Glaucoma and On-Road Driving Performance

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PURPOSE. To investigate the on-road driving performance of patients with glaucoma.

METHODS. The sample comprised 20 patients with glaucoma and 20 subjects with normal vision, all licensed drivers, matched for age and sex. Driving performance was tested over a 10-km route incorporating 55 standardized maneuvers and skills through residential and business districts of Halifax, Nova Scotia, Canada. Testing was conducted by a professional driving instructor and assessed by an occupational therapist certified in driver rehabilitation, masked to participant group membership and level of vision. Main outcome measures were total number of satisfactory maneuvers and skills, overall rating, and incidence of at-fault critical interventions (application of the dual brake and/or steering override by the driving instructor to prevent a potentially unsafe maneuver). Measures of visual function included visual acuity, contrast sensitivity, and visual fields (Humphrey Field Analyzer; Carl Zeiss Meditec, Inc., Dublin, CA; mean deviation [MD] and binocular Esterman points).

RESULTS. There was no significant difference between patients with glaucoma (mean MD = −1.7 dB [SD 2.2] and −6.5 dB [SD 4.9], better and worse eyes, respectively) and control subjects in total satisfactory maneuvers and skills (P = 0.65), or overall rating (P = 0.60). However, 12 (60%) patients with glaucoma had one or more at-fault critical interventions, compared with 4 (20%) control subjects (odds ratio = 6.00, 95% CI, 1.46–24.69; higher still after adjustment for age, sex, medications and driving exposure), the predominant reason being failure to see and yield to a pedestrian. In the glaucoma group, worse-eye MD was associated with the overall rating of driving (r = 0.66, P = 0.002).

CONCLUSIONS. This sample of patients with glaucoma with slight to moderate visual field impairment performed many real-world driving maneuvers safely. However, they were six times as likely as subjects with normal vision to have a driving instructor intervene for reasons suggesting difficulty with detection of peripheral obstacles and hazards and reaction to unexpected events. (Invest Ophthalmol Vis Sci. 2008;49:3035–3041) DOI:10.1167/iovs.07-1609

Glaucoma has been associated with increased risk of involvement in motor vehicle collisions (MVCs). Indeed, previous research studies based on government records estimate the risk to be increased by 1.7 to 3.6 times. A significant finding, because MVCs are a major cause of injury, hospitalization, and death and result in considerable economic cost. To gain a better understanding of this health burden, it is important to study the impact of glaucoma on various components of driving performance. Only a few relevant studies of driving performance have been conducted, each with limitations. For example, Wood and Troutbeck investigated the effect of visual field constriction by having older persons, with otherwise normal vision, wear goggles with restricted apertures while driving. On a closed-road circuit free of other vehicles, reverse parking and reaction to a peripheral LED stimulus were found to take significantly longer with simulated visual-field constriction compared with no constriction (P < 0.05). Differences in speed, road position, maneuvering, central reaction time, and sign detection were not statistically significant (P ≥ 0.05). However, the correlation between closed-road performance and real-world performance is unknown. Moreover, driving with simulated visual field constriction may not be representative of driving with glaucomatous visual field loss. In glaucoma, visual field impairment is usually gradual, not concentric, and defects vary with eye position. Zyk et al. used an interactive driving simulator to study patients with glaucoma. These patients were found to have a higher accident rate than that of normal vision control subjects, yet there were no differences in other measures of performance, perhaps because the measures investigated had limited sensitivity to differences in performance. Regardless, simulator performance may not translate to real-world driving performance. Hitherto, there has been only one real-world study of visual field impairment that included patients with glaucoma. Most were considered to be safe drivers; however, there was no control group. The purpose of the present study was to evaluate in a real-world setting the on-road driving performance of patients with glaucoma compared with that of control subjects with normal vision.

