Kwon, MiYoung, Huisingh, Carrie, Rhodes, Lindsay A., McGwin, Gerald, Wood, Joanne M., & Owsley, Cynthia
(2016)
Association between glaucoma and at–fault motor vehicle collision involvement among older drivers.
Ophthalmology, *123*(1), pp. 109-116.

Association between glaucoma and at-fault motor vehicle collision involvement in older drivers: A population-based study

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Meeting presentation: A part of the material was presented at the Annual Meeting of the Association for Research in Vision and Ophthalmology (ARVO), 2015.

Financial support: This work was supported by the National Eye Institute and the National Institute on Aging of the National Institutes of Health (R01EY18966, P30AG22838); the EyeSight Foundation of Alabama; the Able Trust; and Research to Prevent Blindness Inc. The sponsor or funding organization had no role in the design or conduct of this research.

Conflict of interest: No conflicting relationship exists for any author.

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Objective: To examine the association between glaucoma and motor vehicle collision (MVC) involvement among older drivers, including the role of visual field impairment that may underlie any association found.

Design: A retrospective population-based study

Participants: A sample of 2,000 licensed drivers aged 70 years and older who reside in north central Alabama.

Methods. At-fault MVC involvement for five years prior to enrollment was obtained from state records. Three aspects of visual function were measured: habitual binocular distance visual acuity, binocular contrast sensitivity and the binocular driving visual field constructed from combining the monocular visual fields of each eye. Poisson regression was used to calculate crude and adjusted rate ratios (RR) and 95% confidence intervals (CI).

Main Outcomes Measures: At-fault MVC involvement for five years prior to enrollment.

Results: Drivers with glaucoma (n = 206) had a 1.65 (95% confidence interval [CI] 1.20-2.28, $p = 0.002$) times higher MVC rate compared to those without glaucoma after adjusting for age, gender and mental status. Among those with glaucoma, drivers with severe visual field loss had higher MVC rates (RR = 2.11, 95% CI 1.09-4.09, $p = 0.027$), whereas no significant association was found among those with impaired visual acuity and contrast sensitivity. When the visual field was sub-divided into six regions (upper, lower, left, and right visual fields; horizontal and vertical meridians), we found that impairment in the left, upper or lower visual field was associated with higher MVC rates, and an impaired left visual field showed the highest RR (RR = 3.16, $p = 0.001$) compared to other regions. However, no significant association was found in deficits in the right side or along the horizontal or vertical meridian.

Conclusions: A population-based study suggests that older drivers with glaucoma are more likely to have a history of at-fault MVC involvement than those without glaucoma. Impairment in the driving visual field in drivers with glaucoma appears to have an independent association with at-fault MVC involvement, whereas visual acuity and contrast sensitivity impairments do not.

Keywords: Glaucoma, Motor vehicle collision, Visual field, Visual acuity, Contrast sensitivity, Aging, Driver safety

While driving is the preferred means of travel among older adults in the United States, [1, 2, 3] older drivers have a higher risk of motor vehicle collision (MVC)-related fatal injury than other age groups, and MVC rates in the U.S. show a sharp increase in drivers aged 70 and older. [4] Vision is a critical component of safe driving, and the link between visual impairment and driving has been well documented in many studies.[5, 6]

Among many aging-related eye disorders, glaucoma is a leading cause of irreversible vision loss among the elderly in the United States, characterized by optic nerve damage and associated visual field defects. It has been shown that individuals with more severe visual field loss from a range of causes tend to report difficulty driving.[7] To enhance public safety, it is imperative to understand whether glaucomatous visual field loss puts an elderly driver at a higher risk for MVC involvement. However, there is conflicting evidence regarding the association between visual field loss and MVC rates.

For instance, a California study of 10,000 drivers [8] showed that drivers with severe binocular-field loss had MVC and conviction rates twice as high as those with normal fields, and also reported that glaucoma was one of the leading causes of visual field loss within their sample. A prospective, population-based study of older drivers in Maryland showed that visual field loss as measured by a screening test was associated with MVC involvement while visual acuity and contrast sensitivity were not. [9] A similar association between visual field loss and MVC rates has been also reported in a recent retrospective, population-based study of older drivers in Alabama where visual field testing focused on the area of the visual field used while driving. [10] Simulated binocular visual field studies [11, 12] demonstrated that restricted visual fields results in poor driving performance, suggesting a possible linkage between visual field loss and a higher MVC rate. They found that restriction of the binocular visual field to 90 degrees or less significantly reduced the ability to correctly identify road signs and avoid obstacles, and considerably increased reaction times. While the findings from these studies are consistent with studies of drivers with visual field impairment specifically due to glaucoma, [13-16] several other studies have reported no association between MVC involvement and visual field loss. [17-20] It is possible that the failure to find an association might be related to the way visual field impairment and/or MVC involvement has been defined or the use of non-standard instruments for visual field testing.

