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Driving Cessation and Driving Limitation in Glaucoma: The Salisbury Eye Evaluation Project

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Abstract

Objective—To determine if glaucoma is associated with driving limitation or cessation.

Design—Cross-sectional analysis within a longitudinal, population-based cohort study.

Participants and Controls—One thousand one-hundred and thirty-five ever-drivers between the ages of 73 and 93 years including 70 subjects with unilateral glaucoma and 68 subjects with bilateral glaucoma.

Methods—All subjects reported their driving habits during each of 4 study rounds. During the fourth and final study round, subjects were systematically assessed for the presence of glaucoma.

Main Outcome Measures—Self-reported driving cessation or driving limitation, including cessation of night driving, driving less than 3,000 miles annually, or cessation of driving in unfamiliar areas.

Results—Fifteen percent of subjects without glaucoma were no longer driving at the end of the cohort study compared to 21% of unilateral glaucoma subjects (p=0.2) and 41% of bilateral glaucoma subjects (p<0.001). Multivariable regression analysis showed that bilateral (odds ratio [OR]=2.6, p=0.002), but not unilateral (OR=1.5, p=0.3), glaucoma subjects were more likely to no longer be driving when compared to subjects without glaucoma. The odds that bilateral glaucoma subjects were no longer driving doubled for every 5 dB of visual field (VF) worsening in the better-eye (p<0.001). Driving cessation within the previous 2 years was analyzed using separate multiple regression models, and both bilateral (OR=3.6, p=0.004) and unilateral (OR=2.4, p=0.06) glaucoma subjects were more likely to stop driving over this period when compared to subjects without glaucoma. Driving cessation associated with bilateral glaucoma was present in 0.82% of the population, or 1 in every 122 individuals.

Multivariable ordinal logistic regression models demonstrated driving limitations were not more frequently found amongst subjects with glaucoma than subjects without glaucoma. However, bilateral glaucoma subjects did attribute more driving limitations to difficulties with their vision than subjects without glaucoma (OR=2.2, p=0.02).

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Conclusions—Bilateral, and possibly unilateral, glaucoma is associated with significantly higher rates of driving cessation amongst the elderly. The substantial difference in driving patterns seen with different degrees of better-eye VF damage suggests that minimizing VF loss in the better-seeing eye is associated with better functional outcomes.

INTRO

Glaucoma affects over one million Americans, and millions more are suspects for the disease.[1] To define goals for when glaucoma should be identified and treated, we require an understanding of when and how glaucoma produces impairment. Few data exist, however, quantifying the impact of glaucoma by stage of disease.[2]

Driving represents an important vision-related task which may be affected by relatively early glaucoma. Previous studies have demonstrated that glaucoma patients more frequently complain of difficulty driving[3-5] and have higher crash rates than age-matched controls.[6,7] However, these studies have focused exclusively on those who continue to drive, neglecting the possible impact of glaucoma on driving cessation or limitation.

Indeed, while driving limitation or cessation may increase safety of patients and society, it also decreases independence of daily living, resulting in social isolation.[8] Driving cessation is associated with depression[9] and a greater likelihood of nursing home admission.[10] Thus, understanding if and when glaucoma limits driving is important for understanding the impact of the disease, and for guiding patient treatment such that this impact is minimized.

Previous work from the Salisbury Eye Evaluation (SEE), a cohort study in which subjects reported their driving habits during each of 4 study rounds spanning over 8 years, demonstrated that visual field (VF) loss predisposed to both driving cessation and driving limitation.[11] However, VF deficits can result from glaucoma, cataract, other ocular diseases, and as an artifact in up to 15% of individuals with a normal eye exam.[12] In SEE, glaucoma status was only determined in the fourth and final round of the study (Figure 1). Here, we performed a cross-sectional analysis of driving behavior by glaucoma status using data from the fourth round of SEE to assess the impact of glaucomatous VF loss on driving cessation and limitation.

METHODS

The Johns Hopkins Institutional Review Board approved the protocols for all 4 study rounds of SEE. Data collection for round 1 began in 1993, and data from the fourth and final round were collected between August 2001 and July 2003 (Figure 1). All subjects gave written informed consent prior to participation. Detailed methods of subject enrollment are previously described.[13,14]

Evaluation of Driving Habits

Driving habits were determined using a standardized questionnaire. Interviewers administered the questionnaire during each of the 4 rounds of the study. Subjects were asked “Have you ever driven a car?” and were considered non-drivers, and excluded from the analysis, if they responded “No” during either the first or fourth round of the study. Subjects were asked “Have you driven a car in the last year?” to evaluate for driving cessation. Driving limitation was assessed by asking “During the past 3 months, have you driven at night?”, and “During the past 3 months, have you driven in unfamiliar areas?” Additionally, subjects were asked “About how many miles did you drive last year?”, and driving below 3,000 miles was considered a limitation.[11,20] The total number of yes responses was used to calculate a number of driving limitations ranging from 0 to 3.

Subjects who had stopped or limited their driving were asked follow-up questions to determine if they attributed the changes in their driving patterns to their vision. For example, with regards to driving cessation, subjects were asked "Is it because of any visual problems that you have not driven?" Subjects were not asked if they restricted mileage due to their vision, but were instead asked if they drove less frequently as a result of their vision. Again, vision-attributable driving limitations were totaled for each subject, yielding a number of limitations ranging from 0 to 3.

Measurement of Vision

Binocular visual acuity was measured with subjects wearing their habitual correction. Letters were read from the Early Treatment Diabetic Retinopathy Study chart transilluminated at 130 candelas/m^2. For statistical analysis, the negative log of the minimal angle of resolution was employed (logMAR).[15] Contrast sensitivity was measured as the number of letters correctly read from the Pelli-Robson chart with subjects wearing their best correction. Separate measurements were performed for right and left eyes. Measurements of acuity and contrast sensitivity performed during the fourth round of SEE were used in the present analysis.

Defining Glaucoma Status

Examination Procedures—As previously-described, a two-stage screening procedure was used to identify eyes with glaucoma.[16,17] Glaucoma status was defined in the fourth round of the study, but not in earlier study rounds.

