Is Glaucoma Associated with Motor Vehicle Collision Involvement and Driving Avoidance?

Gerald McGwin, Jr,1,2,3 Andrew Mays,3 Wade Joiner,5 Dawn K. DeCarlo,4 Sandre McNeal,3 and Cynthia Owsley5

PURPOSE. To evaluate the association between the diagnosis of glaucoma and motor vehicle collision (MVC) involvement and driving avoidance in drivers aged ≥50 years.

METHODS. Two groups of patients, one with glaucoma and one without, were identified in three university-affiliated eye care practices. Demographic, clinical, and driving characteristics were obtained by chart abstractions and a patient survey. Information regarding MVC involvement was obtained from police records.

RESULTS. Patients with glaucoma were less likely (relative risk [RR], 0.67; 95% confidence interval [CI], 0.47–0.97) to be involved in collisions than patients without glaucoma. There was no difference between the at-fault crash rates of the patients with glaucoma and those without (RR, 1.22; 95% CI, 0.67–2.22). Patients with glaucoma had significantly higher levels of avoidance for driving at night (odds ratio [OR], 2.06; 95% CI, 1.11–3.82), driving in fog (OR, 3.80; 95% CI, 1.93–7.48), driving in the rain (OR, 2.99; 95% CI, 1.32–6.76), driving during rush hour (OR, 2.24; 95% CI, 1.16–4.34), driving on the highway (OR, 2.81; 95% CI, 1.19–6.64), and high density driving (OR, 2.88; 95% CI, 1.28–6.46). These associations were adjusted for demographic and medical characteristics as well as visual acuity.

CONCLUSIONS. Older persons with glaucoma drive at least as safely as, if not more safely than, older persons without glaucoma. (Invest Ophtalmol Vis Sci. 2004;45:3934–3939) DOI:10.1167/iovs.04-0524

Glaucoma is the second leading cause of vision loss among adults today in the United States1 and is the first among African Americans.2 It affects >2.2 million Americans aged ≥40 years and 67 million people worldwide.3 Glaucoma is a progressive optic neuropathy characterized by changes in the structure of the optic disc, thinning of the retinal nerve fiber layer, and loss of visual function beginning in the peripheral field. Visual impairment from glaucoma has a negative impact on health-related quality of life3–8 and ambulatory mobility.9,10 State driver-licensing agencies in the United States have already enacted, or are now considering, laws requiring mandatory reporting by health care providers of licensed drivers with certain medical conditions. Motor vehicle collisions (MVCs) are among the most potentially adverse mobility-related outcomes that have been reportedly associated with glaucoma.11–16 Hu et al.11 analyzed MVC records in Iowa from 1985 to 1993 and found that older men with self-reported glaucoma were at an increased risk for an MVC. Another study found that glaucoma, as listed in medical records, was independently associated with injurious MVCs,13 although there was only a small number of drivers with glaucoma in the sample. Johnson and Keltner17 reported that persons with bilateral visual field defects (regardless of cause) had a higher frequency of MVCs. Wood and Troutbeck17,18 and Wood et al.19 found that simulated binocular visual field restriction limited to a 40° radius field or smaller compromised some aspects of driving performance, such as obstacle avoidance. Persons with glaucoma report more difficulty driving than do control subjects without glaucoma, as measured in health-related quality of life surveys.7,8 However, not all studies addressing the relationship between glaucoma and driving have reported an association. McCloskey et al.14 found no evidence that glaucoma increases the risk of injuries from collision. The inconsistencies in the literature may be in part due to a person’s ability to compensate for field loss by modifying driving behavior.20,21 to the use of self-report diagnosis as the case definition,11 or to failure to account for driving exposure.12 In fact studies have documented that many persons with visual impairment self-regulate their driving by reducing their exposure to driving situations they find more difficult (rain, night, heavy traffic, and rush hour) and are less likely to engage in risk-taking driving behavior,22 thus potentially reducing their risk of MVCs.20,23

The objective of this retrospective cohort study was to evaluate the relationship between glaucoma and the risk of MVC involvement and driving avoidance in drivers aged ≥55 years. This study improves on the design of earlier studies by incorporating the role of fault and driving exposure in the calculation of MVC rates and by evaluating non-collision-related driving outcomes.

