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Vehicle handling skills of drivers with hemianopia: a simulator assessment

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Abstract. Although prior studies suggested that hemianopia may have adverse effects on vehicle handling, little attention has been paid to how these effects might vary with the type of road segment and the side of the vision loss. We conducted a simulator-based study to systematically investigate the effect of hemianopia on vehicle-handling (steering and lateral-lane position) for specific road segments (straights, curves and turns). In this paper we report results for individual drivers to illustrate our ability to develop measures of vehicle-control skills that probe performance of drivers with hemianopia and normal vision for specific road segments. Analyzing any driving measure across the whole drive is likely to hide important information and may result in false interpretation. Our examples illustrate that lateral lane offset varied with road segment type, and that drivers with right-sided and left-sided field loss exhibited different lane position biases, which also varied with segment type.

Keywords: Hemianopia; Driving simulator; Lane position;

1.0 Introduction

Driving simulators provide a controlled environment in which it is possible to empirically evaluate the driving ability of patients with various types of sensory, motor, and cognitive impairments. We use a high-fidelity driving simulator with a wide field of view to investigate the impact of various types of visual field loss on detection performance, head movement behaviors and vehicle-control when engaged in a realistic driving task. Here we report preliminary data on the lane-positioning behaviors of drivers with hemianopic visual field loss (the loss of half the field of vision on the same side in both eyes due to stroke, head trauma, or brain tumors). Data on the detection performance and head-scanning behaviors of drivers with hemianopia has been reported elsewhere.[1-3]

Hemianopia may adversely affect a driver's ability to control the steering of a vehicle, and hence may impact lane positioning skills. When driving in a simulator, drivers with hemianopia were reported to make more lane boundary crossings and had greater variability in lane position than normally-sighted drivers.[4] However, in that study, only 5 minutes of driving was evaluated and performance was scored across the entire drive without differentiating the various types of roadway geometries (straights, curves, or turns). Furthermore, the small sample (n = 6) included drivers with hemianopia and quadrantanopia, with and without hemi-spatial neglect, making it difficult to isolate the effects of the visual field loss from the effects of hemi-spatial neglect. In a recent on-road study, driving examiners frequently commented on the unstable steering of hemianopic drivers, but quantitative measures of steering stability were not reported.[5] In another recent on-road study, drivers with hemianopia who were rated unsafe to drive had problems with lane positioning and steadiness of steering (scored on 3-point scales by raters in the back seat).[6]

Although these studies provide evidence that hemianopia has adverse effects on steering and lane positioning skills, none addressed whether the effects varied with the type of roadway segment. Drivers with hemianopia might have greater difficulty on specific types of road geometries and these effects may be masked when studied across an entire drive. Therefore, in this study, we evaluated steering and lateral lane position of drivers with hemianopia and case-matched normally-sighted control drivers for specific road segments (straights, curves and turns). In addition, we examined whether there were any lateralized differences in lane position between participants with right and left hemianopia. As some aspects of the data analyses are still being developed, here we report only results for individual drivers to illustrate how the analyses address our research questions.

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2.0 Methods

2.1 Participants

Twelve participants with complete homonymous hemianopia and without hemi-spatial neglect (as determined with the Bells[7] and Schenkenberg line bisection[8] tests) were case-matched with 12 normally-sighted control drivers by age, gender and driving experience. Drivers with hemianopia were either currently active drivers or had driven within the previous 5 years. To ensure that none of the participants had significant cognitive impairments, individuals who scored < 24 on the Mini-Mental State Examination[9] were excluded.

2.2 Simulator assessments

All participants completed two sessions in the driving simulator, separated by 1 week. Details about the simulator environment and the procedures for running the simulator assessments are given in Peli et al.[1]. In brief, we used a PP1000-x5 driving simulator (FAAC Corp., Ann Arbor, MI). This system has five monitors providing a total field of 225º horizontally and 32º vertically. The simulator has a force-feedback steering wheel and automatic transmission. Data such as horn presses, brake pedal pressure, and coordinates and speed of scriptable objects in the virtual world are recorded at 30Hz.