Subjects who could visit the research site completed formal VF analysis using the Swedish interactive thresholding algorithm fast 24−2 testing algorithm on the Humphrey Field Analyzer II (Carl Zeiss Meditec, Dublin, CA). VF testing was repeated in cases of suspected abnormality or poor test-taking.[17] Subjects also received an optometric eye exam including dilated optic nerve examination. The Discam camera (Marcher Enterprises Ltd., Hereford, United Kingdom) was used to obtain optic nerve images. In cases of poor image quality, the vertical cup-to-disc ratio documented in the optometric examination substituted as an assessment of the optic nerve, and was strongly correlated with vertical cup-to-disc ratios taken from the Discam images.[17]

Subjects with features suggestive of glaucoma[17] returned for a definitive examination by a glaucoma specialist (DSF). Repeat SITA fast VF testing using the Humphrey Field Analyzer II, gonioscopy, dilated fundus examination, and optic nerve photographs with a stereo fundus camera (Topcon America Corp., Paramus, NJ) were performed as part of this visit.

Glaucoma status designation—Each eye of each subject was classified as having no, possible, probable, or definite glaucoma using previously described criteria.[17] For statistical analysis, eyes with no or possible glaucoma were classified as not having glaucoma, while eyes with probable or definite glaucoma were classified as having glaucoma. Glaucoma was designated as open angle, angle closure or secondary.[17] Six patients (5 with unilateral glaucoma, 1 with bilateral glaucoma) were excluded from this analysis because they had secondary glaucoma, and may have had vision loss attributable to their primary ocular condition.

Selection of VF for analysis—As many subjects completed more than one VF in each eye, it was necessary to choose a single VF for use in our analysis. VF tests were first classified as reliable or unreliable using the revised criteria from the Ocular Hypertension Treatment Study.[22] The first VF was chosen for analysis except when the second, but not the first, VF was reliable. Mean deviations ≥ +2 dB were converted to +2 dB in the analysis. Three subjects with bilateral glaucoma who completed a VF in only one eye, and who had a best corrected acuity

worse than 20/100 in the second eye, were assigned a mean deviation of −30 dB for the second eye.

Measurement of Covariates

Demographic and health-related information including date of birth, race, gender, and total years of education were collected using standardized forms and questionnaires during the first round of the study. Time-varying covariates including a comorbidity index, the presence of depressive symptoms, and cognitive ability, were measured at each study round, with data for the analysis taken from fourth round measurements. Subjects were queried as to whether they had been diagnosed with one of 15 different medical conditions. One point was given for each positive response, and points were totaled into a comorbidity index. A positive response to any question from part D of the General Health Questionnaire[18] was taken to indicate the presence of depressive symptoms. The mini-mental state exam (MMSE)[19] was used to measure cognitive ability, with possible scores ranging from 0 to 30.

Data Gathered from earlier rounds of SEE

The current analysis was primarily a cross-sectional study, with all of the above information, except for measurement of time-invariant covariates such as age, race, gender, and level of education, assessed during study round 4. However, suprathreshold VFs were performed in both eyes during rounds 1−3, and are incorporated into this analysis as a way of judging VF loss at a time more proximate to when driving cessation was first reported. As previously described,[11] 96 visual locations spanning 60 degrees were tested using a 24 dB stimulus in each eye. Binocular fields were generated by superimposing results from both eyes at corresponding points in space.[21] The number of points missed in both eyes within the central 20° was then calculated. Comparisons were made only to other individuals who completed their suprathreshold fields in the same study round, with no comparisons made across study rounds.

Data from earlier rounds of SEE were also used to assess which subjects had already stopped or limited their driving prior to round 4. These subjects were subsequently excluded from analyses designed to look for driving cessation or limitation specifically occurring in the 2 year period prior to the glaucoma evaluation (between study rounds 3 and 4).

Statistical Analysis

Student's t-test was used to evaluate whether differences in continuous covariates were significant across glaucoma status, while chi-squared analysis was used to test for significant differences in categorical covariates (race, gender, depressive symptoms), as well as the likelihood of driving cessation or limitation. Given the strong effect of age and sex on driving cessation and driving limitation, other covariates were assessed for significance after age and sex adjustment using multivariable logistic and ordinal logistic regression models.

Additional multivariable regression models were used to assess further the association of unilateral and bilateral glaucoma with driving cessation and limitation. Logistic regression was used for binary outcomes, while ordinal logistic regression was used to evaluate the number of driving restrictions. Ordinal logistic models were confirmed to meet the proportional odds assumption using both a likelihood ratio test and the Brant test ($p>0.05$ for all models shown). Each number of driving limitations was viewed as a separate category, except when vision-dependent driving restrictions were analyzed. In this case, a single group was created by combining the small number of subjects with either 2 or 3 driving limitations. Covariates included in analyses included age, race, and sex, as well as other attributes that were found to be significant at the $p = 0.05$ level in the preliminary analyses adjusting for age and sex. As severe glaucoma can affect visual acuity, models were run with and without visual acuity

measured during the fourth round of the study. VF loss in glaucoma subjects was measured according to the better eye mean deviation (i.e. the eye with the higher or less negative mean deviation).

Multinomial regression models were created comparing unilateral and bilateral glaucoma subjects to subjects without glaucoma to determine if glaucoma subjects were more likely to have stopped driving during specific time periods. Three time periods were created which divided those who had stopped driving into nearly equal numbers: prior to the first round of SEE (> 8 years ago), between the first and third round of SEE (2−8 years ago), and between the third and fourth round of SEE (<2 years ago).

Bilateral glaucoma subjects were analyzed by tertile of better-eye VF loss to determine if more severe VF damage was more frequently associated with driving cessation. Additionally, better-eye MD was added to a multivariable logistic regression model (with centered covariates) including only bilateral glaucoma subjects. Model results were used to predict the odds of driving cessation by better-eye MD after adjusting for covariates. Results were plotted after converting odds to probabilities.

The probability of driving cessation due to glaucoma for an individual in the population was obtained by first deriving p_2 from the formula $OR=[p_2/(1-p_2)]/[p_1/(1-p_1)]$, where OR represents the adjusted odds ratio of driving cessation for bilateral glaucoma subjects and p_1 represents the probability of driving cessation amongst subjects without glaucoma. The difference between p_2 and p_1 was then multiplied by the observed prevalence of bilateral glaucoma in study round 4.

