On-road Driving Performance by Persons with Hemianopia and Quadrantanopia

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ABSTRACT

Purpose: To examine the on-road driving performance of drivers with hemianopia and quadrantanopia compared with age-matched controls.

Methods: Participants included persons with hemianopia or quadrantanopia and those with normal visual fields. Visual and cognitive function tests were administered, including confirmation of hemianopia and quadrantanopia through visual field testing. Driving performance was assessed using a dual-brake vehicle and monitored by a certified driving rehabilitation specialist. The route was 14.1 miles of city and interstate driving. Two "back-seat" evaluators masked to drivers' clinical characteristics independently assessed driving performance using a standard scoring system.

Results: Participants were 22 hemianopes and 8 quadrantanopes (mean age 53±20 years) and 30 participants with normal fields (mean age 52±19 years). Inter-rater agreement for backseat evaluators was 96%. All drivers with normal fields were rated as safe to drive, while 73% (16/22) of hemianopic and 88% (7/8) of quadrantanopic drivers received safe ratings. Hemianopic and quadrantanopic drivers who displayed on-road performance problems tended to have difficulty with lane position, steering steadiness, and gap judgment compared to controls. Clinical characteristics associated with unsafe driving were slowed visual processing speed, reduced contrast sensitivity and visual field sensitivity.

Conclusions: Some drivers with hemianopia or quadrantanopia are fit to drive compared with age-matched control drivers. Results call into question the fairness of governmental policies that categorically deny licensure to persons with hemianopia or quadrantanopia without the opportunity for on-road evaluation.

INTRODUCTION

Homonymous visual field defects occur when field loss is in the same relative position in visual space in each eye. The term hemianopia is used if one half of the field is involved, and quadrantanopia if only one quadrant is affected. These conditions result from post-chiasmal damage to the visual pathways, with the most common etiology being stroke with other causes including traumatic brain injury and tumor.[1-3] The prevalence of homonymous hemianopic visual field defects was recently estimated to be 0.8% within a community-dwelling population ≥ 49 years old, with 52% of these reporting a history of stroke.[4]

Individuals with hemianopic or quadrantanopic field defects, regardless of the cause or prognosis, are considered unsafe to drive in many jurisdictions around the world and are prohibited from licensure.[5] However, there is little evidence to support this policy. One study suggested that severe binocular field loss increases the risk for crash involvement,[6] however, the extent to which this study included persons with hemianopic or quadrantanopic field loss was not reported.

A few studies have examined driving performance in persons with hemianopia, either on-road driving or performance in a driving simulator. Szlyk et al.[7] reported significantly worse performance on an interactive driving simulator for six persons with homonymous hemianopia secondary to stroke compared to age-matched controls, with lane boundary crossings being higher for hemianopes compared to controls. Hemianopes were tested within two months of their stroke so it is highly likely the recovery process was still ongoing.[1] Tant et al.[8] also found problems with on-road steering stability in a group of 28 patients with homonymous hemianopia, reporting that only 14% passed a driving assessment similar to the road test used by the local licensing authority. This study specifically recruited hemianopes whose driving was suspected to be unsafe by the carer or patient themselves. More recently, Racette and Casson[9] conducted a retrospective chart review of occupational therapists' assessments of the on-road driving of persons with visual field impairment, including a subgroup of twenty drivers with hemianopia or quadrantanopia. They reported that localized visual field loss in the left hemifield and diffuse loss in the right hemifield were associated with impaired driving performance in this subgroup. However, as acknowledged by the authors, study limitations included its retrospective design, lack of a standardised driving route, different occupational therapists undertaking the assessments, and no reference group of drivers with normal visual fields to serve as a basis for comparison.

The aim of the current study was to evaluate the on-road driving performance of persons with homonymous hemianopia or quadrantanopia in comparison to age-matched persons with normal visual fields. Backseat evaluators masked to the clinical characteristics of participants independently rated driving performance on a standardised route with respect to several common driving behaviors.

METHODS

Participants

Potential hemianopic and quadrantanopic participants were identified through the Neuro-Ophthalmology service of the Department of Ophthalmology clinic at the University of Alabama at Birmingham through ICD-9 codes 368.46 (homonymous bilateral field defects), 368.47 (heteronymous bilateral field defects) and 368.40

(visual field defect, unspecified) for two years retrospective to the starting date of the study. They were contacted by a letter from their neuro-ophthalmologist describing the study, and those interested were scheduled for participation. Persons with normal visual fields were recruited from a list of volunteers interested in research participation in the Clinical Research Unit. In order to create an age-matched reference group, as each hemianopic or quadrantanopic participant was enrolled, an individual from the research volunteer database was selected whose age was ±2 years of the age of the hemianopic or quadrantanopic participant just enrolled.

To be included in the study all participants were required to be aged 19 years old or above, have visual acuity of 20/60 or better in at least one eye, have no lateral spatial neglect as determined by the Stars test,[10] and have a current driver's license in the State of Alabama. If a participant had not driven in the past 2 years but had an interest in returning to driving, the person was considered eligible as long as the driver's license had not expired. Exclusion criteria included Parkinson's disease, multiple sclerosis, Alzheimer's disease, hemiparesis and other types of paralysis, ophthalmic or neurologic conditions characterized by visual field impairment (other than hemianopia or quadrantanopia for the visual field loss group). Participants were also excluded if they required adaptive equipment in their vehicle in order to drive.