METHODS

Participants

The sample comprised a group of patients with glaucoma and a group of control subjects with normal vision, participating in a prospective study of falls and MVCs in glaucoma. The patients with glaucoma were recruited from the Glaucoma Clinic of the Eye Care Centre, Queen Elizabeth II Health Sciences Centre (Halifax, Nova Scotia [NS]). The charts of consecutively scheduled patients were reviewed for potential eligibility. After clinical consultation, patients who met the eligibility criteria were provided with study information. Those interested were requested to telephone the coordinator for further explanation and to schedule a visit. Normal-vision control subjects were...
recruited by public notice within the Centre and by spoken communication and also responded by telephone. To be eligible, all participants had to be aged over 50 years. For the glaucoma group, the inclusion criteria were a glaucoma specialist’s diagnosis of glaucoma, glaucomatous optic nerve damage (e.g., notching or progressive thinning of the neuroretinal rim), and corresponding visual field impairment detected with standard automated perimetry (Humphrey Field Analyzer [HFA]; Carl Zeiss Meditec Inc., Dublin, CA). Inclusion criteria for the control group were normal findings in an ocular examination and visual acuity (VA) better than 0.30 logMAR (20/40) in each eye. Volunteers for the control group were ineligible if they were a patient at the Eye Care Centre or were related to a participant with glaucoma. Exclusion criteria for both groups were cataract (worse than grade II, Lens Opacities Classification System III165), or other concomitant ocular disease, systemic disease or medication known to affect the visual field, cognitive impairment (more than two errors on the Short Portable Mental Status Questionnaire),17 nursing home residency, and use of a mobility device.

In addition, all participants were required to hold a current driver’s license, meet the visual standard for driving a private motor vehicle in NS (VA no less than 20/40 in at least one eye; field of vision no less than 120° with both eyes open),3,4 and drive at least 30 km per week. Of 35 patients with glaucoma enrolled in the prospective study who were eligible and able to be contacted, 20 volunteered to participate. Forty-three control subjects from the prospective study were eligible and matched to the patients with glaucoma for age and sex. They were invited in the order enrolled, and the first 20 to agree participated. Thus, the final sample for this on-road driving substudy comprised 20 patients with glaucoma and 20 control subjects with normal vision.

Data Collection and Outcome Measures

**Demographic, Medical, and Driving Exposure Data.** Demographic and medical data were collected from participants by structured questions and checklists that included age, sex, medical conditions, and systemic medications. For patients, number of years since glaucoma diagnosis was obtained from clinical records. The Driving Habits Questionnaire19 was used to estimate the driving exposure (average kilometers per week) of all participants.

**Vision Measures.** Distance VA was measured monocularly with logMAR charts with per-letter scoring.20,21 Contrast sensitivity (CS) was measured with the Pelli-Robson CS Chart, also monocularly with per-letter scoring.22,23 Visual fields were assessed with standard automated perimetry (HFA 24-2 program), and mean deviation (MD) was used as the main global index of impairment.24 The HFA binocular Estern program was also administered,25,26 as it provides a direct binocular measure of functional visual field (percentage of points detected), and has been recommended for determining fitness to drive.20–28 In addition, the Useful Field of View test (UFOV; Visual Awareness Inc., Birmingham, AL) was administered.29–31 Also performed under binocular conditions, the UFOV is an assessment of cognitive as well as visual function that has been shown to be predictive of at-fault MVCs.32–35 It comprises three subtests of increasing difficulty (central vision and processing speed, divided attention, and selective attention), each requiring identification of targets displayed on computer for 17 to 500 ms with a double-staircase method. Subtests are scored as the duration required for a 75% correct response rate, the sum of which was used as a measure of overall visual information processing speed.31 All vision tests were performed with optimal refractive error correction, under standardized conditions, in accordance with the manufacturer’s recommendations.

**On-Road Driving Test and Main Outcome Measures.** Driving performance was assessed on a standardized 10-km route through residential and business districts of Halifax. All participants drove the same mid-size automatic-transmission vehicle, equipped with a dual brake-control system, such that the brake could be applied by either the driver or instructor. All tests were conducted by the same professional driving instructor and assessed by the same occupational therapist (a Certified Driver Rehabilitation Specialist from the NS Rehabilitation Centre Occupational Therapy Driver Program, Queen Elizabeth II Health Sciences Centre). The driving instructor gave directions from the front passenger seat and was responsible for safety, whereas the occupational therapist evaluated participant performance from the rear seat and was responsible for assessment. Neither had prior knowledge regarding the participant’s group or level of vision.

