

Driving With Visual Field Loss: An Exploratory Simulation Study

Technical Report



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Technical Report Documentation Page

1. Report No. DOT HS 811 062		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Driving With Visual Field Loss: An Exploratory Simulation Study				5. Report Date January 2009	
				6. Performing Organization Code	
7. Author(s) Julie Lockhart, Linda Ng Boyle, and Mark Wilkinson*				8. Performing Organization Report No.	
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				11. Contract or Grant No. Contract No. DTNH22-00-C-07009, Task Order No. 05	
12. Sponsoring Agency Name and Address Office of Behavioral Safety Research National Highway Traffic Safety Administration U.S. Department of Transportation 1200 New Jersey Avenue SE. Washington, DC 20590				13. Type of Report and Period Covered Final Report, March 2008	
				14. Sponsoring Agency Code	
15. Supplementary Notes Dr. Kathy Sifrit was the NHTSA Task Order Manager on this project.					
16. Abstract The goal of this study was to identify the influence of peripheral visual field loss (VFL) on driving performance in a motion-based driving simulator. Sixteen drivers (6 with VFL and 10 with normal visual fields) completed a 14 km simulated drive. The simulated scenarios included changes in road geometry, merging, lead vehicle braking and incursion events; outcome measures were head movements, lane position, accelerator release time, collisions, and subjective assessment of driving patterns. There were significant differences between groups in some driving performance measures. Those with VFL demonstrated more variability in lane maintenance on curves and when departing the freeway, as well as delayed accelerator release and reduced time to simulated collision during an unexpected hazard event. VFL participants did not exhibit expected compensatory behaviors such as greater variability in head movements. The results suggest some differences in driving performance and driving patterns between the groups.					
17. Key Words Visual field loss, driving performance, driving simulator, compensation, head movements			18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 52	22. Price

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EXECUTIVE SUMMARY

This National Highway Traffic Safety Administration (NHTSA) project examined driving performance and sign detection in drivers with peripheral visual field loss (VFL) and those with normal visual fields using the National Advanced Driving Simulator (NADS). Researchers compared differences in driving performance measures between groups.

BACKGROUND

Drivers rely on peripheral vision to support a number of tasks including maintaining speed and lane position and detecting potential hazards such as pedestrians or other vehicles. The visual field, the area within which a person focusing on a central point can detect a stimulus, is normally about 180 degrees. A number of medical conditions result in VFL, however it is not clear whether drivers with VFL can drive safely.

The purpose of this exploratory study was to use NADS to compare simulated driving performance of people who have VFL with that of drivers with normal vision, and to determine whether those with VFL use strategies to compensate for their reduced peripheral vision. This project was conducted in response to Congressional direction to evaluate the effects of low vision on driving performance using NADS (Transportation, Treasury and General Government Appropriations Bill, 2005).

NADS is a high-fidelity driving simulator that replicates the visual, auditory, and haptic (tactile) experience of real world driving. The simulated driving tasks were designed to capture strategies such as increased head movements, eye-scanning patterns, and frequent mirror glances, that a driver with VFL might use to compensate for a limited visual field, in addition to driving performance measures.

METHODS

Sixteen licensed drivers between the ages of 24 and 64 (6 with VFL and 10 with normal vision) participated in the study. VFL group members had horizontal visual fields <100 degrees while the control group participants had normal visual fields (approximately 180 degrees). The groups did not differ significantly in miles driven per year (10,000), driving frequency, driving years, self-ratings of driving quality, driving preferences, driving locations, avoidance of driving conditions or situations, or number of self-reported crashes within the past five years.

Participants completed a 12-minute simulator drive that included 5 scenarios: a sign detection and recognition task, merging on and off the freeway, straight and curved sections of roadway, 2 lead vehicle braking events, and an intersection incursion event. Speed limits were 45 mph on the rural highway and 65 mph on the freeway.

Participants identified eight signs on both sides of the road during one segment of roadway. An eye tracker collected data on participants' glance frequency and duration to the roadway, mirrors, and the speedometer.

RESULTS

Glances

The groups performed similarly in most eye-glance behaviors, but there were differences in the duration of glances toward two areas of interest. The VFL group made significantly longer glances toward the speedometer, and the control group made longer glances toward the rearview mirror. The drivers with VFL may have spent more time looking at the speedometer in order to maintain their speed, a dimension where the use of peripheral vision has been shown to be relevant.

Lane Position

The groups' driving performance measures were similar on most sections of the roadway; however, the VFL group showed greater variability in lane position, particularly during the latter part of the drive. When exiting the freeway, the control group's mean maximum lane deviation was 2.6 ft; that of the VFL group, 3.7 ft., was significantly greater.

Lead Vehicle Braking

There were two lead vehicle braking events. Each began when the brake lights of a lead vehicle (the car ahead of the participant's vehicle) turned on and ended when the participant depressed the accelerator pedal following the braking response. The groups responded similarly to the event with the exception that, in the second event, the VFL group exhibited more variation in lane position during this event.

Intersection Incursion

At the end of the simulator drive, participants faced a hazardous event when a vehicle on an intersecting roadway failed to stop at a stop sign. Participants could avoid colliding with the vehicle by either stopping or by swerving around the other vehicle. This intersection incursion event was defined as the time interval that started when the incurring vehicle was three seconds from the intersection stop-line to the time the participant either came to a stop or crossed through the intersection (for those who choose to drive around the oncoming vehicle). Ten participants came to a stop and six steered around the incurring vehicle. There were no significant differences between the groups for the action taken (steering or braking) to avoid the incursion event. The VFL group took 0.86 seconds longer on average to release the accelerator in response to the incurring vehicle; among those who stopped, the VFL group had a 4.44 second smaller (riskier) time to (simulated) collision.

Head Movements

Although studies have shown that drivers with VFL may compensate for their limited visual fields by moving their heads more than other drivers, participants in the current study did not use this strategy. The participants the VFL and control groups made similar head movements.

Sign Recognition Task

The groups did not differ significantly in the number of correct responses to the road signs, in the distance from which the signs were identified, or in the number of signs they recognized after the simulation.

CONCLUSIONS

The results from this study indicate that, although VFL and control participants' performance were similar in most tasks, the groups differed significantly in some driving performance measures. Participants with VFL exhibited some difficulty with lane maintenance on curves and when departing the freeway. They also took longer to respond to the vehicle incursion, an unanticipated hazard that originated in the periphery during the simulated driving task.

LIMITATIONS

The number of participants, particularly in the VFL group, was small. This is of particular concern given differences in characteristics of visual field restrictions within the VFL group; some had symmetrical field loss while others had restriction on only one side. It is also important to note that participants may behave differently in a simulated driving task than in real world driving.

INTRODUCTION

Vision is important to safe driving. Drivers constantly scan the environment for way-finding, vehicle and hazard avoidance, and lane maintenance (Bhise & Rockwell, 1971). The visual field is the total area from which a viewer can detect stimuli in the visual field when the eyes are focused on a central forward point (Rizzo & Kellison, 2004). Normal aging or diseases associated with the eye can result in deterioration in vision. However, to date there is no conclusive evidence that visual field loss (VFL) has significant negative effects on driving performance and safety (American Medical Association [AMA] & NHTSA, 2003; North, 1985).

Several studies have examined the relationship between VFL and driving (Ball, Owsley, Sloane, Roenker & Bruni, 1993; Bowers, Peli, Elgin, McGwin, & Owsley, 2005) with some showing visual impairments contributing to driving strategies and performance changes (Lamble, Summala, & Hyvarinen, 2002; MacDougall & Moore, 2005; Moore & Miller, 2005). The goal of this exploratory study is to identify the influence of peripheral VFL on the driving performance of adult drivers under age 65 using the National Advanced Driving Simulator (NADS).

Driving is a daily part of life for many individuals and equates to independence and freedom. In a survey on public transportation of 55 visually impaired individuals, 90% indicated that driving cessation was a significant disadvantage in today's environment (Golledge, Marston, & Costanzo, 1997). Seventy-eight percent reported high degrees of frustration with being dependent on others for transportation, and 62% agreed that not being able to drive had a negative impact on their quality of life. Since driving is so highly valued, it is imperative that any cancellation or restriction of licensure is based on valid and strong empirical evidence.

Prevalence

Aging Population

Vision deteriorates through normal aging, and from eye diseases such as Retinitis Pigmentosa (RP), cataract, or macular degeneration. The prevalence of visual impairment and blindness increases significantly with age (Klaver, Wolfs, Vingerling, Hofman, & de Jong, 1998; Johnson & Keltner, 1983; The Eye Diseases Prevalence Research Group, 2004; The National Eye Institute, 2002). Examining the effect of visual impairments on driving performance has policy implications due to the increasing proportion of individuals over 65 years old in the United States. In 2000, approximately 12.4% of the population was over the age of 65, and this percentage will increase as the baby boom generation ages (U.S. Census Bureau, 2005). As a consequence of the aging population, the incidence of visual impairment will also increase, resulting in potentially significant implications for road safety.

General Visual Impairment

A recent U.S. study indicated that low vision and blindness increased significantly with age for all races and ethnicities (The Eye Diseases Prevalence Research Group, 2004). The report estimated that 2.4 million (1.98%) people in the United States had low vision, and projected that the number would increase to 3.9 million (2.5%) by 2020. Approximately 2.85% of Americans are visually impaired or blind. In the United States, approximately 3.4 million individuals age 40 and older are blind or visually impaired. Interestingly, Iowa and North Dakota had the highest

rates of visual impairment, 3.73% and 3.74% respectively (The National Eye Institute, 2002). Johnson and Keltner (1983) tested the visual fields of approximately 10,000 volunteers ages 16-60 applying for driving licensure. They found the incidence of VFL to be 3.0 to 3.5%, with the occurrence increasing to 13% for those 65 and older.

Visual Field Loss

The visual field is defined as the total area in which stimuli can be seen in the peripheral vision with the eye focused on a central point. The binocular human visual field normally extends horizontally over approximately 180 degrees. The peripheral visual fields have low visual acuity but good temporal resolution and motion detection (Rizzo & Kellison, 2004).

Homonymous hemianopia is the loss of half the visual field on one side in both eyes; Figure 1(b) illustrates a depiction of the driving scene of someone with homonymous hemianopia. This loss most often occurs due to stroke, but can also stem from trauma or tumors. There are an estimated 5.4 million stroke survivors in the United States; as many as one third of those in rehabilitation have either homonymous hemianopia or hemi-neglect. Retinitis Pigmentosa (RP) is related to a group of disorders associated with the retina. It is distinguished by gradual deterioration of the light-sensitive cells (photoreceptors) of the retina and ultimately leads to some VFL. RP is typically first characterized by night-blindness, and then progressive loss of the peripheral visual field. Over the course of the disease, the central field can be affected and result in legal blindness. This disorder affects 1 in 4,000 people (Ammann, Klein, & Franceschetti, 1965; Berson, 1993; Boughman, Conneally, & Nance, 1980; Jay, 1982). Figure 1(c) provides an illustration of what a driving scene could look like to a driver with RP.



Figure 1. Roadway scene as viewed by a driver with (a) normal vision; (b) homonymous hemianopia; and (c) RP.