Additional inclusion criteria for hemianopic and quadrantanopic participants were a homonymous hemianopic or quadrantanopic visual field defect as indicated by the most recent visual field assessment in the medical record and ≥ 6 months from the brain injury date. Additional inclusion criteria for the age-matched reference group were normal visual fields (see below), and no history of brain injury (e.g., stroke, trauma, tumor, arteriovenous malformation).

The protocol was approved by the Institutional Review Board for Human Use at the University of Alabama at Birmingham. After the purpose of the study was explained, participants were asked to sign a document of informed consent before enrolling.

Procedures

Demographic information (age, gender, race) was obtained by medical record review and confirmed by interview. The number of co-morbid medical conditions was estimated using a general health questionnaire which has been used extensively in previous studies.[11] Participants were asked to report all prescription and non-prescription medications they were taking. The Driving Habits Questionnaire[12] was used to confirm driving status and licensure and estimate driving exposure (days/week, miles/week driven) in the recent past. All questionnaires were interviewer-administered by trained staff.

Visual acuity was assessed binocularly using the standard protocol of the Early Treatment for Diabetic Retinopathy Study chart[13] and expressed as logMAR. Binocular letter contrast sensitivity was measured using the Pelli-Robson chart under the recommended testing conditions[14] and scored by the letter-by-letter method.[15] Visual acuity and contrast sensitivity were evaluated with the habitual correction (whichever correction the person used while driving, if any). All participants had undergone a comprehensive eye examination within the past year.

Visual fields were assessed monocularly and binocularly using automated static perimetry (Humphrey Field Analyzer Model 750i, Carl Zeiss Meditec, California, USA). Right and left monocular fields were measured using the central threshold 24-2 test with the SITA standard testing strategy using a near correction based upon the participants' habitual correction adjusted for the working distance of the test. Binocular visual fields were measured using the Binocular Esterman test with participants wearing the refractive correction usually worn when driving, if any. Results were used to confirm the presence of homonymous hemianopia, quadrantanopia, or normal visual fields. For hemianopes, field loss was also classified as left versus right, complete versus incomplete, and whether macular sparing was present according to standard clinical definitions.[16] For quadrantanopes, field loss was classified by quadrant and whether it was complete or not. Classifications were undertaken by a rater masked to all other clinical and driving performance characteristics of participants.

Several cognitive screening tests previously shown to be related to driving performance[17-20] were also administered. General cognitive status was screened using the Mini-Mental Status Examination (MMSE).[21] Processing speed, short-term memory and attention switching were measured using the Digit Symbol Substitution Test (DSST),[22] which is part of the Wechsler Adult Intelligence Scale. Trails A and B were used to examine visual search, processing speed, mental flexibility, and executive function.[23] Medical record review also identified if participants had undergone previous scanning training during occupational therapy.

On-road driving performance was assessed under in-traffic conditions in a dual-brake vehicle (Chevrolet Impala 2007 with automatic transmission) using the same route for each participant. A certified driving rehabilitation specialist (CDRS) who was also a licensed occupational therapist sat in the front passenger seat, had access to the dual brake, and was responsible for monitoring safety. The design of the route and the methods for evaluating performance were based on our previous work.[24-28] The route covered 14.1 miles with 6.3 miles of non-interstate driving in residential and commercial areas of a city and 7.8 miles of interstate driving in a city. It included both simple and complex intersections and encompassed a broad range of traffic densities and operational maneuvers.

Before beginning the on-road assessment, participants completed a series of basic driving maneuvers in a parking lot to ensure they had adequate vehicle control and to become familiar with the vehicle. Once the CDRS was satisfied that the participant exhibited adequate control, the on-road driving evaluation began. It started on low traffic city streets in a residential neighborhood and proceeded to busier roads, then interstate driving, and finally city non-interstate driving in a commercial area. Driving evaluations were held between 9am and 3pm to avoid rush hour traffic and were cancelled if it was raining or the road was wet. If a participant did not wish to drive on the interstate, the interstate portion of the route was omitted.

Performance at each of 43 locations along the route (31 on non-interstate and 12 interstate) was rated on a 3-point scale by two independent “backseat” evaluators masked to the driver’s clinical characteristics including visual field status. One backseat evaluator – designated as the primary evaluator– sat in the middle of the backseat and thus had a good view of the driving scene, with the second evaluator sitting behind the driver. Examples of the locations that were rated are “left on Glenview Avenue”, “driving along Cliff Road”, and “merging onto I-20/I-59”. At each location, several driving behaviors (Table 1) were evaluated including scanning, lane position, steering steadiness, speed, gap selection, braking, blinker/indicator use, and whether the driver obeyed signs and signals. Table 1 defines the 3-point scale for each maneuver. If a given maneuver was not relevant at a given location, it was not rated (e.g., using one’s indicator signal would not be relevant if there was no turn or lane change involved at that location). After the drive was complete, each rater also provided a global rating of performance for each behavior on a 5-point scale, which summarized the rater’s overall impression of the quality of driving for that behavior; this was done separately for non-interstate and interstate driving. The 5-point scale was 1 = driver is unsafe and the drive was, or should have been, terminated; 2 = driver is unsafe, the drive was completed; 3 = driver’s performance was unsatisfactory but not unsafe; 4 = driver was safe but demonstrated several minor flaws; and 5 = driver was safe and demonstrated either flawless or near flawless driving performance.

