Ophthalmic Epidemiology
0928-6586/98/US$ 12.00

*Ophthalmic Epidemiology
– 1998, Vol. 5, No. 2,
pp. 101-113*

Accepted 24 November 1997

Vision impairment, eye disease, and injurious motor vehicle crashes in the elderly

Cynthia Owsley[1]
Gerald McGwin Jr.[1,2]
Karlene Ball[3]

Departments of [1]Ophthalmology, School of Medicine, [2]Epidemiology, School of Public Health, and [3]Psychology, School of Social and Behavioral Sciences, University of Alabama at Birmingham, Birmingham, Alabama, USA.

Abstract The objective of this case-control study was to identify visual risk factors for vehicle crashes by elderly drivers which result in injury. The sample consisted of licensed current drivers between 55 and 87 years of age who resided in Jefferson County, Alabama. Subjects were identified through Alabama Department of Public Safety (ADPS) files. Two groups of cases were identified. One group (N=78) was defined as those drivers who had incurred at least one vehicle crash between 1985 and 1990 resulting in an injury to anyone in the involved vehicles according to the accident report. The other case group (N=101) consisted of drivers involved in non-injurious crashes during the same time period. Controls (N=115), also selected from ADPS files, were older drivers not involved in crashes during the same five-year period. Subjects underwent a battery of visual processing tests and a comprehensive eye examination. The main results were that restricted useful field of view and glaucoma were the only significant independent predictors of injurious crash involvement. Odds ratios (ORs) for reductions in the useful field of view of 23-40%, 41-60% and greater than 60% were 4.2 (95% confidence interval [CI], 1.5-11.8), 13.6 (95% CI, 5.8-39.7), and 17.2 (95% CI, 5.3-55.6), respectively, compared to reductions of less than 23% (p for trend <0.001). The OR for glaucoma was 3.6 (95% CI, 1.0-12.6). Useful field of view impairment was the only variable independently associated with non-injurious crash involvement. This study implies that impaired visual processing and glaucoma may play a role in the etiology of older driver crashes which result in injury.

Key words Motor vehicle accidents; vision impairment; injury; elderly subjects; eye disease; aging

Correspondence and reprint requests to:
Cynthia Owsley, Ph.D.
Dept. Ophthalmology
School of Medicine
Eye Foundation Hosp.
University of Alabama
Birmingham, AL 35294-0009
Tel.: +1-(205) 325-8635
Fax: +1-(205) 325-8692
E-mail: owsley@eyes.uab.edu

Acknowledgements:
We thank the Alabama Department of Public Safety for providing crash data and accident reports, and Jeffrey Roseman, MD, PhD, MPH and John Waterbor, MD, DrPH for commenting on an earlier version of this paper. This study was supported by NIH grant R01 AG14684-01, P50 AG11684 (the Edward R. Roybal Center for Research in Applied Gerontology), NIH R01 AG04212, the Rich Retinal Research Foundation, and Research to Prevent Blindness, Inc. Research facilities were provided by a grant from the Alabama Eye Institute.

Introduction Driving is a complex task obviously involving visual skills for its successful execution. Vision problems, including deficits in visual acuity, contrast sensitivity, peripheral vision and visual attention, are increasingly common in the later decades of life,[1,2] and have been associated with increased risk of crash involvement in older drivers[3-9]. Chronic diseases (e.g., diabetes) that can engender visual impairments have also been identified as increasing the crash risk for older adults.[10,11] Compared to other age groups, persons aged 70 and older have the second highest rates of motor vehicle collisions and fatal and non-fatal crash injuries per vehicle mile of travel.[12,13] With the aging of the U.S. population, there is a pressing need to understand the causes of crashes by older drivers so that preventive strategies can be developed.[14-16]

The focus of this report is to identify visual risk factors for vehicle crashes by elderly drivers *which result in injury*. Injurious crashes are the most catastrophic type of collision from a public health standpoint. Once involved in a vehicle crash, an individual's risk of being fatally injured increases with age.[17-19] Given two crashes of similar circumstances and equal severity, an older person is more likely to sustain severe injuries than a younger adult.[17-19] However, little information exists on risk factors for older drivers' involvement in injurious crashes, as will be discussed below. Nearly all existing studies on risk factors for motor vehicle collisions in the elderly have focused on crashing regardless of whether an injury ensues (for a review, see ref. no. 12). Research focused on injurious crashes could clarify the path of injury causation in older adult drivers and could lead to the development of injury prevention and control strategies.