Here we report the results from a retrospective, population-based study of older drivers. In this study, we asked the following questions: 1) whether older drivers with glaucoma have a higher MVC rate compared to those without glaucoma; 2) if that is the case, whether glaucomatous visual field loss is associated with at-fault MVC involvement among drivers with glaucoma after controlling for other types of visual impairment such as visual acuity or contrast sensitivity; 3) whether region-specific visual field loss is associated with elevated at-fault MVC involvement among drivers with glaucoma as reported in previous studies of populations with field loss from a range of causes. [9, 10]

It should be noted that Huisingh et al.[10] used the same population-based study of older drivers to examine the association between MVC involvement and driving visual field, regardless of the etiology of field loss. In the current study we specifically focused on older drivers with glaucoma and their MVC rate as compared to non-glaucomatous drivers, as well as investigating how the characteristics of their field loss related to MVC involvement.

Methods

The study was based on a population-based sample of 2000 licensed drivers aged 70 years and older who reside in north central Alabama. Potential participants were identified from contact information available through a list of persons in this geographic region obtained from a direct marketing company (Pinpoint Technologies, Tustin, CA, USA). Potential participants were randomly selected from the final list, driver licensure in the state of Alabama was verified, and they were then contacted by letter, followed by a phone call. Individuals who confirmed that they had a current Alabama license and had driven within the last three months, were ≥ 70 years old, and spoke English were invited for a single study visit. The final sample consisted of 2,000 drivers enrolled between October 2008 and August 2011. A detailed description of the enrollment procedure is given elsewhere. [21]

Informed consent was obtained from participants in accordance with procedures approved by the Institutional Review Board of the University of Alabama at Birmingham and complying with the Declaration of Helsinki. Trained research assistants confirmed demographic information (age, gender, race/ethnicity) and administered all vision tests along with a general health questionnaire. [19] General cognitive status was assessed with the mini-mental status examination (MMSE). [22] An estimate of driving exposure (i.e., miles driven in a typical week) was obtained from administrating the Driving Habits Questionnaire (DHQ); [23] previous research indicates that drivers can reliably provide these estimates. [24] Information about participants' MVC involvement occurring within five years prior to enrollment was obtained through accident reports made available to the study by the Alabama Department of Public Safety. At-fault status was indicated on the report by the police officer at the scene who investigated the collision.

Glaucoma was confirmed through medical records using the following protocol as described previously. [21] A copy of each participant's most recent comprehensive eye examination by an ophthalmologist or optometrist was obtained after the participant completed a signed medical record release authorizing the study to access these records. An experienced coder of eye medical records recorded whether the participant had a diagnosis of glaucoma as indicated in the section of the chart where diagnoses are listed by the ophthalmologist; participants with a diagnosis of ocular hypertension or who were categorized as a glaucoma suspect were not included in the glaucoma category. The coder was masked to all other data collected on the participant including MVC involvement. Agreement with a second coder was high (91.4%). [21] There were a total of 206 drivers with confirmed glaucoma in the study sample after excluding 101 drivers where we were unable to obtain the medical record from the most recent eye examination.

Measures of visual function included binocular distance visual acuity, binocular contrast sensitivity and the driving visual field. [10] Participants wore whatever spectacles or contact lenses they normally wore when driving for acuity and contrast sensitivity testing. Binocular visual acuity was assessed using the Electronic Visual Acuity (EVA) system, [25] and expressed as log minimum angle of resolution (logMAR). Contrast sensitivity was measured using the Pelli-Robson Contrast Sensitivity chart [26] and scored using the letter-by-letter method and expressed as log sensitivity. [27]

