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Vision, Driving Exposure, and Collisions in Bioptic Drivers

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Abstract

Significance.—Lack of knowledge regarding the mileage driven by drivers with low vision who use bioptic telescopes could obscure the relationship between vision and road safety. This study provides data suggesting that worse vision is correlated with less mileage driven but more collisions per mile in bioptic drivers.

Purpose.—The purpose of this study was to determine whether vision or demographic factors predict mileage driven in bioptic drivers and per-mile motor vehicle collision rate, and also to compare the collision rate of bioptic drivers to previous estimates for the general population.

Methods.—Driver data were collected retrospectively from clinic records. Collision data were collected from the Ohio BMV database. Subjects were also asked to estimate their yearly mileage. Regression models were used to investigate relationships between vision and collision rates.

Results.—73 licensed Ohio bioptic drivers (36 male) were included. Mean (±SD) age was 51±16 years. Mean logMAR visual acuity was 0.67 (approximately 20/100). Mean log contrast sensitivity was 1.57. Mean reported annual mileage was 9,746. Age, gender, and previous (non-bioptic) driving experience were not associated with mileage. LogMAR visual acuity was inversely related to mileage ($P = .020$), and contrast sensitivity ($P = .012$) and horizontal visual field ($P = .019$) were directly associated with mileage. Visual acuity ($P = .017$) and visual field ($P = .005$), but not contrast sensitivity ($P = .193$), were associated with number of collisions.

Conclusions.—Visual acuity, visual field, and contrast sensitivity were associated with driving exposure in bioptic drivers (with drivers with poorer vision reporting lower annual mileage) and poorer visual acuity and visual field were associated with more collisions. The per mile collision rate for bioptic drivers was within the range of that previously reported for fully-sighted drivers, though higher than would be expected for fully-sighted drivers of similar age distribution.

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Bioptic telescopic spectacles can be used by people with moderate central vision impairment to operate a motor vehicle in most U.S. states and some other countries.[1,2] Such bioptic glasses typically consist of a patient's standard distance refractive correction (the carrier lenses) with a small telescope mounted above the habitual line of sight for one eye. Bioptic drivers view through the carrier lenses most of the time while driving, and can use a slight dip of the head to briefly sight through the telescope to obtain magnified views of distant objects like road signs.

The inability to obtain or maintain driving licensure has been linked to many negative outcomes, including increased rates of depression, reduced quality of life, and increased feelings of isolation.[3-5] While use of bioptic telescopic spectacles may allow drivers with low vision to avoid these negative outcomes, there is still much that is not known about the characteristics, performance, and safety of bioptic drivers.[1, 6] There have been a few studies comparing the motor vehicle collision rates of bioptic drivers to those of control drivers, with mixed findings, though those using state records have generally shown an increased collision risk for bioptic drivers. [7-12] One difficulty with interpretation of these studies is a lack of knowledge about the driving exposure (mileage driven) of bioptic drivers, which may influence the risk of involvement in collisions. Similarly, we have previously failed to find a relationship between vision and annual crash rate,[13] but the lack of exposure data may obscure these relationships if drivers with poorer vision also drive fewer miles and thus expose themselves to less crash risk.

There have been a number of studies examining the relationship between vision and driving exposure in older drivers. Poorer visual acuity, contrast sensitivity, or both have been found to predict lower mileage, driving restriction, or driving cessation in these older adults.[14-17] Though there have been a few published studies of driving exposure in bioptic drivers,[18,19] we are not aware of any studies examining its relationships with visual factors or collisions.

The goals of this study were to determine the self-reported driving exposure of a group of licensed bioptic drivers and to determine whether vision was associated with driving exposure or other driving habits, such as the number of weekly trips. Additionally, we sought to use the self-reported exposure data to calculate collision rates accounting for exposure for the group of bioptic drivers for comparison to previous rates reported for the general population and to explore whether vision was predictive of exposure-adjusted collision rate.

METHODS

The study was approved by the Biomedical Sciences Institutional Review Board of the Ohio State University, and all participants provided informed consent before participation.

Participants in this study were established bioptic drivers possessing valid Ohio driver's licenses with bioptic restriction who were patients at the Ohio State University College of Optometry in the years 2014 and 2015 (the time of enrollment in the study and mileage survey). The Ohio Bureau of Motor Vehicles requires a visual acuity with both eyes together of 20/40 or better for unrestricted licensure. Drivers with visual acuity worse than 20/40 but of at least 20/70 may be licensed for daylight only. A second requirement is a horizontal visual field of at least 70 degrees to one side and 45 degrees to the other side. For bioptic drivers, the visual acuity requirement remains unchanged, but can be met using the bioptic telescope. The visual field requirement is also unchanged for bioptic drivers, but it is not tested with the individual sighting through the telescope.