Regulations Associated With Visual Field Loss

Visual field requirements for licensure vary from State to State. A study in which questionnaires sent to all the 51 U.S. jurisdictions to collect information on screening procedures and visual field requirements for driving licensure reported diverse policies (Peli, 2002). A minimal visual field was required in 37 jurisdictions; 4 required screening only for a commercial license. Most jurisdictions required more than a 100-degree field of view, but values ranged from 70 to 140 degrees. The author was unable to determine which jurisdictions actually enforced the visual field screening. Twelve of the 51 jurisdictions required restricted licenses for individuals with visual field impairments, and some required additional mirrors for these drivers. None of the jurisdictions had guidelines regarding the use of field enhancement devices to meet the license visual standards. The Federal government requires commercial drivers to have more than

a 70-degree horizontal field of view. Peli (2005) noted that regulators have made arbitrary rules and regulations regarding visual field. Due to this inconsistency, medical practitioners often bear the responsibility to advise patients on whether they are fit to drive safely (Moore & Miller, 2005). This study underscores the need to examine the effects of VFL on driving performance so that reliable, valid, empirical evidence can guide licensure decisions.

Compensation Strategies

The visual field facilitates accurately detecting and locating an object, even in the periphery, and is more important for drivers than the ability to clearly detect details in an object (visual acuity) (Owsley & McGwin, 1999). Peripheral vision has been shown to support a number of driving tasks including lane maintenance, speed estimation (Bhise & Rockwell, 1971), and the detection of abrupt onsets or changes in the periphery such as hazard detection (Crundall, Underwood, & Chapman, 2002). However, the minimum visual field consistent with safe driving has not been determined. Research has shown that drivers with and without VFL may neglect peripheral targets. Attention (Recarte & Nunes, 2000) and driving experience (Crundall, Underwood, & Chapman, 1999) play substantial roles in visual scanning and eye movement strategies, and as a result, influence peripheral stimuli detection. Some propose that drivers can use head movements and mirrors to compensate for detriments in visual field (North, 1985). Stationary vision tests do not assess strategies used to compensate for VFL; although these tests are useful in diagnosing and assessing visual impairment, they do not take into account the complex behaviors carried out by drivers (Owsley & McGwin, 1999).

Drivers with VFL use strategies to compensate for their disability, which can enhance practical field of view. Some drivers move their heads and eyes and use mirrors to compensate for their VFL (Coecklbergh et al., 2002; North, 1985). A positive relationship has been reported between head movement and intersection target detection rates in participants with hemianopia, suggesting this could be a beneficial compensatory behavior (Bowers, Mandel, Goldstein & Peli, 2007). Others compensate by avoiding potentially risky conditions such as rush hour, adverse weather conditions, night driving, roadways with higher speeds, or unfamiliar environments (Ball, Owsley, Stalvey, Roenker, Sloane, & Graves, 1998; Fishman, Anderson, Stinson, & Haque, 1982; Keeffe, Jin, Weih, McCarty, & Taylor, 2002; Moore & Miller, 2005; Owsley & McGwin, 1999; Szlyk et al., 1995). Some drivers with central visual impairments have compensated for their difficulty with reading road signs by planning their route when driving in unfamiliar locations to avoid relying on signage (Lamble, Summala, & Hyvarinen, 2002). Drivers with lower levels of cognitive and visual function may drive fewer annual miles and avoid high-risk driving situations (Stutts, 1998). Ball and colleagues (1998) found that those with severe functional impairments were more likely than other drivers to report avoiding risky driving situations.

A number of studies have focused on the scanning behavior of people with VFL outside of the driving domain. In one study, participants viewed a picture of a scene, such as a city landscape. The visual scanning behavior of participants with homonymous hemianopia (also referred to as hemianopsia) was compared to normally sighted participants (Pambakian et al., 2000). Participants with hemianopia fixated on different spatial positions, made more fixations, which were more widely distributed, and of shorter duration. This group spent a greater proportion of their total fixation time in the area corresponding to their blind hemifield. Participants with hemianopia made more saccades to their blind hemifield, these saccades had

shorter latencies and shorter amplitudes than those made into their seeing field, and had larger scan paths than normal sighted individuals. The authors suggest that these results may reflect compensatory eye movement strategies.

Zihl (1995) used a computer task to examine scanning behavior and target detection in participants with homonymous hemianopia. The study found that 40% of the participants had normal scanning behavior while the remaining 60% showed significantly increased target search times. The disordered spatial organization of scanning in the affected hemifield influenced visual scanning to a lesser degree, in the intact hemifield. The participants showed significant improvement after visual search training. Drivers who do not compensate for their VFL may not always correctly assess and avoid a risky driving situation, so may put themselves and others in danger.

Previous Visual Field Loss and Driving Research

Researchers have used various driving performance measures including crash statistics and performance based measurement (on-road or in a simulator) to assess the effects of VFL on driving performance.

Crash Statistics and Self-Reports

A number of studies have focused on crash statistics of drivers with impaired visual acuity or visual field as compared to those with normal vision with mixed results. A widely cited study by Johnson and Keltner (1983) found that participants with severe VFL ($n = 196$) had crash and conviction rates twice as high as those of the control group matched by age, gender, and annual kilometers driven. However, others have found that drivers who were visually impaired did not have elevated crash risk. One study reported that RP participants ($n=42$) had more self-reported crashes than members of a control group ($n=87$; matched on age) (Fishman, Anderson, Stinson, & Haque, 1981).

Concil and Allen (1974) tested the visual fields of 52,000 North Carolina drivers to investigate the relationship between lateral vision loss and crash involvement. They found that less than one percent of the sample had a bilateral visual field of less than or equal to 120 degrees. The incidence of limited visual field increased with age. The participants' State driving records indicated no significant differences in overall crash rates, however those with limited visual field (120 degrees or less) were involved in significantly more side collisions than those with normal visual field (greater than 160 degrees).

A self-report study revealed a similar pattern. Participants with RP and a normally sighted control group matched on age and driving experience reported their crash history over the previous five years (Szlyk, Alexander, Severing, & Fishman, 1992). The RP group had a significantly greater number of members involved in at least one crash, and these crashes were significantly more likely result from incidents located in the driver's peripheral visual field.

Since vision is essential for driving, it is interesting to note that many studies show a low correlation between vision impairment and crash rates. As mentioned earlier, drivers may use compensatory behaviors that diminish the effects of their impairment, which can be reflected in lower-than-expected crash statistics in this population (Charman, 1997). The low correlation may also be due to the inconsistent type and severity of VFL across studies. In Johnson and Keltner

(1983) and Szlyk et al. (1992) studies, the VFL was quite severe, while in Fishman et al. (1981) impairment was mild. Differences in findings may also be due to inadequate visual screening and methodological problems (Lövsund, Hedin, & Törnros, 1991), or participants underreporting crashes, (McGwin, Owsely, & Ball, 1998).

On-Road Performance Evaluations

Studies have used on-road driving performance to examine the effects of various visual impairments including peripheral decrements, ocular abnormalities, and VFL on driving safety. This section summarizes some of these studies.

Evaluators assessed on-road driving performance of 28 participants (mean age = 67) with mild to moderate peripheral field loss due to glaucoma or RP (Bowers, Peli, Elgin, McGwin, & Owsley, 2005). The 14-mile course covered a variety of road types and traffic conditions. Those with greater visual field restriction displayed poorer performance in speed matching when changing lanes, path-keeping during curves, positioning during curves, maintaining appropriate following distances during curves, anticipatory skills, interaction with other traffic, adjusting speed, and reacting to unexpected events. There were no significant correlations to maneuvers that did not require peripheral vision (e.g., following distances and speed maintenance on straight roadways).

In another on-road study, participants with VFL (13 with hemianopia, 7 with quadrantanopia, 25 with monocular vision, and 76 with mild and 10 with moderate peripheral field loss) drove on a familiar roadway. Evaluators rated them on tasks such as signaling, steering, following traffic, reversing, turning, and changing lanes (Racette & Casson, 2005). The goal of the study was to assess the impact of extent and location of VFL on driving performance. When all VFL types were included in the analysis, the *extent*, rather than the *location*, of the VFL had a significant impact on the outcome of the driving assessment. Those with more severe loss received a greater percentage of “unsafe” driving ratings.

The impact of visual field defects due to ocular abnormalities on driving performance was examined in a driving simulator and on the road. Participants (60 men and 27 women) had visual field defects due to macular degeneration, glaucoma, or RP. During the on-road portion of the study, participants drove in their own vehicles on a variety of road types and geometries at varying speeds. Trained examiners assessed fitness-to-drive and scored participants on a pass or fail basis. The examiners observed differences in driving speed, steering stability, lateral position, and headway in participants with central, peripheral, and mild field loss. Twenty-two percent of the participants with central VFL, 43% with peripheral VFL, and 57% with mild visual field defects passed the on-road assessment. Those with peripheral VFL showed increased standard deviation of lateral position and made more lane boundary crossings. Participants with central VFL, who passed the on-road test, drove significantly slower than those who did not. Those who passed the assessment demonstrated more compensatory behavior (more head movements, and scanning at a longer distance from an intersection) to mitigate their field loss (Coeckelbergh, Brouwer, Cornelissen, & Kooijman, 2002).

Coeckelbergh and colleagues (2004) used an on-road course to determine fitness-to-drive in 100 participants with central VFL as compared to a group with peripheral VFL. Fitness-to-drive was examined with a checklist of behaviors used in the Netherlands to examine drivers

who do not meet the vision requirements. Participants were tested in their own cars, in their own neighborhoods. Scores ranged from 0 (insufficient) to 3 (good); a score of 2 or 3 was necessary to pass the evaluation. They reported that 64% of participants with mild field loss, 42% with peripheral field loss, and only 25% with central loss passed the driving test. Many people failed the test even in highly familiar environments (Coeckelbergh, Brouwer, Cornelissen, Van Wolffelaar, & Kooijman, 2004).

Simulator Driving Performance

Over the years, simulation has been widely used in transportation research (Kaptein, Theeuwes, Van Der Horst, 1996). Simulators provide precise driving performance measures that may offer objective insights into potential performance detriments and allow control over extraneous variables.

Researchers used a simulator to test the ability of drivers with VFL to detect stimuli of different sizes appearing at different locations on a screen. Twenty normally sighted participants, 31 with VFL, 3 with monocular vision, 3 with myopia, and 1 with hyperopia (with glasses or contacts) participated in this study. The participants reacted to the stimuli by pressing the brake pedal. Prolonged reaction times (over 3 seconds) to a stimulus were graphed on a perimetric chart. If several prolonged reaction times to the stimuli were within the affected area the researchers concluded that those participants were not compensating for their impairment. Only 4 of the 31 participants were identified as compensating for their impairments. A second part of the study focused on the visual scanning behavior of two participants who had good detection capacity in their blind areas. Upon closer monitoring, one of these participants showed capacity to compensate while the other did not. The results of eye movement analysis showed that a greater proportion of fixations to the affected area of their visual field could have accounted for the differences in the reaction time performance. Although the sample size was small, the study provides some indication that participants with homonymous defects may not compensate for their VFL (Lövsund, Hedin, & Törnros, 1991).