During the driving test, participants were instructed to perform common driving maneuvers, such as entering traffic, turning, negotiating intersections, exiting traffic, and parking. Skills assessed included observation (vehicles, road signs, traffic signals, crosswalks, pedestrians, cyclists, obstacles, and hazards), safety (signaling, steering control, speed control, road position, and distance judgment). The test incorporated 34 maneuvers. The primary skills required for each were evaluated as either satisfactory or unsatisfactory. The maneuvers and skills were specified in a checklist, where one point was given for each satisfactory performance (Fig. 1). The highest possible score was 55. The maneuvers and skills were derived primarily in consultation with the study occupational therapist and specialists from the NS Rehabilitation Centre Occupational Therapy Driver Program, after a review of the provincial driver’s license testing protocol and the scientific literature.34–36 In addition to the checklist assessment of maneuvers and skills, overall driving performance was rated on a scale of 0 to 10, where 0 is poor performance, and 10 is excellent performance.

Any critical interventions during the test were also recorded. Critical interventions were actions made by the driving instructor to avert what he judged to be a potentially unsafe situation, and included application of the dual brake, and/or taking over steering control. The intention of the driving instructor was to implement caution and maximize safety at all times. The cause of each intervention was described and fault attributed, in the opinion of the assessing occupational therapist.

**Protocol**

Informed written consent was obtained before enrollment. The participants were then interviewed and clinical records reviewed to obtain demographic and medical data. Data collection was followed by refraction, vision testing, and full ocular health examination. Next, participants were given a short practice driving session to familiarize them with the test vehicle and requirements, immediately followed by the on-road test. All tests were conducted in fair-to-fine weather conditions between 10 AM and 4 PM weekdays, from July to December, 2006. The study adhered to the tenets of the Declaration of Helsinki and the design, recruitment, consent, and procedures were approved by the Capital Health Research Ethics Board.

**Statistical Analysis**

Data were analyzed with commercial software (SPSS, ver. 15.0; SPSS Inc., Chicago, IL). Analyses were two-tailed, and P < 0.05 was considered statistically significant. Assumptions underlying all statistical tests were verified. Descriptive statistics were calculated for demographic, medical, vision, and driving performance data. Group differences were evaluated with the Student’s t-test, Mann-Whitney U test, and χ2 test for continuous, ordinal, and nominal data, respectively. Logistic regression analysis was used to calculate an odds ratio (OR) and corresponding 95% confidence interval (CI) for the association between glaucoma and critical interventions during the driving test, with adjustment for the possible confounding effects of age, sex, number of systemic medications, use of psychotropic medication, and driving exposure. For the glaucoma group, associations between visual functions, number of satisfactory driving maneuvers, and overall rating of driving skills were evaluated using Spearman’s rank correlation coefficient. Associations between visual functions and critical interventions were evaluated by using logistic regression analysis to calculate ORs and 95% CIs, where vision measures were dichotomized using cutoff criteria considered to be clinically important (e.g., MD cutoff at 2 SD less than the control
RESULTS

Participant Characteristics

Differences in age, driving exposure, VA, and MD between participants and eligible nonparticipants were nonsignificant, for both the glaucoma and normal vision group ($P \geq 0.07$). Characteristics of participants, by group, are presented in Table 1. The mean age of patients with glaucoma was 68 years (SD 7), and mean time since diagnosis 17 years (SD 8). There were no significant differences between the glaucoma and control groups with respect to age, sex, number of medical conditions, number of systemic medications and driving exposure ($P \geq 0.49$). As expected, the patients with glaucoma had significantly decreased MD compared with the control subjects ($P < 0.01$), which ranged from slight to moderate impairment (better eye mean MD = $-1.66$ dB [SD 2.19] and worse eye mean MD = $-6.53$ dB [SD 4.88]). In addition, worse eye distance VA, worse eye CS, and binocular Esterman visual field ($P \geq 0.30$).