METHODS

Study Cohort

The study cohort consisted of two groups of subjects: those with a diagnosis of glaucoma and those without. Subjects with glaucoma consisted of individuals aged ≥55 who, between January 1994 and December 1995, had been seen at least once in any of three university-affiliated ophthalmology and optometry practices specializing in the diagnosis and treatment of glaucoma. All potentially eligible patients with glaucoma seen at each location during this time were identified according to the International Classification of Diseases, 9th Revision (ICD-9) codes 365.1 and 365.2. After a medical record review and

From the 1Department of Epidemiology and International Health, School of Public Health; the 2Section of Trauma, Burns, and Surgical Critical Care, Division of General Surgery, Department of Surgery, School of Medicine; and the 3Department of Ophthalmology, School of Medicine, University of Alabama at Birmingham; and the 4College of Optometry, Nova Southeastern University, Fort Lauderdale, Florida.

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Corresponding author: Gerald McGwin, Jr, Department of Ophthalmology, School of Medicine, University of Alabama at Birmingham, 700 S. 18th Street, Suite 609, Birmingham, AL 35294-0009; mcgwin@uab.edu.

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verification of the diagnosis, patients were excluded from the study cohort if the primary eye disorder and cause of vision limitation listed in the medical record was an ocular disorder other than glaucoma (e.g., macular degeneration, diabetic retinopathy, or clinically significant cataract for which surgery had been recommended). The patients without glaucoma were selected from university-affiliated ophthalmology and optometry practices and had to be free of any eye disease. Persons with diagnoses of refractive error, dry eye, and early cataract were eligible for either group. Because the focus of the study was driving-related outcomes, subjects in either group who were not legally licensed to drive were also excluded. Information on licensure status was obtained by cross-referencing each subject’s demographic and residential information obtained from the medical record with the Alabama Department of Public Safety (ADPS) database. Only 576 potentially eligible patients with glaucoma, 576 were ultimately deemed eligible for participation in the study. Of the 115 patients without glaucoma, all were eligible for participation.

**Data Collection**

The data for this study were obtained from a variety of sources. First, medical records were abstracted to confirm the diagnosis (absence of a diagnosis) of glaucoma and to obtain information on best corrected visual acuity in each eye from January 1994 through December 1995. A telephone survey was conducted between February and June 2000. The survey instrument collected information on sociodemographics, alcohol use, smoking, self-reported medical conditions, and driving characteristics. With the exception of demographic characteristics, subjects were asked to respond to certain questions using the year 1995 as the reference point. With respect to sociodemographic characteristics, standard questions related to age, gender, race, education, and marital status were used. Subjects were asked whether they had ever smoked and/or consumed alcohol and, if so, how much. Cognitive status was assessed by using a version of the Short Portable Mental Status Questionnaire (SPMSQ) that was modified for telephonic administration.25 - 27 Driving Habits Questionnaire (DHQ)26 was used to collect information on driving exposure defined in terms of estimated weekly mileage, which previous work has indicated can be estimated reliably and validly by older drivers.27 The DHQ was also used to estimate the extent to which the respondent reported avoiding certain driving situations, many of which are known to be especially problematic for older drivers: driving in darkness, in fog, in rain, while alone, during rush hour, on the highway/expressway, with children, or in high-density traffic and passing other cars, changing lanes, making left turns at intersections, and parallel parking. The possible responses were “Always,” “Often,” “Sometimes,” “Rarely,” or “Never.” For analytic purposes, subjects who reported ‘Always’ or ‘Often’ avoiding a specific situation were defined as avoiders and those who reported ‘Sometimes,’ ‘Rarely,’ or ‘Never’ were defined as nonavoiders. A composite variable to reflect overall driving avoidance was created by summing the binary avoider/nonavoider variables. Given the 12 situations, the composite variable had a range of 12 (minimum, 0; maximum, 12).

For both groups, information on crash involvement was obtained from the ADPS. The names and driver’s license numbers of all study participants were sent to the ADPS, and they provided accident reports for all MVCs that occurred between the time of the subject’s first examination and December 1999 wherein the subject was identified as the driver. Whether the crash was defined as the fault of the driver by the police officer at the scene was noted on the accident report.