Most of what is known on risk factors for injurious crash involvement in older drivers is based on just two studies. A study on Washington State older drivers enrolled in a health maintenance organization indicated that those involved in an injurious crash were 2.6 times more likely to have a diagnosis of diabetes than were those who were crash free.[20] This study, along with a Tennessee study on a Medicaid population, also found that medications elevated injurious crash risk, specifically cyclic antidepressants and opioid analgesics.[21,22] The Washington State study also evaluated the relationship between vision impairment and injurious crash involvement;[23] however, no significant associations were noted. As the authors point out themselves, many aspects of visual function that would seem to be pertinent to driving were not assessed in this study (e.g., visual attention, speed of visual processing), and thus a failure to find associations between visual processing and injurious crashes in the Washington State study is not indicative of the irrelevance of visual variables in understanding injurious crash risk. Besides this study, no other research to date has investigated associations between injurious crashes, visual function, and eye disease, even though it would seem that visual skills are critical for controlling a vehicle and that visual deficits could lead to severe crashes resulting in injury. Here we report the results of a study addressing whether visual impairment and eye conditions are associated with injurious crashes by older drivers, in which a broad array of visual processing variables are evaluated as risk factors.

Materials and methods

SUBJECTS The sample was originally assembled for the purposes of a study whose aim was to develop a structural equation model predicting older drivers' crash frequency over a five-year period, based on visual and cognitive function data.[24] The source population for this sample was all licensed drivers in Jefferson County, Alabama age 55 years and older (118,553), as listed in Alabama Department of Public Safety (ADPS) records. Ultimately we wanted to achieve a sample of approximately 300 drivers that was balanced with respect to two variables: crash frequency during the previous five-year period (regardless of injury), and age. The population was first sorted into 21 cells, representing three crash categories (0, 1-3, and 4 or more over the prior five years) and seven age categories (55-59, 60-64, 65-69, 70-74, 75-79, 80-84, and 85+ years old). Seventy-five drivers were randomly selected from each cell, and contact letters were sent to those listed in the local phone directory. Our goal was to assess approximately 300 older drivers in a six-week period in 1990. We succeeded in enrolling 302 subjects. Six subjects were excluded from analysis because they did not drive even though they maintained a current driver's license, and two additional subjects were excluded because they did not complete the protocol. The final sample consisted of 294 older drivers. Of the overall sample, 33% had 0 crashes on record, 49% had 1-3 crashes, and 18% had 4 or more crashes over the prior five years.

For the purposes of the present study, we defined two groups of cases. The first group (N=78) was defined as those who had incurred at least one vehicle crash between 1985 and 1990 resulting in an injury to anyone in the involved vehicles according to the accident report. Information on whether or not an injury occurred was obtained directly from the accident report, which has a special field for injury occurrence coding. The second group (N=101) was defined as those who had incurred at least one vehicle crash between 1985 and 1990 *not* resulting in an injury to anyone in the involved vehicles according to the accident report. Controls (N=115), also selected from ADPS files, were persons not involved in crashes during the same five-year period. Thus, the final sample consisted of 294 subjects with a mean age of 71 years (range 55-87); 54% were male, 47% female, and 80% were white with the remaining African American. This study was approved by the Institutional Review Board for Human Use of the University of Alabama at Birmingham, and the study protocol was performed according to the guidelines of the Declaration of Helsinki.

PROCEDURE During a single visit to the Clinical Research Unit in the University of Alabama at Birmingham Department of Ophthalmology in 1990, all subjects completed a protocol consisting of tests of visual processing as described below. In choosing these visual processing tests, an effort was made to include both visual sensory tests as commonly used in the clinic and when applying for a driver's license, as well as tests of higher order aspects of visual processing, such as visual processing speed and visual attention.

All vision tests were performed under photopic conditions (100 cd/

m2), except where noted. Letter acuity was measured using the ETDRS chart[25] and expressed as log minimum angle resolvable (logMAR). Acuity impairment was defined as resolution worse than 20/40. Contrast sensitivity was measured using the Pelli-Robson chart[26] and expressed as log contrast sensitivity. Impaired contrast sensitivity was defined as a score of 1.5 or worse. Stereoacuity was measured using the TNO test[27] and expressed as arcseconds. Impaired stereoacuity was defined as 500 arcseconds or worse. Disability glare was measured with the MCT-8000 (Vis Tech) and defined as the difference in letter acuity (logMAR) under conditions of glare versus no glare. Impairment was defined as values greater than zero. Visual field sensitivity was measured with the Humphrey Field Analyzer's 120-point screening program for the central 60 degrees radius field using the quantify defect option.[28] A pre-set initialization value of 34 dB (both central and peripheral) was used, which served as a baseline, 'normal' visual field[29] against which performance was compared. This standard was based on the normal visual field sensitivity for adults in their 50s who are in good eye health. Background luminance was 10 cd/m2. For each eye, visual field defect for the central 30 degree and the peripheral 30 to 60 degree field was expressed as the average defect depth of all points in the region. The eye with the smaller defect depth ("better" eye) was used in all subsequent data analysis. Impaired visual field sensitivity (for both the central and peripheral visual fields) was defined as a loss of sensitivity of more than 1 log unit (10dB).