Colinearity of tested covariates was excluded after calculation of variance inflation factors. All logistic regression models were checked with (and met) Pearson's goodness-of-fit tests. Data analysis was completed using STATA 10.0 (College Station, TX).

RESULTS

One thousand two-hundred fifty-three subjects participated in SEE through round 4. As glaucoma status was determined only during the fourth round of the study, only those who continued to participate through round 4 were included in this analysis. Ninety-four subjects were excluded after reporting that they had never driven a car, including 4.8% of subjects without glaucoma, 6.6% of subjects with unilateral glaucoma, and 6.8% of subjects with bilateral glaucoma ($p>0.4$ when comparing either glaucoma group to non-glaucoma controls). Glaucoma status was determined in 1,135 of these subjects (97.9%), with 70 subjects (6.2%) having unilateral glaucoma and 68 subjects (6.0%) having bilateral glaucoma. Both unilateral and bilateral glaucoma subjects were older, had lower contrast sensitivity, and demonstrated more extensive VF loss compared to subjects without glaucoma (Table 1). Compared to non-glaucoma subjects, unilateral, but not bilateral, glaucoma subjects were more frequently male, while bilateral, but not unilateral, glaucoma subjects were less educated, had more cognitive impairment, had more comorbid illnesses, and were more frequently black.

Univariate analyses (Table 2) demonstrated that subjects with bilateral, but not unilateral, glaucoma were more likely to have stopped driving by round 4 of SEE when compared to subjects without glaucoma (40.6% vs 15.0%, $p<0.001$). Drivers with bilateral glaucoma were also more likely to have more driving limitations than drivers without glaucoma (OR=1.8, $p=0.05$). When asked about driving limitation specifically attributable to poor vision, drivers with bilateral glaucoma more commonly reported cessation of night driving, less frequent driving, and cessation of driving in unfamiliar places compared to drivers without glaucoma ($p<0.05$ for each, univariate analysis). Drivers with unilateral glaucoma were more likely to report cutting back on the frequency of driving due to poor vision when compared to subjects

without glaucoma (9.1 vs. 3.7%, p<0.05), but were not more likely to have stopped driving at night or in unfamiliar areas as a result of vision. A higher number of vision-attributable driving limitations was more common in drivers with bilateral (OR=3.0, p=0.001), but not unilateral (OR=1.3, p=0.4), glaucoma when compared to drivers without glaucoma.

Covariates potentially relevant to driving cessation and/or limitation were assessed in models adjusting for age and gender (Table 3). Driving cessation was more common with older age, female gender, black race, lower education, lower MMSE score, more comorbid illnesses, depressive symptoms, worse acuity, and lower contrast sensitivity. All these variables were also observed to produce more driving limitations except for depressive symptoms.

In multivariable logistic regression models, bilateral glaucoma subjects were more likely to no longer be driving when compared to those without glaucoma (OR = 2.6, 95% confidence interval [CI] = 1.4 to 4.8, p=0.002), but were not more likely to have limited their driving (Table 4). The association between bilateral glaucoma and driving cessation persisted when visual acuity was added to the model (OR=2.1, 95% CI = 1.1 to 4.2, p=0.03), but was neutralized after VF mean deviation was added (OR=1.1, 95% CI = 0.5 to 2.3, p=0.8). Driving cessation associated with bilateral glaucoma was present in 0.82% of the cohort, or 1 in every 122 individuals. Subjects with unilateral glaucoma were not more likely to have stopped driving than subjects without glaucoma (OR=1.5, 95% CI=0.7 to 2.9, p=0.25).

Bilateral glaucoma subjects were further analyzed by tertile of VF damage, with 21% of subjects in the lowest tertile of VF damage (less than 3 dB of VF loss in better-eye) having stopped driving compared to 36% of subjects in the middle tertile (better-eye VF mean deviation between −3 and −9 dB) and 52% in the highest tertile (better eye VF mean deviation <-9 dB). In a multivariable model including only bilateral glaucoma subjects, the odds of driving cessation increased 2.0 fold (95% CI = 1.6 to 2.5, p<0.001) for every 5 dB of additional VF damage (Figure 2).

Multivariable models were used to determine the likelihood of having stopped driving as a result of vision, and showed that subjects with bilateral glaucoma had 4.1 times higher odds (95% CI = 1.8 to 9.0, p<0.001) of no longer driving as a result of vision when compared to subjects without glaucoma. In comparison, bilateral glaucoma subjects who stopped driving for non-visual reasons had only 2.1 times the odds of driving cessation (95% CI = 0.9 to 4.2, p=0.07) when compared to controls without glaucoma. Bilateral glaucoma subjects who stopped driving because of their vision also had significantly worse better-eye VF loss than subjects who did not attribute their driving cessation to visual causes (average MD = −19 vs. −6 dB, p=0.001).

In addition to stopping driving more frequently, multivariable logistic regression demonstrated that bilateral glaucoma subjects were more likely to *limit* their driving as a result of their vision. When compared to controls without glaucoma, bilateral glaucoma subjects more frequently reported vision-associated discontinuation of driving at night (OR=1.8, 95% CI = 0.8 to 4.2, p=0.15), vision-associated decreased driving frequency (OR=2.5, 95% CI = 0.8 to 7.4, p=0.11), and vision-associated cessation of driving in unfamiliar areas (OR=2.9, 95% CI = 0.7 to 11.5, p=0.13). Multiple ordinal logistic regression demonstrated that bilateral glaucoma subjects were more likely attribute a higher number of driving limitations to difficulties with their vision than controls without glaucoma (OR=2.2, 95% CI = 1.1 to 4.9, p=0.02).

Using data from previous rounds of SEE, we were able to specifically assess outcomes that occurred during different time periods (Figure 3). Multinomial multiple regression was used to separately assess driving cessation over three time periods: more than 8 years ago (prior to the first round of SEE), between 2 and 8 years ago (between the first and third rounds of SEE), and less than 2 years ago (between the third and fourth rounds of SEE). Bilateral glaucoma

subjects were more likely to have stopped driving greater than 8 years ago (conditional OR = 3.0, 95% CI = 1.4 to 6.4, p=0.001) and less than 2 years ago (conditional OR = 3.6, 95% CI = 1.5 to 5.8, p=0.004) when compared to non-glaucoma subjects. Unilateral glaucoma subjects were also more likely to have stopped driving in the prior 2 years when compared to subjects without glaucoma (conditional OR=2.4, 95% CI=1.0 to 6.0, p=0.06), while no differences were noted for the other time periods (p>0.8 for both). However, more driving limitation was not observed for either unilateral or bilateral glaucoma subjects over the prior 2 years (p>0.5 for both).