Measurement procedures for the binocular driving visual field have been described previously, [10] and are summarized here. Visual field sensitivity of each eye was measured with a custom test designed for the Humphrey Field Analyzer (HFA) Model II-I (Carl Zeiss Meditec, Dublin, CA, USA). The selection of test target locations was based on the visual field area relevant to when a driver gazes toward the roadway environment through a vehicle's windshield [28] or at the vehicle's dashboard. The selection and description of the driving visual field test are provided in detail by Huisingh et al.[10] Briefly, we selected test target locations in the HFA that covered the widest possible horizontal extent of the field that could be tested for each eye (up to 60°), with targets extending out to 15° superiorly and 30° inferiorly, consistent with a previous analysis of the driving visual field and our own measurements of a series of vehicles. The number of target locations was chosen so that the protocol covered the visual field area relevant to driving safety while minimizing the testing duration in order to make the test practical for assessing visual fitness to drive. Each monocular visual field consisting of 20 target locations was assessed with the HFA's full threshold procedure using a white stimulus-size III target. Best correction for the HFA test distance was provided with trial lenses when testing targets within the 30° radius field, and were removed for targets outside the 30° field. The duration of the test was approximately 5 minutes per eye. As shown in Fig. 1a, the binocular visual field was then constructed by combining the monocular visual fields based on the more sensitive of the two eyes at each visual field location. The binocular field was thus composed of a total of 21 test target locations, spanning 60° to the right and left, 15° to the superior field, and 30° to the inferior field.

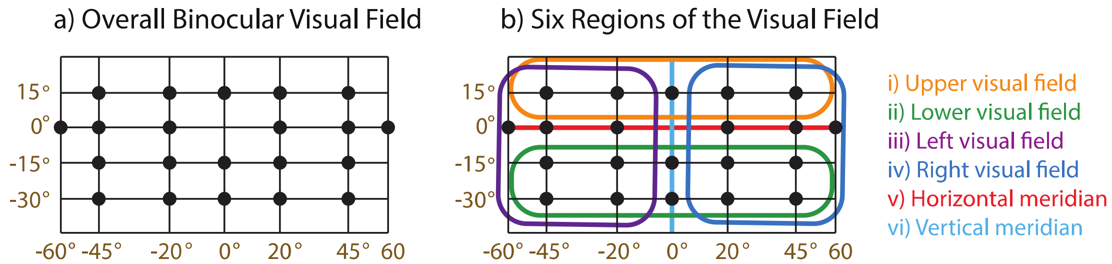

Figure 1. Illustrations of the binocular visual field (a) and six subregions (b).

Visual acuity (VA) impairment was defined as worse than 20/40 (0.3 logMAR) since this is the commonly used visual acuity standard for licensure in the US. [29] Quartiles for contrast sensitivity (CS) were calculated; participants were defined as having impaired contrast sensitivity if their contrast sensitivity fell in the lowest quartile (≤ 1.6 log sensitivity). Similarly, quartiles for average sensitivity (dB) were calculated for the overall visual field; participants were defined as having severe impairment if their average field sensitivity fell in the lowest quartile (≤22.5 dB was impaired visual field). To examine which part of the visual field is more relevant to MVC involvement, the overall visual field was further analyzed into the same six subregions used in a previous paper. [10] As shown in Fig. 1b, the vertical meridian region contains the points along the vertical meridian, whereas the horizontal meridian region contains the points along the horizontal meridian. The upper visual field refers to all the testing points above the horizontal meridian while the lower field means all the testing points below the horizontal meridian. The left field means all the points to the left side of the vertical meridian and the right field indicates the points to the right side of the vertical meridian. Quartiles for average sensitivity were calculated for each subregion; participants were classified as having severe visual field impairment if their average sensitivity in that subregion fell in the lowest quartile. As such, participants could have visual field impairment in more than one region, particularly for more advanced field loss. The range of sensitivity values for each subregion was comparable as summarized in Table 1. The cutoff points were 22.4 dB, 24.0 dB, 21.9 dB, 22.3 dB, 23.0 dB and 24.7 dB for the upper, lower, left, right sides, and the horizontal and vertical meridian, respectively.