On-Road Driving Performance

Outcomes of the driving test for each group are given in Table 2. There was no significant difference in time to completion ($P = 0.24$). The median number of driving maneuvers and skills scored as satisfactory was 50 (range, 41–54) and 51 (range, 44–53) of 55, for the glaucoma and control groups, respectively, the difference being nonsignificant ($P = 0.65$). With regard to individual maneuvers and skills, few discriminated between subjects. Forty-one (75%) maneuvers and skills were performed satisfactorily by at least 18 (90%) patients with glaucoma and 18 (90%) control subjects. Five of 14 (36%) maneuvers and skills performed unsatisfactorily were related to poor practices that can develop in experienced drivers, (e.g., failure to use an indicator when pulling out from a parked position and failure to shoulder check), with both groups performing similarly. As with maneuvers and skills, there was no significant difference between groups in overall rating of driving performance ($P = 0.60$), with each group scoring highly (median rating, 7 of 10, in the glaucoma and control groups).
However, a significantly greater proportion of patients with glaucoma had one or more critical interventions during the test (Table 2), that is, incidences where the driving instructor applied the dual brake and/or took over steering to stop a potentially unsafe maneuver. Twelve (60%) patients with glaucoma had one or more at-fault critical interventions compared with four (20%) control subjects (P = 0.01). Logistic regression analysis indicated the odds of critical intervention in the glaucoma group were six times that in the control group (OR = 6.00; 95% CI, 1.46–24.69), and greater still after adjustment for age, sex, number of systemic medications, use of psychotropic medication, and driving exposure (OR = 8.33; 95% CI, 1.03–67.14). However, the strength of the association was reduced after adjustment for age, sex, number of systemic medications, use of psychotropic medication and driving exposure (OR = 4.37; 95% CI, 0.26–72.25).

Although correlation coefficients were also determined for number of locations identified as outside normal limits in the HFA pattern deviation plot, for the upper, lower, left, and right visual field of each eye, none had a stronger association with any of the driving performance measures than did MD.

**DISCUSSION**

Driving a private motor vehicle is of unquestionable importance in society today. It is the primary mode of transportation for many people in many countries and is linked to one’s autonomy, self-esteem, and quality of life. Studies have shown that glaucoma may be associated with driving difficulties, avoidance of challenging driving conditions, cessation of night driving, and increased risk of involvement in motor vehicle collisions. However, little is known about the effect of glaucoma on actual driving performance and in what way it may bring about these problems. To minimize difficulties and plan risk reduction programs, further research is needed. In this study, we have presented data comparing the correlation was worse eye MD (r = 0.66, P = 0.002; Fig. 2), followed by better eye CS (r = 0.54, P = 0.01).

The worse eye MD was the only vision measure associated with critical intervention. Ten (77%) of 13 patients with glaucoma with worse eye MD > −4.0 dB had one or more at-fault critical interventions compared with 2 (29%) of 7 with worse eye MD > −4.0 dB (OR = 8.53; 95% CI, 1.03–67.14). However, the strength of the association was reduced after adjustment for age, sex, number of systemic medications, use of psychotropic medication and driving exposure (OR = 4.37; 95% CI, 0.26–72.25).