The standard protocols for all the above tests were followed as described in the manufacturers' manuals. All tests were administered binocularly, except the visual field test in which each eye was tested separately. For all tests except visual field testing, subjects wore their habitual correction because their everyday visual performance capabilities were of primary interest. With respect to visual field testing, the Humphrey Field Analyzer's validity rests upon use of optimal optical correction for the near target distance so this was implemented in the protocol.

Visual processing speed and visual attention were assessed together using the useful field of view test.[30] The useful field of view (UFOV) is defined as the visual field area over which one can make rapid use of briefly presented visual information. Unlike conventional measures of visual field which assess visual sensory sensitivity, the UFOV test additionally relies on 'higher order' processing skills such as divided and selective attention, and rapid processing speed. The test consists of a radial localization task in which a subject must identify the radial direction of a target (a silhouette of a car) presented up to 30 degrees in the periphery, while simultaneously discriminating two targets presented in central vision (a silhouette of a car vs. a truck). By varying the eccentricity of the peripheral target (at 10, 20, or 30 degrees), the visual field area over which a subject can acquire information rapidly can be estimated. In some trials the peripheral target is embedded in distracting stimuli. Thus, the task has both a divided attention component (i.e., the subject must perform a central discrimination task at fixation while localizing a simultaneously presented target), and a selective attention component (i.e., the subject indicates the radial direction of the peripheral target even though it is embedded in other distracting stimuli in the periphery). Another variable manipulated is the duration of the test display, which varies from 40 to 240 ms. Performance is expressed as a function of three variables – the minimum target duration required to perform the central discrimination task, the ability to divide attention between central and peripheral tasks successfully, and the ability to filter out distracting stimuli. Performance in each of the three subtests is scaled from 0 to 30. Performance in the useful field of view task is expressed as a composite score expressed as percent reduction (range 0-90) of a maximum 30 degree field size (maximum field size of the test apparatus' screen at the viewing distance).

All subjects received an eye examination by an ophthalmologist, which included direct and indirect ophthalmoscopy after dilation, biomicroscopy, applanation tonometry, a refraction for distance and an assessment of external eye health. The primary diagnosis of each subject (other than refractive error) was noted (e.g., cataract, age-related maculopathy, glaucoma, diabetic retinopathy). Prior to all testing, subjects were interviewed using a checklist of chronic medical conditions (including a review of major eye diseases common in the elderly) and indicated which conditions they had. For the purposes of data analysis, the presence of an eye disease was defined as either ophthalmologist diagnosed on the basis of the eye examination or self-reported.

To estimate driving or 'on-the-road' exposure, subjects were asked to fill out a brief questionnaire asking how many days per week and how many miles per year they drove. An interviewer reviewed a checklist of common chronic medical conditions with each subject to determine their presence versus absence. Finally, mental status was evaluated by the Mattis Organic Mental Syndrome Screening Examination (MOMSSE),[31] which is specifically designed to assess cognitive function in the elderly. This test, lasting about 20 minutes, provides a composite score of cognitive function that summarizes performance in several domains, including general information, abstraction, attention, orientation, verbal and visual memory, speech, naming, comprehension, sentence repetition, writing, reading, drawing, and block design. Composite scores range from 0 to 28, with lower scores representing higher functioning.

Examiners and interviewers were unaware of the crash histories of all subjects. Prior to execution of the protocol, written informed consent was obtained from all subjects after the nature and purpose of the study were explained.

STATISTICAL ANALYSIS We estimated odds ratios (ORs) and 95% confidence intervals (CIs) for the association between injurious and non-injurious motor vehicle crash involvement and visual impairment using logistic regression. ORs and 95% CIs were calculated separately for each case group as compared to the single group of controls. In order to identify independent predictors of crash involvement, we followed a procedure similar to that described by Kleinbaum.[32] First, we evaluated the univariate relationship between selected measures of visual impairment and crash involvement. All variables that had significant associations ($\alpha = 0.10$) at the univariate level were included in a multivari-