Table 1. Descriptive statistics of visual field sensitivity for older drivers with glaucoma

	Mean	SD	Cut-off for 25th percentile	Min	Max
Overall visual field	23.8	3.2	22.5	5.8	49.0
Upper visual field	23.8	3.8	22.4	0.0	50.0
Lower visual field	23.5	3.4	24.0	3.9	50.0
Left visual field	23.2	3.6	21.9	3.6	48.4
Right visual field	23.5	3.4	22.3	4.4	49.3
Horizontal meridian	24.3	3.2	23.0	6.0	50.0
Vertical meridian	26.4	3.8	24.7	7.0	50.0

* Note that values are reported in decibels

Statistical Analysis

Demographic, medical, visual, and driving characteristics were described for the overall sample. Poisson regression models were used to calculate rate ratios (RR) and 95% confidence intervals (CIs) to examine the association between having a diagnosis of glaucoma and at-fault MVC involvement after adjusting for known potential confounders with MVC involvement, which include age, sex, and mental status. For the remaining analyses, the dataset was limited to those with a diagnosis of glaucoma. We ensured the assumptions of Poisson regression were met by checking the dispersion of our data: the unconditional mean and variance of the outcome variable were approximately equal (mean = 0.15, variance = 0.18), as well as the conditional mean and variance when limited to those with glaucoma (mean = 0.21, variance = 0.25).

To determine the independent effect of visual function on at-fault crash rates, the three measures of visual function were evaluated simultaneously with additional adjustments for age, sex, and mental status. Separate models were used to calculate the RR for the overall visual field and region-specific fields as defined above. All models used a log link function and accounted for the natural log of the annual miles driven as an offset. A p-value of < 0.05 (two-tailed) was used to define statistical significance.

For visualization (Fig. 4), we have illustrated the driving visual field sensitivity of two older drivers with glaucoma who were involved in at-fault motor vehicle crash in comparison with those of two others who did not have any at-fault MVC involvement. In the illustration of impaired visual fields and MVC, we gauged the degree of "true" visual field impairment of our elderly drivers by comparing their visual field results to those of a young normally-sighted individual whose visual sensitivity is likely to be optimum. This was undertaken on a point by point basis by normalizing the light sensitivity (dB) at each of the 21 binocular visual field locations of each of the four patients using the corresponding normative sensitivity obtained from this young normally sighted individual (i.e., difference in log sensitivity between the patient results and the normal reference values). The participant who served as the normal reference was a 21-year-old normally-sighted individual (VA: -0.26 logMAR; CS: 2.1). In Figure 4, a normalized sensitivity value of 0 dB means the sensitivity at a given location is as good as that of our normative data whereas the sensitivity value of -10 dB indicates that there is a decrease in light sensitivity by a factor of ten with respect to normative data.

Results

Characteristics of the total study sample and the stratified sample by glaucoma are summarized in Table 2. The age of the sample ranged from 70 to 98 years old. 72% were 70-79 years old and the remaining were ≥ 80 years. 56% of drivers were male. Approximately 17% were African American and 82% were White. Almost half of the drivers had three or fewer medical conditions. The vast majority (98%) of drivers had MMSE scores in the non-demented range (≥ 24). Approximately 11% of drivers were confirmed to have a diagnosis of glaucoma. 57% of drivers had binocular visual acuity of 20/20 or better and more than 90% had a visual acuity of 20/40 or better. The majority of drivers (73%) had contrast sensitivity scores of better than 1.6 log units. Approximately 75% of drivers had binocular visual field sensitivity of 22.6 dB or better. 78% of drivers had their last eye exam within the past two years. According to the questionnaire survey (DHQ), the annual average miles driven per driver were 9,503 miles. Approximately 14% of drivers had been involved in one or more at-fault MVCs in the prior five years.

Table 2. Characteristics of the study sample (N = 1,899*)

Characteristic	N (%) or Mean (SD)		
	Glaucoma	Without Glaucoma	Total
Age (year)			
70 - 79	131 (64%)	1227 (72%)	1358 (72%)
80 - 89	63 (31%)	439 (26%)	502 (26%)
90 - 98	12 (6%)	27 (2%)	39 (2%)
Gender			
Men	120 (58%)	947 (56%)	1067 (56%)
Women	86 (42%)	746 (44%)	832 (44%)
Race			
African American	83 (40%)	237 (14%)	320 (17%)