Szlyk and colleagues (1992) conducted a simulator study to determine whether drivers with RP and peripheral field loss were at greater risk for being involved in a crash than normally sighted drivers. There were 21 participants with RP and varying degrees of VFL and 31 normally sighted participants, matched by age, sex, and driving experience. Participants completed a five-minute driving scenario presented on a low-fidelity driving simulator with a 160-degree video display, steering wheel, seat, and pedals. The scenario consisted of six peripheral events: three intersections with cross traffic, a car passing on the left, a cow approaching from the right and crossing the roadway, and a car merging onto the roadway from an on ramp. The simulator collected data on speed, braking pedal pressure, lane deviation, number of lane boundary crossings, and braking response times. The RP group experienced four crashes, which was significantly more than the control group, which had none. Visual field measures proved the strongest predictors of crash involvement (Szlyk et al., 1992).

Participants with central vision loss were added in a follow-up study. Participants completed the simulator task described above. The authors combined the results with those of the previous study (Szlyk et al., 1992) with RP participants. The three groups (RP, central loss and control) differed significantly in lane boundary crossings, response time to a stop sign, and response time to a traffic signal. A significantly higher proportion of the central and RP groups

had at least one lane boundary crossing. The authors found that the RP and central vision loss groups had significantly lower risk-taking scores than the controls on a subjective measure of risk-taking (Szlyk, et al., 1993).

Participants with visual field defects that resulted from a variety of ocular abnormalities performed driving tasks on a driving simulator and on the road in a study to investigate the impact of these conditions on driving performance. Participants ($n = 87$) in the simulator portion of the study had visual field defects due to macular degeneration, glaucoma, or RP. Participants completed a 10-minute practice session followed by a 30-minute test drive consisting of various road types and driving situations. Participants with central vision field defects did not react as quickly to speed changes in the lead car, and had the shortest (riskiest) minimum time-headway. However, their mean lateral position was less affected by road curvature. Those with peripheral visual field defects had larger variations in lateral position and made more lane boundary crossings (Coeckelbergh et al., 2002).

Sign Task

Drivers scan the environment for hazards and for information found on traffic signs; eye movement analysis of sign tasks provides a measure of drivers' scanning patterns. This method is beneficial because eye movements are usually involuntary and unbiased (Bhise & Rockwell, 1973); however, sign fixation may not indicate perception or awareness of the sign. The viewer may fixate on a sign without attending to it, or may perceive a sign without fixating on it (Li, Hamilton, & Morrisroe, 2006). Other methods of assessing scanning patterns include instructing participants to report signs in the driving environment. This method demonstrates participants' ability to search for signs but does not represent normal driving behavior (Ericsson & Simon, 1980). Despite its limitations, this method provides insight into the process underlying driving performance, which can complement eye movement data.

Research Goals

The present research study compared driving performance and sign detection in adult drivers (age 25-64) with normal vision and those with peripheral VFL using the National Advanced Driving Simulator (NADS). In addition to driving the simulator, participants provided information about their driving behaviors, experience, and history. Data on head movements and eye scanning patterns provided information about the degree to which participants with VFL employed these compensation strategies.

Research Questions

The present study addressed two research questions: How does the driving performance of those with VFL differ from that of drivers with normal vision? Do drivers with VFL exhibit significantly larger variability in head movements and greater number of glances to the defined areas of interest to compensate for their restricted field of view? Drivers with VFL and control participants with normal visual fields completed simulated scenarios using NADS. It was hypothesized that the groups would differ significantly only in self-reported measures (driving experience, record histories, and driving behavior) and in head movement and eye scanning compensation strategies.

METHODOLOGY

This study involved screening to assess the participants' visual status and a short simulator drive including five scenarios; sign recognition task, merging (on and off the freeway), road geometry change (curved and straight), two lead-vehicle braking events, and an intersection incursion event.

Participants

Sixteen drivers, twelve males and four females ranging in age from 28 to 61, participated in this study. Ten had normal vision and six had VFL due to Retinitis Pigmentosa ($n=3$), or stroke, which resulted in homonymous hemianopia ($n=3$).

The participants with VFL were recruited through the Department of Ophthalmology and Visual Sciences. One of the investigators, an optometrist, determined the cause and degree of the VFL within the past two years. The Iowa Department of Transportation discretionary review process demonstrated that the VFL participants had the skills required to continue to operate a vehicle safely.

The control participants were members of the Iowa City public with no known visual loss. They were recruited through: (1) advertisement through the local Iowa City newspapers, (2) notices posted in the hospital and on the University of Iowa campus, (3) the NADS participant database, and (4) word of mouth. Participants received \$25 compensation.

Screening Procedure

Participants were contacted by phone to verify that they met the screening requirements. All participants were in good physical and mental health, and not under the influence of medications or recreational drugs that could potentially affect their driving or cognitive performance. They drove regularly, a minimum of 3,000 miles per year.

Following the telephone screening, the investigating optometrist and a research assistant assessed and recorded participants' visual status at the University of Iowa Health Care (UIHC) Department of Ophthalmology and Visual Sciences. This session lasted approximately 30 minutes. Prior to participation, participants read and signed the informed consent, which contained all the information regarding the study, and any risks involved. At that time, they were given the opportunity to ask any questions regarding their participation.

At the UIHC the participants' visual acuity was tested monocularly and binocularly using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Ferris, Kassoff, Brensnick, & Bailey; 1982). All participants met visual acuity requirement with one or both eyes of +0.3 logarithm of the minimum angle of resolution (logMAR) (Snellen equivalent of 20/40), the legal requirement for an unrestricted driver's license in the state of Iowa (Iowa Department of Transportation, 2005). Participants' contrast sensitivity was assessed binocularly using a Pelli Robson chart (Pelli, Robson, & Wilkins, 1988). Useful field of view (UFOV) has been defined as the area from which one can extract visual information in a brief glance without head or eye movements (Ball & Owsley, 1992). Participants completed the three-part UFOV computer test (Visual Attention Analyzer Model 2000, Visual Resources, Inc., Chicago, IL). Visual field was assessed using an Octopus automated perimeter. All participants met the visual requirements for

this study. Table 1 summarizes the results from the visual screening session. As a note, the -logMar acuity is better than 20/20, + is poorer than 20/20, and +1.00 = 20/200.

Table 1. Visual screening summary means (standard deviation)

Test	VFL	Control	df	t-Test	CI	Pr> t
Acuity (LogMAR)	+0.07 (0.128)	+0.26 (0.623)	14	-1.26	-0.888, 0.232	NS
Contrast (log score)	1.52 (0.117)	1.79 (0.139)	14	4.02	0.4191, 0.096	0.001
Peripheral (degrees)	71.51 (13.17)	175.63 (3.178)	14	21.67	83.40, 101.73	<.0001
UFOV 1 (ms)	15.40 (1.897)	16.00 (0.00)	14	-0.76	-2.29, 1.08	NS
UFOV 2 (ms)	102.50 (3.950)	18.40 (98.92)	14	-2.75	-149.7, -18.53	0.016
UFOV 3 (ms)	258.00 (161.82)	92.20 (60.41)	14	-2.97	-285.6, -46.01	0.010

Demographics

According to self-reported information collected following the simulated drive, all participants were Caucasian and had at least a high school education. With the exception of one VFL participant who was unemployed and one control participant who was retired, all participants were employed on a full- or part-time basis. Seventy percent of the control participants and 83.3% of the VFL group were married.

Table 2. Participant demographics.

	Control Group	VFL Group	Total
N	10	6	16
Age	M 41 (SD=11.9)	M 44 (SD=10.0)	M 42 (SD=11.2)
Gender			
male	7 (70%)	5 (83.33%)	12 (75%)
female	3 (30%)	1 (16.67%)	4 (25%)

Driving Experience

Table 3 provides participants' self-reported average miles driven per year. Most participants, (70% of the comparison group and 50% of the VFL group) reported receiving driver education. On a 4-point scale of driving quality, 60% of the comparison group rated their quality of driving as good (second highest rating) while 66.7% of the VFL group gave themselves the same rating. Forty percent of the comparison group and 66.7% of the VFL group reported that some of their driving was work-related. The groups did not differ significantly in miles driven per year, number of driving years, or self-rated driving quality.

Table 3. Driving history.

	Control Group	VFL Group	Total
Miles driven per year	<i>M</i> 9,604 (<i>SD</i> 8,375)	<i>M</i> 10,758 (<i>SD</i> 8,919)	<i>M</i> 10,037 (<i>SD</i> 8,303)
Driving years	27 (13)	28 (11)	27 (12)

With the exception of one VFL participant, those in the study preferred to drive themselves. All of the VFL group and 70% of the comparison group reported driving at least once a day, and the remaining members of the comparison participants drove at least once a week. The majority of the comparison group (90%) said they most frequently drove in suburban environments, while half of the VFL participants most frequently drove in small towns. Three participants (1 VFL and 2 comparison participants) reported being in a crash in the previous 5 years. The groups did not differ significantly on any of these factors.

Driving Preferences

Participants reported the degree to which they avoided driving in darkness, fog, snow/sleet, rain, rush hour traffic, or on highways or freeways using a 4-point scale (0: *never* and 3: *frequently*). The groups did not differ significantly in their responses.

Apparatus

Driving Simulator

The National Advanced Driving Simulator (NADS) is a high-fidelity motion-based driving simulator located on the Oakdale Research Campus at the University of Iowa (Figure 2).

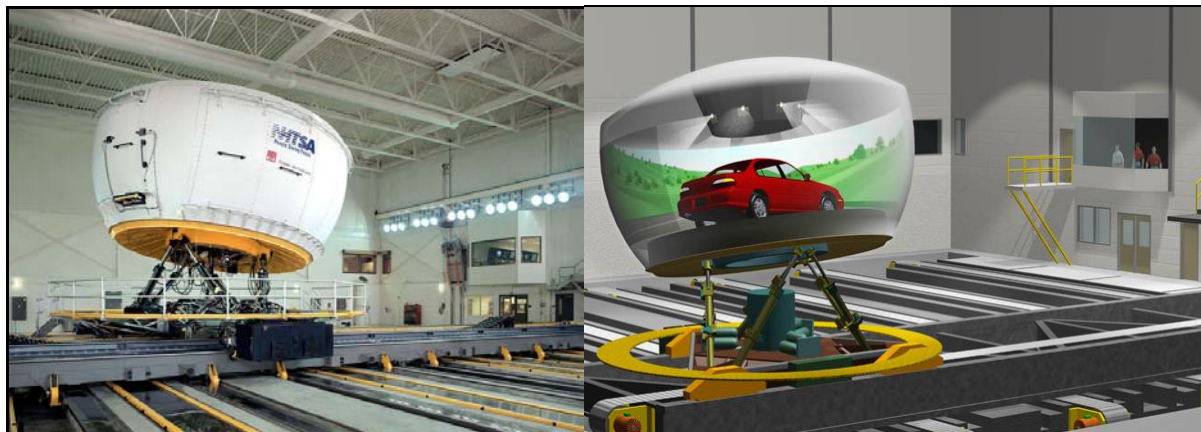


Figure 2. The National Advance Driving Simulator.

The simulator consisted of an entire car cab (a Chevrolet Malibu), which was located inside a 24-foot dome. The driving scene was displayed 360 degrees around the driver with eight Liquid Crystal Display (LCD) projectors and was updated and displayed 60 times per second. The forward field-of-view displayed higher resolution to accommodate enhanced feature recognition and lessen eye fatigue. The audio system produced sounds that emulated vehicle noise, surrounding traffic, and ambient noises.