Each simulator session included about 45 minutes of practice driving to familiarize the driver with the simulator environment and the driving tasks. This was followed by 6 different scripted test drives, each about 10 minutes in duration; 4 took place in the city (at 30 mph) and 2 on rural highways (at 60 mph). Each drive included a variety of maneuvers and roadway segments (described below) with other scripted traffic on the road. As participants drove along predetermined routes, guided by pre-recorded verbal directions, pedestrian targets appeared at scripted, but unpredictable times, to the right or left of the road. Participants were instructed to obey the normal rules of the road and to honk the horn whenever they saw the pedestrian figure. Full details of the pedestrian detection task are beyond the scope of this paper (see Peli et al.[1]). Lateral lane position and steering were subsequently analyzed from data logged during each simulator session. While driving, participants were unaware of which segments would subsequently be scored.

2.3 Roadway segments

Lateral lane position was evaluated for three specific roadway segment types: straight road (city and highway), curved road (right and left; city and highway), and turns (right and left; city driving only). Specifications for a typical city drive are listed in Table 1. Equal numbers of right and left turns and curves have been selected from each drive to enable lateralized differences in vehicle-handling of right and left hemianopes to be compared. Across the 6 drives at each session, a total of 8 city and 4 highway straight segments, 4 city and 6 highway left and right curves, and 8 city right and left turns were analyzed.

Table 1: Segment specifications for a specific city (30 mph) drive

Segment type	Length scored	Number analyzed	Constraints
Straight road	Segment 1: 230 m Segment 2: 230 m	2	No lane changes and no target presentations
Curved road	Right curve: 20 m Left curve: 24 m	1 right & 1 left	Same as above
Turns	Right turn 1 & 2: 11 m Left turn 1: 23m; Left turn 2: 20.5m	2 right turns & 2 left turns	Driver changes heading by 90º

2.4 Analysis of lateral lane position

We have developed the following measurements of lane position and steering stability, which were scored for each segment: mean and standard deviation (variability) of lateral lane offset, duration and number of lane boundary crossings, and number of steering wheel movements and reversals.[3] Lateral lane offset was the distance between the center of the front axle of the car and the center of the driving lane on straight and curved road segments, or the 'ideal' path on a turn (described below). A lane boundary crossing occurred when one of the front wheels crossed into the next driving lane by an amount greater than 0.05 meters.

To determine the lateral lane offsets within turns, we defined an ideal path through each intersection. We used ellipses to model the path shape. In left turns, depending on the number of lanes going into and out from the intersection, the ideal path was either 90° of a circle or 90° of an ellipse (Figure 1). The axis of the ellipse at the start of the turn was determined by adding the width of the sidewalk (5m) and the width of the driving lanes crossed on the pre-turn side of the intersection (distance x in Figure 1). For left turns this varied from 7m (crossing only 1/2 lane and sidewalk) to 15m (crossing 2.5 lanes plus sidewalk). The other axis length was determined by adding the width of the sidewalk to the width of the driving lanes crossed on the post-turn side of the intersection; the width of this axis (distance y in Figure 1) varied from 11m to 15m (1.5-2.5 lanes crossed). In right turns, the axes were always equal in length (0.5 lanes crossed plus sidewalk = 7m); hence, the ideal path was 90° of arc of a circle (Figure 2).

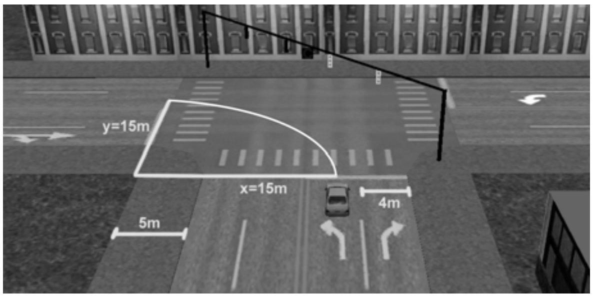

Figure 1: A left turn showing the "ideal" navigation path (white arc) and the distances which were used to define the axes of the ellipse. In this example the axes are equal in length (15m) and the ideal path is the arc of a circle.