White	121 (59%)	1449 (86%)	1570 (83%)
Other	2 (1%)	7 (<1%)	9 (<1%)
Confirmed glaucoma			
Yes	206 (100%)	0 (0%)	206 (11%)
No	0 (0%)	1693 (100%)	1693 (89%)
Number of medical co-morbidities			
0 – 1	23 (11%)	184 (11%)	207 (11%)
2 – 3	73 (35%)	612 (36%)	685 (36%)
4 – 5	76 (37%)	579 (34%)	655 (34%)
> 5	34 (16%)	318 (19%)	352 (19%)
Mental status (MMSE score)			
24 - 30	201 (98%)	1660 (98%)	1861 (98%)
17 - 23	4 (2%)	32 (2%)	36 (2%)
1 - 16	1 (<1%)	1 (<1%)	2 (<1%)
Binocular visual acuity			
20/20 or better	99 (48%)	989 (58%)	1088 (57%)
20/20 to 20/40	89 (43%)	576 (34%)	665 (35%)
20/40 to 20/100	18 (9%)	125 (7%)	143 (8%)
20/100 to 20/200	0 (0%)	2 (<1%)	2 (<1%)
Binocular contrast sensitivity			
≤ 1.6 (worse)	86 (41%)	432 (25%)	518 (27%)
1.6-1.65	65 (32%)	546 (32%)	611 (32%)
1.65-1.75	27 (13%)	311 (18%)	338 (18%)
> 1.75 (better)	28 (14%)	403 (24%)	431 (23%)
Overall visual field sensitivity (dB)			
≤ 22.5 (worse)	91 (44%)	378 (22%)	469 (25%)
22.6-24.2	37 (18%)	430 (25%)	467 (25%)
24.3-25.6	40 (19%)	438 (26%)	478 (25%)
≥ 25.7 (better)	38 (18%)	447 (26%)	485 (26%)
Annual mileage	7848 (5796)	9704 (9731)	9503 (9401)
Number of at-fault MVCs			
0	169 (82%)	1474 (87%)	1643 (87%)
1	32 (16%)	192 (11%)	224 (12%)
2 or more	5 (2%)	27 (2%)	32 (2%)

* Note that we only reported the data from 1,899 out of 2,000 after excluding 101 drivers whose ocular medical record was unavailable from the most recent eye examination.

Drivers with glaucoma (n = 206) had a 1.65 (95% CI 1.20-2.28, $p = 0.002$) times higher MVC rate compared to those without glaucoma after adjusting for age, gender, and mental status.

Figure 2 shows the adjusted RR comparing at-fault MVC rates between drivers (those with glaucoma) with and without severe visual impairment in acuity, contrast sensitivity or visual field. Among drivers with glaucoma, severe visual field loss (sensitivity in the lower quartile ≤ 22.5 dB) was significantly associated with crash involvement even after controlling for other aspects of visual function such as visual acuity and contrast sensitivity (RR = 2.11, 95% CI 1.09-4.09, $p = 0.027$), indicating that severe visual field impairment in glaucomatous drivers might have an independent association with at-fault

MVC involvement. On the other hand, no significant association was found between either impaired visual acuity (RR = 1.51, 95% CI 0.55-4.16, $p = 0.425$) or impaired contrast sensitivity (RR = 0.72, 95% CI 0.36-1.42, $p = 0.342$) and MVC involvement. Although the adjusted RR for contrast sensitivity showed a value of less than 1.00 that some might interpret as a potential protective effect of impaired contrast sensitivity for MVC involvement, it is important to note that the confidence interval straddles the null of 1.0.

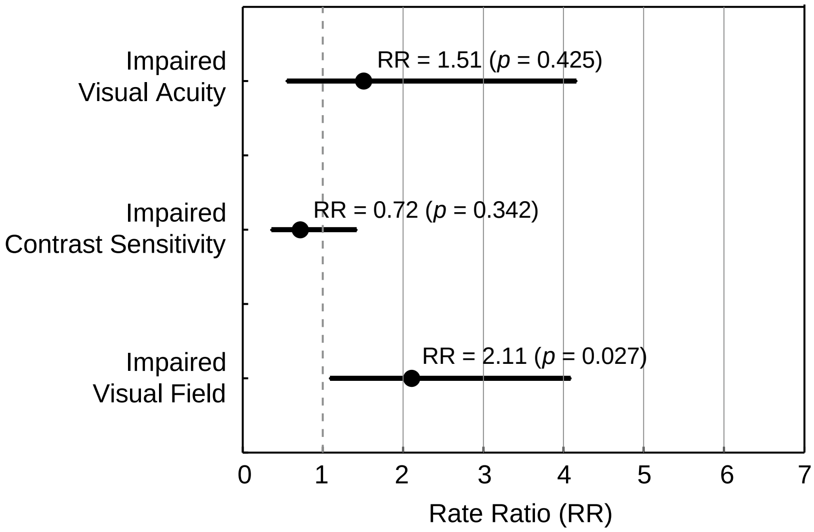

Figure 2. Association between binocular visual impairment and rates of at-fault crashes among drivers with glaucoma (n = 206). Rate ratios were adjusted for age, gender, mental status and the other two visual impairments. The rate ratios are indicated by the horizontal position of the solid black dots. The 95% confidence intervals (CI) around the rate ratios are indicated by the width of the horizontal lines.