Bilateral glaucoma subjects who stopped driving in the 2 years prior to round 4 had less VF loss (mean better-eye MD = −8 dB) when compared to bilateral glaucoma subjects who stopped driving earlier (mean better-eye MD = −14 dB), though the difference was not statistically significant (p=0.2). Nineteen subjects who stopped driving prior to study round 4 completed suprathreshold VFs in both eyes during the study round in which driving cessation was first reported. Eleven of these 19 subjects (58%) were in the top decile of overlapping binocular VF loss for the population evaluated during the corresponding study round. Of the 8 subjects who stopped driving prior to round 4 and were not in the top decile of binocularly overlapping VF loss, 6 (75%) said they did not stop driving as a result of their vision.

Depressive symptoms were noted more frequently in non-drivers than drivers in both univariate analyses (13.7 vs. 5.8%, p<0.001) and multivariable models adjusting for age, race, gender, and comorbid illness (OR=2.6, 95% CI = 1.5 to 4.4, p<0.001). Amongst subjects with bilateral glaucoma, depressive symptoms were more common in non-drivers than drivers, though not at a statistically significant level (7.1 vs. 2.5%, p=0.35).

DISCUSSION

In older residents of the Eastern Shore of Maryland bilateral glaucoma was a strong risk factor for driving cessation, conferring a risk nearly as great as female gender or a substantial drop in cognition (Table 4). Driving cessation was most strongly associated with bilateral glaucoma during the 2 year period immediately preceding the glaucoma evaluation, and unilateral glaucoma also demonstrated an association with driving cessation during this period. Glaucoma was not associated with more limitation of driving, though bilateral glaucoma subjects more frequently reported limiting their driving as a result of their vision.

Our study is limited by the fact that glaucoma status was defined after outcomes (i.e. driving limitation) had already occurred, and the presence and/or stage of glaucoma at the time of the outcome is not known. However, several lines of evidence suggest that VF loss from glaucoma was an important factor in driving cessation. First, when comparing bilateral glaucoma subjects to subjects without glaucoma, the odds ratio of driving cessation was higher for vision-related driving cessation (OR=4.6) than for vision-unrelated driving cessation (OR=2.1) suggesting that perceived visual difficulty contributed to driving cessation. Second, the extent of better-eye VF loss was a significant predictor of the risk of driving cessation within subjects with bilateral glaucoma, again suggesting that driving cessation was a result of a worsening field of vision. Third, bilateral glaucoma was a risk factor for driving cessation occurring only between the third and fourth round of the study, and progression over this 2 year period was likely minimal. Finally, the bilateral glaucoma subjects who stopped driving during the final round of SEE had less VF damage than bilateral glaucoma subjects who stopped driving earlier, suggesting that those with less VF loss were able to continue driving while those with more severe VF damage stopped. While these data suggest that VF loss was often present at the time of driving cessation, and may have been relevant to driving cessation, we cannot definitively ascribe this field loss to glaucoma in earlier study rounds.

While we cannot be sure of the extent of VF loss at the moment driving ceased, our data suggest that most of the bilateral glaucoma-associated driving cessation occurred when bilateral VF loss was present. Over half of bilateral glaucoma subjects who stopped driving prior to study round 4 were in the top decile of binocularly overlapping VF loss for the population at the time that driving cessation was first reported, and over half would have had at least 3 dB of better-eye VF loss when driving cessation was reported assuming a progression rate of 1 dB/year.[23] Additionally, the large majority of those who stopped driving who were not in the top decile of binocularly overlapping VF loss denied a visual basis for their driving cessation, suggesting they may have stopped driving even without glaucoma. However, as glaucoma status was only determined in round 4 of the study, we cannot know definitely that bilateral VF loss measured during earlier study rounds resulted from bilateral glaucoma. Indeed, given the higher risk of driving cessation associated with unilateral glaucoma within 2 years of the glaucoma evaluation, it remains possible some of our bilateral glaucoma subjects may only have had unilateral disease at the time of driving cessation, or may have had VF loss resulting from other ocular conditions.

Higher rates of driving cessation may also occur with unilateral glaucoma. While a purely cross-sectional analysis showed that unilateral glaucoma subjects were not more likely to have stopped driving than subjects without glaucoma, such an analysis may miss an effect only occurring more proximally to the time of the glaucoma evaluation. Indeed, unilateral glaucoma subjects had over twice the odds of driving cessation in the 2 years prior to assessment of glaucoma, though the small number of events over this period limits the certainty of this conclusion ($p=0.06$).

Our finding that glaucoma is associated with more frequent driving cessation is corroborated by previous work from the Blue Mountain Eye Study, which reported 2.5-fold higher age and sex-adjusted odds of driving cessation among subjects with glaucoma,[24] and work from clinic samples which showed more frequent driving avoidance with glaucoma.[25] Many additional covariates relevant to driving were evaluated in SEE, which allowed us to adjust for important factors such as cognitive status[20,26,27] and medical comorbidities.[28] Additionally, the current study distinguishes between different degrees of glaucoma, yielding insight into the level of glaucoma necessary to produce driving cessation and/or limitation.