The cab handling mimicked that of an actual Chevrolet Malibu. Manipulation of the accelerator and brake pedals and steering wheel provided appropriate response and feedback. The original manufacturer's dashboard indicators were fully operational, and the majority of control switches were instrumented. The cab was equipped with multiple in-vehicle cameras, which provided customized views of the cab environment.

The cab was mounted to the floor of the dome via four hydraulic actuators that created vibrations simulating road feel. The mounting allowed the dome to rotate about its vertical axis by 330 degrees in each direction. The mounting assembly was on top of a traditional hydraulic hexapod, which was secured to two belt-driven beams that moved independently along the X and Y axes. The entire assembly moved about a 64-foot by 64-foot bay.

Eye movement system

Visual scanning of the interior and exterior of the vehicle are critical components to driving (Burns & Lansdown, 2000; Horrey & Wickens, 2004; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003; Wierwille, 1993). Therefore, the participant's natural eye and head movements were collected with the FaceLab 4.0™ system. The system used cameras located on the dashboard to collect head and eye position to calculate gaze direction. The software package allowed the researcher to create a virtual world consisting of the participant's head-model, display screen, and vehicle mirrors.

Experimental Procedure

This simulated driving task took place at the NADS and required approximately 45 minutes to complete. This included calibrating the FaceLab™ eye movement system, experimental briefing, recording of participant demographic information and driving experience, simulator driving, and debriefing. Each participant spent approximately 15 minutes in the simulator (3 minutes of cab familiarization, and 12 minutes of data collection). Immediately after the driving portion of the experiment, participants completed a multiple-choice test to assess sign recall from the sign task. Participants were then debriefed and compensated \$25 for their time.

Simulator Drive

During the startup procedure, a research assistant instructed the participants on the basic functions of the simulator and instructed them to drive as they would in their own vehicles. The drive in this study consisted of a rural single-lane highway, and one section of divided freeway (Figure 3). The drive included two exit ramps (one entering and the other exiting the freeway), three curves, and six stop-sign-controlled intersections with one left turn and right turn (Figure 4). Light to moderate ambient traffic was created throughout. The participants were instructed to maintain the posted speed limit of 45 mph on the rural highway, and 65 mph on the freeway. Participants began driving slowly on a straight roadway, which allowed them to become accustomed to the sensation of the simulator and for the investigator to screen for potential simulator sickness.



Figure 3. Example of the simulated rural roadway in NADS

The informed consent warned participants that simulator sickness (discomfort associated with simulator disorientation, similar to motion sickness) was a potential risk of participation in the study. Some people experience mild to moderate effects, which consist of slight uneasiness, warmth, or eyestrain. The effects typically last for a short time, usually 10-15 minutes, after leaving the simulator. If participants had reported any discomfort, they would have been given the opportunity to end the experiment at once. Fortunately, none of the participants reported experiencing simulator sickness during the drive.

EXPERIMENTAL DESIGN

Independent Variables

Visual Field Loss

VFL was a between-subjects variable. Participants were in the group with VFL (<100 degrees of binocular visual field of view; see Table 1) or the control group.

Scenarios

Participants from each group completed five scenarios within the drive: sign recognition task, merging (on and off the freeway), road geometry change (curved vs. straight), two lead-vehicle braking events, and an intersection incursion (Figure 4b).

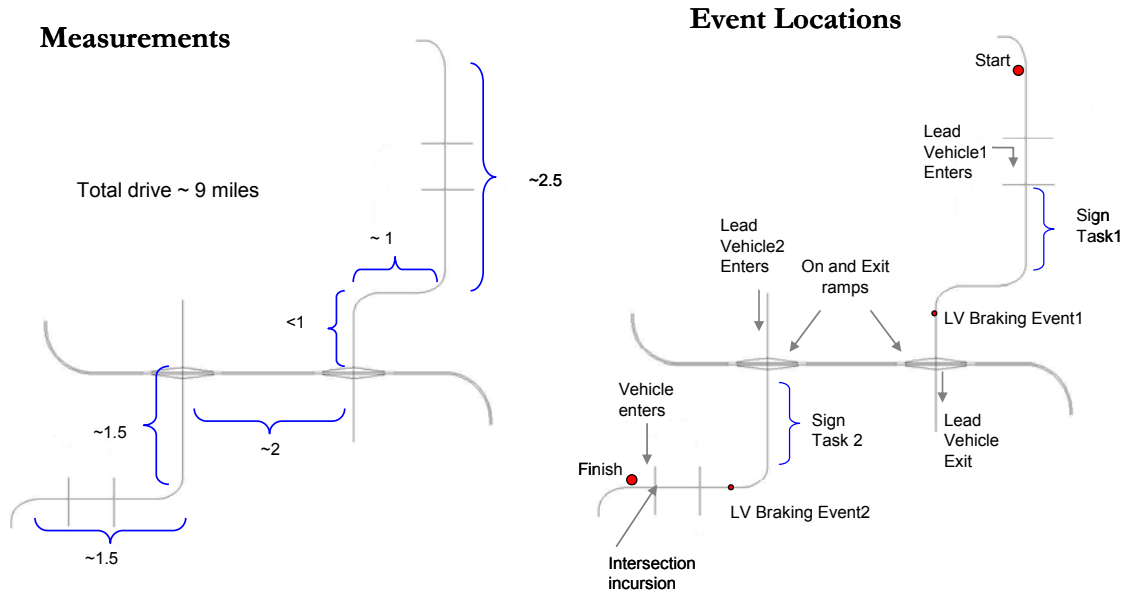


Figure 4. (a) The drive scenario distances in miles. (b) The locations of drive start/end, and events.

1. *Sign Recognition Task.* The sign task was partially replicated from Featherstone et al. (1999). There were eight signs located on a straight rural roadway in the road sign detection task (see Figure 4b & Figure 5). The signs were placed on either side of the road, 13 feet from the road edge and approximately 800 feet from each other (with the exception of sign three which could not be moved within the scenario). The signs were randomly chosen and consisted of approximately equal numbers of regulatory, warning, and route types (Table 4). A research assistant instructed participants to respond when they could identify a sign by clicking the high-beam lever and then by calling out the sign as soon as they could do so. Six signs located in an early rural roadway section were provided as a baseline comparison for the eye movement measures. Only eye movement (not sign recognition) data were collected for this comparison set of signs.

Table 4. Sign names and MUTCD code included in the sign task.

Sign	Description	MUTCD code
1	Speed Limit (45)	R2-1
2	City (Aurora)	I Series
3	Highway Route Marker	--
4	Deer Crossing	W11-3
5	Highway 10 Route with arrows	Route Sign and directional Assemblies
6	Warning - Soft Shoulder	W8-4
7	Speed Limit (45)	R2-1
8	Warning - Right curve	W1-2



Figure 5. Illustration of a sign on the side of the road (circled) in the sign task.

2. *Merging.* The participants completed a merge onto and off of a freeway section of the drive. These sections were just less than 2,000 feet.
3. *Road Geometry Change.* Participants were required to traverse both straight and curved sections of rural roadways. Driving performance data were collected on the 2,000-foot sections of straight and curved roadway.
4. *Lead Vehicle Braking (LVB) Event.* In two portions of the drive (see Figure 4b), a lead vehicle was traveling in front of the participants' vehicle with a programmed headway distance of 200 feet. In both instances, the lead vehicle suddenly broke at a deceleration rate of 4 m/s^2 .
5. *Intersection Incursion.* Participants experienced an unexpected intersection incursion during the last section of the drive (Figure 6). This occurred at a two-way stop intersection, where the crossing traffic had a stop sign. A vehicle approaching from either the right or left (*B*) ran the stop sign and came to a hard brake in the middle of the roadway, eliciting a braking response or steering maneuver from the participant (*A*).

The participant triggered the incurring vehicle, so the timing of the event was approximately the same across all participants. “*B*” was at its final position approximately 5 s before “*A*” reached the intersection. This was calculated by the speed and position of “*A*” when the trigger was fired. A semi-tractor trailer truck was parked on the side of the road, approximately 210 feet from the middle of the intersection and a vehicle (*C*) stopped and was stationed at the intersection.

If the participant had homonymous hemianopia, the origin of the incurring vehicle and location of the parked truck was matched with side of VFL; for those with left VFL, the incurring vehicle approached from the left, and for those with VFL on the right, the approaching vehicle approached from the right. For all other participants, the side of origin was counterbalanced.

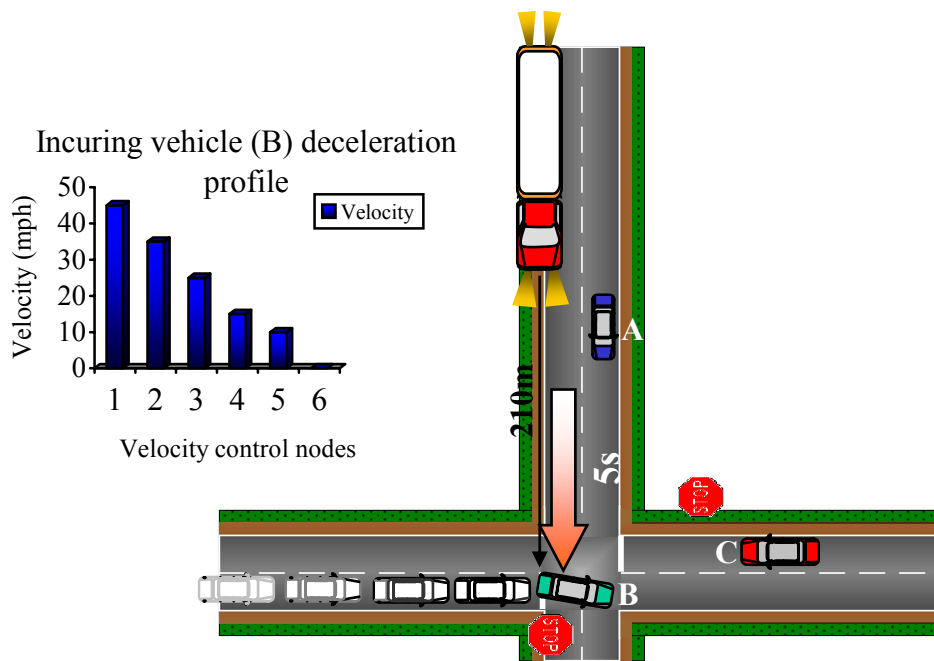


Figure 6. The right hand side intersection incursion; Semi-tractor trailer is parked on the shoulder of the road. Labels: A: the participant's vehicle, B: the incurring vehicle, and C: the stopped vehicle. The bar graph is of the incurring vehicle deceleration triggers.

Dependent Variables

Eye Scanning Measures

The eye tracking software recorded percent of glance frequency and average duration to the roadway, mirrors, speedometer, instrument panel, and off-road. Head movement data were collected in the same manner in order to analyze variability in the vertical and horizontal planes. The eye and head movement data were collected at 60Hz; reported values are averages for each section type. Cameras recorded the overhead view of the driver, face view, foot view, and forward field of view. Each of these views was placed on a quadplex with text superimposed on the screen denoting measures such as time and speed.