Characteristics	Injurious crashes (N=78) %	OR	(95% CI)	Non-injurious crashes (N=101) %	OR	(95% CI)	Non-crash (N=115) %
Age (in years)							
55-64	21.8	1.0	(Referent)	24.3	1.0	(Referent)	33.9
65-69	24.4	1.5	(0.6,3.3)	19.8	1.1	(0.5,2.2)	26.1
70-77	19.2	1.4	(0.6,3.4)	27.9	1.9	(0.9,3.9)	20.9
78-87	34.6	2.8	(1.3,6.3)	27.9	2.0	(1.0,4.2)	19.1
p for trend			0.02			0.03	
Race							
White	74.4	1.0	(Referent)	76.6	1.0	(Referent)	89.3
Black	25.6	2.9	(1.3,6.5)	23.4	2.6	(1.2,5.5)	10.7
Sex							
Female	42.3	1.0	(Referent)	45.0	1.0	(Referent)	51.5
Male	57.7	1.4	(0.8,2.6)	55.0	1.3	(0.8,2.2)	48.5
Annual Miles Driven							
>20 000	12.3	1.0	(Referent)	11.7	1.0	(Referent)	4.0
10 000 - 19 999	17.8	0.4	(0.1,1.0)	28.2	0.4	(0.1,1.5)	23.2
5 000 - 9 999	30.1	0.3	(0.1,1.1)	26.2	0.3	(0.1,1.0)	32.3
1 000 - 4 999	23.3	0.3	(0.1,1.0)	20.4	0.3	(0.1,0.9)	28.3
< 1 000	16.4	0.3	(0.1,1.8)	13.6	0.4	(0.1,1.5)	12.1
p for trend			0.51			0.12	
Days per Week Driven							
7	49.3	1.0	(Referent)	58.3	1.0	(Referent)	50.5
< 7	50.7	1.1	(0.6,1.9)	41.7	0.7	(0.4,1.3)	49.5
Chronic Diseases+							
0	16.7	1.0	(Referent)	15.3	1.0	(Referent)	30.4
≥ 1	83.3	2.2	(1.1,4.5)	84.7	2.7	(1.5,4.9)	69.6
Cognitive Score+§							
≤ 9.0	71.8	1.0	(Referent)	76.6	1.0	(Referent)	84.5
> 9.0	28.2	2.1	(1.1,4.4)	23.4	1.7	(0.8,3.3)	15.5

\+ Higher values represent greater impairment except for Contrast Sensitivity where lower values represent greater impairment.

§ Score on Mattis Organic Mental Status Syndrome Examination (range: 0-28)

TABLE 1. Demographic, driving, and health characteristics of drivers involved in injurious crashes, non-injurious crashes, and no crashes.

able logistic regression model. Each variable was then individually removed from the model, and likelihood ratio tests (LRTs) were performed to determine which variables had significant independent associations with crash involvement. Variables not demonstrating significant independent associations were removed from the model and point estimates and confidence intervals for the remaining variables computed. This process was repeated separately for each case group until the most parsimonious model was obtained. Tests of linear trend were performed by entering a continuous variable into the logistic regression models and assessing the significance of the term using the Wald chi-square test. All statistical analyses were conducted using the SAS software (SAS Institute, Cary, NC). All significance tests were conducted at the α=0.05 level (two-tailed).

Results Table 1 shows the results of the univariate analyses for demographic variables, driving exposure, mental status, and the presence of chronic medical conditions. In the injurious case group there were higher proportions of older, black and male drivers as compared to controls. The same pattern was observed for the non-injurious case group. No significant differences between injurious and non-injurious cases and controls were noted with respect to driving habits. For injurious crashes, the odds ratio for having one or more chronic diseases was 2.2 (95% CI 1.1-4.5). The OR was similarly elevated for the non-injurious crash group (OR=2.7; 95% CI 1.5-4.9). Elevated odds ratios were also observed for the cognitive score. Cases involved in injurious crashes and non-injurious crashes were 2.1- and 1.7-times more likely to receive a score of greater than 9.0 as compared to controls, respectively.

Table 2 displays the univariate results for visual processing variables. Those older drivers involved in injurious crashes were more likely to have impairment in stereoacuity, visual field sensitivity, and the useful field of view. Associations between non-injurious crash involvement and visual field sensitivity and useful field of view were also observed. For the injurious crash case group, the OR for impaired stereoacuity (≥ 500 arcseconds) was 2.2 (95% CI 1.0-3.3). Impairment in central visual field sensitivity (defect depth > 10 dB) was associated with 2.6-times (95% CI 1.1-6.3) the risk of injurious crash involvement. For non-injurious cases, an elevated, non-significant association was observed for impaired central visual field sensitivity (OR=1.8; 95% CI 0.8-2.2). Injurious and non-injurious crash cases were 2.4-times (95% CI 1.3-4.5) and 1.8-times (95% CI 1.0-3.1) more likely to have defect depths greater than 10 dB as compared to controls, respectively. For the injurious crash case group, ORs for reductions in the useful field of view of 23-40%, 41-60% and >60% were 5.3 (95% CI, 1.9-14.0), 16.3 (95% CI, 5.8-46.0), and 22.0 (95% CI, 7.0-69.0), respectively, compared to reductions of less than 23% (p for trend <0.001). For non-injurious cases, the ORs and 95% CIs for these percentage reductions in the useful field of view were: 2.3 (95% CI, 1.1-4.5), 4.6 (95% CI, 2.1-10.1), and 7.1 (95% CI, 2.9-17.5). The trend was significant (p <0.001).

The univariate analyses for common eye conditions in the elderly are listed in Table 3. Of the four conditions considered (glaucoma, cataract, macular degeneration, diabetic retinopathy), for injurious crash cases, only glaucoma and macular degeneration had significantly elevated point estimates. Subjects involved in injurious crashes were 3.6-times (95% CI 1.2-10.9) more likely to report a diagnosis of glaucoma compared to controls. The OR for macular degeneration was 3.3 (95% CI 1.2-9.2). For non-injurious cases, no significantly elevated point estimates were observed.