When the visual field was further divided into six subregions, drivers with any region-specific impairment had elevated MVC rates. Figure 3 shows the adjusted RR comparing at-fault MVC rates between glaucomatous drivers (those with glaucoma) with and without severe visual field impairment in the area of interest. We found that three out of six subregions reached statistical significance. The region with the highest RR was the region on the left (RR = 3.16, 95% CI 1.55-6.46, $p = 0.001$), which was immediately followed by the region in the upper (RR = 2.37, 95% CI 1.19-4.74, $p = 0.014$) and the lower (RR = 2.32, 95% CI 1.13-4.75, $p = 0.021$) fields. However, there was no significant association in visual field loss in the right side (RR = 1.63, 95% CI 0.84-3.14, $p = 0.145$) or deficits along the vertical (RR = 1.09, 95% CI 0.56-2.11, $p = 0.081$) and horizontal meridians (RR = 1.78, 95% CI 0.92-3.44, $p = 0.085$).

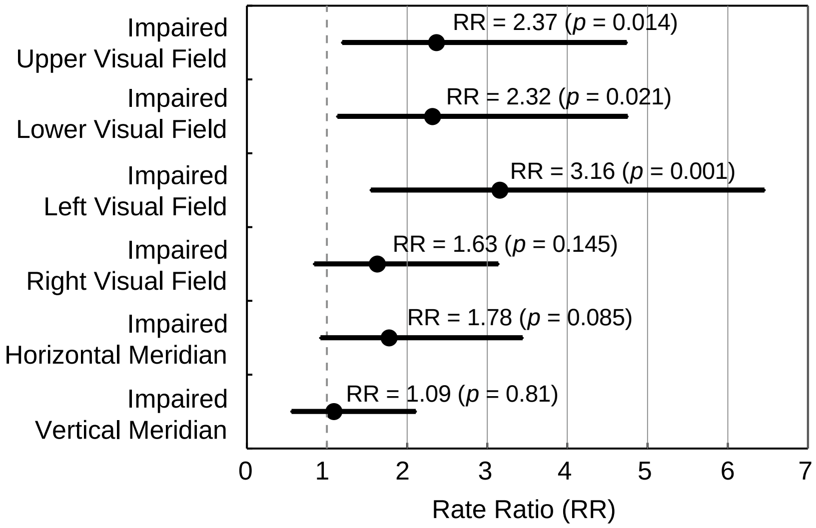

Figure 3. Association between binocular visual field impairment and rates of at-fault crashes among drivers with glaucoma (n = 206). Rate ratios were adjusted for age, gender, and mental status. The rate ratios are indicated by the horizontal position of the solid black dots. The 95% confidence intervals (CI) around the rate ratios are indicated by the width of the horizontal lines.

In Figure 4 which illustrates the degree of visual field impairment for four individual drivers with glaucoma with respect to normative sensitivity data (see the Methods for detailed information), higher sensitivity values shown by cold (blue) colors mean normal or near normal sensitivity whereas lower sensitivity values shown by warm (red, orange, yellow) colors indicate more impaired visual field. The driver's driving visual field map was superimposed on the driver's view through the windshield, side windows of a vehicle, and the dashboard. Both patient 1 (Fig. 4a) and patient 3 (Fig. 4c) exhibited severe visual field impairment (i.e., its overall sensitivity fell within the lowest quartile) with a history of one or more than one at-fault MVC involvement. On the other hand, patient 2 (Fig. 4b) and patient 4 (Fig. 4d) exhibited relatively mild visual field impairment (i.e., its overall sensitivity was not within the lowest quartile) with no history of at-fault MVC involvement even though their age, visual acuity and contrast sensitivity were comparable to those of their counterpart, highlighting the significant role of impaired visual field in at-fault MVC involvement.