Driving Performance Measures

The driving performance data, including measures of steering wheel behavior; brake pedal position; accelerator pedal position; longitudinal velocity of the vehicle; accelerations in the x, y, and z directions; heading angle; and yaw rate were collected in the simulator at 240 Hz. Lane deviation (vehicle offset from the center line of the lane) was collected at 120 Hz. Accelerator release time, brake release time, steer response time, mean and standard deviation of vehicle speed, maximum and standard deviation lane deviation, lane departures, time to collision, and minimum and maximum acceleration were derived from these data. These computed values have been previously used to gain insight on declining driving performance (Donmez, Boyle, & Lee, in press; Paul, Boyle, Tippin, & Rizzo, 2005).

Scenarios

1. Sign Recognition Task

The number of correctly identified road signs, the number incorrect, and the number missed as well as distance from the sign when the in-cab button was pressed were recorded.

2. Merging & Road Geometry

During the merging, curves, and selected straight portions of the drives, the participants' maximum and minimum speed, maximum and standard deviation of lane deviation (calculated based on deviation from center of the roadway), lane departures, position, and minimum and maximum acceleration were reduced and analyzed. (Each analyzed section of straight and curved roadway measured 2,000 ft; the merge sections were slightly shorter.) The percent and average duration of glances towards six areas – front view, instrument panel, speedometer, driver side mirror, rearview mirror, and undefined regions – were calculated for the merging and road geometry scenarios. Head position and variability in the vertical and horizontal planes were also analyzed.

3. Lead Vehicle Braking Event

The following measures were calculated for the lead-vehicle braking (LVB) events, defined as the interval from the time the brake lights of the lead vehicle illuminated to the time the participant pressed the accelerator after the brake response:

Initial velocity. The participant's velocity at the instant the lead vehicle's brake lights were illuminated.

Accelerator release time. The time from the initiation of the braking event, when the braking lights illuminated, to the time the participant released the accelerator pedal.

The maximum rate of deceleration. The participants' lowest acceleration during the LVB events in m/s^2 .

Brake response time. The time (in seconds) the participant required to detect and respond to the vehicle braking, calculated from the onset of the lead vehicle's brake lights until the participant depressed the brake pedal.

Steer response time. This was determined at two thresholds: steering 3.0 and 6.5 degrees in either direction. If the participant passed one of these thresholds, a steer response was calculated from the time of the initiation of the event.

Time to collision (TTC). The time (in seconds) before simulated impact with the lead vehicle would occur if the prevailing conditions continued. This measure depended on the participants' reaction time and braking intensity. The minimum TTC was recorded.

Lane deviation. The distance of deviation from the center of the roadway in either direction, measured in feet. Lane deviation data were collected from the onset of the lead vehicle's brake lights to the end of the LVB event. The maximum and standard deviation of lane deviation were analyzed.

4. Intersection Incursion

The intersection incursion event began when the incurring vehicle was three seconds from the intersection stop-line and ended when the participant either (a) came to a stop, or (b) crossed through the intersection after swerving around the vehicle. Driving performance measures included:

Initial velocity. This was collected at two points: first when the incurring vehicle was created (from a trigger fired by the participant) and again at the time of the beginning of the event.

Accelerator release time. This began when the incurring vehicle was 3 seconds from the intersection stop-line and ended when the participant released the accelerator pedal; it was calculated as in the lead-vehicle braking events.

Brake Response Time. The time (in seconds) participants required to detect and respond to the incurring vehicle. It began the start of the event and ended when the participant depressed the brake.

TTC. The time, in seconds, before simulated impact with the incurring vehicle would have occurred had the prevailing conditions continued. The minimum TTC was recorded.

Lane deviation. The distance of deviation from the center of the roadway in either direction, measured in feet. The maximum and standard deviation of lane deviation were recorded.

Maximum rate of deceleration and steer response time were calculated and recorded as in the LVB events.

Post Drive Measures

Sign Recognition Test. Participants completed a multiple-choice test to evaluate their memory for signs they encountered during the simulated drive.

Demographic information. Age, gender, ethnicity, education, marital status, employment, income bracket, and general health status described above.

Driving Experience. The year participants started driving, amount of driver education, driving frequency, type of vehicle(s) driven, if driving was part of an occupation, miles driven per year, self-reported violations and/or crashes.

Driving Behavior. Travel preferences, typical speed and destinations, driving conditions or locations participants avoid, frequency of driving maneuvers, and comfort with driving maneuvers and various driving environments.

Mental Effort. Participants' perception of effort exerted during the drive.

Realism. The degree to which the simulation represented real world driving.

RESULTS

Data analyses included the Wilcoxon-Mann-Whitney Test with exact statement for small sample sizes, using SAS 9.1 (proc npar1way) software, to analyze significant differences between groups. T-tests (proc t-test) were performed, and when appropriate the Satterthwaite method was used for unequal variances. For the two-way Analysis of Variance (ANOVA), the procedure for general linear model was performed. See the appendix for T-tests and significance levels for these comparisons.

Driving Performance

Data for the sign task, driving measures on curved and straight roadway sections, and during merges on and off the freeway were analyzed using t-tests to identify group differences. In addition, a 2 x (2) ANOVA was conducted on the data from straight and curved roadway sections to determine whether there were interactions between group and road type. Appendix Tables II through VI contain detailed results of the driving performance analyses.

Sign Task

Signs ($N=8$) were posted on both sides of the road during one segment of roadway. Participants were instructed to click the high-beam lever when they detected a sign, and to name the sign as soon as they could do so. T-tests indicated no significant group differences in number of signs detected, distance at which they were reported, accuracy in identifying the signs, or in performance on the post drive sign recognition test.

Road Geometry

The groups differed significantly in maximum lane deviation during the merge off of the freeway ($F(1,1) = 4.05, p = 0.047$) (Figure 7), and during the final curve ($t(11.1) = -2.50, p = 0.030$). When merging off the freeway, the control group's mean lane deviation was 2.59 ft ($SD=0.877$) and the VFL group's was 3.69 ft ($SD=0.840$). During the final curve the VFL group had a marginally significantly greater maximum lane deviation ($M= 3.22, SD=0.877$) than the control group ($M=2.270, SD=0.779$).

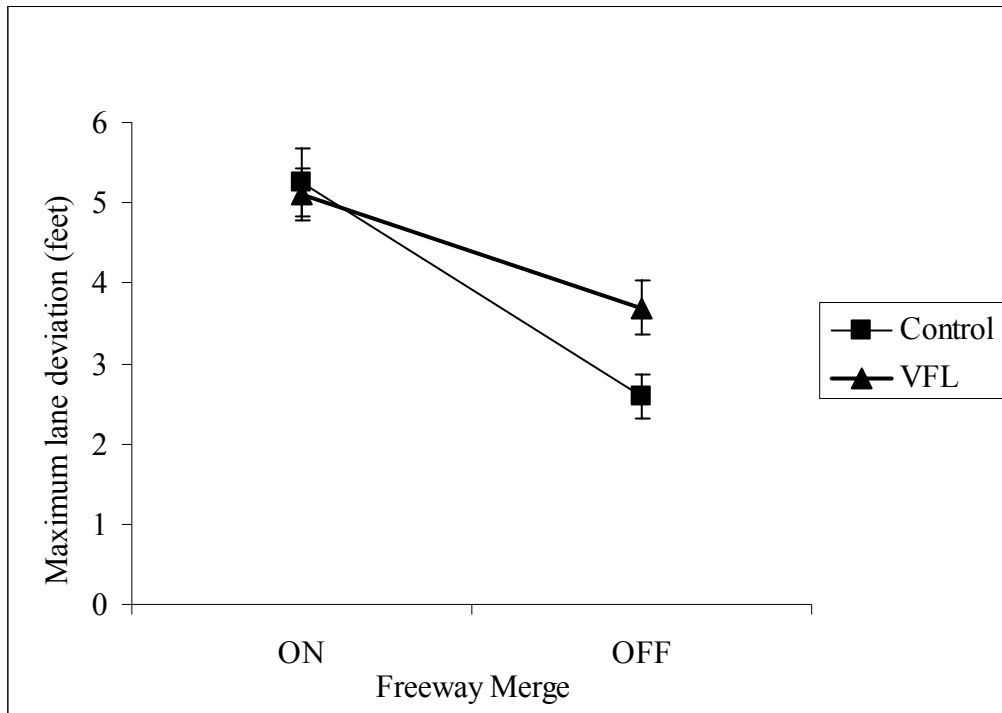


Figure 7. Maximum lane deviation on and off the freeway.

A mixed ANOVA (group by roadway type) was conducted to determine whether the groups differed in the performance measures, and to identify interactions between group and road type. There was a main effect of group; the VFL participants had a significantly larger standard deviation of lane deviation, ($F(3,76) = 4.05, p < 0.05$). There were no significant interactions for the curved versus straight roadways.

Eye Glances and Head Movements

Two-way ANOVAs were performed on the eye glance data. The groups differed significantly in glance duration towards two areas of interest. The VFL group showed significantly longer glances toward the instrument panel, while the control group made longer glances toward the rearview mirror. The groups did not differ significantly in the percent of glances toward the six areas of interest (front, speedometer, instrument panel, rearview mirror, driver side mirror, and undefined regions), and the analysis revealed no significant interactions between roadway (straight versus curved) and group. There were no significant interaction effects in eye glances during the merge on and off the freeway. The groups did not differ significantly in head position variability during the merge, straight or curved road geometry. Appendix Tables VII to XII contain the full results of these analyses.

Lead Vehicle Braking Events

The lead-vehicle braking (LVB) events were defined as the interval that began when the brake lights of the lead vehicle turned on, to the time the accelerator pedal was depressed following the participant's braking response. If the participant was not depressing the accelerator pedal at the beginning of the event then neither the accelerator nor the braking response time was included in the reaction time analysis. Accelerator reaction time data were missing for three participants in the first four participants in the second LVB event.

The steer response time was recorded if the participant passed one of two thresholds; 6.5 and 3.0 degrees. Participants who did not surpass the threshold did not have a steering response and therefore were not included in the steering response analysis. All participants passed the 3.0-degree threshold in both LVB events. In the first event, 11 participants did not surpass the 6.5-degree threshold; in the second, seven did not surpass the 6.5-degree threshold. There were no simulated collisions or lane departures in either event. The VFL group posted a significantly larger standard deviation of lane deviation, $t(7.04)=-2.40$, $p<0.05$ (M , 0.3602, SD 0.157) during the second LVB event than did the control group (M , 0.1919, SD , 0.090) (see Figure 8).