The Institutional Review Board for Human Use at The University of Alabama Birmingham (UAB) approved the study protocol. This study adhered to the tenets of the Declaration of Helsinki, and informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study.

**Statistical Analysis**

Of the 691 eligible study subjects, telephone interviews were completed for 468 (67.7%): 66.8% of subjects with glaucomatous and 72.2% of those without. Of those not completing the survey, 50 subjects were confirmed deceased by Social Security death data, and 136 could not be interviewed because an incorrect telephone number was listed in the medical record and the number was unavailable from directory assistance or other sources. Only 37 subjects who were contacted refused to complete the survey. With respect to death, incorrect telephone numbers, and refusals, there was no difference between the groups. Thus, information on demographics, behavior, health, and driving exposure and avoidance was not available for 223 subjects. To prevent the exclusion of these subjects from the analysis (since we had medical records and crash data on subjects who were not interviewed), multiple imputation was used to create values for missing observations by using a Markov Chain Monte Carlo (MCMC) method.28 - 30 The MCMC method was chosen because the pattern of missing data tended to be monotone (i.e., for a given subject, groups of variables are missing information), and because this imputation method is appropriate with this pattern of missing data. Specifically, imputation was performed using the following characteristics: age, gender, race, education, smoking status, alcohol consumption, health status, cognitive status, driving avoidance, and characteristics (e.g., annual mileage). Not all these variables had missing data (e.g., age, because it was obtained from the medical record), and these were used in the imputation process to yield improved estimates for missing values. Boundaries were placed on each variable to ensure that the imputation process would not yield imputed values outside those of the real, observed values.

Descriptive statistics were generated for demographic, medical conditions, and visual function characteristics. These variables were compared between the glaucoma and nonglaucoma groups using χ² and t-tests for categorical and continuous variables, respectively.

As noted earlier, this study had two outcomes of interest. For assessment of collision outcomes, relative risk (RR) and 95% confidence intervals (CIs) were calculated to compare crash rates among subjects with glaucoma and those without, by using Poisson regression. Crash rates were calculated considering all collisions as well as just those in which the subject was considered to be at fault. Two denominators for crash rate calculations were used. Person-time was defined as the period from the subject’s first examination to the end of follow-up (December 1999). Person-miles of travel represent the total amount of travel during the follow-up period and was calculated as the product of person-time and each subject’s estimated average annual mileage based on estimated weekly mileage from the telephone survey. Crude and adjusted RRs and 95% CIs were calculated. Adjusted analyses accounted for the possible confounding effects of demographic and medical characteristics.

The second outcome of interest is avoidance of challenging driving situations, as measured by the DHQ.26 As noted earlier, subjects were asked how frequently they avoided each situation. As noted previously, for analytic purposes, subjects who reported ‘Always’ or ‘Often’ avoiding a specific situation were defined as avoiders and those who reported ‘Sometimes,’ ‘Rarely,’ or ‘Never’ were defined as nonavoiders. A composite variable to reflect overall driving avoidance was created by summing the binary avoider/nonavoider variables. Given the 12 situations, the composite variable had a range of 12 (minimum, 0; maximum, 12).

For both groups, information on crash involvement was obtained from the ADPS. The names and driver’s license numbers of all study participants were sent to the ADPS, and they provided accident reports for all MVCs that occurred between the time of the subject’s first examination and December 1999 wherein the subject was identified as the driver. Whether the crash was defined as the fault of the driver by the police officer at the scene was noted on the accident report.

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**Statistical Analysis**

Of the 691 eligible study subjects, telephone interviews were completed for 468 (67.7%): 66.8% of subjects with glaucomatous and 72.2%
RESULTS

Five hundred and seventy-six patients with glaucoma and 115 without were enrolled in the study. The two groups did not differ in gender but demonstrated a statistically significant difference in age, race, and education (Table 1). Patients with glaucoma were, on average, 2 years older ($P = 0.0040$), and more were African-American ($P = 0.0003$) and were less likely to have a college education ($P = 0.0043$) than the patients without glaucoma. Patients with glaucoma reported consuming less alcohol, whereas both groups indicated similar smoking status. The driving avoidance score was significantly higher among the patients with glaucoma than those without, indicating a greater propensity to avoid challenging driving situations. With respect to medical conditions self-reported during the survey interview, patients with glaucoma had a significantly higher frequency of cataracts, high blood pressure, and diabetes than those without, whereas there was no significant difference in heart disease, cancer, stroke, diabetic retinopathy, and age-related maculopathy between the two groups. Cognitive impairment was more common among the patients with glaucoma than in those without glaucoma, but the difference was not statistically significant. The acuity (better and worse eyes) of patients with glaucoma was significantly worse than that of those without disease.