Statistical analysis.

Analysis of variance and Fisher’s exact test were used to compare the field loss and normal groups, the field loss drivers rated as safe vs. unsafe, and the current drivers versus those who weren’t currently driving, with respect to continuous and categorical variables, respectively. An intra-class correlation coefficient (ICC) was used to evaluate the agreement between the two backseat evaluators’ ratings of participants’ performance with respect to non-interstate and interstate driving. For analytic purposes, the driving performance score of the primary evaluator was used. P-values of ≤ 0.05 (two-sided) were considered statistically significant.

RESULTS

Of the 802 hemianopic and quadrantanopic potential participants identified, 70 were excluded because their medical records were unavailable (e.g., archived to a remote site). Of the remaining 732 medical records reviewed, 58 met the eligibility criteria following chart review. Common reasons for ineligibility based on medical record review were the person did not have homonymous hemianopia or quadrantanopia, had given up driving permanently, paralysis, or had medical conditions that were exclusion criteria (e.g., Alzheimer's disease, glaucoma). Of the 58 eligible patients, 30 persons with hemianopia or quadrantanopia enrolled in the study. Reasons for not enrolling included deceased (4), could not be contacted (4) and declined participation (20).

The sample consisted of 22 participants with hemianopia, 8 with quadrantanopia and 30 participants with normal visual fields. Their demographic and general health characteristics are given in Table 2. There was no age difference between the participants with field loss and those with normal fields (p=0.96), reflecting the age-matching. The field loss participants were more likely to be male compared to those with normal fields (p=0.02); there was no difference with respect to race (p=0.42). The number of chronic medical conditions was significantly higher in the field loss groups compared to the controls ($p < 0.0001$), and they also reported taking more medications ($p < 0.01$). However, there were no differences in age (p=0.9144), gender (p=0.8498), race (p=0.6592), number of chronic medical conditions (p=0.6861), or medications (0.3225) between those participants with field loss who were current drivers (n=24) and those who were not (n=6).

Table 3 shows the type of field loss for individual hemianopes and quadrantanopes along with the etiology of, and time since, the brain injury. Twelve of the 22 hemianopia cases and five of eight quandrantanopia cases were due to cerebrovascular accident (CVA), with the balance attributable to trauma, tumor, arteriovenous malformation, or presumed congenital abnormalities. All brain injuries with one exception occurred at least one or more years prior to the date of enrolment in this study and for almost half (14 of 30, 47%) their brain injury occurred more than 4 years prior to their participation in the study. With respect to hemianopes, the majority had left hemianopia (17 of 22, 77%) compared to 23% with right hemianopia, and for nine of 22 hemianopes the field loss was complete. Eight of 22 hemianopes had macular sparing. For the quadrantanopes, the quadrant with loss was half the time on the right versus left. Five of eight were in quadrants in the superior field with the balance in the inferior field. Two of eight quadrantanopes had field loss in the affected quadrant that was complete.

The visual and cognitive characteristics of participants are in Table 4. Although the hemianopia and quadrantanopia groups had slightly worse visual acuity and contrast sensitivity than the control group (both $p < 0.04$), in all three groups visual acuity averaged 20/25 or better and contrast sensitivity was high (averaging 1.7-1.8). Those participants in the visual field loss group who were not current drivers had significantly worse contrast sensitivity than those who were current drivers (p=0.0079), however, there were no significant between group differences in visual acuity (p=0.0690).

General mental status as revealed by the MMSE had similar values in all three groups ($p > 0.17$), with all participants scoring ≥ 24 (non-demented range). Scores for visual processing speed and attentional skills as assessed by Trails A, Trails B and the DSST were moderately worse in the combined hemianopia or quadrantanopia group compared to the normal group (p = 0.025, p = 0.0193, p = 0.0003, respectively). The Trails A scores were significantly worse for the participants in the visual field group who were not current drivers compared to those with field loss who currently drove (p=0.0125), but their MMSE, DSST, Trails B scores were not significantly different (p=0.7044, p=0.3020 and p=0.1301 respectively).

Inter-rater agreement for the two backseat evaluators' ratings was high for both non-interstate and interstate driving (both ICCs = 0.96). Table 5 shows how drivers were distributed on the 3-point rating scale for each of the component driving behaviors. With respect to non-interstate driving, the hemianopic and quadrantanopic drivers were more likely to have ratings of 1 and 2 for lane position, steering steadiness, and gap judgments compared to drivers with normal visual fields. This was also the case when hemianopes by themselves were compared to controls. For example, 50% of drivers with hemianopia or quadrantanopia had ratings of 1 or 2 on steering steadiness and lane position, whereas < 25% of drivers with normal visual fields received such ratings. Ratings for the other component driving behaviors were not different between groups.