Variables demonstrating significant (α=0.10) univariate associations were selected as candidate predictor variables in multivariable analyses. For injurious cases, these variables included age, gender, race, chronic diseases, cognitive score, letter acuity, stereoacuity, central and

Visual characteristics	Injurious crashes (N=78) %	OR	(95% CI)	Non-injurious crashes (N=101) %	OR	(95% CI)	Non-crash (N=115) %
Letter Acuity							
20/40 or better	85.9	1.0	(Referent)	85.6	1.0	(Referent)	90.4
Worse than 20/40	14.1	1.6	(0.6,3.8)	14.4	1.6	(0.7,3.6)	9.6
Log_{10} Contrast Sensitivity+							
> 1.5	79.5	1.0	(Referent)	83.8	1.0	(Referent)	77.4
≤ 1.5	20.5	0.9	(0.4,1.8)	16.2	0.7	(0.3,1.3)	22.6
Stereoacuity+							
< 500 Arcseconds	59.0	1.0	(Referent)	71.8	1.0	(Referent)	75.7
≥ 500 Arcseconds	41.0	2.2	(1.1,4.1)	28.2	1.2	(0.7,2.3)	24.3
Disability Glare+‡							
≤ 0	54.0	1.0	(Referent)	55.0	1.0	(Referent)	61.7
> 0	46.1	1.4	(0.8,2.5)	45.0	1.3	(0.8,2.2)	38.3
Central 30° Visual Field Sensitivity+†							
0 to 10	82.1	1.0	(Referent)	86.5	1.0	(Referent)	92.1
> 10	18.0	2.6	(1.1,6.3)	13.5	1.8	(0.8,4.4)	7.8
Peripheral 30-60° Visual Field Sensitivity+†							
0 to 10	52.6	1.0	(Referent)	60.4	1.0	(Referent)	73.0
> 10	47.4	2.4	(1.3,4.5)	39.6	1.8	(1.0,3.1)	27.0
Useful Field of View+¶							
< 23.0	7.7	1.0	(Referent)	19.8	1.0	(Referent)	47.0
23.0 to 40.0	26.9	5.3	(1.9,14)	29.7	2.3	(1.1,4.5)	31.3
41.0 to 60.0	37.2	16.3	(5.8,46)	27.0	4.6	(2.1,10.1)	13.9
> 60.0	28.2	22.0	(7.0,69)	23.4	7.1	(2.9,17.5)	7.8
p for trend			<0.001			<0.001	

+ Higher values represent greater impairment, except for Contrast Sensitivity where lower values represent greater impairment.
† Average defect depth
‡ LogMAR acuity with glare minus LogMAR acuity without glare.
¶ Percent reduction score in useful field of view.

TABLE 2. Visual characteristics of drivers involved in injurious crashes, non-injurious crashes and no crashes.

peripheral visual field sensitivity, useful field of view, and glaucoma. With the exception of glaucoma, these same variables were selected as candidate predictors for the non-injurious crash case group. For injurious cases, with the inclusion of glaucoma and useful field of view impairment in the multivariable logistic regression model, no other candidate predictor variables remained statistically significant. Thus, in the final model, these two variables were identified as having independent associations with crash risk (Table 4). Useful field of view reductions of 22.5-40%, 41-60% and >60% were associated with a 5.2-, 16.5-, and 21.5-fold increased risk of an injurious crash, respec-

Eye conditions	Injurious crashes (N=78) %	OR+	(95% CI)	Non-injurious crashes (N=101) %	OR+	(95% CI)	Non-crash (N=115) %
Glaucoma	14.1	3.6	(1.2,10.9)	6.3	1.5	(0.5,4.8)	4.4
Cataract	47.4	1.0	(0.6,1.8)	49.5	1.1	(0.6,1.8)	47.8
Macular Degeneration	15.4	3.3	(1.2,9.2)	5.4	1.0	(0.3,3.3)	5.2
Diabetic Retinopathy	1.3	0.7	(0.1,8.2)	1.8	1.0	(0.1,7.5)	1.7

+ Referent is those without condition.

TABLE 3. Eye conditions of drivers involved in injurious crashes, non-injurious crashes and no crashes.

TABLE 4. Odds ratios and 95% confidence intervals for significant variables from multiple logistic regression models for injurious crashes and non-injurious crashes.