Tables 2 and 3 present the crude and adjusted RRs for overall crash rates and at-fault crash rates, respectively. When taking into consideration person-miles of travel, patients with glaucoma were less likely (RR, 0.64; 95% CI, 0.46–0.90) to crash than the patients without glaucoma. This relationship held true, even after adjusting for age, gender, race, education, smoking, alcohol consumption, specific self-reported medical conditions, and cognitive status (RR, 0.67; 95% CI, 0.47–0.97). There was also a reduction in crash rates when person-time rather than person-miles was used in the evaluation (RR, 0.58; 95% CI, 0.40–0.85).

There was no difference among the at-fault crash rates of the patients with and those without glaucoma (RR, 1.09; 95% CI, 0.62–1.92) using person-miles for calculation. The risk was changed slightly after adjustment (RR, 1.22; 95% CI, 0.67–2.22). The pattern of results was similar when person-time was used instead of person-miles (RR, 1.07; 95% CI, 0.59–1.96).

With respect to driving avoidance (Table 4), patients with glaucoma had a higher level of avoidance of all 12 situations. Statistically significant differences between the two groups existed for driving at night (OR, 2.06; 95% CI, 1.11–3.82), in fog (OR, 3.80; 95% CI, 1.93–7.48), in the rain (OR, 2.99; 95% CI, 1.32–6.76), during rush hour (OR, 2.24; 95% CI, 1.16–4.34), on the highway (OR, 2.81; 95% CI, 1.19–6.64), and in high-density traffic (OR, 2.88; 95% CI, 1.28–6.46). In general, adjustment for the potentially confounding effects of age, gender, race, education, smoking, alcohol consumption, specific medical conditions, and cognitive status increased the magnitude of these associations.

DISCUSSION

Older drivers with diagnoses of glaucoma had a rate of crash involvement that was approximately 40% to 50% lower than that of patients without glaucoma, adjusting for demographic, medical, and visual functional characteristics of the drivers. Unlike an earlier study reporting that older drivers with glaucoma had an increased collision risk, the present study expressed the collision outcome as a rate, thus taking into account driving exposure (person-miles of travel and person-years of travel). In addition, the present study did not rely on self-reported diagnoses of glaucoma, as did the earlier study. When analyses focused on at-fault crashes as the outcome (i.e., collisions where the officer at the scene indicated on the accident report that our subject was at fault), the crash rate of drivers with glaucoma was not different from that of the
### Table 2. Overall Crash Rates, Crude and Adjusted RRs, and 95% CIs

<table>
<thead>
<tr>
<th></th>
<th>Total Collisions</th>
<th>Person-Miles</th>
<th>Crash Rate</th>
<th>Crude RR (95% CI)</th>
<th>Adjusted RR* (95% CI)</th>
<th>Adjusted RR† (95% CI)</th>
<th>Person-Time</th>
<th>Crash Rate</th>
<th>Crude RR (95% CI)</th>
<th>Adjusted RR* (95% CI)</th>
<th>Adjusted RR† (95% CI)</th>
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<tr>
<td>Glaucoma</td>
<td>153</td>
<td>26,697,441</td>
<td>5.73</td>
<td>0.64 (0.46–0.90)</td>
<td>0.58 (0.40–0.83)</td>
<td>0.51 (0.33–0.80)</td>
<td>3,165</td>
<td>4.83</td>
<td>0.59 (0.41–0.84)</td>
<td>0.57 (0.39–0.83)</td>
<td>0.50 (0.32–0.79)</td>
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<tr>
<td>Nonglaucoma</td>
<td>42</td>
<td>4,691,277</td>
<td>8.95</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>530</td>
<td>7.92</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
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* Adjusted for all variables in Table 1.
† Adjusted for all variables in Table 1, excluding imputed data.