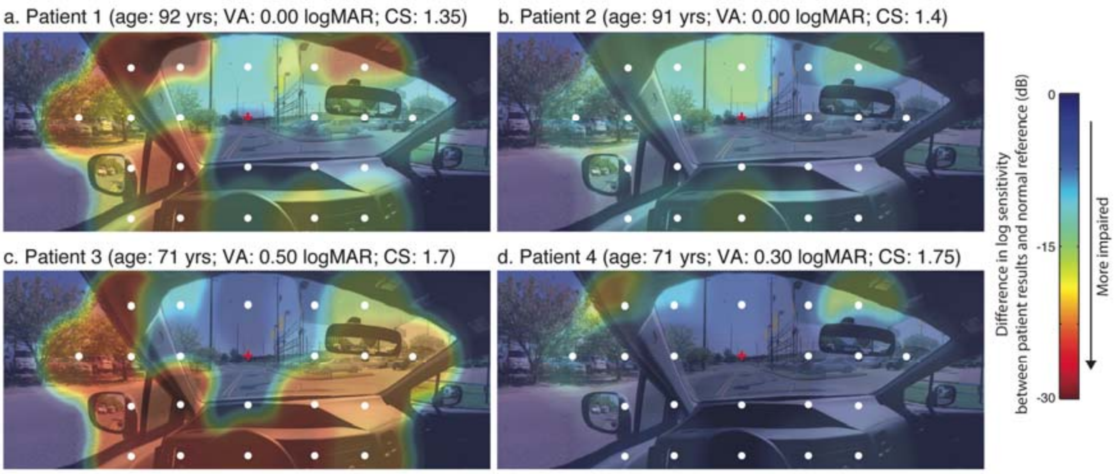

Figure 4. Illustrations of normalized driving visual field sensitivity for four individual drivers with glaucoma. Each driving visual field map was superimposed on a driver's view of the windshield, side windows of a vehicle, and the dashboard. White solid dots represent the target locations for the driving visual field test and red crosshair indicates the driver's presumed gaze while driving. Warm colors indicate more visual field defects compared to reference normative data (see the Methods for detailed information). The panels (**4a**, **4c**) on the left side show the visual field maps of two drivers who had a history of at-fault MVC involvement while the panels (**4b**, **4d**) on the right side show those of drivers who were not involved in any at-fault MVC. The patients in the same row had similar age, visual acuity and contrast sensitivity whereas the degree of visual field impairment considerably differed: the ones on the left side had severe visual field impairment (within the lowest quartile); the ones on the right side did not.

Discussion

This population-based study on older drivers indicates that drivers with glaucoma had an approximately 65% higher rate of at-fault MVC involvement in the prior 5 years than those without glaucoma. This result is consistent with other studies indicating that MVC involvement in drivers with glaucoma is higher than those without glaucoma.[8, 9, 14, 30] The current study also demonstrates that among three major aspects of visual function (i.e., visual acuity, contrast sensitivity and visual field), visual field impairment was independently associated with an increase in at-fault MVC involvement in older drivers with glaucoma, whereas deficits in acuity and contrast sensitivity were not, implying that visual field loss is the important visual mechanism underlying increased crash risk in older glaucomatous drivers. The rate of at-fault MVC involvement was almost 2.11 times higher among those with severe visual field impairment compared to those with normal to moderate field loss agreeing with earlier reports. [9, 31]

When the visual field data were stratified into six subregions, our results showed that drivers with glaucoma with impairment in the left, upper or lower visual field had elevated MVC rates while no significant association was found in the right visual field and areas along the vertical or horizontal meridan. More specifically, impairment in the left visual field exhibited the highest RR (RR = 3.16, p = 0.001) followed by impairment in the upper and lower visual fields. An important question is whether this finding is simply because some regions, such as the left visual field, had more severe impairment than other regions. However, this is unlikely given the fact that the range of visual field sensitivity values including its mean and standard deviation was reasonably comparable across different regions as shown in Table 1. Therefore, our findings appear to support the idea that damages in some regions of the visual field seems to identify those with functional impairment better.