Previous research provides evidence to support a causal association between bilateral, and possibly unilateral, glaucomatous VF loss and driving cessation or limitation. Questionnaire-based studies have demonstrated that the presence of VF loss increases perceived difficulties in driving which could motivate individuals to stop or limit their driving.[3-5,29,30] While some studies suggested that unilateral VF loss is sufficient to cause difficulty driving,[29] previous analyses from SEE found that bilateral, but not unilateral, glaucoma was associated with reported difficulty driving at night.[4] Studies have also shown that glaucoma and/or more advanced VF damage increases the risk of motor vehicle crashes, which reinforces the notion that those with glaucoma may feel (and be) less safe drivers.[7,31-33] In one study, worse eye MD was more correlated with crash frequency than better-eye MD, suggesting that unilateral glaucoma may be sufficient to increase accident rates.[7] Finally, several papers have provided plausible mechanisms for driving impairment using driving simulators or on-road driving tests. Simulated binocular field restriction in normal subjects produces slowed reverse driving, as well as increased reaction time to peripheral objects, though no differences were observed even with complete monocular occlusion.[34] However, a separate study found that even relatively early glaucoma (average better-eye MD=−1.7 dB) produced difficulty seeing peripheral objects such as pedestrians.[35]

The present study has limitations which may limit the generalizability of our findings. The study population was intentionally selected to represent older Americans and had a mean age

of nearly 80 years. Younger individuals who compensate more effectively for VF deficits may not stop or limit driving at the same level of visual compromise. We also studied a rural population, which may differ from urban populations where driving might be more difficult and public transportation more accessible. Additionally, the SEE study attempted to recruit and follow a large proportion of the community-dwelling residents of Salisbury, Maryland. Subjects living in nursing homes were excluded, and therefore some who were unable to care from themselves were excluded. Loss to follow-up was indeed more common in those with worse baseline-vision, as well as those with other medical comorbidities.[36] As these subjects might be more likely to stop driving as a result of vision-impairing conditions such as glaucoma, our estimate for the effect of glaucoma on driving cessation and limitation might be underestimated.

While we cannot determine that driving cessation was caused by progression of glaucomatous VF loss in the subjects studied, the substantial difference in driving patterns seen amongst those with different degrees of better-eye VF damage strongly suggests that minimizing VF loss in the better-seeing eye is associated with better functional outcomes. The effect of VF loss appears to occur fairly early, with bilateral glaucoma subjects in the middle tertile for better-eye VF loss (3−9 dB of VF loss) having nearly twice the probability (36% vs. 21%) of driving cessation than subjects in the lowest tertile of VF loss (less than 3 dB). Our data also suggest a possible effect of unilateral glaucoma on driving cessation, which if confirmed would suggest that minimization of VF loss in the more-affected eye might also be associated with better functional outcomes.

These findings point to a substantial social impact caused by glaucomatous VF loss. If glaucoma truly causes driving cessation, then nearly one percent of the SEE cohort had stopped driving as a result of glaucoma. Given that 18.8 million citizens age 75 and older are predicted to reside in the US by 2010 (http://www.census.gov/population/www/projections/summarytables.html, accessed 1/8/09), the number of elderly who have stopped driving as a result of glaucoma may extend into the hundreds of thousands. While driving cessation among those with VF loss may increase the safety of these individuals and others, driving cessation results in social isolation,[8] increased burden and reliance on friends and family members for transportation, higher rates of institutional living,[10] and more frequent depression.[9] Preventing glaucoma from progressing to more advanced stages could have a major impact on aging populations.

References

1. Eye Diseases Prevalence Research Group. Prevalence of open-angle glaucoma among adults in the United States. Arch Ophthalmol 2004;122:532–8. [PubMed: 15078671]
2. Ramulu P. Glaucoma and disability: which tasks are affected, and at what stage of disease? Curr Opin Ophthalmol 2009;20:92–8. [PubMed: 19240541]
3. Broman AT, Munoz B, Rodriguez J, et al. The impact of visual impairment and eye disease on vision-related quality of life in a Mexican-American population: Proyecto VER. Invest Ophthalmol Vis Sci 2002;43:3393–8. [PubMed: 12407148]
4. Freeman EE, Munoz B, West SK, et al. Glaucoma and quality of life: the Salisbury Eye Evaluation. Ophthalmology 2008;115:233–8. [PubMed: 17655930]
5. Gutierrez P, Wilson MR, Johnson C, et al. Influence of glaucomatous visual field loss on health-related quality of life. Arch Ophthalmol 1997;115:777–84. [PubMed: 9194730]
6. Haymes SA, Leblanc RP, Nicolela MT, et al. Risk of falls and motor vehicle collisions in glaucoma. Invest Ophthalmol Vis Sci 2007;48:1149–55. [PubMed: 17325158]
7. McGwin G Jr, Xie A, Mays A, et al. Visual field defects and the risk of motor vehicle collisions among patients with glaucoma. Invest Ophthalmol Vis Sci 2005;46:4437–41. [PubMed: 16303931]