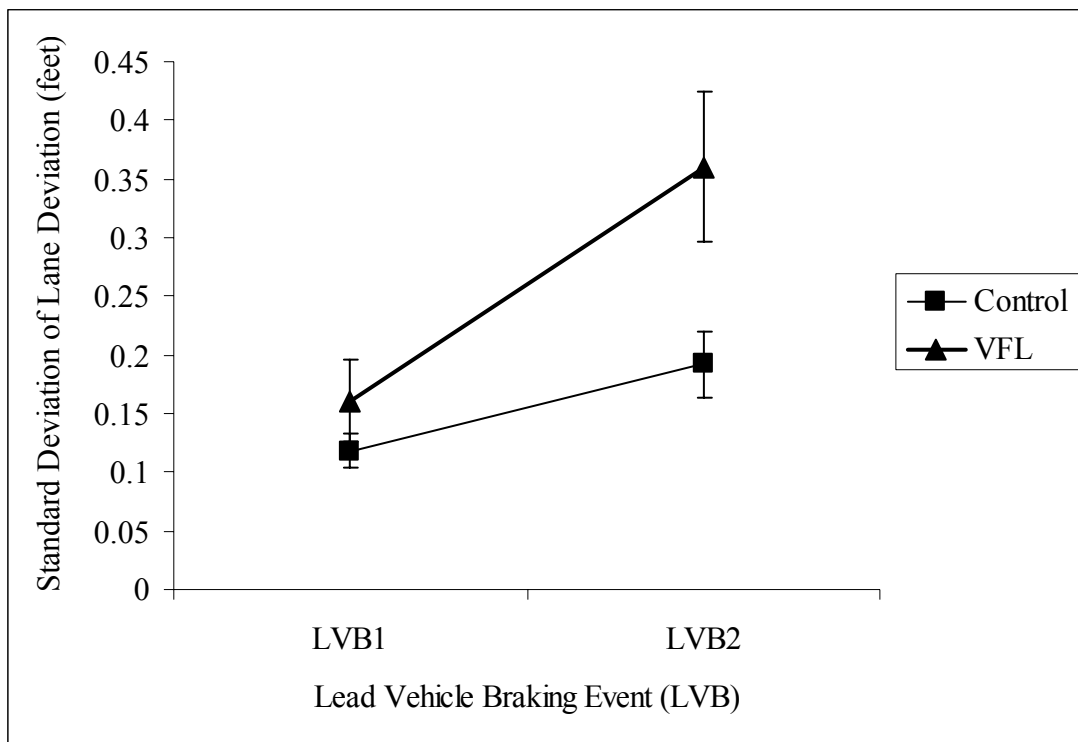


Figure 8. Standard deviation of lane deviation (feet) for lead-vehicle braking events.

Intersection Incursion Event

Participants could avoid the incursion vehicle in two ways: by coming to a stop or steering around the vehicle. Six of the participants steered around the vehicle, while 10 came to a stop. There were no significant differences between the groups in the action taken to avoid the incursion event ($\chi^2 = 0.07$, $p = 0.79$). One VFL participant, whose gaze was within the vehicle at the time of approach, collided with the incurring vehicle in the simulated scenario. Three participants did not have an accelerator release time so were not included in the reaction time analysis. One participant did not surpass the steering threshold of 6.5 so was not included in the steering reaction time analysis. The control group had significantly faster accelerator release time ($M= 0.659$, $SD=0.570$) than the VFL group ($M=1.516$, $SD = 0.612$). However, the difference in accelerator release time was not significant when examining only those who stopped. The control group also had a longer (safer) time to simulated collision ($M=7.7697$, $SD=1.960$) than the VFL group ($M=3.3308$, $SD=1.148$).

Table 5. Frequency of stopping or avoiding the incursion event.

Group	Action		Total
	Avoid	Stop	
Control	4 (25%)	6 (37%)	10 (62%)
VFL	2 (12%)	4 (25%)	6 (37%)
Total	6 (37%)	10 (62%)	

Ratings of Simulator Experience

Self Rated Performance

After the drive, participants rated their overall performance on a scale from 1 (very poor) to 10 (excellent). The 13 participants who found parts of the drive challenging most frequently specified difficulty in stopping (61% of the sample) and turning (38% of the sample). The participants reported any disorientation during the drive on a scale of 1 (not at all) to 10 (very disoriented), and rated the extent of simulator sickness they experienced on a scale of 1 (none) to 10 (severe). The groups did not significantly differ in their self-rated performance, or on responses to questions about task difficulty, disorientation, or simulator sickness.

Rating of Mental Effort

After completing the drive, participants rated their mental effort on a standard scale; scores ranged from 0 (absolutely no effort) to 110 (extreme effort). The control group's mean mental effort score of 40.1 ($SD=22.07$) and the VFL group's score of 43.33 ($SD= 17.51$) did not differ significantly.

Simulator Realism

The participants rated simulator realism on a 6-point scale from 0 (not at all realistic) to 6 (completely realistic). Participants' mean score was 4.38 ($SD=1.15$); the groups' ratings were not significantly different.

DISCUSSION

The aim of this study was to examine differences in the general driving and sign detection performance between drivers with peripheral VFL and controls with normal visual fields in a driving simulator. The results suggest a few significant differences in driving performance measures between the VFL and control groups.

The VFL group exhibited greater variation in lane deviation during the final curve and when departing the freeway. These findings are consistent with those of Bowers et al (2005), that drivers with more restricted fields of view had difficulty maintaining lane position and keeping the path of a curve. Some have also found that those with VFL compensate by reducing their speed while driving (Coeckelbergh et al., 2002), but that technique was not revealed in this present study.

The groups responded somewhat differently to the hazard events. The VFL group took significantly longer to release the accelerator, and had a smaller (riskier) time to simulated collision during the intersection incursion. The VFL group also exhibited more variation in lane position during one lead-vehicle braking event. This may indicate that those with VFL used a strategy of steering to avoid a hazard. This could be a poor choice given that these drivers may have difficulty monitoring for drivers in adjacent lanes. Although there is not clear evidence of elevated crash risk associated with VFL, these findings provide information that may be valuable in making safety recommendations to drivers with VFL.

The findings from the current study did not support the hypothesis that people with VFL would compensate for their restricted field of view with greater variability in head movements and increased eye glances. In preliminary findings of drivers with hemianopia, some authors have found a positive relationship between head movement and intersection target detection rates, suggesting this could be a beneficial compensatory behavior (Bowers, Mandel, Goldstein, & Peli, 2007). Driving examiners have noted head movements as an effective compensation strategy for those with restricted fields of view (Coeckelbergh et al., 2002). However, the groups in the current study had similar head position variability in the horizontal and vertical planes and made similar eye glances to peripheral locations. The failure to find significant differences between groups in head movements and eye glance behaviors may have resulted from the small sample size in the current study, the relatively short simulated drive, or to differences in the type and degree of participants' VFL in this study and those cited in the literature review.

There were unexpected differences between groups in average glance duration. The VFL group made significantly longer glances to the speedometer, and the control group had longer glances towards the rearview mirror. The drivers with VFL may have spent more time looking at the speedometer in order to maintain their speed, a dimension where the use of peripheral vision has been shown to be relevant (Bhise & Rockwell, 1971).

Unstructured dialogs with some of the VFL participants indicated that, in the real world, they do take more time, especially at intersections, to conduct multiple checks of their periphery before executing a maneuver. Bao and Boyle (2007) observed differences in visual scanning behavior in an instrumented vehicle study on older drivers that support this finding.

Both groups reported similar driving habits and history, and the VFL participants did not show any deficits in comparison to those with normal vision in responding to and identifying roadway signs.

Limitations of the study

There were a number of limitations to this study. First, there was only one 15-minute experimental drive. Participants spent approximately the first 3 minutes becoming familiar with the simulator. This limited the capability to counterbalance drives (i.e., change events/scenarios around) to identify learning effects or effects of scenario transitions, and limited the total number of scenarios. Second, the experiment was run over two days, which proved to be problematic for participant recruitment and scheduling. Third, the sample size was too small to allow generalization to the larger population. This is of particular concern given differences in characteristics of visual field restrictions within the VFL group; half had symmetrical field loss while the remaining half had restriction on only one side. Finally, due to the wide range of participant age (28-61), age effects may have influenced the results.

SUMMARY

This document provides a literature review of studies related to VFL in the driving domain, experimental procedure, and results of the VFL study. The studies reviewed used a variety of methods ranging from on-road field tests, driving simulators, crash data, and surveys. The majority of studies indicated that drivers with visual impairments tend to compensate somewhat for their impairment by restricting their driving to times when they feel more comfortable. Others have grown accustomed to their impairment, and have changed the way they physically view the environment. This exploratory motion-based simulator study focused on some performance and behavioral measures. Differences in performance measures were found for lane maintenance and lane deviation as well as responses to unexpected events between participants with mixed field loss and a control group of participants with normal visual fields. Future research might examine compensation strategies used by drivers with VFL.

ACKNOWLEDGEMENTS

We would like to acknowledge the assistance and time provided by Dr. Matthew Rizzo; the NADS research team: Tim Brown, Omar Ahmad, Larry Hynes, Shawn Allen, Yefei He, Scott Egerton, Jeff Gordon, Ben Dow, Tara Smyser, Catherine Mize, Chris Schwarz, Cheryl Roe, Jane Moeckli, and Sue Ellen Salisbury; and Darcy Wolf at the Department of Ophthalmology and Visual Sciences Department for her assistance with the visual screening. The research team at the HFSM lab at the University of Iowa: Jenna Smith, Shan Bao, Greggor Vesser, Kendra Meyer, Audrey Leung, Dave Neyens, and Birsen Donmez for their assistance and support during this project.

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APPENDIX

Avoided Roadway Conditions

Table I: Roadway conditions which would keep participants from driving.

Condition	Mean	SD	Z	p>= S-M
Nighttime/darkness	0.688	1.195	1.193	NS
Fog	1.00	1.095	0.4585	NS
Snow/sleet	0.688	1.078	0.814	NS
Rain	0.813	0.834	-0.464	NS
Rush hour traffic	1.06	1.181	0.1769	NS
Highway/freeway	0.31	0.602	0.358	NS

Sign Task Results.

Table II. Performance on sign tasks.

	VFL Mean (SD)	Control Mean (SD)	Mean Difference	Confidence Limits	df	t	Pr> t
Correctly Identified Signs	6.33 (2.066)	6.89 (1.167)	0.556	2.348,-1.237	7.15	0.60	0.5681
Distance From Sign At Button Press (ft)	304.46 (198.53)	486.78 (218.57)	182.32	416.71, -52.07	11.5	1.71	0.1137
Post Drive Sign Test (perfect score =6)	5.1 (1.287)	4.67 (4.51)	0.4333	2.159, 1.002	9.35	0.59	0.5705
Perceived Accuracy (scale 1-10)	7.33 (1.96)	7.30 (1.77)	-0.033	2.005, -2.072	9.75	-0.03	0.9735

Driving Performance Analyses

Table III. Driving performance during curves.