### Table 1. Demographic, Medical, Driving and Vision Characteristics of Study Participants by Group

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Glaucoma (n = 20)</th>
<th>Normal Control (n = 20)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>68 (7)</td>
<td>67 (7)</td>
<td>0.62</td>
</tr>
<tr>
<td>Sex, male-female, n (%)</td>
<td>14 (70):6 (30)</td>
<td>14 (70):6 (30)</td>
<td></td>
</tr>
<tr>
<td><strong>Medical</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical conditions, median (range), count</td>
<td>3 (0–6)</td>
<td>3 (0–7)</td>
<td>0.90</td>
</tr>
<tr>
<td>Systemic medications, median (range), count</td>
<td>3 (0–7)</td>
<td>2 (0–6)</td>
<td>0.49</td>
</tr>
<tr>
<td>Use of psychotropic medication, n (%)</td>
<td>2 (10)</td>
<td>3 (15)</td>
<td></td>
</tr>
<tr>
<td><strong>Driving</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure, median (range), km/wk</td>
<td>159 (40–1839)</td>
<td>119 (58–3050)</td>
<td>0.88</td>
</tr>
<tr>
<td>Distance visual acuity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better eye, mean (SD), logMAR</td>
<td>0.05 (0.10)</td>
<td>0.05 (0.09)</td>
<td>0.85</td>
</tr>
<tr>
<td>Worse eye, mean (SD), logMAR</td>
<td>0.19 (0.18)</td>
<td>0.11 (0.10)</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Contrast sensitivity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better eye, mean (SD), log CS</td>
<td>1.62 (0.16)</td>
<td>1.66 (0.11)</td>
<td>0.30</td>
</tr>
<tr>
<td>Worse eye, mean (SD), log CS</td>
<td>1.49 (0.28)</td>
<td>1.61 (0.10)</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>HFA MD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better eye, mean (SD), dB</td>
<td>−1.66 (2.19)</td>
<td>0.32 (1.48)</td>
<td>0.002</td>
</tr>
<tr>
<td>Worse eye, mean (SD), dB</td>
<td>−6.53 (4.88)</td>
<td>−0.48 (1.69)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>HFA binocular Esterman, median (range), % detected</strong></td>
<td>99 (85–100)</td>
<td>99 (88–100)</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>UFOV total subtest scores, mean (SD), ms</strong></td>
<td>391 (233)</td>
<td>275 (145)</td>
<td>0.07</td>
</tr>
</tbody>
</table>

### Table 2. On-Road Driving Performance by Group

<table>
<thead>
<tr>
<th>Driving Performance Variable</th>
<th>Glaucoma (n = 20)</th>
<th>Normal Control (n = 20)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to completion, mean (SD), minutes</td>
<td>33 (3)</td>
<td>34 (4)</td>
<td>0.24</td>
</tr>
<tr>
<td>Total satisfactory driving maneuvers/skills, median (range), of 55 skills</td>
<td>50 (41–54)</td>
<td>51 (44–53)</td>
<td>0.65</td>
</tr>
<tr>
<td>Overall rating of driving performance, median (range), on a scale of 10</td>
<td>7 (3–9)</td>
<td>7 (2–9)</td>
<td>0.60</td>
</tr>
<tr>
<td>Critical interventions, n (%), ≥1 at-fault</td>
<td>12 (60)</td>
<td>4 (20)</td>
<td>0.01</td>
</tr>
</tbody>
</table>
driving performance of patients with glaucoma to that of control subjects with normal vision in an on-road test.

We did not find a significant difference between patients with glaucoma with slight to moderate visual field impairment and control subjects in time taken to complete a standardized test of driving performance ($P = 0.24$). In addition, there was no significant difference between groups in the number of maneuvers and skills passed and overall rating ($P = 0.65$ and 0.60, respectively), with each group scoring highly on both measures. To our knowledge, there are no other on-road glaucoma studies that have included a control group for comparison with our findings. However, our findings are consistent with the closed-road study of simulated impairment by Wood and Troutbeck, in which there was no significant effect of moderate visual field constriction on several measures of performance, including driving time, peripheral awareness (sign detection), maneuvering time, maneuvering errors, reversing angle, central reaction time, speed estimation, and road position ($P \geq 0.05$). Furthermore, the high total number of maneuvers and skills passed and high overall ratings for patients with glaucoma in this study are consistent with similarly high on-road performance ratings noted by Bowers et al. Thus, we might conclude that patients with glaucoma who meet the visual standard for driving a private motor vehicle have good general driving skills and perform standard driving maneuvers as well as age-matched normal vision subjects do.