8. Eberhard JW. Driving is transportation for most older adults. Geriatrics 1998;53(suppl):S53–5. [PubMed: 9745639]
9. Marottoli RA, Mendes de Leon CF, Glass TA, et al. Driving cessation and increased depressive symptoms: prospective evidence from the New Haven EPESE. J Am Geriatr Soc 1997;45:202–6. [PubMed: 9033520]
10. Freeman EE, Gange SJ, Munoz B, West SK. Driving status and risk of entry into long-term care in older adults. Am J Public Health 2006;96:1254–9. [PubMed: 16735633]
11. Freeman EE, Munoz B, Turano KA, West SK. Measures of visual function and their association with driving modification in older adults. Invest Ophthalmol Vis Sci 2006;47:514–20. [PubMed: 16431944]
12. Coleman AL. Sources of binocular suprathreshold visual field loss in a cohort of older women being followed for risk of falls (an American Ophthalmological Society thesis). Trans Am Ophthalmol Soc 2007;105:312–29. [PubMed: 18427619]
13. Rubin GS, West SK, Munoz B, et al. A comprehensive assessment of visual impairment in a population of older Americans: the SEE Study. Salisbury Eye Evaluation Project. Invest Ophthalmol Vis Sci 1997;38:557–68. [PubMed: 9071208]
14. Munoz B, West S, Rubin GS, et al. Who participates in population based studies of visual impairment? The Salisbury Eye Eevaluation Project experience. Ann Epidemiol 1999;9:53–9. [PubMed: 9915609]
15. Bailey IL, Bullimore MA, Raasch TW, Taylor HR. Clinical grading and the effects of scaling. Invest Ophthalmol Vis Sci 1991;32:422–32. [PubMed: 1993595]
16. Friedman DS, Freeman E, Munoz B, et al. Glaucoma and mobility performance: The Salisbury Eye Evaluation Project. Ophthalmology 2007;114:2232–7. [PubMed: 17980433]
17. Friedman DS, Jampel HD, Munoz B, West SK. The prevalence of open-angle glaucoma among blacks and whites 73 years and older: the Salisbury Eye Evaluation Glaucoma Study. Arch Ophthalmol 2006;124:1625–30. [PubMed: 17102012]
18. Goldberg DP, Hillier VF. A scaled version of the General Health Questionnaire. Psychol Med 1979;9:139–45. [PubMed: 424481]
19. Folstein MF, Folstein SE, McHugh PR. “Mini-mental state”: a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–98. [PubMed: 1202204]
20. Stutts JC. Do older drivers with visual and cognitive impairments drive less? J Am Geriatr Soc 1998;46:854–61. [PubMed: 9670872]
21. Nelson-Quigg JM, Cello K, Johnson CA. Predicting binocular visual field sensitivity from monocular visual field results. Invest Ophthalmol Vis Sci 2000;41:2212–21. [PubMed: 10892865]
22. Keltner JL, Johnson CA, Cello KE, et al. Ocular Hypertension Treatment Study Group. Visual field quality control in the Ocular Hypertension Treatment Study (OHTS). J Glaucoma 2007;16:665–9. [PubMed: 18091452]
23. Broman AT, Quigley HA, West SK, et al. Estimating the rate of progressive visual field damage in those with open-angle glaucoma, from cross-sectional data. Invest Ophthalmol Vis Sci 2008;49:66–76. [PubMed: 18172076]
24. Gilhotra JS, Mitchell P, Ivers R, Cumming RG. Impaired vision and other factors associated with driving cessation in the elderly: the Blue Mountains Eye Study. Clin Experiment Ophthalmol 2001;29:104–7. [PubMed: 11446445]
25. Owsley C, McGwin G Jr, Phillips JM, et al. Impact of an educational program on the safety of high-risk, visually impaired, older drivers. Am J Prev Med 2004;26:222–9. [PubMed: 15026102]
26. Freund B, Szinovacz M. Effects of cognition on driving involvement among the oldest old: variations by gender and alternative transportation opportunities. Gerontologist 2002;42:621–33. [PubMed: 12351797]
27. Gallo JJ, Rebok GW, Lesikar SE. The driving habits of adults aged 60 years and older. J Am Geriatr Soc 1999;47:335–41. [PubMed: 10078897]
28. Forrest KY, Bunker CH, Songer TJ, et al. Driving patterns and medical conditions in older women. J Am Geriatr Soc 1997;45:1214–8. [PubMed: 9329483]
29. McKean-Cowdin R, Wang Y, Wu J, et al. Los Angeles Latino Eye Study Group. Impact of visual field loss on health-related quality of life in glaucoma: the Los Angeles Latino Eye Study. Ophthalmology 2008;115:941–8. [PubMed: 17997485]

30. Ivers RQ, Mitchell P, Cumming RG. Visual function tests, eye disease and symptoms of visual disability: a population-based assessment. Clin Experiment Ophthalmol 2000;28:41–7. [PubMed: 11345345]

31. McGwin G Jr, Owsley C, Ball K. Identifying crash involvement among older drivers: agreement between self-report and state records. Accid Anal Prev 1998;30:781–91. [PubMed: 9805521]

32. Owsley C, McGwin G Jr, Ball K. Vision impairment, eye disease, and injurious motor vehicle crashes in the elderly. Ophthalmic Epidemiol 1998;5:101–13. [PubMed: 9672910]

33. Hu PS, Trumble DA, Foley DJ, et al. Crash risks of older drivers: a panel data analysis. Accid Anal Prev 1998;30:569–81. [PubMed: 9678211]

34. Wood JM, Troutbeck R. Elderly drivers and simulated visual impairment. Optom Vis Sci 1995;72:115–24. [PubMed: 7753525]

35. Haymes SA, LeBlanc RP, Nicolela MT, et al. Glaucoma and on-road driving performance. Invest Ophthalmol Vis Sci 2008;49:3035–41. [PubMed: 18326696]

36. Freeman EE, Munoz B, Turano KA, West SK. Measures of visual function and time to driving cessation in older adults. Optom Vis Sci 2005;82:765–73. [PubMed: 16127343]

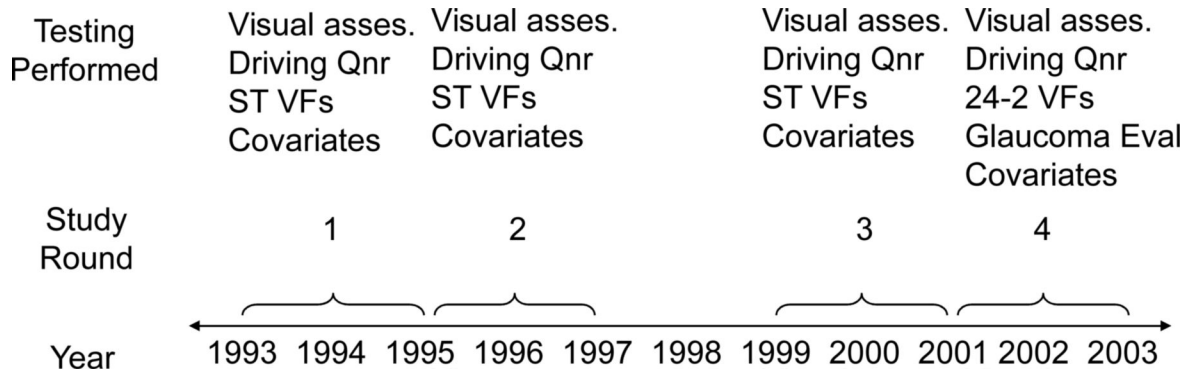

Figure 1.

Timeline of Salisbury Eye Evaluation and Testing Performed Visual asses = Visual Assessment, including binocular acuity with habitual correction and contrast sensitivity in each eye; Driving Qnr = Driving Questionnaire; ST VFs = suprathreshold visual fields; 24−2 VFs = Visual fields using Humphrey SITA fast 24−2 algorithm.

Covariates include time-invariant variables (age, race, sex, education) and time-varying covariates (medical comorbidities and cognitive status). Data for time-varying covariates was taken from study round 4.