For interstate driving, there were no significant differences among the groups on any driving behavior ratings. Note that not all participants drove on the interstate so sample size is reduced for the interstate driving condition. Twelve of the 22 hemianopic and seven of the eight quadrantanopic drivers participated in the interstate component of the driving assessment. Of the eleven drivers with field loss (ten hemianopes and one quadrantanope) that did not drive on the interstate, seven chose not to because they reported avoiding interstate driving, and four were deemed unsafe to proceed onto the interstate by the CDRS. Thus, it is not surprising that the driving performance of the field loss groups did not significantly differ from those with normal fields, since those likely to experience problems on the interstate (either as deemed by the CDRS or by self-report) were not present in the sample for this part of the route. There were no significant differences between those with visual field loss who did or did not drive on the interstate for age (p=0.9511), gender (p=0.9791), race (p=0.3810), number of medical conditions (p=0.2368) or medications (p=0.5443). Those who drove on the interstate had significantly better scores on the DSST (p=0.0128) and Trails A tests (p=0.0044), but there were no significant differences in visual acuity (p=0.1477), contrast sensitivity (p=0.0567), MMSE (p=0.0531) or Trails B (p=0.3066).

Table 6 shows how drivers were distributed on the 5-point rating scale of overall global driving performance. For non-interstate driving, this rating was significantly lower for the hemianopic compared to the control drivers but not when the combined hemianopic and quadrantanopic groups were compared to the normal drivers. There were no differences in interstate overall global ratings between heminopes and the normal visual field groups, or between the combined visual field loss group and the normal visual field group.

On the 5-point global rating scale, ratings of 3, 4, or 5 signify that the back-seat evalautor believed that the participant engaged in safe driving behaviors. By this definition, all drivers with normal visual fields, 73% of the hemianopes and 88% of the quadrantanopes were rated as safe drivers on the non-interstate drive (Table 7). Of those that did drive on the interstate, 97% of the drivers with normal fields, 83% of the hemianopes and 100% of the quadrantanopes evaluated were judged by the back-seat evaluator to be safe drivers.

A question of interest is which characteristics differentiate between the hemianopic or quadrantanopic drivers who were deemed safe versus unsafe. While our sample size precludes multivariate modeling to address this issue, univariate comparisons for exploratory purposes were carried out (Table 8). Among hemianopic and quadrantanopic drivers, unsafe driving behaviors (global ratings of 1 or 2) were associated with slower visual processing speed as measured with the Trails A, poorer executive function as measured with the DSST, and reduced contrast sensitivity. Those with fewer seen points on the Esterman test were more likely to be rated as unsafe drivers, as were those with lower binocular mean sensitivity, (calculated by merging the right and left 24-2 fields to create a binocular visual field, based on the more sensitive of the two visual field locations).[29] In addition, those hemianopic and quadrantanopic participants who were current drivers were significantly more likely to be rated as a safe driver compared to those who were not current drivers.

DISCUSSION

This study suggests that some drivers with hemianopia or quadrantanopia are capable of safe driving performance, where 73% (16/22) of the hemianopes tested, and an even higher percentage of quadrantanopes 88%, (7/8) were rated as safe to drive in non-interstate settings. Our results show that even with a significant portion of the binocular field missing, it is possible for some hemianopic and quadrantanopic drivers to safely engage in driving manuevers in commonplace roadway environments in a fashion that cannot be differentiated from the driving performances of persons with normal visual fields. These findings are consistent with a recent retrospective chart review study on occupational therapists' ratings of on-road driving, where 74% of hemianopic and quadrantanopic drivers evaluated were rated as either safe or having the potential for safe driving.[9]

Although our findings illustrate that some hemianopic and quadrantanopic drivers are fit to drive, there were several component driving behaviors that, on average, were performed less well than those with normal visual fields, namely steadiness or smoothness in steering, lane position, and gap judgment. These findings are consistent with earlier reports.[7,8] These driving behaviors heavily rely on processing of information from the periphery generating a spatial representation of the environment,[30, 31] visual skills that are likely to be hampered by a total or partial absence of one side of the field. While drivers in the hemianopic and quadrantanopic group on average exhibited performance problems in steering, lane position, and gap judgment, it is important to point out that many of them displayed no difficulty with these maneuvers. For example, 50% of drivers with hemianopia or quadrantanopia received a superior rating (i.e., rating of 3) on steering steadiness and lane position, with 80% receiving a superior rating on gap judgment. These individual differences imply that even though all drivers had severe binocular visual field loss in either half or one-quarter of the visual field, some drivers successfully maintained stable steering and lane position and exercised good gap judgment. A challenge for future work is to identify which strategies these drivers use to compensate for severe binocular field loss, so that these strategies can be incorporated into driving rehabilitation programs designed for the hemianopic and quadrantanopic population.

Our finding that a large percentage of our sample of hemianopic drivers (73%) exhibited safe driving is, on the surface, at odds with a study by Tant et al.[8] who found that only 14% (4/28) of hemianopes were rated as safe. However, there is a noteworthy difference between their sample and that of the present study. In the Tant et al.[8] study participants were hemianopes specifically referred to the study for a driving evaluation because of safety concerns. In contrast, in the current study, hemianopes who had a current driver’s licence and were current drivers or who wished to return to driving were eligible for participation.