	Curve	Control Mean (SD)	VFL Mean (SD)	Mean Difference	Confidence Limits	df	t	Pr> t
Mean Velocity (mph)	1	43.10 (3.300)	41.45 (6.193)	4.550	6.687, -3.391	6.74	0.60	NS
	2	47.75 (3.197)	45.751 (3.228)	1.996	5.250, -1.427	8.30	1.13	NS
	3	42.47 (4.791)	42.29 (5.549)	0.181	5.801, -5.44	9.42	0.07	NS
Maximum Velocity (mph)	1	46.25 (3.492)	45.55 (3.912)	0.702	4.742, -3.338	9.69	0.36	NS
	2	47.75 (3.197)	45.75 (3.228)	1.996	5.549, -1.557	10.60	1.20	NS
	3	46.87 (4.209)	45.97 (3.663)	0.900	5.355, -3.555	11.90	0.45	NS
Minimum Velocity (mph)	1	40.15 (2.776)	45.71 (4.730)	8.550	8.553, -3.776	6.74	0.71	NS
	2	40.91 (2.957)	39.86 (3.997)	1.048	4.775, -2.68	8.32	0.56	NS
	3	38.67 (5.695)	38.50 (6.396)	0.167	6.762, -6.428	9.67	0.05	NS
Maximum Lane Deviation (feet)	1	2.53 (1.153)	3.01 (0.925)	-0.475	0.718, -1.667	12.60	-0.90	NS
	2	1.94 (0.412)	1.95 (0.505)	-0.017	5.549, -1.557	9	-0.07	NS
	3	2.270 (0.779)	3.22 (0.877)	-0.95	-0.047, -1.853	9.65	-2.19	0.0545
SD Lane Deviation (feet)	1	0.561 (0.195)	0.737 (0.272)	-0.176	0.074, -0.426	8.14	-1.38	NS
	2	0.448 (0.104)	0.505 (0.135)	-0.057	0.071, -0.186	8.57	-0.90	NS
	3	0.550 (0.224)	0.659 (0.264)	-0.108	0.156, -0.373	9.26	-0.84	NS
Maximum Acceleration (feet/s ²)	1	1.054 (0.465)	1.378 (0.504)	-0.324	1.387, 0.721	9.98	-1.28	NS
	2	0.916 (0.284)	0.862 (0.615)	0.054	0.532, -0.425	6.30	0.20	NS
	3	1.270 (0.496)	1.1331 (0.461)	0.137	0.673, -0.399	11.30	0.56	NS
Minimum Acceleration (feet/s ²)	1	-1.718 (0.100)	-1.672 (0.204)	-0.045	0.853, -0.943	10.20	-0.14	NS
	2	-2.337 (1.480)	-1.804 (0.723)	-0.533	0.866, -1.931	13.70	-0.96	NS
	3	-1.807 (1.071)	-2.019 (1.327)	0.212	1.507, -1.083	8.92	0.33	NS

Table IV. Performance on straight roadway sections.

	Straight	Control Mean (SD)	VFL Mean (SD)	Mean difference	Confidence Limits	df	t	Pr> t
Mean Velocity (mph)	1	43.11 (3.023)	44.41 (3.214)	-1.30	2.125, -4.725	10.10	-0.80	NS
	2	49.19 (3.193)	47.19 (2.421)	2.00	5.260, -1.255	13	1.42	NS
Maximum Velocity (mph)	1	46.88 (3.570)	47.53 (2.385)	-0.65	2.892, -4.191	13.70	-0.44	NS
	2	51.08 (3.306)	49.25 (1.648)	1.83	4.958, -1.306	13.80	1.47	NS
Minimum Velocity (mph)	1	39.29 (4.048)	41.09 (4.859)	-1.80	3.023, -6.624	9.15	-0.76	NS
	2	44.41 (3.007)	44.37 (3.932)	0.044	3.772, -3.685	8.54	0.02	NS
Maximum Lane Deviation (feet)	1	1.52 (0.461)	1.48 (0.480)	0.039	0.558, -0.479	10.30	0.16	NS
	2	1.58 (0.529)	1.78 (0.709)	1.826	0.458, -0.870	8.38	-0.62	NS
SD Lane Deviation (feet)	1	0.364 (0.119)	0.43 (0.177)	-0.069	0.089, -0.226	7.74	-0.84	NS
	2	0.392 (0.176)	0.45 (0.150)	-0.056	0.129, -0.241	12.1	-0.68	NS
Maximum Acceleration (feet/s ²)	1	1.53 (0.865)	1.21 (0.937)	0.320	1.307, -0.667	9.97	0.68	NS
	2	1.90 (0.858)	1.25 (0.931)	0.648	1.628, -0.332	9.95	1.39	NS
Minimum Acceleration (feet/s ²)	1	-2.63 (1.528)	-2.59 (1.596)	-0.044	1.676, -1.764	10.3	-0.05	NS
	2	-2.24 (2.230)	-1.92 (0.975)	-0.313	1.770, -2.396	13.2	-0.39	NS

Table V. Performance during merges on and off the freeway.

	Merge	Control Mean (SD)	VFL Mean (SD)	Mean difference	Confidence Limits	df	t	Pr> t
Mean Velocity (mph)	ON	59.803 (5.145)	53.787 (6.650)	6.015	12.359, -0.329	8.62	1.90	NS
	OFF	49.633 (4.399)	45.399 (10.910)	4.234	12.44, -3.976	14	1.11	NS
Maximum Velocity (mph)	ON	62.333 (4.160)	57.572 (4.668)	4.761	9.577, -0.055	9.68	2.06	NS
	OFF	54.009 (5.264)	50.117 (10.831)	3.893	12.451, -4.666	14	0.98	NS
Minimum Velocity (mph)	ON	57.742 (6.132)	50.789 (8.182)	6.953	14.633, -0.728	8.41	1.80	NS
	OFF	47.005 (4.352)	42.282 (9.749)	4.723	12.245, -2.799	14	1.35	NS
Maximum Lane Deviation (feet)	ON	5.258 (1.355)	5.1092 (0.777)	0.149	1.458, -1.16	14	0.28	NS
	OFF	2.594 (0.877)	3.6945 (0.840)	-1.101	-0.144, -2.057	11.1	-2.50	0.0296
SD Lane Deviation (feet)	ON	1.543 (0.470)	1.3782 (0.281)	0.164	0.621, -0.293	14	0.88	NS
	OFF	0.575 (0.210)	0.742 (0.147)	-0.167	0.043, -0.377	13.5	-1.87	NS
Maximum Acceleration (feet/s ²)	ON	1.719 (1.138)	2.292 (1.388)	-0.573	0.792, -1.939	9.03	-0.85	NS
	OFF	0.364 (1.098)	0.388 (1.238)	-0.023	-0.144, -2.057	9.64	-0.04	NS
Minimum Acceleration (feet/s ²)	ON	-0.925 (1.063)	-0.713 (1.194)	-0.212	1.018, -1.443	9.67	-0.36	NS
	OFF	-3.858 (2.088)	-4.343 (2.222)	0.486	2.852, -1.881	10.1	0.43	NS

Table VI. Driving performance measures: 2x2 ANOVA, road type (curved versus straight) by group (VFL versus control).

Measure	Source	df	F	Pr>F
Mean Velocity (mph)	Road type	1	11.06	0.0014
	Group	1	0.69	NS
	Road type* Group	1	0.22	NS
Maximum Velocity (mph)	Road type	1	8.07	0.0058
	Group	1	1.19	NS
	Road type* Group	1	0.14	NS
Minimum Velocity (mph)	Road type	1	7.10	0.0094
	Group	1	0.02	NS
	Road type* Group	1	0.86	NS
Maximum Lane Deviation (feet)	Road type	1	24.92	<.0001
	Group	1	2.47	NS
	Road type* Group	1	1.23	NS
SD Lane Deviation (feet)	Road type	1	14.65	0.0003
	Group	1	4.05	0.0478
	Road type* Group	1	0.35	NS
Maximum Acceleration (feet/s ²)	Road type	1	5.56	0.0209
	Group	1	1.98	NS
	Road type* Group	1	2.86	NS
Minimum Acceleration (feet/s ²)	Road type	1	2.01	NS
	Group	1	0.22	NS
	Road type* Group	1	0.01	NS

Eye Glance and Head Movement Analyses

Table VII. Percent of glances towards areas of interest during straight and curved roadway sections.

Measure	Source	df	F	Pr>F
Front	Road type	1	1.35	NS
	Group	1	0.01	NS
	Road type* Group	1	0.12	NS
Speedometer	Road type	1	1.44	NS
	Group	1	0.41	NS
	Road type* Group	1	0.04	NS
Instrument Panel	Road type	1	0.05	NS
	Group	1	2.95	NS
	Road type* Group	1	0.02	NS
Rearview Mirror	Road type	1	0.02	NS
	Group	1	2.12	NS
	Road type* Group	1	2.22	NS
Driver Side Mirror	Road type	1	0.00	NS
	Group	1	0.33	NS
	Road type* Group	1	0.03	NS
Undefined Regions	Road type	1	0.27	NS
	Group	1	0.14	NS
	Road type* Group	1	1.83	NS

Table VIII. Percent of glances towards areas of interest during merges on and off the freeway.

Measure	Source	df	F	Pr>F
Front	Road type	1	35.50	<.0001
	Group	1	0.07	NS
	Road type* Group	1	0.17	NS
Speedometer	Road type	1	0.05	NS
	Group	1	2.33	NS
	Road type* Group	1	0.22	NS
Instrument Panel	Road type	1	0.06	NS
	Group	1	0.03	NS
	Road type* Group	1	0.09	NS
Rearview Mirror	Road type	1	4.43	0.0443
	Group	1	0.00	NS
	Road type* Group	1	0.01	NS
Driver Side Mirror	Road type	1	32.86	<.0001
	Group	1	0.30	NS
	Road type* Group	1	0.08	NS
Undefined Regions	Road type	1	65.52	<.0001
	Group	1	1.35	NS
	Road type* Group	1	0.00	NS

Table IX. Average glance durations during straight and curve roadway sections.

Measure	Source	df	F	Pr>F
Front	Road type	1	3.52	NS
	Group	1	0.21	NS
	Road type* Group	1	0.07	NS
Speedometer	Road type	1	0.50	NS
	Group	1	3.75	NS
	Road type* Group	1	0.79	NS
Instrument Panel	Road type	1	0.15	NS
	Group	1	14.01	0.0004
	Road type* Group	1	0.30	NS
Rearview Mirror	Road type	1	0.10	NS
	Group	1	4.85	0.0307
	Road type* Group	1	1.58	NS
Driver Side Mirror	Road type	1	0.42	NS
	Group	1	0.08	NS
	Road type* Group	1	0.03	NS
Undefined Regions	Road type	1	2.37	NS
	Group	1	2.73	NS
	Road type* Group	1	3.38	NS

Table X. Average glance durations towards areas of interest during merges on and off the freeway.

Measure	Source	df	F	Pr>F
Front	Road type	1	0.79	NS
	Group	1	0.70	NS
	Road type* Group	1	0.01	NS
Speedometer	Road type	1	0.16	NS
	Group	1	0.80	NS
	Road type* Group	1	1.00	NS
Instrument Panel	Road type	1	3.43	NS
	Group	1	1.54	NS
	Road type* Group	1	0.72	NS
Rearview Mirror	Road type	1	1.22	NS
	Group	1	1.48	NS
	Road type* Group	1	0.79	NS
Driver Side Mirror	Road type	1	10.35	0.0033
	Group	1	1.84	NS
	Road type* Group	1	1.84	NS
Undefined Regions	Road type	1	15.83	0.0004
	Group	1	0.94	NS
	Road type* Group	1	3.16	NS

Table XI. Horizontal and vertical head position variability during straight and curve roadway sections.

Measure	Source	df	F	Pr>F
Horizontal head position variability (meters)	Road type	1	1.58	NS
	Group	1	3.78	NS
	Road type* Group	1	0.35	NS
Vertical head position variability (meters)	Road type	1	1.28	NS
	Group	1	0.35	NS
	Road type* Group	1	1.47	NS

Table XII. Horizontal and vertical head position variability during merges on and off the freeway.

