two different eccentricities (4º and 14º 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 Fig. 1b) and is similar to the range that would be illuminated by automobile headlamps. A unique aspect of our scenario design was the inclusion of pedestrian targets, placed at certain locations near intersections to present specific challenges to hemianopic drivers.



(a) (b)

FIGURE 1 Hemianopia is a loss of half of the visual field on the same side in both eyes. (a) The binocular field of a patient with left hemianopia shows a complete loss on the left (gray shading) and a normal field to the right of fixation (fovea), when fixating on a target at the center of the field (0,0). (b) The binocular field of the same patient with the peripheral prisms. Two areas of about 20^o by 20^o of field expansion are seen.

Scenario Specifics

Scenarios were scripted using an authoring tool, the Scenario Toolbox (version 1.3), and implemented on a PP-1000-X5 driving simulator (FAAC, Inc., Ann Arbor, MI). The authoring software was used to add the necessary objects (e.g., pedestrians, other moving vehicles, special purpose signs and barriers, etc.) 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).

Five scenario types (Table 1) were designed to provide a range of driving situations and driving difficulty: 4 low-speed in city streets (30 mph (48 km/h)) and one high-speed on curved roads (60 mph (96 km/h)). All but one scenario type (low-speed 1) included other scripted traffic. The traffic density was approximately one vehicle every 30 seconds with vehicles programmed to proceed when the participant’s car reached a predetermined location. Scenario lengths (15,000 feet (4,570 m) for low-speed and 30,000 feet (9,100 m) for high-speed) were chosen so that each route would take approximately 6 minutes. Each version of each scenario type followed a different route (Fig. 2a). Scenarios contained an approximately equal number of left and right turns as well as left and right curves.

The pedestrian target used throughout the study was a static model of a male in white shirt and blue pants (Fig. 2b). The time between successive pedestrian appearances was varied pseudo-randomly and ranged from 10 to 50 seconds. There were 12 regular pedestrian targets in each of the five scenario types, balanced left and right, with 3 targets appearing at each eccentricity (4º and 14º). The target pedestrians were scripted to appear suddenly when the subject was at 220 feet or 440 feet (for low and high-speed scenarios, respectively) from the appearance location, and to disappear once the car had passed that location.

TABLE 1 Details of the 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	None
Low-speed 2	30 mph	City	Yes	Yes	Yes	None
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

(a) **(b)**

FIGURE 2 Scenario details. (a) A typical route for a city-driving scenario (view from above as provided by the development tool) with locations of pedestrian targets marked (filled white circle, "G", "T", "F"). Intersection pedestrians are at locations D_R and A_L (as defined in Fig. 3). (b) An example of an "attention getting" setup as previewed from the driver's perspective with the scenario development toolkit software. 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 appears about 14º to the right of the space between the bus and barrel.

In addition, there were 5 *intersection* pedestrian targets per scenario set, which were only included in the 3 low-speed scenarios with traffic. Four placement locations were used (Fig. 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 feet (5.3 m) from the white stop stripe. The four locations represent areas that could provide critical information about potential road hazards (Fig. 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.