Huisingh et al. [10] also reported increased collision rates in older drivers with impaired left and lower visual fields, regardless of whether they had glaucoma or not. Rubin et al.[9] first reported the differential impact of different subregions of visual field on crash risk in older drivers. In their study, the overall visual field was analyzed into three subregions (central, upper, and lower fields). They found that impairment in the lower periphery is the best predictor for future crash rate (a 96% increased risk with respect to the baseline). While Rubin et al. [9] used a single suprathreshold target intensity for measuring visual field sensitivity, Huisingh et al. [10] relied on a full threshold procedure for assessing the visual field relevant to driving. Despite obvious methodological differences, both studies highlight the important role of the lower periphery in crash involvement with less significance of the upper field. On the other hand, a recent simulated visual-field loss study showed that the greater importance of upper visual field in the ability to detect driving hazards down the road. [32] Our results also showed that the upper visual field is relevant to the increased risk of MVC involvement. While the apparently discrepant findings with respect to the upper visual field between the present study and the Huisingh [10] and Rubin [9] studies calls for further investigation, the discrepancy is likely to arise from the difference in the study sample: older drivers with glaucoma versus older drivers in general. Patients with glaucoma are more likely to have deficits in more than one subregion of the visual field. It is possible that those with impaired left or lower visual field are likely to have impairment in other regions of the field including the upper and right visual field. Our results indeed showed that approximately 52% of older drivers with glaucoma had more than one impaired visual field region and there was a 16% increase in MVC involvement as the number of impaired regions increased by one (RR = 1.16, 95% CI 1.02-1.33, $p = 0.028$). That multiple regions of the visual field are typically impaired in glaucoma may have contributed to the differential results. A more detailed analysis on the underlying "pattern" of impairment will be the subject of further analysis.

Our study has the following strengths. The current study used an unbiased measure of police-reported at-fault MVCs rather than relying on either subjective self-reports or MVC involvement regardless of at-fault status. At-fault collisions are more likely to reflect the individual's driving ability rather than collisions that are not the driver's fault. [20, 33] The current study also included a full-threshold measurement procedure to assess visual field impairment while other previous population based sample studies [8, 9] have relied on a visual field screening test with an arbitrary cutoff point for pass-fail and a single intensity test target. Unlike many other states in the United States, Alabama does not require the administration of visual acuity or visual field screening test for driver's license renewal. [29] This makes the state of Alabama a unique place to study visual impairment and driving because there is no screening system to de-license drivers who do not meet the vision standards. Of course, it is possible that some older drivers with severe visual impairment may still have limited or stopped driving even of their own accord. Nevertheless, the use of a large, population-based sample of older drivers (2000 drivers ≥ 70 years) and the fact that glaucoma is prevalent in this age range places the study at an advantage for examining the role of glaucomatous visual field defects in driving safety of older drivers while maintaining its generalizability to older drivers as a whole.

Potential limitations of our study include the fact that our study is based on the use of retrospective data (i.e., crash occurring during the previous 5 years). It is possible that our study might have underestimated the degree of association between glaucoma/other visual impairment (e.g., field defects, reduced contrast sensitivity or acuity) and increased crash rates due to drivers' self-limiting behaviors, that is those with severe vision loss may have ceased driving. Although speculative, this self-regulation might explain the reason why we did not observe any significant association with decreased visual acuity and contrast sensitivity. Impaired visual acuity or contrast sensitivity is likely to be noticeable to drivers whereas visual field loss can easily go unnoticed. Those older drivers with severe visual field defects might have continued driving despite having sizeable visual deficits unlike those with severe contrast or acuity deficits. Indeed, the findings from a population-based study [34] of drivers in Los Angeles supports this hypothesis. They found that while impaired visual acuity was significantly associated with driving cessation, no such association was found for visual field loss. Moreover, those with impaired visual acuity are more likely to report difficulty driving compared to those with visual field loss. The role of self-awareness of compromised vision remains to be addressed in future studies, since previous research suggests that it can lead older adults to self-regulate their driving to less challenging times (e.g., daylight, low traffic, or no inclement weather). [35] Another limitation of our retrospective study is that all patients had their visual function assessed after crash occurrence, which may overestimate their degree of their visual field loss. However, we do not think that it has had any substantial consequence on our results given the fact that all of our participants were being managed by their ophthalmologist or optometrist for glaucoma, and rates of visual field progression under treatment are relatively slow (< 1 dB/year).[36]

In conclusion, older drivers with glaucoma are more likely to have a higher MVC rate than those without glaucoma. Impairment in the driving visual field appears to contribute to this increased MVC rate rather than impairment in visual acuity or contrast sensitivity, highlighting the importance of clinicians discussing driving safety with glaucoma patients, particularly those with severe visual field defects. Taken together, early detection and awareness of visual field defects appear to be critical in enhancing older driver safety.

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