Variables	Injurious crashes (N=78) OR (95% CI)	Non-injurious crashes (N=101) OR (95% CI)
Useful Field of View+¶		
< 22.5	1.0 (Referent)	1.0 (Referent)
23.0 to 40.0	5.2 (1.8,12.6)	2.3 (1.1,4.5)
41.0 to 60.0	16.5 (5.8,47.3)	4.6 (2.1,10.1)
> 60.0	21.5 (6.8,68.4)	7.1 (2.9,17.5)
p for trend	<0.001	<0.001
Glaucoma	3.6 (1.0,12.6)	-

+ Higher values represent greater impairment.
¶ Percent reduction score in useful field of view.

tively (p for trend <0.01), compared to those with reductions of <22.5%. Cases were 3.6-times more likely (OR=3.6, 95% CI 1.0-12.6) to report glaucoma compared to controls. Other variables demonstrating significant associations at the univariate level did not demonstrate significant, independent associations with injurious crash involvement. The only variable retained in the non-injurious crash logistic regression model was useful field of view impairment. None of the other candidate variables remained significant when included in a model with this variable. Subjects involved in non-injurious crashes were 2.3-, 4.6-, and 7.1-times more likely to have useful field of view impairments of 22.5-40%, 41.0-60.0%, and >60.0%, respectively, compared to controls (p for trend <0.001).

Discussion The results of this exploratory study support the hypothesis that older drivers involved in injurious vehicle crashes are more likely to have visual processing impairments and eye conditions than are those who are crash free. Elderly drivers in our sample with substantial useful field of view reduction (>40%) were at least 20-times more likely to be involved in an injurious crash than were those with no or more minor reductions. To our knowledge, this is the first study to link visual deficits of any type to the most serious form of collision from a public health standpoint – those where injuries result. Similarly, we found that drivers involved in non-injurious crashes were 5.5-times more likely to have a substantial useful field of view impairment. Useful field of view performance, an independent predictor in our analyses, relies on several visual processing domains, including visual sensory function, processing speed, and divided and selective attention skills, and assesses the peripheral field, not only central vision.[30,33] Its stronger association with injurious crashes, as compared to visual sensory measures (e.g., acuity, light sensitivity in the visual field), may stem from its tapping into several domains of visual processing. It is important to recognize that visual sensory tests do not adequately reflect the visual complexity of the driving task that involves the simultaneous use of central and peripheral vision, both primary and secondary task demands, and the filtering out of irrelevant environmental events. Visual sensory tests as performed in the clinic and laboratory do not typically incorporate these types of stimulus features. Thus, it is not surprising that tests such as visual acuity are not strong independent predictors of crash involvement and are inadequate for identifying crash-prone drivers, which has been long recognized in the driver safety literature.[34]

This study also identified glaucoma as an independent risk factor for injurious crash occurrence by older drivers. Other studies have hinted at the potential importance of glaucoma in vehicle crash etiology in the elderly. The Washington State study mentioned earlier found that older drivers involved in injurious crashes were 50% more likely to have glaucoma than those who were not crash involved,[23] although the confounding role of other relevant variables in this association was not evaluated. A prospective study by Foley et al. on crashes regardless of injury also found an unadjusted elevated crash risk among older drivers with glaucoma.[35] In the present study it is interesting that glaucoma *per se*, not visual field sensitivity loss (often a functional manifestation of the condition), was an independent predictor in this study. Glynn and colleagues have reported that the use of topical eye medications in elderly patients with glaucoma increases their risk for another adverse mobility outcome, falling.[36] Medication information was not collected in our study, so this hypothesis cannot be addressed in the present context. The possibility that glaucoma and/or medications to treat it may contribute to injurious crash occurrence is deserving of further investigation, given that glaucoma is a leading cause of blindness worldwide.[37] We also found that AMD had a significant crude association with injurious crashes by older drivers. Given that AMD is the leading cause of untreatable blindness in the elderly, its role in injurious crash etiology deserves further scrutiny. A prior study examining the association between driver safety and juvenile forms of macular dystrophy in middle-aged and young drivers reported no differences between visually impaired and non-impaired subjects in either crash involvement or performance in a driving simulator.[38] However, its relevance to the present study is not clear since the focus here is on older drivers who often have co-morbid functional impairments known to impact driving and whose driving exposure patterns are known to be different from those of younger drivers.[12]

Several earlier studies have emphasized the importance of the visual field in road safety.[5,6,39-41] Drivers regardless of age who have significant binocular visual field loss exhibit deficiencies in performance in a driving simulator and an elevation in crash risk. Our own results underscore this finding in that we found a significant univariate association between injurious crash involvement and average visual field sensitivity impairment that exceeded 1 log unit. Peripheral visual field loss did not emerge as in independent risk factor in the multivariable model. Rather, useful field of view restriction, which is in part dependent on visual field sensitivity, had an independent impact on crash involvement. As discussed earlier, the strength of the association between crash involvement and the useful field of view may stem from its dependence on several aspects of visual processing throughout the visual field, such as selective and divided attention, processing speed, and light sensitivity.