The finding that many hemianopes and all of the quadrantanopes were rated as safe on the interstate drive is not unexpected given that those evaluated on the interstate excluded drivers who preferred not to drive on the interstate and/or who were judged by the CDRS as seriously lacking safe driving skills based on their non-interstate driving. Regardless of the selection bias of this interstate sample, our data do imply that at least some drivers with hemianopia and quadrantanopia have interstate driving skills indistinguishable from those with normal visual fields.

This study was not specifically designed to identify characteristics associated with unsafe driving in hemianopes and quadrantanopes, which would require a very large sample size. However, it does shed light on factors deserving further study as potentially useful prognostic indicators about whether a return to driving following a brain injury that causes hemianopia or quadrantanopia might be possible. Drivers rated as unsafe had on average slower processing speed (as revealed by Trails A and the DSST) than those rated as safe. This finding is consistent with the extensive literature demonstrating that slowed processing speed, regardless of etiology, places one at risk for unsafe driving.[18,32-35] Unsafe drivers had on average lower contrast sensitivity and greater binocular visual field impairments, which is also consistent with earlier work.[6, 36-39] A number of factors were not different between safe and unsafe drivers (age, visual acuity, spatial completeness of hemianopia or quadrantanopia, laterality or quadrant of defect, time since brain injury, traumatic etiology of injury, macular sparing, previous scanning training), however, the small sample size prevents any conclusions about their actual relevance to safe driving in this population. Drivers with safe ratings were more likely to be current drivers, which may imply the critical nature of routine practice for the maintenance of safe driving skills in this population.

Results should be considered in the context of the study's strengths and limitations. This was the first masked evaluation of actual open-road driving behavior of persons with hemianopia and quadrantanopia presented in the literature. The importance of masking the backseat evaluators to the clinical characteristics of drivers cannot be over-emphasized, because of the strong and pervasive stereotype that these persons are unsafe and unfit to drive. Driving was carried out amidst the challenges of real traffic in a wide range of on-road environments. The judgment of the primary backseat evaluator was found to be highly reliable in that there was strong agreement with a second backseat evaluator, also masked to driver characteristics. Driving performance for hemianopes and quadrantanopes was not considered in isolation but rather with reference to how drivers with normal visual fields perform on the same driving route. A study limitation is the relatively small sample size, yet the sample size is still larger than studies on hemianopia and driving published to date.[7, 8] Of those who met eligibility criteria and were alive at the time of enrolment, 44% did not participate, and might have been problematic drivers. However, this study was not designed to provide an estimate of the prevalence of safe driving in this population, but rather was an attempt to demonstrate whether safe driving was possible in any segment of this population. In addition, this study does not provide information about the motor vehicle collision rates of drivers with hemianopia or quadrantanopia, an issue for further research.

In conclusion, this study suggests that some drivers with hemianopic and quadrantanopic field defects have safe driving skills that are indistinguishable from those of drivers with normal fields. This finding has important implications for licensing policies given that many jurisdictions throughout the world are currently denying drivers with these field defects the opportunity to drive. Based on our findings, it is very likely that some drivers with hemianopia or quadrantanopia have been prohibited from driving in spite of their having on-road driving skills that are safe and indistinguishable from those with normal fields who are granted licenses. Since driving of the personal vehicle is a primary mode of transportation in many countries, denial of licensure and driving cessation have great potential for reducing independence, employment options, and access to healthcare and increasing the risk of depression.[40-42] Owing to these considerations, in the interest of fairness we recommend that jurisdictions consider offering persons with hemianopia and quadrantanopia the opportunity for an on-road driving evaluation by a driving rehabilitation specialist, rather than categorically denying licensure based on their hemianopia or quadrantanopia, a policy which has no scientific basis.

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Table 1: Driving skills measured during the on-road assessment and the scoring criteria used by the back-seat raters

	Score		
Driving Skill	**1**	**2**	**3**
Scanning: Includes scanning and attention to other road users, road signs and markings	Fails to scan	Driver scans the roadway to some extent (but not as much as required) and fails to use mirrors or check blindspot where appropriate	Scans road scene appropriately and uses mirrors and checks blindspots BS = when changing lanes/merging drivers should turn their head around to check the appropriate blindspot
Lane Position: The position of the vehicle within the lane	Driving to the right or the left instead of staying centrally within the lane markings, or driving in the incorrect lane prior to, or after, entering an intersection	Veers slightly to right or left in lane	Drives in the correct lane and in the centre of the lane
Steering Steadiness: Smoothness of steering at any point of the drive	Variable/erratic steering	Steering slightly too jerky/too slow	Smooth steering around any maneuvers and on straight drives
Speed: Driving speed relevant to road conditions and speed limit	Drives too fast or too slow	Drives slightly too fast or too slow	Drives at an appropriate speed within posted speed limits
Gap selection: Gap between driver and other cars either when entering traffic flow at intersections or passing either moving or parked cars and following distance	Chooses an unsafe gap or waits for too large a gap causing traffic flow to be affected. Drives too closely to other vehicles in a manner that is unsafe	Chooses appropriate gaps that are slightly too small or too large to enter traffic at intersections or passes either moving or parked cars, and follows at a distance that is slightly too close	Chooses appropriate gaps to enter traffic at intersections or pass either moving or parked cars and follows at an appropriate and safe distance
Braking: Appropriate use of brakes allowing smooth driving and stopping as required	Excessive or inappropriate braking	Slightly sharp braking or slightly delayed braking	Braking that is appropriate and timely
Blinker: Use of blinker/indicator to signal to other road users intention to change direction	Fails to use blinker when appropriate	Uses blinker but too early or too late	Uses blinker in a timely and appropriate manner
Obeys Signs and Signals: Response of driver to signs and signals	Fails to obey signal/sign	Obeys signal/sign but does so slightly late or a rolling stop etc	Obeys all signs and signals in a timely manner