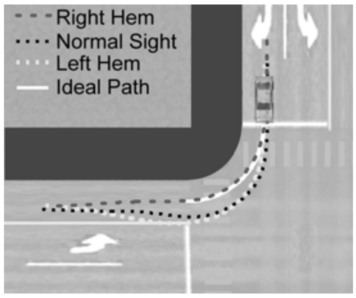

Figure 2: A right turn showing the "ideal" navigation path (white arc) and car paths (dotted lines) for three drivers. The driver with right hemianopia tended to take a tighter path (more to the right) than the drivers with normal sight and left hemianopia.

3.0 Results

Here we present data from participants who are representative of the general trends in our sample. Data for city left turns are still being processed and are not included in the results.

3.1 Do drivers with hemianopia show lateralized lane offset biases?

Figure 3 shows sample plots of lateral lane position on straight road segments. The normally-sighted driver maintained an average vehicle position near the center of the lane (Figure 3a). By comparison, the driver with right hemianopia had a consistent bias in lane position toward the left side of the road (away from the side of the visual field defect; Figure 3b), while the drivers with left hemianopia had biases toward the right side of the road (again, away from the side of the visual field defect; Figures 3c and 3d). Interestingly, when taking a right turn, the driver with right hemianopia shows the opposite lane position bias to that which was observed in straight segments; his lane position is now to the right of the normally-sighted driver (Figure 2). Both the left hemianope and the normally-sighted driver took a wide path on this right turn (lateral lane offset to the left) and only brought the car back to the center of the driving lane after the end of the turn arc.

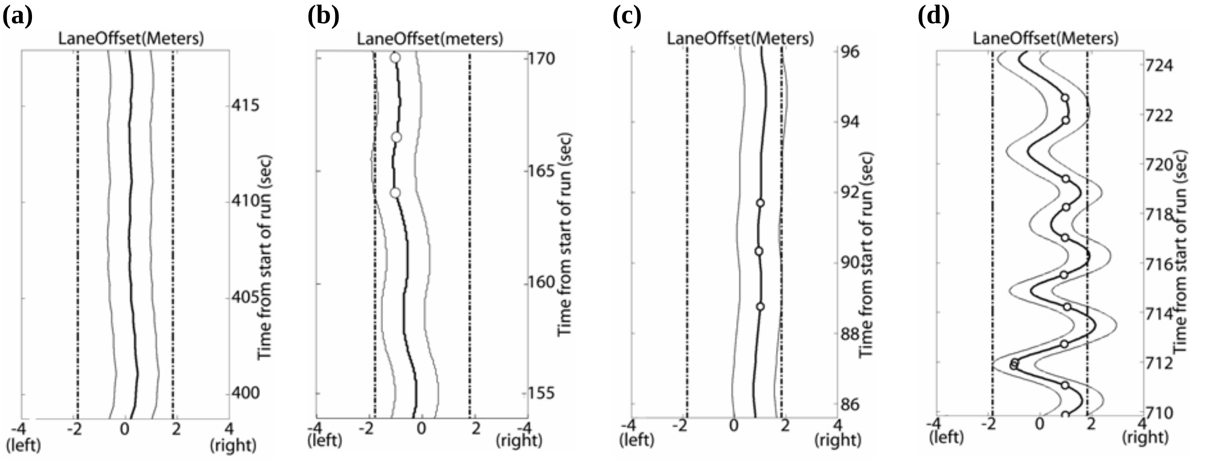

Figure 3: Sample plots of lateral lane offsets on straight road segments. The dark line is the center of the vehicle, lighter lines represent the width of the car, dashed-dotted lines are the extent of the driving lane; and small open circles are lane boundary crossings. **(a)** A driver with normal vision; **(b)** A driver with right hemianopia demonstrating a lane position bias to the left; **(c)** A driver with left hemianopia demonstrating a right bias; and **(d)** A different driver with left hemianopia who exhibits poor steering control and a large number of lane boundary crossings.