In addition to the incorporation of visual processing tests with high face validity to the driving task, another strength of this study is its reliance on accident reports provided by the state for defining the outcome of interest, injurious crash involvement. Many earlier studies on risk factors for crash involvement have relied on older adults' self-reports as to whether they were involved in crashes in recent years.[9,42,43] The extent to which subjects exhibit veridical recall and frank reporting of crashes incurred in prior years is highly variable across different types of older adult populations, with some studies reporting good correspondence between self-reports and state records,[44] and others finding poor correspondence.[24] Thus, for our purposes, the most prudent approach was to use state records. An additional advantage of state records is that they constitute formal public documents about the occurrence of injury, which serve as a basis for public policy in the traffic safety area.

Study limitations also bear mentioning. This study was not originally designed to examine associations between injurious crashes, vision impairment and eye disease, so that the data analysis was exploratory in nature. Visual processing and eye disease were measured after crash occurrence (in some cases several years later) rather than prior to the outcome. Thus it is possible that some misclassification with respect to visual function variables exists. However, since such misclassification is not likely to be related to case status, the effect will be point estimates biased towards the null value. It should also be noted that more than half of the crashes occurred post-1986; thus, the average length of time between crash involvement and measurement of visual function was 3 years. Another limitation is the low prevalence of eye conditions (e.g., glaucoma, AMD) in the sample. Consequently, the power to detect significant associations for these conditions was low; this would also result in imprecise point estimates for measures of association for these conditions. With respect to injury, injury severity information was unavailable from the accident records, and thus associations between injury severity and visual processing impairment and eye disease could not be examined. A larger prospective design is needed to confirm the findings reported here, to characterize impairments and disease more precisely prior to the crash occurrence, and to relate vision impairment and eye disease more directly to injury outcomes.

This study suggests that visual processing impairment, a major cause of disability in older adults,[45,46] and glaucoma, projected to affect almost

1.6 million older adults in the U.S. by the year 2000,[37] increase older drivers' risk for involvement in an injurious crash. If future research confirms the trends reported here, it would be useful to determine whether visual screening tests such as the useful field of view task could reduce motor vehicle crash and injury rates among older drivers. Similarly, it may be beneficial to determine if effective treatment and control of glaucoma, as well as other eye conditions in the elderly, lowers the risk for crashes and injury. Both of the independent risk factors identified in this preliminary study are potentially modifiable, through the treatment of eye conditions or training to improve visual processing capabilities.[47] Interventions to reverse vision impairment may ultimately assist in reducing motor vehicle morbidity and mortality in the elderly.

References

1 Kahn HA, Leibowitz HM, Ganley, JP et al. The Framingham eye study. I. Outline and major prevalence findings. Am J Epidemiol 1977;106:17-41.

2 Tielsch JM, Sommer A, Witt K, Katz J, Royall RM, The Baltimore Eye Survey Group. Blindness and visual impairment in an American urban population. Arch Ophthalmol 1990;108:286-90.

3 Owsley C, Ball K, Sloane ME, Roenker DL, Bruni JR. Visual/cognitive correlates of vehicle accidents in older drivers. Psych Aging 1991;6:403-14.

4 Decina LE, Staplin L. Retrospective evaluation of alternative criteria for older and younger drivers. Accid Anal Prev 1993;25:267-75.

5 Johnson CA, Keltner JL. Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. Arch Ophthalmol 1983;101:371-5.

6 Keltner JL, Johnson CA. Mass visual field screening in a driving population. Ophthalmology 1980;94:1180-8.

7 Hills BL, Burg A. A re-analysis of California driver vision data: General findings. (Report 768). Crowthorne, England: Transport and Road Research Laboratory, 1977.

8 Henderson R, Burg A. Vision and audition in driving (Technical Report Number TM(l)-5297/000/000). Washington, DC: US Department of Transportation, 1974.

9 Shinar D. Driver visual limitations: Diagnosis and treatment. (Contract DOT-HS-5-1275). Washington, DC: US Department of Transportation, 1977.

10 Koepsell TD, Wolf M, McCloskey L, Buchner DM, Louie D, Wagner EH. Medical conditions and motor vehicle collision injuries in older adults. J Am Geriatr Soc 1994;42:695-700.

11 Hansotia P, Broste SK. The effect of epilepsy or diabetes mellitus on the risk of automobile accidents. N Engl J Med 1991;324:22-6.

12 National Highway Traffic Safety Administration. Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers. (Report No. DOT HS 807 316). Washington, DC: US Department of Transportation, 1989.

13 Accident Facts. Chicago: National Safety Council, 1993.

14 Keltner JL, Johnson CA. Visual function and driving safety (editorial). Arch Ophthalmol 1992;110:1697-8.

15 Lichter PR. The ophthalmologist's role in licensing drivers. Ophthalmology 1989;96:1457-9.

16 Keeney AH. The visually impaired driver and physician responsibilities. Am J Ophthalmol 1976;82:799-801.

17 Barancik JI, Chatterjee BF, Greene-Cadden YC, Michenzi EM, et al. Motor vehicle trauma in northeastern Ohio. I. Incidence and outcome by age, sex, road-use category. Am J Epidemiol 1986;74:473-8.