### Table 3. At-Fault Crash Rates, Crude and Adjusted RRs, and 95% CIs

<table>
<thead>
<tr>
<th></th>
<th>At-Fault Collisions</th>
<th>Person-Miles</th>
<th>Crash Rate</th>
<th>Crude RR (95% CI)</th>
<th>Adjusted RR* (95% CI)</th>
<th>Adjusted RR† (95% CI)</th>
<th>Person-Time</th>
<th>Crash Rate</th>
<th>Crude RR (95% CI)</th>
<th>Adjusted RR* (95% CI)</th>
<th>Adjusted RR† (95% CI)</th>
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<tr>
<td>Glaucoma</td>
<td>87</td>
<td>26,697,441</td>
<td>3.26</td>
<td>1.09 (0.62–1.92)</td>
<td>0.99 (0.54–1.80)</td>
<td>0.84 (0.42–1.66)</td>
<td>3,165</td>
<td>2.75</td>
<td>1.04 (0.59–1.85)</td>
<td>1.02 (0.56–1.87)</td>
<td>0.78 (0.40–1.53)</td>
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<tr>
<td>Nonglaucoma</td>
<td>14</td>
<td>4,697,277</td>
<td>2.98</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>530</td>
<td>2.64</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
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</table>

* Adjusted for all variables in Table 1.
† Adjusted for all variables in Table 1, excluding imputed data.
drivers without glaucoma. From a public safety standpoint, drivers with glaucoma as a group should not be viewed as more unsafe on the road than older drivers who are free of this disease, and in fact, when all collisions are considered regardless of at-fault status, drivers with glaucoma are safer on the road than their disease-free counterparts.

Drivers with glaucoma appear to self-regulate their driving by avoiding potentially difficult driving situations, including those in which collisions are more likely to occur. Compared with drivers without the disease, they were two to three times more likely to avoid driving at night, in the fog, in the rain, during rush hour traffic, and on the highway or interstate, all of which are visually challenging tasks. The avoidance of driving conditions in which there is poor visibility or a fast-paced visual environment has also been reported to be true of older drivers with vision impairment and eye conditions, including cataract and age-related maculopathy. Our findings in the current study imply that drivers with glaucoma may be self-limiting their exposure to the road in response to eye disease. The implicit personal benefit of this approach is that even though these drivers have glaucoma, they maintain their driving mobility while enhancing their safety by reducing their exposure to situations on the road in which collisions are more likely to occur.

A question of interest is whether the lower crash rate of drivers with glaucoma compared with glaucoma-free drivers may be due to their increased avoidance of challenging driving situations. To investigate, we created a driving-avoidance variable and included it as an independent variable in the multivariate analyses. The similarity of the unadjusted and adjusted results implies that the reduced crash rate exhibited by older drivers with glaucoma cannot be explained by their tendency to avoid difficult driving situations, but rather is due to other factors. Previous work has suggested that drivers with visual field impairment adapt their viewing behavior on the road by increasing scanning. Whether this type of compensatory behavior improves their safety on the road (i.e., reduces their crash risk) is worthy of further investigation because of its potentially practical value in driver rehabilitation of those with visual field defects due to diseases such as glaucoma.

Given that subjects with glaucoma and those without had similar at-fault crash rates, yet subjects with glaucoma had lower overall crash rates, this also means that subjects with glaucoma had a reduced risk of not-at-fault collisions. As with the overall reduced risk, the explanation for why this reduced risk is limited to not-at-fault collisions is not immediately clear, although it may stem from subtle and/or measured driving habit differences in the two groups that impact risk.

The results of this study must be interpreted in light of several strengths and limitations. Information on sociodemographics, alcohol use and smoking, and medical and driving characteristics was obtained in a telephone survey conducted several years after the beginning of the follow-up period. Subjects had to recall information several years in the past. Although we have no reason to suspect that the veracity of the information provided was differential according to glaucoma status, there is the potential for simple inaccuracies. Second, although two thirds of subjects were reached, the inability to obtain survey data on the remaining subjects would have reduced the sample size available for analyses and thus the statistical power. To minimize the impact of this information loss and retain these subjects in our analyses, multiple imputation was conducted to provide informed estimates for observations for which there were missing data. Imputation for such a large proportion of the study population increases the concern for bias. To evaluate this possibility, for the outcomes of interest, the analyses were conducted with and without the imputed observations. Fortunately, the two approaches produced essentially the same results, and therefore one can conclude that the imputation process resulted in little, if any, bias. Finally, information on the clinical and functional aspects of glaucoma was not considered in this study. It is possible that there is a subgroup of patients with glaucoma with more severe disease or with certain functional impairments that do represent a traffic safety risk, a question in need of further study.