Table 2. Demographic and general health characteristics of participants with field loss (hemianopia or quadrantanopia) and participants with normal visual fields

	Participants with Field Loss N = 30			Participants with Normal Fields N = 30
	Hemianopia N = 22	Quadranopia N = 8	Combined N = 30	
Age, years, mean (SD)	52 (20)	55 (22)	53 (20)	52 (19)
Gender, n (%)				
Female	9 (41)	2 (25)*	11 (37)*	20 (67)
Male	13 (59)	6 (75)*	19 (63)*	10 (33)
Race, n (%)				
African American	2 (9)	0 (0)	2 (7)	5 (17)
White, non-Hispanic	19 (86)	8 (100)	27 (90)	25 (83)
Other [1]	1 (5)	0 (0)	1 (3)	0 (0)
# Chronic Medical Conditions, mean (SD)	5.5 (3.2)**	4.8 (1.8)**	5.3 (2.9)**	2.2 (1.5)
# Current Medications, mean (SD)	5.0 (4.0)**	5.5 (4.3)**	5.1 (4.0)**	2.3 (2.1)

[1] One participant chose not to respond to this item.
Significant differences compared to controls with normal fields are denoted at the *p<0.05 and **p<0.01 levels

Table 3. Visual field characteristics and etiology of brain injury for hemianopia and quadrantanopia participants

Participant #	Type	Etiology[1]	Years Since Injury
Hemianopia (N=22)			
110	Left incomplete homonymous with no macular sparing	CVA[2]	2
115	Right incomplete homonymous with macular sparing	CVA – left mesial occipital lobe	1
116	Left incomplete homonymous with macular sparing	CVA – occipital lobe	1
118	Right incomplete homonymous with macular sparing	Arteriovenous malformation – left occipital lobe	17
122	Left incomplete homonymous with macular sparing	CVA – occipital lobe	6
129	Left incomplete homonymous with macular sparing	CVA	2
132	Left complete homonymous with no macular sparing	CVA associated with cardiac surgery	5
134	Left complete homonymous with no macular sparing	Congenital brain abnormality	congenital
135	Left complete homonymous with no macular sparing	Trauma – multiple incidents of trauma associated with boxing career and assault	> 10
137	Left complete homonymous with no macular sparing	CVA	6
142	Left incomplete homonymous with macular sparing	CVA	4
144	Left complete homonymous with no macular sparing	Tumor – right ventricle	4
145	Left incomplete homonymous with no macular sparing	CVA – right occipital lobe	unknown
146	Left incomplete homonymous with macular sparing	Tumor – craniopharyngioma treated by resection and radiation	1
150	Left complete homonymous with no macular sparing	Right temporal lobectomy as treatment for epilepsy following trauma	10
151	Left incomplete homonymous with macular sparing	CVA associated with cardiac surgery	2
154	Right incomplete homonymous with no macular sparing	Trauma – parietal and occipital fractures; subarachnoid hemorrhage, from motor vehicle collision	7
156	Left complete homonymous with no macular sparing	Arteriovenous malformation - occipital lobe, treated by gamma knife and radiation	4
158	Left complete homonymous with no macular sparing	CVA associated with cardiac surgery	3
159	Right incomplete homonymous with no macular sparing	CVA – left occipital lobe	5
165	Left incomplete homonymous with no macular sparing	Trauma – closed head injury with subarachnoid, intraventricular, subdural and right basal ganglia hemorrhages, from motor vehicle collision	1
166	Right complete homonymous with no macular sparing	Trauma – occipital lobe, from motor vehicle collision	3
Quadrantanopia (N=8)			
102	Right complete superior	CA secondary to vasospasm	2
106	Left incomplete superior	CVA – right medial temporal lobe and right external capsule	2

107	Left incomplete inferior	CVA	3
108	Left incomplete superior	CVA	2
112	Right incomplete superior	CVA – left occipital lobe	1
149	Right incomplete inferior	Left parietal lobe brain tumor	13
152	Left incomplete inferior	Congenital brain abnormality	congenital
160	Right complete superior	CVA – occipital lobe	0.5

[1] If brain loci information is not listed in Table 2, it was not available in the medical record.