However, we found differences in other potentially important aspects of driving performance, related to hazard detection and reaction to unexpected events, which were not captured by using a checklist count of standard maneuvers and skills or a global rating. Patients with glaucoma in this study were more than six times as likely as control subjects to have the driving instructor intervene to avoid an unsafe maneuver. In most cases, the instructor applied the dual brake or took over steering control. Similarly, in a previous on-road study of older licensed drivers, instructor interventions were required for those with normal vision and those with slight visual impairment (various causes); although the frequency of intervention was different. The frequency of intervention may depend on route difficulty, type and severity of visual impairment, instructor safety threshold, and instructor bias. Although the frequency of control case interventions in this study suggests that the instructor may have had a low threshold for intervening, he was masked to participant group membership and level of vision. His criteria for intervening were the same for all participants, and it is the difference between the proportion of glaucoma and control group interventions that is important (60% vs. 20%, respectively; $P = 0.01$). Whether the incidence of instructor intervention for potentially unsafe maneuvers during an on-road test is predictive of real-world collisions is unknown and remains to be investigated.

Several measures of vision were associated with the driving performance of patients with glaucoma in this study. The strongest correlation was obtained between worse eye MD and overall rating of driving ($r = 0.66, P = 0.002$). Moderately strong correlations were also obtained for better eye CS and UFOV total ($P \leq 0.01$). Likewise, significant correlations were found for better eye CS and UFOV selective attention in the on-road study conducted by Bowers et al. However, in that study, the correlation between binocular visual field extent (degrees), measured with Goldmann perimetry, and overall driving performance was weak ($r = 0.26, P = 0.19$). Possibly this is because such a measure is not sufficiently sensitive to differences in visual field impairment between patients, which was our experience with the binocular Esterman measure (percentage of points detected).

In addition, we found an association between visual field impairment and critical interventions. Patients with glaucoma with worse eye MD $\leq -4$ dB were more than four times as likely as those with better visual fields to have the driving instructor intervene, the predominant cause being failure to see and yield to a pedestrian. Considering pedestrians are relatively small and can quickly and unexpectedly emerge from the periphery, it is not surprising that patients with glaucomatous visual field impairment might experience difficulty in such circumstances. From the findings of this study, we suggest that it is possible that patients with glaucoma with even slight to moderate visual field damage may be less able to detect and respond to pedestrians.

![Figure 2](https://example.com/fig2.png)  
**Figure 2.** Scatterplot of overall rating of performance on a standardized, masked on-road driving test and worse-eye HFA MD, showing better performance of patients with glaucoma with better residual visual fields (Spearman $r = 0.66, P = 0.002; n = 20$).
respond to peripheral obstacles and hazards, and unexpected events. This hypothesis is further supported by the closed-road study of moderate simulated visual field restriction by Wood and Troutbeck, in which reaction to a small peripheral stimulus was significantly slower than in the control condition, and the on-road study of moderate real impairment by Bowers et al., which indicated a possible association between visual field extent and reaction to unexpected events (r = 0.49, P = 0.055).

Worse eye MD was more strongly correlated with all on-road driving performance outcomes than better eye MD. Indeed, other glaucoma studies have also found worse eye function to be more important in mobility (walking speed) and driving (risk for involvement in MVCs). It is possible that worse-eye MD better represents extent of glaucomatous damage and overall functional binocular deficit. Location of visual field defect correlated better with any of the measures of on-road driving performance investigated than MD. However, this may be because our sample was limited to patients who met the provincial visual standards for driving, having no more than moderate visual field impairment. The importance of the location of visual field damage may become apparent with a larger sample of patients with a wider range of impairment.

These results are based on comparisons between a small sample of clinical patients with glaucoma with slight to moderate visual field impairment and a small sample of volunteer control subjects. In addition, on-road driving tests were restricted to nonpeak times and days with fair weather, in an attempt to control for variations in vehicle and pedestrian traffic, road condition, and visibility. The likely effect of these limitations is that our results are conservative and underestimate the impact of glaucoma on driving performance. The limitations seem acceptable, and the findings important considering our partial understanding of the driving difficulty reported by patients with glaucoma and the seriousness of their increased risk for MVCs.

CONCLUSIONS

The results of this study indicate patients with glaucoma with slight to moderate visual field impairment perform standard driving maneuvers safely. However, peripheral obstacle and hazard detection and unexpected events may present a problem for some, in particular those with worse visual field impairment. These findings may be useful in providing guidelines on driving and establishing programs to facilitate safe, lifelong mobility for patients with glaucoma. We suggest that clinicians discuss driving with all patients with glaucoma.

Acknowledgments

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