3.2 Does lateral lane offset vary with segment type?

Both hemianopic and normally-sighted participants showed clear differences in lateral lane offsets across different segment types in city and highway drives. For example, the normally-sighted driver in Figure 4a maintained a lane position slightly to the right of the center of the driving lane in straight segments, but he had a large leftward offset in left curves (i.e. he "cut" the left curve) and he had a leftward offset in right turns (took the turn wide). The driver with right hemianopia and the driver with left hemianopia also show clear variations in lateral lane offset across the different roadway segments (Figures 4b and 4c). If the data were averaged across all segment types (the bottom bar in all the plots), all information about lateralized biases and differences with segment type would be masked, and there would appear to be no differences in lateral lane offsets between the normally-sighted and hemianopic drivers.

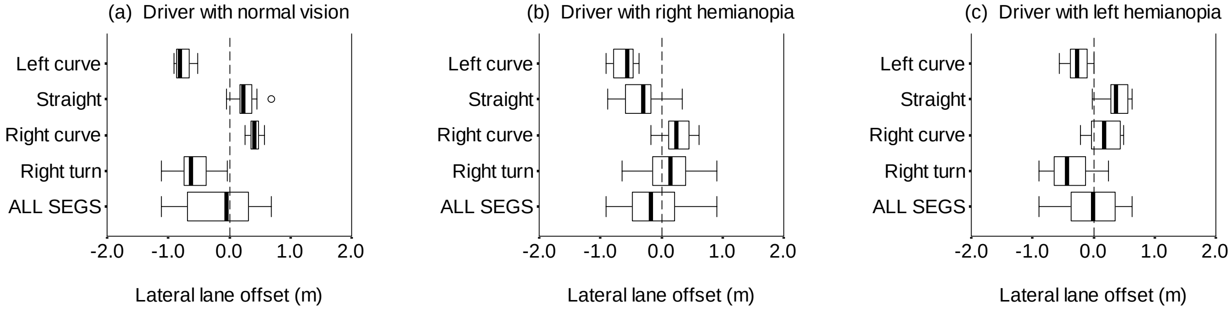

Figure 4. Lateral lane offsets for each segment type in city drives. **(a)** A driver with normal vision; **(b)** A driver with right hemianopia; and **(c)** A driver with left hemianopia. Offsets varied with segment type and vision status. Data for each driver is averaged across segments in each of the 6 drives at the 2 simulator sessions.

4.0 Discussion

This paper demonstrates our ability to develop measures of vehicle-control skills that probe performance of drivers with hemianopia and normal vision for specific road segments. We argue that simulator analyses should address specific questions at specific road segments, and in relation to specific maneuvers. Analyzing any behavior or skill across the whole drive is likely to hide important information and may result in false interpretation. As our examples clearly illustrate, lateral lane offset varied with road segment type. If an "average" lane offset had been calculated across all city roadway segments the effect of "cutting" the curve and the wide path on right turns would have been masked. Moreover, drivers with right-sided and left-sided field loss exhibit different driving behaviors in different segments. The lane offset bias of both left and right hemianopes appeared to be away from the side of the field defect in straight road segments, as if giving themselves a safety "cushion" on the side of the field defect. In right turns, however, the right hemianope appeared to show the opposite bias (taking a path to the right of the normally-sighted driver).

One of the limiting factors in our analysis of turning behaviors is the limited realism of the simulator steering wheel feedback in small radius turns. This is a characteristic found in many simulators. However, the mechanical limitations of the simulator do not seem to mask the effects of the vision loss on steering behaviors. We are able to evaluate lateralized differences (in turns) between drivers with right and left hemianopia. Interestingly however, the lane position biases that we have observed in the virtual environment are opposite to those anecdotally observed in Tant et al's[5] on-road study of driving with hemianopia where right hemianopes were noted to drive too close to the right side of the road and to take right turns too widely.

The data plots included in this paper illustrate interesting examples of how the measures we are developing address our research questions. We do not imply that these "case reports" are representative of the behaviors of all drivers with hemianopia. Group data and statistics for this study will be reported in a subsequent paper.

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