18 McCoy GF, Johnson RA, Duthie RB. Injury to the elderly in road traffic accidents. J Trauma 1989;29:494-7.

19 Evans L. Traffic Safety and the Driver. New York: Van Nostrand Reinhold, 1991.

20 Koepsell TD, Wolf M, McCloskey L, Buchner DM, Louie D, Wagner EH. Medical conditions and motor vehicle collision injuries in older adults. J Am Geriatr Soc 1994;42:695-700.

21 Leveille SG, Buchner DM, Koepsell TD, McCloskey LW, Wolf ME, Wagner EH. Psychoactive medications and injurious motor vehicle collisions involving older drivers. Epidemiology 1994;5:591-8.

22 Ray WA, Fought RL, Decker MD. Psychoactive drugs and the risk of injurious motor vehicle crashes in elderly drivers. Am J Epidemiol 1992;136:873-83.

23 McCloskey LW, Koepsell TD, Wolf ME, Buchner DM. Motor vehicle collision injuries and sensory impairments of older drivers. Age Ageing 1994;23:267-73.

24 Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR. Visual attention problems as a predictor of vehicle crashes in older drivers. Invest Ophthalmol Vis Sci 1993;34:3110-23.

25 Ferris FL, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. Am J Ophthalmol 1991;94:91-6.

26 Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clin Vision Sci 1988;2:187-99.

27 Simons K. A comparison of the Frisby, Random-Dot E, TNO and

Randot Circles Stereotests in screening and office use. Arch Ophthalmol 1981;99:446-52.
28 Haley MJ, editor. The Field Analyzer Primer. San Leandro, CA: Allergan Humphrey, 1987.
29 Brenton RS, Phelps CD. The normal visual field on the Humphrey field analyzer. Ophthalmologica 1986;193:56-74.
30 Ball K, Roenker DL, Bruni JR. Developmental changes in attention and visual search throughout adulthood. In: Enns J, editor. Advances in Psychology. Amsterdam: North Holland/Elsevier Science Publishers, 1990:489-508.
31 Mattis S. Mental status examination for organic mental syndrome in the elderly patient. In: Bella L, Karasu TB, editors. Geriatric Psychiatry (Second edition). New York: Oxford University Press, 1976.
32 Kleinbaum DG. Logistic Regression: A Self-learning Text. New York: Springer-Verlag, 1994.
33 Owsley C, Ball K, Keeton DM. Relationship between visual sensitivity and target localization in older adults. Vision Res 1995;35:579-87.
34 Brody L. The role of vision in motor vehicle operation. A review. Int Record Med Gen Pract Clinics 1954;167:365-77.
35 Foley DJ, Wallace RB, Eberhard J. Risk factors for motor vehicle crashes among older drivers in a rural community. J Am Geriatr Soc 1995;43:776-81.
36 Glynn RJ, Seddon JM, Krug JH, Sahagian CR, Chiavelli ME, Campion EW. Falls in elderly patients with glaucoma. Arch Ophthalmol 1991;109:205-10.
37 Quigley HA, Vitale S. Models of open-angle glaucoma prevalence and incidence in the United States. Invest Ophthalmol Vis Sci 1997;38:83-91.
38 Szlyk JP, Fishman GA, Severing K, Alexander KR, Viana M. Evaluation of driving performance in patients with juvenile macular dystrophies. Arch Ophthalmol 1993;111:207-12.
39 Szlyk JP, Alexander KR, Severing K, Fishman GA. Assessment of driving performance in patients with retinitis pigmentosa. Arch Ophthalmol 1992;110:1709-13.
40 Hedin A, Lovsund P. Effects of visual field defects on driving performance. Doc Ophthalmol Proc Series 1986;49:541-7.
41 Wood JM, Troutback R. Effect of restriction of the binocular visual field on driving performance. Ophthalm Physiol Optics 1992;12:291-8.
42 Marottoli RA, Cooney LM Jr, Wagner DR, Doucette J, Tinetti ME. Predictors of automobile crashes and moving violations among elderly drivers. Ann Intern Med 1994;121:842-6.
43 Hoffstetter HW. Visual acuity and highway accidents. J Am Optom Assoc 1976;47:887-93.
44 Marottoli RA, Cooney LM, Tinetti ME. Self-report versus state records for identifying crashes among older drivers. J Gerontol 1997;52A:M184-7.
45 Verbrugge LM, Patrick DL. Seven chronic conditions: Their impact on US adults' activity level, and use of medical services. Am J Publ Health 1995;85:173-82.
46 West SK, Munoz B, Rubin GS, Schein OD, Bandeen-Roche K, Zeger S, German PS, Fried LP, SEE Project Team. Function and visual impairment in a population-based study of older adults. Invest Ophthalmol Vis Sci 1997;38:72-82.
47 Ball KK, Beard BL, Roenker DL, Miller RL, Griggs DS. Age and visual search: Expanding the useful field of view. J Opt Soc Am A 1988;5:2210-9.