This study also has several strengths. First, although the patients with glaucoma were initially identified on the basis of ICD-9 codes, chart reviews were subsequently conducted to verify that the primary cause of vision limitation was in fact glaucoma. Similarly, medical records of the patients without glaucoma were reviewed to ensure that these individuals were free of any eye disease. Although, according to Table 1, other eye diseases were present in both groups, this information was by self-report. Thus, we were able to reduce any potential misclassification of glaucoma status. Second, information on the primary outcome of interest (i.e., crash involvement) was obtained from an independent, objective source. This reduces the potential for bias or underreporting that may occur when such information is obtained by self-report. The use of police reports precludes our ability to include collisions not reported to the police in our study. However, we have no reason to suspect that patients with glaucoma and those without would have a differential rate of non-police-reported collisions.

In summary, the results of this study indicate that individuals with glaucoma are at least as safe as, if not safer than, older

### Table 4. Driving Avoidance in the Glaucoma and Nonglaucoma Groups

| Overall | Glaucoma | Nonglaucoma | OR (95% CI) | OR (95% CI)* | OR (95% CI)†
|---------|----------|-------------|-------------|--------------|--------------|
| Driving at night | 41.7 | 44.1 | 29.6 | 1.88 (1.22–2.90) | 2.06 (1.11–3.82) | 2.06 (1.12–3.81)
| Driving in fog | 45.4 | 49.1 | 27.0 | 2.62 (1.68–4.08) | 3.80 (1.93–7.38) | 3.65 (1.86–7.19)
| Driving in rain | 30.7 | 32.6 | 20.9 | 1.84 (1.13–2.98) | 2.99 (1.32–6.76) | 2.47 (1.14–5.38)
| Driving alone | 8.7 | 9.2 | 6.1 | 1.56 (0.69–3.53) | 1.52 (0.41–5.25) | 1.84 (0.60–5.72)
| Driving during rush hour | 41.0 | 42.7 | 32.2 | 1.57 (1.03–2.40) | 2.24 (1.16–4.34) | 2.26 (1.17–4.36)
| Driving on the highway | 31.3 | 33.5 | 20.0 | 2.02 (1.24–3.29) | 2.81 (1.19–6.46) | 2.59 (1.11–6.07)
| Driving with children | 13.2 | 14.1 | 8.7 | 1.72 (0.86–3.43) | 1.42 (0.55–3.68) | 1.53 (0.59–4.01)
| High-density driving | 34.6 | 37.2 | 21.7 | 2.13 (1.52–3.42) | 2.88 (1.28–6.46) | 2.99 (1.33–6.72)
| Passing other cars | 20.6 | 21.2 | 17.4 | 1.28 (0.76–2.15) | 1.45 (0.59–3.54) | 1.54 (0.64–3.74)
| Changing lanes | 19.0 | 19.4 | 16.5 | 1.22 (0.72–2.08) | 1.94 (0.71–5.31) | 2.09 (0.76–5.74)
| Left turns | 7.7 | 8.5 | 3.5 | 2.58 (0.91–7.29) | 2.56 (0.69–9.52) | 3.05 (0.85–10.99)
| Parallel parking | 28.5 | 28.8 | 27.0 | 1.10 (0.70–1.72) | 1.20 (0.61–2.37) | 1.03 (0.52–2.06)

* Adjusted for all variables in Table 1 except the driving avoidance score.
† Adjusted for all variables in Table 1 except the driving avoidance score and excluding imputed data.
drivers without the disease. Moreover, they are more risk averse when it comes to difficult driving situations, reflecting insight into their own driving skills. This self-regulation, however, does not appear to explain their reduced risk of crash involvement. Future research should evaluate clinical and functional characteristics of patients with glaucoma to confirm that a subgroup of these individuals (e.g., perhaps those with severe field loss) do not pose an adverse traffic safety risk.

References