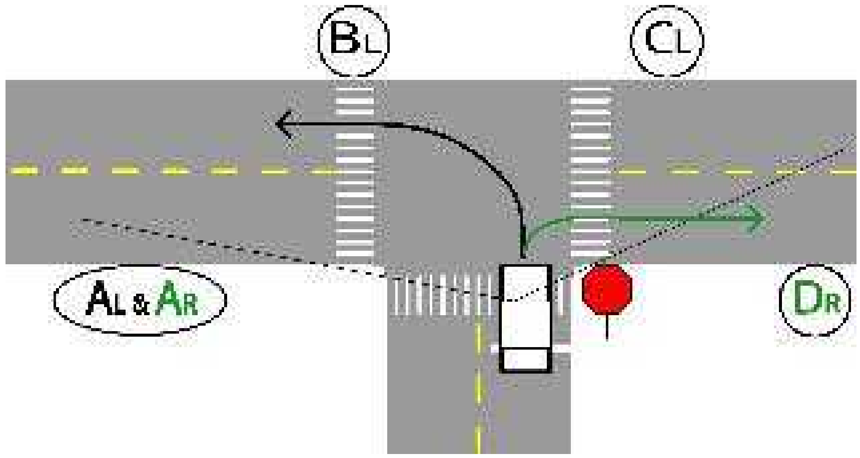


FIGURE 3 Pedestrian placements (A – D) at intersections to assess the effect of hemianopia on detection of traffic relevant objects while planning a (R) right or (L) left turn. The two diagonal straight thin lines represent directions of gaze that a driver may take before making a right turn or left turn. Objects at location A (on the left side) 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_R); objects at locations B_L and C_L might be missed by both left and right hemianopes when making a left turn; object at location D_R might be missed by a 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, as this was assumed to be the predominant direction of the driver's gaze. While this assumption might be reasonable when 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 occasionally 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, we introduced objects 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 a vehicle driven in an erratic fashion (Fig. 2b). We assume that the driver will fixate on these "attention getters" (AGs) when they appear, thereby enabling us to assess 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 1-2 seconds 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, as 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 (4 pedestrians per scenario, 1 at each side and eccentricity combination).

b) Pilot Testing of Scenarios

To evaluate the scenarios, 2 pilot studies were conducted during the development phase. The purpose of these studies was to determine whether or not the outcome measures were sensitive to differences in detection performance on the blind side and 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 4 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 using sets of 5 scenarios that conformed in every respect to the final design criteria described in (a) above.

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

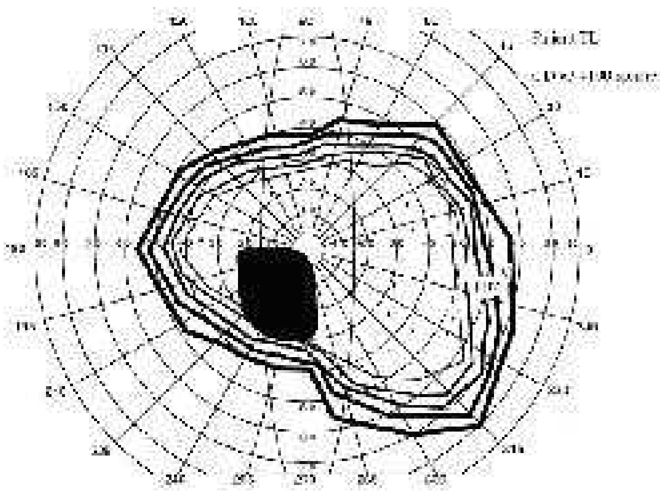


FIGURE 4 Visual field plot for the right eye of the subject with lower left partial quadranopic field loss due to a surgical procedure (the left eye had an essentially identical field loss).

Simulator
The PP-1000-X5 simulator's driving console consists of a seat mounted on a shaker platform with three 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 buttons or brake pedal) and software (e.g. coordinates of the driver or target stimulus) at 30 Hz. Five 29" (73 cm) diagonal XGA resolution (1024×768) monitors, refreshing at 60Hz, provided a 225° horizontal × 32° vertical field of the virtual environment with the driver sitting approximately 29 inches (73 cm) from the central monitor. The simulator also provided "inset" displays for the rear and side view mirrors and a heads-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 situations that increasingly approached the setup of the actual experiment. Once the participant decided he/she felt both comfortable in the virtual environment and capable of controlling the vehicle in that environment, he/she was introduced to the actual experimental task (i.e. the detection of pedestrian targets). This was achieved 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 15–30 minutes 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 15 seconds after the time of appearance.