Measure	Source	df	F	Pr>F
Horizontal head position variability (meters)	Road type	1	13.96	0.0008
	Group	1	3.58	NS
	Road type* Group	1	0.00	NS
Vertical head position variability (meters)	Road type	1	9.86	0.004
	Group	1	0.17	NS
	Road type* Group	1	0.19	NS

Responses to Unexpected Events

Table XIII. Lead vehicle braking event performance measures.

	Event	Control Mean (SD)	VFL Mean (SD)	Mean Difference	Confidence Limits	df	t	Pr> t
Accelerator Release Time (s)	LVB1	0.547 (0.198)	0.654 (0.300)	-0.107	0.199, -0.412	8.46	-0.74	NS
	LVB2	0.595 (0.211)	0.722 (0.359)	-0.127	0.238, -0.492	5.98	-0.71	NS
Brake Response Time (s)	LVB1	0.940 (0.231)	1.049 (0.359)	-0.109	0.252, -0.47	8.34	-0.64	NS
	LVB2	0.893 (0.167)	1.126 (0.321)	-0.233	0.081, -0.547	5.55	-1.48	NS
Initial Velocity (mph)	LVB1	43.635 (3.229)	45.183 (2.525)	-1.548	1.770, -4.867	12.8	-1.07	NS
	LVB2	45.949 (4.882)	45.868 (2.649)	0.0808	3.091, -4.596	14	0.04	NS
Steer Response Time (s) (at 6.5 degrees)	LVB1	3.4163 (1.013)	3.969 (3.715)	-0.553	7.578, -5.779	1.1	0.33	NS
	LVB2	3.4163 (0.956)	3.969 (2.561)	-0.553	2.344, -3.449	3.67	-0.41	NS
Steer Response Time (s) (at 3.0 degrees)	LVB1	2.5129 (1.010)	2.1154 (1.145)	0.3975	1.572, -0.777	9.59	0.70	NS
	LVB2	2.5679 (0.733)	2.7097 (1.954)	-0.142	1.306, -1.59	14	-0.21	NS
Max Steer Rate (Degrees/s)	LVB1	16.622 (5.570)	18.283 (13.193)	-1.661	8.375, -11.7	14	-0.35	NS
	LVB2	17.423 (5.696)	31.987 (29.417)	-14.56	5.553, -34.68	14	-1.55	NS
Max Deceleration (feet/s ²)	LVB1	-22.81 (4.469)	-23.36 (6.072)	0.552	6.200, -5.097	8.29	0.19	NS
	LVB2	-19.03 (2.391)	-20.51 (6.609)	1.487	-13.58, -27.45	14	0.66	NS
Time to Collision (s)	LVB1	88.66 (14.630)	89.179 (26.869)	-0.519	21.503, -22.54	6.82	-0.04	NS
	LVB2	96.371 (13.369)	87.168 (30.061)	9.203	32.373, -13.97	6.21	0.71	NS
Max Lane Deviation (feet)	LVB1	1.3707 (0.756)	1.746 (0.899)	-0.376	0.5212, -1.273	9.22	-0.86	NS
	LVB2	1.031 (0.497)	1.389 (0.472)	-0.358	0.1826, -0.899	11.1	-1.44	NS
SD Lane Deviation (feet)	LVB1	0.118 (0.046)	0.161 (0.084)	-0.044	0.0255, -0.113	6.81	-1.17	NS
	LVB2	0.1919 (0.090)	0.3602 (0.157)	-0.168	-0.037, -0.299	7.04	-2.40	0.0470

Table XIV. Incursion event performance measures (all participants).

	Control Mean (SD)	VFL Mean (SD)	Mean Difference	Confidence Limits	df	t	Pr> t
Accelerator Release Time (s)	0.659 (0.570)	1.5155 (0.612)	-0.857	-0.208, -1.505	10.10	-2.78	0.0193
Brake Response Time (s)	1.1899 (0.742)	1.7836 (0.748)	-0.594	0.230, -1.418	10.60	-1.54	NS
Velocity at Vehicle Creation (mph)	46.842 (5.562)	46.493 (2.720)	0.348	5.606, -4.909	13.70	0.17	NS
Velocity at Event Start (mph)	46.692 (5.621)	46.486 (2.790)	0.206	5.528, -5.116	13.70	0.10	NS
Steer Response Time 6.5 (s)	2.431 (0.811)	2.780 (0.680)	-0.348	0.521, -1.216	12.10	-0.90	NS
Steer Response Time 3.0 (s)	1.967 (0.943)	1.605 (0.988)	0.362	1.421, -0.701	10.30	0.72	NS
Max Steer Rate (Degrees/s)	95.100 (69.05)	296.65 (236.54)	-201.5	-33.40, -369.7	5.52	-2.04	NS
Max Deceleration (feet/s ²)	-21.88 (8.573)	-26.36 (9.044)	4.474	14.158, -5.211	10.20	0.98	NS
Time to Collision (s)	4.463 (3.908)	1.598 (2.108)	2.865	7.596, -1.867	9.79	1.65	NS
Max Lane Deviation (feet)	3.454 (2.261)	4.060 (2.148)	-0.606	1.855, -3.066	11.10	-0.54	NS
SD Lane Deviation (feet)	0.8168 (0.669)	0.8015 (0.614)	0.015	0.735, -0.704	11.40	0.05	NS

Table XV. Incursion event performance measures for those who stopped (N=10).

	Control Mean (SD)	VFL Mean (SD)	Mean Difference	Confidence Limits	df	t	Pr> t
Accelerator Release Time (s)	0.6643 (0.424)	1.4627 (0.732)	-0.798	0.035, -1.63	4.36	-1.97	NS
Brake Response Time (s)	1.0094 (0.291)	1.6653 (0.730)	-0.656	0.093, -1.40	3.64	-1.71	NS
Velocity at Vehicle Creation (mph)	44.57 (5.285)	46.173 (2.652)	-1.602	5.070 -8.28	7.67	-0.63	NS
Velocity at Event Start (mph)	44.447 (5.417)	46.263 (2.634)	-1.815	4.997, -8.63	7.58	-0.71	NS
Steer Response Time 6.5 (s)	2.4032 (1.085)	2.5725 (0.769)	-0.169	1.357, -1.7	6.95	-0.27	NS
Steer Response Time 3.0 (s)	2.0195 (1.176)	1.7241 (0.834)	0.2954	2.717, 0.844	7.9	0.46	NS
Max Steer Rate (Degrees/s)	68.435 (5.567)	376.19 (13.193)	-307.8	-56.86, -559.00	3.28	-2.31	NS
Max Deceleration (feet/s ²)	-27.64 (3.934)	-29.35 (2.329)	1.7104	6.803, -3.38	7.97	0.86	NS
Time to Collision (s)	7.7697 (1.960)	3.3308 (1.148)	4.439	8.747, 0.131	3.54	3.49	0.0307
Max Lane Deviation (feet)	1.7803 (0.892)	3.1391 (2.072)	-1.359	0.802, -3.52	3.75	-1.24	NS
SD Lane Deviation (feet)	0.3247 (0.258)	0.527 (0.394)	-0.202	0.268, -0.670	4.73	-0.91	NS

Simulator Experience

Table XVI. Self-rated simulator experience.

	Control Mean (SD)	VFL Mean (SD)	Mean Difference	Confidence Limits	df	t	Pr> t
Overall Performance (scale from 1 to10)	6.5 (1.78)	6.75 (1.17)	-0.25	1.511, -2.011	13.8	-0.34	0.7402
Disorientation (scale from 1 to10)	3.4 (2.32)	2.33 (1.21)	1.067	-1.143, 3.277	14	1.04	0.3181
Simulator Sickness (scale from 1 to10)	2.5 (2.72)	1.67 (1.21)	0.833	-1.71, 3.377	14	0.70	0.4938
Simulator Realism (scale from 1 to 6)	4.3 (1.25)	4.50 (1.05)	-0.2	1.111, -1.51	12.2	-0.34	0.7374
Mental Effort (scale from 1to110)	40.1 (22.07)	43.33 (17.51)	-3.233	19.535, 15.05	12.7	-0.32	0.7515

Realism Survey

For each of the following items, circle the number that best indicates how closely the simulator resembles an actual car in terms of appearance, sound, and response.

	<u>General Driving</u>	Not at all realistic						Completely Realistic	
1	Response of the seat adjustment levers	0	1	2	3	4	5	6	NA
2	Response of the mirror adjustment levers	0	1	2	3	4	5	6	NA
3	Response of the door locks and handles	0	1	2	3	4	5	6	NA
4	Response of the fans	0	1	2	3	4	5	6	NA
5	Response of the gear shift	0	1	2	3	4	5	6	NA
6	Response of the brake pedal	0	1	2	3	4	5	6	NA
7	Response of accelerator pedal	0	1	2	3	4	5	6	NA
8	Response of the speedometer	0	1	2	3	4	5	6	NA
9	Response of the steering wheel while driving straight	0	1	2	3	4	5	6	NA
10	Response of the steering wheel while driving on curves	0	1	2	3	4	5	6	NA
11	Feel when accelerating	0	1	2	3	4	5	6	NA
12	Feel when braking	0	1	2	3	4	5	6	NA
13	Feel when passing other cars	0	1	2	3	4	5	6	NA
14	Feel when driving straight	0	1	2	3	4	5	6	NA
15	Feel when driving on curves	0	1	2	3	4	5	6	NA
16	Ability to read road and warning signs	0	1	2	3	4	5	6	NA
17	Appearance of roads and road markings	0	1	2	3	4	5	6	NA
18	Appearance of signs	0	1	2	3	4	5	6	NA
19	Appearance of intersections	0	1	2	3	4	5	6	NA
20	Appearance of car interior	0	1	2	3	4	5	6	NA
21	Appearance of roadside scenery	0	1	2	3	4	5	6	NA
22	Appearance of other vehicles	0	1	2	3	4	5	6	NA
23	Appearance of rear-view mirror image	0	1	2	3	4	5	6	NA
24	Sound of the car	0	1	2	3	4	5	6	NA
25	Sound of other vehicles	0	1	2	3	4	5	6	NA
26	Overall feel of the car when driving	0	1	2	3	4	5	6	NA
27	Overall similarity to real driving	0	1	2	3	4	5	6	NA
	<u>Rural Highway Driving</u>								
28	Feel of approximate speed when driving 65 mph	0	1	2	3	4	5	6	NA
29	Appearance of rural scenery	0	1	2	3	4	5	6	NA
30	Ability to respond to other vehicles	0	1	2	3	4	5	6	NA
31	Ability to negotiate curves	0	1	2	3	4	5	6	NA
32	Ability to keep straight in your lane	0	1	2	3	4	5	6	NA
33	Ability to respond to traffic	0	1	2	3	4	5	6	NA
34	Ability to maintain control while driving straight	0	1	2	3	4	5	6	NA
35	Ability to maintain control while in curve	0	1	2	3	4	5	6	NA
36	Ability to change lanes	0	1	2	3	4	5	6	NA
37	Ability to steer around objects	0	1	2	3	4	5	6	NA
38	Overall appearance of driving scenes	0	1	2	3	4	5	6	NA

DOT HS 811 062
January 2009



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