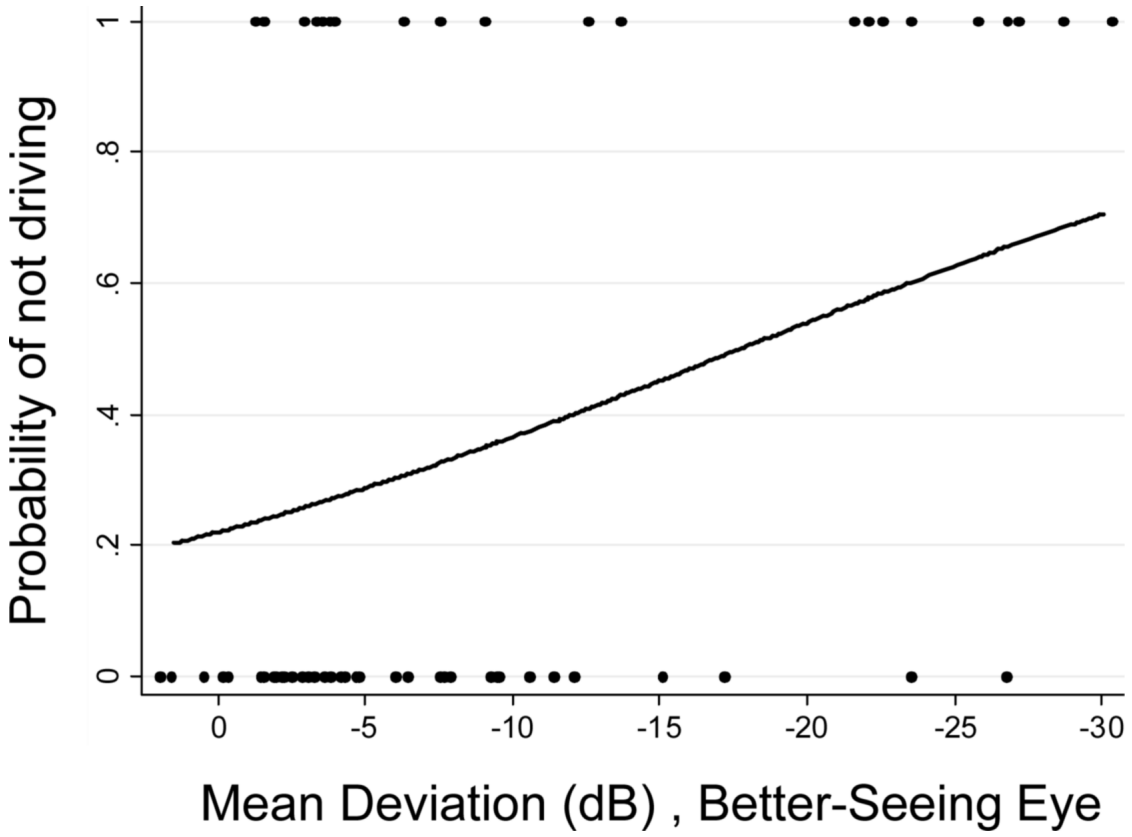

Figure 2.

Modeled probability for driving cessation amongst subjects with bilateral glaucoma.

Both the probability of not driving, and mean deviation of the better-seeing eye are adjusted for confounding variables.

Outcomes for study subjects with bilateral glaucoma are displayed as individual points, with subjects who are still driving having a probability of 0, and subjects who have stopped driving having a probability of 1.

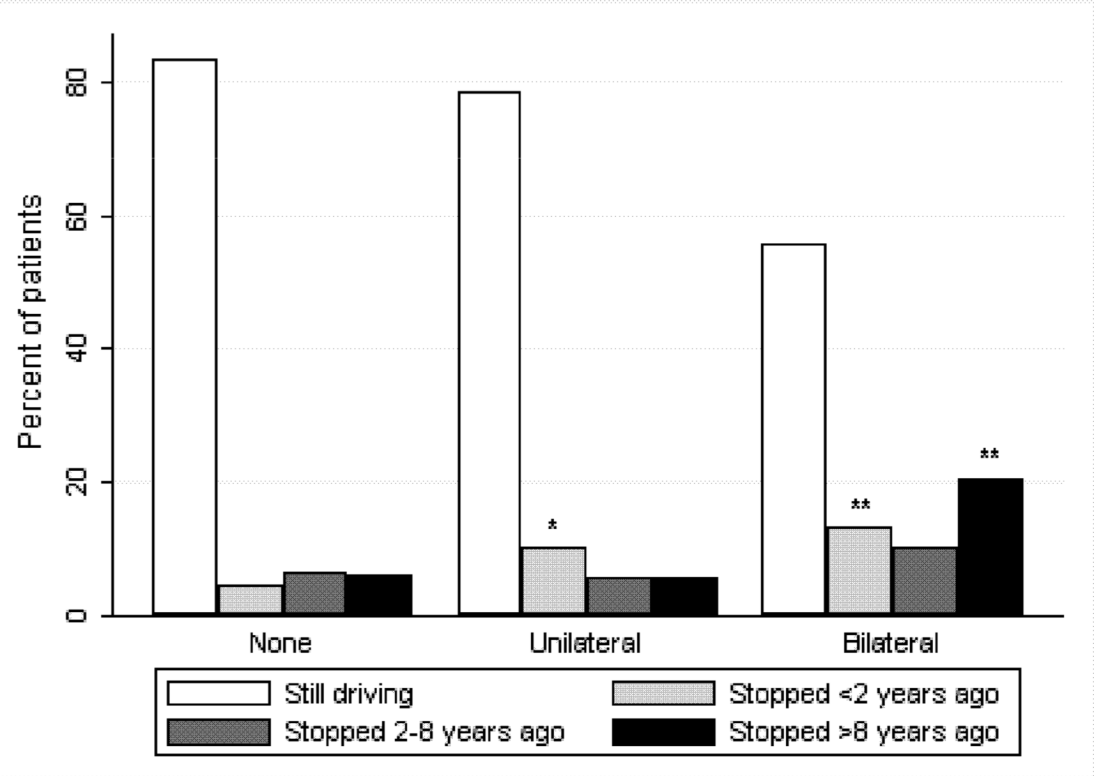

Figure 3.

Duration of discontinued driving by glaucoma status.

Unilateral and bilateral glaucoma subjects were compared to subjects without glaucoma for each time interval using multinomial logistic regression.