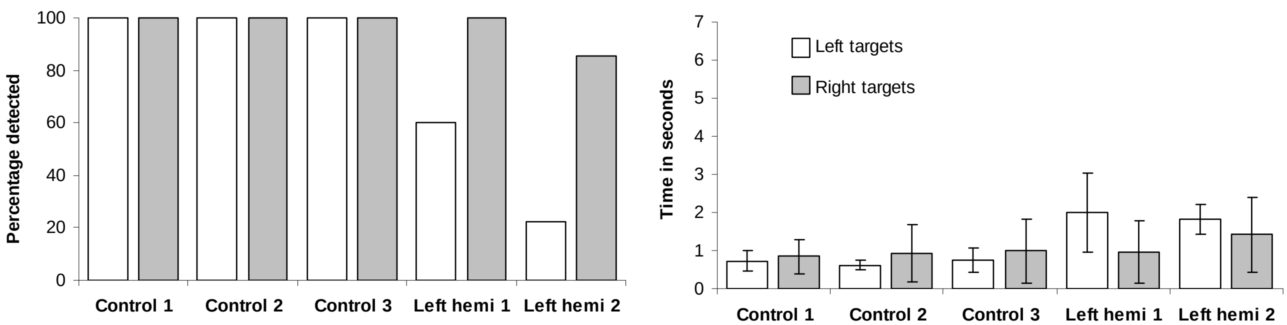
Two measures of steering stability - mean and variability (standard deviation) of vehicle lateral offset from the center of the driving lane - were included as secondary measures of driving performance. While the impact of certain drugs on steering ability and stability are well known [16], the impact 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, in particular 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, our analysis of the steering was evaluated separately for straight road segments, curved road segments, right turns and left turns.

RESULTS (PILOT STUDIES)

The results of the pilot studies shown below 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 low-speed) included in the first pilot study. There were clear differences in detection performance between subjects with hemianopia and the normally sighted controls (Fig. 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; $z = -5.9$, $p < 0.001$; Fig. 5a). 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, while controls saw all targets ($z = -2.11$, $p = 0.02$). One of the two hemianopic subjects missed 3 of 21 pedestrians on the right. While 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) (b)

FIGURE 5 (a) Detection performance (percentage of targets seen) and (b) mean reaction times by subject and target position obtained in the first pilot study. Subjects with left hemianopia showed poorer detection performance and longer reaction times on the blind (left) side than the seeing (right) side whereas control (normally-sighted) subjects showed no difference in performance between targets presented on the left and right. For targets on the left, there were 13-16 presentations for controls, 20 for left hemianope 1 and 18 for left hemianope 2. For targets on the right, there were 16-23 presentations for controls, 20 for left hemianope 1 and 21 for left hemianope 2. Error bars represent ± 1SD.

A two-factor ANOVA was used to investigate the effect of visual field loss (control versus hemianope) and target position (left versus right) on reaction times. Both factors had highly significant effects (Fig. 5b). 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 the right side ($F(1, 155) = 8.1$, $p = 0.005$). In addition, there was a significant interaction between field loss and position ($F(1, 155) = 21.1$, $p = 0.001$), 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 4 low-speed scenarios and 1 high-speed scenario. 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).

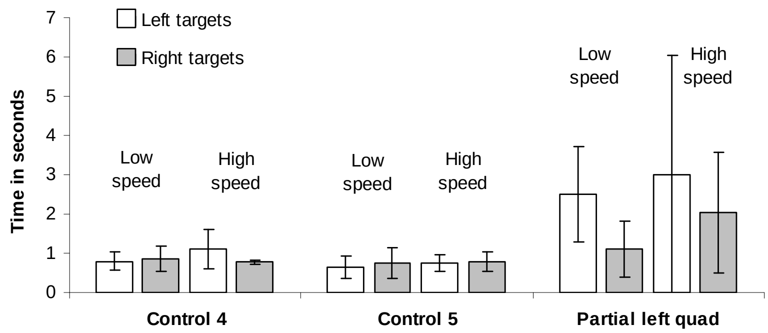


FIGURE 6 Mean reaction times obtained using four low-speed scenarios and one high-speed scenario for the second pilot study. Reaction times for the left quadranope were longer for targets on the side of the field deficiency (left) and, were on average longer than those of the control subjects, especially in the high-speed scenario. For the low-speed scenarios there were a total of 23-25 target presentations on the left and on the right. For the high-speed scenario there were 5-7 target presentations on the left and on the right. Error bars represent ± 1SD.