[2] Cerebral vascular accident

Table 4. Visual and cognitive characteristics of hemianopia, quadrantanopia, and normal participants

	Visual Field Loss			Normal N = 30
	Hemianopia N = 22	Quadrantanopia N = 8	Combined N = 30	
Visual acuity, OU, logMAR, M (SD)	0.08 (.32)	-0.02 (.32)	0.06 (.32)	-0.13 (.27)
Contrast sensitivity, OU, log sensitivity, M (SD)	1.73 (.19)	1.79 (.13)	1.75 (.18)	1.83 (.12)
MMSE score, M (SD)	28.4 (1.6)	28.6 (.7)	28.5 (1.4)	29.0 (1.4)
Trails A, time to complete, seconds, M (SD)	51 (30)	45 (19)	50 (27)	33 (11)
Trails B, time to complete, seconds, M (SD)	127 (93)	106 (48)	122 (83)	81 (37)
Digit Symbol Substitution, # correct, M (SD)	40.7 (14.2)	42.4 (11.6)	41.1 (13.4)	54.2 (12.8)

Table 5. Component ratings of driving performance by back-seat evaluator

	Visual Field Loss									Normal Visual Field			P-value Combined vs. Normal Visual Field[1]	P-value Heminopia vs. Normal Visual Field[1]
	Heminopia			Quadrantanopia			Combined Group							
Driving Behaviors	Rating, n (%)			Rating, n (%)			Rating, n (%)			Rating, n (%)				
	1	2	3	1	2	3	1	2	3	1	2	3		
Non-Interstate Driving	N=22			N=8			N=30			N=30				
Scanning	1 (4.6)	6 (27.3)	15 (68.2)	0 (0.0)	2 (25.0)	6 (75.0)	1 (3.3)	8 (26.7)	21 (70.0)	0 (0.0)	4 (13.3)	26 (86.7)	0.209	0.210
Lane position	6 (27.3)	6 (27.3)	10 (45.4)	0 (0.0)	3 (37.5)	5 (62.5)	6 (20.0)	9 (30.0)	15 (50.0)	1 (3.3)	6 (20.0)	23 (76.7)	0.049*	0.025*
Steering steadiness	5 (22.7)	7 (31.8)	10 (45.5)	1 (12.5)	2 (25.0)	5 (62.5)	6 (20.0)	9 (30.0)	15 (50.0)	0 (0.0)	6 (20.0)	24 (80.0)	0.012*	0.006**
Speed	2 (9.1)	12 (54.6)	8 (36.4)	1 (12.5)	2 (25.0)	5 (62.5)	3 (10.0)	14 (46.7)	13 (43.3)	1 (3.3)	9 (30.0)	20 (66.7)	0.239	0.083
Gap judgment	0 (0.0)	5 (22.7)	17 (77.3)	1 (12.5)	0 (0.0)	7 (87.5)	1 (3.3)	5 (16.7)	24 (80.0)	1 (3.3)	0 (0.0)	29 (96.7)	0.052	0.010*
Braking	0 (0.0)	3 (13.6)	19 (86.4)	1 (12.5)	1 (12.5)	6 (75.0)	1 (3.3)	4 (13.3)	25 (83.3)	0 (0.0)	1 (3.3)	29 (96.7)	0.195	0.299
Using directional indicator	0 (0.0)	5 (22.7)	17 (77.3)	1 (12.5)	2 (25.0)	5 (62.5)	1 (3.3)	7 (23.3)	22 (73.3)	1 (3.3)	9 (30.0)	20 (66.7)	1.000	0.738
Obeying traffic signals	0 (0.0)	0 (0.0)	22 (100.0)	0 (0.0)	3 (37.5)	5 (62.5)	0 (0.0)	3 (10.0)	27 (90.0)	0 (0.0)	2 (6.7)	28 (93.3)	0.883	0.502
Interstate Driving[2]	N=12			N=7			N=19			N=30				
Scanning	1 (8.3)	4 (33.3)	7 (58.3)	0 (0.0)	2 (28.6)	5 (71.4)	1 (5.3)	6 (31.6)	12 (63.2)	0 (0.0)	10 (33.3)	20 (66.7)	0.606	0.484
Lane position	1 (8.3)	4 (33.3)	7 (58.3)	0 (0.0)	3 (42.9)	4 (57.1)	1 (5.3)	7 (36.8)	11 (57.9)	0 (0.0)	6 (20.0)	24 (80.0)	0.133	0.147
Steering steadiness	1 (8.3)	3 (25.0)	8 (66.7)	0 (0.0)	3 (42.9)	4 (57.1)	1 (5.3)	6 (31.6)	12 (63.2)	1 (3.3)	3 (10.0)	26 (86.7)	0.117	0.287
Speed	2 (16.7)	6 (50.0)	4 (33.3)	0 (0.0)	3 (42.9)	4 (57.1)	2 (10.5)	9 (47.4)	8 (42.1)	1 (3.3)	14 (46.7)	15 (50.0)	0.715	0.276
Gap judgment	1 (8.3)	3 (25.0)	8 (66.7)	0 (0.0)	1 (14.3)	6 (85.7)	1 (5.3)	4 (21.1)	14 (73.7)	0 (0.0)	4 (13.3)	26 (86.7)	0.319	0.221
Braking	0 (0.0)	2 (16.7)	10 (83.3)	0 (0.0)	0 (0.0)	7 (100.0)	0 (0.0)	2 (10.5)	17 (89.5)	0 (0.0)	0 (0.0)	30 (100.0)	0.145	0.077
Using directional indicator	0 (0.0)	7 (58.3)	5 (41.7)	2 (28.6)	2 (28.6)	3 (42.9)	2 (10.5)	9 (47.4)	8 (42.1)	3 (10.0)	10 (33.3)	17 (56.7)	0.587	0.321