* p=0.06, **p<0.05 in multinomial regression model when compared to subjects without glaucoma. In all other time periods, no significant difference in driving cessation was observed when compared to subjects without glaucoma.

Table 1

Characteristics of Salisbury Eye Evaluation subjects who had ever driven a car by glaucoma status (n=1135)

	No Glaucoma (n=997)	Unilateral Glaucoma (n=70)	Bilateral Glaucoma (n=68)
Demographics			
Age (Years)	79.5	80.7[1]	81.1[2]
Black Race (%)	19.5	28.6	48.5[3]
Female Gender (%)	58.6	45.7[1]	57.4
Education (years)	11.9	11.6	10.9[1]
Health			
Comorbidities (#)	3.4	3.2	4.0[1]
Depressive symptoms (%)	6.7	10.0	4.4
MMSE score	26.0	25.4	24.1[3]
Vision			
Binocular Acuity, logMAR	0.06	0.10	0.18[3]
Contrast Sens, better eye*	33.3	31.6[2]	28.5[3]
Contrast Sens, worse eye*	30.2	25.4[3]	23.4[3]
Visual field MD (better eye)	−1.6	−3.3[3]	−8.6[3]
Visual field MD (worse eye)	−3.9	−9.4[3]	−12.7[3]

SEE = Salisbury Eye Evaluation;, MMSE = Mini-mental status examination; logMAR = logarithm of the minimum angle of resolution; Sens = sensitivity; MD = mean deviation

No glaucoma group is reference for comparison.

*Measured as number of letters correctly read of Pelli Robson chart.

[1]p<0.05

[2]p<0.01

[3]p<0.001.

Table 2

Effect of glaucoma status on driving cessation and limitation, univariate analysis.

Glaucoma Status	% Not Driving	% Not driving at night	% Driving <3,000 miles	% Not Driving in Unfamiliar Places	Mean # of limitations†
None	15.0	29.0	44.0	51.0	1.24
Unilateral	21.4	38.2	32.8	50.9	1.22
Bilateral	**40.6****	40.0	55.0	62.5	1.58*

No other comparisons significant at p<0.05.

*p=0.05

**p<0.001.

†Group differences assessed using ordinal logistic models testing whether subjects were more likely to have a higher number of driving limitations.

Table 3

Impact of vision, demographic, and health variables on the continued driving and driving restriction, age and gender-adjusted analysis

		Not Driving		Not Night Driving		<3,000 miles/yr		Not Driving in Unfamiliar Areas		Number of Limitations	
Variable	**Interval**	**OR**	**p**	**OR**	**p**	**OR**	**p**	**OR**	**p**	**OR**[¶]	**p**
Demographics											
Age	5 yrs older	1.9	<0.001	1.9	<0.001	1.5	<0.001	1.3	0.003	1.7	<0.001
Gender	Female	2.1	<0.001	4.2	<0.001	7.4	<0.001	2.3	<0.001	5.4	<0.001
Race	Black	2.9	<0.001	1.4	0.07	2.9	<0.001	1.4	0.06	1.9	<0.001
Education	4 yrs less	1.9	<0.001	1.8	<0.001	1.7	<0.001	1.4	<0.001	1.7	<0.001
Health/Cognition											
MMSE score	5 pts lower	3.7	<0.001	1.9	<0.001	2.6	<0.001	1.5	0.004	2.1	<0.001
Comorbidities	1 illness	1.2	<0.001	1.1	0.02	1.1	0.12	1.0	0.5	1.1	0.009
Depressive sx	Present	2.9	<0.001	1.8	0.06	1.6	0.13	1.0	0.9	1.4	0.15
Vision											
Binocular acuity	0.1 worse[*]	1.5	<0.001	1.4	<0.001	1.2	0.001	1.2	<0.001	1.3	<0.001
CS[†], better eye	5 let worse	3.0	<0.001	2.6	<0.001	1.6	<0.001	1.5	<0.001	2.1	<0.001

OR = odds ratio; yrs = years; MMSE = Mini-mental state examination; pts = points; sx = symptoms; CS = contrast sensitivity; let = letters Age measured in gender-adjusted analysis. Gender measured in age-adjusted analysis. Other variables reflect age and gender-adjusted analyses.

[¶]Odds ratio derived from ordinal logistic regression model. Values represents risk of having one additional driving limitation, given a maximum total of 3 limitations.

[*]logarithm of the minimum angle of resolution (logMAR) units

[†]Measured as number of letters correctly read of Pelli Robson chart.

Table 4

Impact of glaucoma status and other variables on driving cessation and driving limitation, multivariable analysis

		Not Driving		Not Night Driving		<3,000 miles/yr		Not Driving in Unfamiliar Areas		Number of Limitations	
Variable	**Interval**	**OR**	**p**	**OR**	**p**	**OR**	**p**	**OR**	**p**	**OR[¶]**	**p**
Bilateral Glaucoma[†]	Present	2.6[*]	0.002	1.2	0.7	1.1	0.9	1.5	0.4	1.3	0.36
Age	5 yrs older	1.6	<0.001	1.8	<0.001	1.4	0.002	1.2	0.06	1.5	<0.001
Gender	Female	2.9	<0.001	5.3	<0.001	11.1	<0.001	2.7	<0.001	6.9	<0.001
Race	Black	1.6	0.04	1.0	0.9	2.3	<0.001	1.0	0.9	1.4	0.07
Education	4 yrs less	1.0	0.8	1.7	<0.001	1.3	0.02	1.3	0.003	1.5	<0.001
MMSE	5 pts lower	3.1	<0.001	1.3	0.12	2.0	<0.001	1.3	0.1	1.6	0.001
Comorbidities	1 illness	1.2	<0.001	1.1	0.05	1.1	0.02	1.0	1.0	1.1	0.04

OR = odds ratio, yrs = years; MMSE = Mini-mental state exam; pts = points

All variables were analyzed as part of a single logistic, or ordinal logistic, regression model including age, race, gender, education, MMSE score, and number of comorbid illnesses.

[¶]Odds ratio derived from ordinal logistic regression model. Values represents the risk of having one additional driving limitation, given a maximum total of 3 limitations.

[†]Compared to subjects without glaucoma.

[*]Effect persisted when binocular acuity or better eye mean deviation were included in the model, but was eliminated when contrast sensitivity was included in the model.