Reaction time results (Fig. 6) were analyzed using a three factor ANOVA: visual field loss (control versus hemianope), position (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 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 position was also significant (F(1, 166) = 9.0, p = 0.003), indicating that the subject with 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 5 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 & Fig. 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.

TABLE 2 Detection of Intersection Pedestrian Targets

	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
Partial left quadranope	Detected	Missed	Missed	Detected	Detected
Prediction Pedestrian missed by:	Left hemianope	Left hemianope	Left & right hemianope	Left & right hemianope	Right hemianope

Finally, in the second pilot experiment, secondary measures of vehicle steering - mean lane offset and mean lane offset variability - were examined. Fig. 7a and 7b show the three subjects' performance on straight roadway segments and on segments requiring 90º 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 Fig. 7a, it is clear that there were considerable individual differences, even between 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 (Fig. 7b), 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 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.

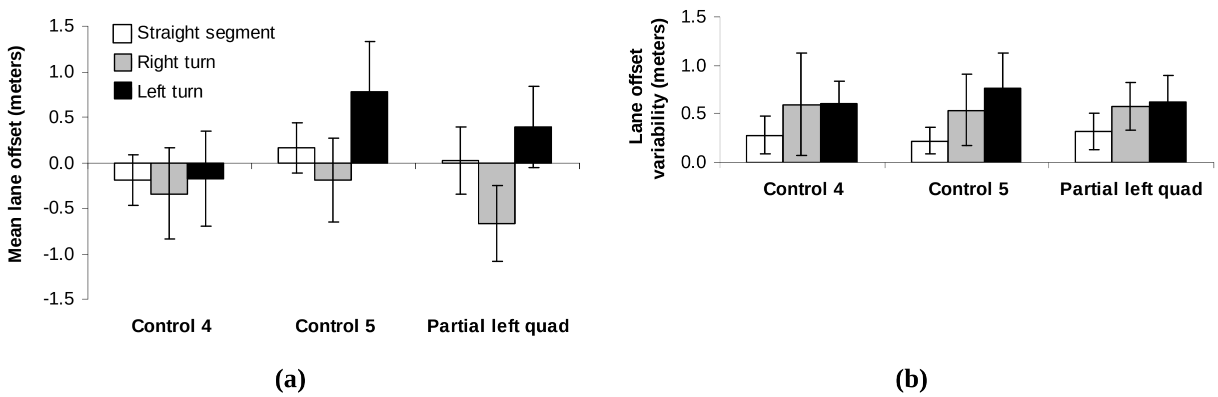


FIGURE 7 (a) Mean lane offset from center of driving lane and (b) lane offset variability (standard deviation of lane offset) are shown by subject and roadway segment type for all scenarios in the second pilot study. Mean lane offset and offset variability were greater for turns than straight road segments. There were 11 samples per subject for straight segments and 6-8 per subject for turns. Error bars represent ± 1SD.

DISCUSSION

Designing and deploying customized simulator scenarios for testing driver functionality is a lengthy and expensive process. We estimate that we 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 usage 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, no such test scenario (and accompanying data analysis system) has been developed or even proposed thus far. 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, we 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 our first effort in designing such a study is the purpose of this paper.

The pilot studies reported here were neither meant to address 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. If a method is sensitive enough to distinguish visually impaired patients from normally sighted subjects with such a small sample size, it may be sensitive enough to distinguish among several groups, where each group represents a slightly greater degree of, for example, peripheral field constriction.

In assessing particular effects of specific vision loss, one should not lose sight of all the other components of the driving task. It is important to determine that the subject is performing reasonably on the basic driving task while being tested for the specific effects of his/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/devices being evaluated even when analyzing these variables. Earlier studies of simulator driving by patients with vision loss measured such variables, some of which might be dependent on vision loss, e.g., lane boundary crossings and lane position variability [10, 12, 13]. We have suggested, and our pilot results support the idea, that it is important to account for roadway geometry and potential simulator issues (e.g., steering limitations) when analyzing such measures. In this study, the partial hemianope 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 suggests that analysis of steering control that addresses different maneuvers separately is important.

CONCLUSIONS

The results of our pilot studies demonstrate that we have designed scenarios and analysis methods 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.

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