[1]Fisher's Exact Test
[2]Some drivers were not evaluated on the interstate since they preferred not to drive on the interstate or the CDRS did not allow interstate driving.
Significant differences are highlighted at the p<0.05* and p<0.01** levels

Table 6: Overall global rating of driving performance by back-seat evaluator

	Non-interstate						Interstate[2]					
	Visual Field Loss			Normal Visual Field	P-value Combined vs. Normal Visual Field[1]	P-value Hemi vs. Normal Visual Field[1]	Visual Field Loss			Normal Visual Field	P-value Combined vs. Normal Visual Field[1]	P-value Hemi vs. Normal Visual Field[1]
Rating	**Hemi**	**Quad**	**Combined Hemi and Quad**				**Hemi**	**Quad**	**Combined Hemi and Quad**			
1	3 (13.6)	1 (12.5)	4 (13.3)	0 (0.0)	0.068	0.027	1 (8.3)	0 (0.0)	1 (5.3)	0 (0.0)	0.264	0.257
2	3 (13.6)	0 (0.0)	3 (10.0)	0 (0.0)			1 (8.3)	0 (0.0)	1 (5.3)	1 (3.3)		
3	2 (9.1)	1 (12.5)	3 (10.0)	3 (10.0)			2 (16.7)	2 (28.6)	4 (21.1)	2 (6.7)		
4	7 (31.8)	2 (25.0)	9 (30.0)	9 (30.0)			3 (25.0)	2 (28.6)	5 (26.3)	8 (26.7)		
5	7 (31.8)	4 (50.0)	11 (36.7)	18 (60.0)			5 (41.7)	3 (42.9)	8 (42.1)	19 (63.3)		

[1]Fisher's Exact Test
[2]Some drivers were not evaluated on the interstate since they preferred not to drive on the interstate or the CDRS did allow interstate driving.

Table 7. The extent to which the global driving performance ratings for hemianopic and quadrantanopic drivers were judged to fall within safe driving[1]

Driver Group	n (%)
Hemianopic Drivers	
Non-Interstate (N=22)	16 (72.7%)
Interstate (N=12)[2]	10 (83.3%)
Quadrantanopic Drivers	
Non-Interstate (N=8)	7 (87.5%)
Interstate (N=7)[2]	7 (100%)
Normal Drivers	
Non-Interstate (N=30)	30 (100%)
Interstate (N=30)	29 (97%)

[1] Safe driving is defined as scores of 3, 4, or 5 on the overall global driving performance rating scale.

[2] 11 drivers were not evaluated on the interstate since they preferred not to drive on the interstate (n=7) or because the CDRS did not permit them to go on the interstate based on their driving on the initial part of the route (n=4).

Table 8. For hemianopic and quadrantanopic drivers, characteristics of drivers who were rated as "safe" versus "unsafe" drivers on non-interstate roads [1]

Characteristic	Safe drivers N=23	Unsafe drivers N=7	p-value
Age, years, M (SD)	53 (18)	53 (27)	0.93
Visual acuity, logMAR, M (SD)	0.00 (0.25)	0.23 (0.46)	0.10
Contrast sensitivity, log, M (SD)	1.79 (0.13)	1.60 (0.24)	0.01
Esterman binocular field test, % seen, M (SD)	91.0 (17.4)	72.1 (16.5)	0.02
Mean sensitivity in 24-2 field test, dB, M (SD)[2]	20.1 (4.4)	15.8 (2.8)	0.02
MMSE, M (SD)	28.7 (1.3)	27.9 (1.8)	0.20
Digit symbol substitution, M (SD)	44 (12)	30 (12)	0.007
Trails A, seconds, M (SD)	41 (13)	76 (42)	0.001
Trails B, seconds, M (SD)	108 (52)	164 (144)	0.12
Time since brain injury, years, M (SD)	9 (16)	5 (4)	0.50
Current driver, n (%)	21 (91.3)	3 (42.8)	0.02
Brain injury due to trauma, n (%)	2 (8.7)	2 (28.6)	0.22
Complete field loss (as opposed to incomplete field loss), n (%)	12 (52.2)	5 (71.4)	0.43
Left side effected (as opposed to right), n (%)	18 (78.3)	3 (42.9)	0.15
Superior field affected (as opposed to inferior field)[3]	4 (80)	1 (20)	0.41
Macular sparing, n (%)[4]	7 (43.8)	1 (16.7)	0.35
Previously received scanning training during occupational therapy, n (%)	1 (14.3)	5 (21.7)	0.40

[1] Safe driving is defined as a global rating by the backseat evaluator of 3, 4, or 5; for unsafe driving, rating of 1 or 2.

[2]For the binocular field computed based on the monocular fields, see text.

[3]This characteristic only applies to quadrantanopic drivers.

[4]This characteristic only applies to hemianopic drivers.