The Ohio State University serves as one of only two entry points to the Ohio bioptic program and serves approximately 75% of Ohio bioptic drivers. After an initial vision examination, the bioptic telescopic spectacles are fit and the driver begins training. The candidate must then pass road testing for licensure at the Ohio Highway Patrol. Licensure renewal requires mandatory vision re-testing and occurs every one or four years, depending on the expected stability of vision.

Potential participants were identified by review of clinic schedules, and eligible participants were recruited following their licensure renewal examinations or by telephone. Patients who indicated interest in the study completed a driving survey in one of two ways: in person immediately following the renewal vision testing appointment or by mail at a later date. Participant information recorded from the medical record included gender, age, and whether the patient had previously held a driver's license that did not require bioptic use. Because the date of first licensure is not included in the Bureau of Motor Vehicles records, an estimation of the date of initial bioptic licensure was required. For this, we used a method devised for previous studies[13] in which initial licensure date was estimated as seven months after the intake exam date, based on the average time from intake to licensure for Ohio bioptic drivers.

Vision information was obtained from the medical record from the most recent clinical visit for the purpose of vision testing for driver's license renewal. At these visits, monocular and binocular visual acuity are measured through the refractive correction provided by the carrier lenses in the bioptic glasses using Bailey-Lovie[20] or ETDRS[21] logMAR charts. Visual acuity is also measured through the bioptic telescope (Bailey-Lovie or ETDRS logMAR chart), with correction for testing distance. At the time of this study, telescope magnification in the Ohio program generally ranged from 3X to 6X, with the majority using unilateral telescopes of either 4X or 6X magnification. Contrast sensitivity is measured with a Pelli Robson chart[22] at one meter or a Mars[23] chart at 50 cm with by-letter scoring. Temporal and nasal visual field are measured kinetically with an arc or Goldmann perimeter using a large standard white target.

Participants were asked to estimate the total mileage they had driven over the past year. Each subject also completed a partial, modified, large print version of the Driving Habits Questionnaire[24] to assess the number of unique locations visited and number of trips taken in a typical week. Driving records of participants were obtained from the Ohio Bureau of Motor Vehicles in order to assess the number of collisions experienced during bioptic licensure. The driving record includes a list of all police-reported collisions. The record contains only limited description of collisions, such as the date of occurrence and whether there was an injury or property damage. No information is available from the Bureau of Motor Vehicles record on the circumstances of the collisions or whether fault was assigned to the driver. The observation window for collisions in the Bureau of Motor Vehicles record was from the time of bioptic licensure to the time of study enrollment and mileage survey. All collisions since the date of bioptic licensure were recorded.

Descriptive statistics were used to summarize demographic, vision and mileage data and, when appropriate, non-parametric statistics were used for variables not normally-distributed. Spearman correlation was used to examine whether there were bivariate relationships between age or vision (visual acuity, contrast sensitivity, and total horizontal visual field) and number of destinations and number of trips in a week. Non-parametric partial correlations (adjusting for age at time of study enrollment) were used to examine relationships among vision measures and self-reported mileage.

In order to calculate a collision rate adjusted for driving exposure for bioptic drivers, we used a method similar to that of Massie et al. to calculate a crash rate for the general U.S. population.[25] The total number of motor vehicle collisions in the Bureau of Motor Vehicles record for all bioptic drivers was divided by the total estimated self-reported miles driven for these drivers over the observation period (estimated annual mileage times the number of years of licensure). Then, we calculated how many collisions the group of subjects experienced per million miles driven.

In order to investigate whether visual acuity, contrast sensitivity, or horizontal visual field were associated with collisions in bioptic drivers, we performed a Poisson loglinear regression with number of collisions in the BMV record as the outcome. In order to account for differences in exposure to collision risk resulting from differences in mileage or time of licensure, we used the natural log of an estimate of the total miles driven as an offset variable in the model. The estimate of total miles driven was made by multiplying each driver's reported annual mileage by the number of years of bioptic licensure. Rate ratios were calculated for the relationships between collisions and visual acuity, contrast sensitivity, and horizontal visual field. Adjustment for age was made in all models. Deviance was assessed to ensure model assumptions were met. *P*-values of less than .05 were considered evidence for statistical significance. All statistical testing was performed using IBM SPSS version 26.

RESULTS

Seventy-three (73) bioptic drivers were enrolled in the study. Of these, 49 participants completed the survey in person and 24 subjects completed it by mail. Twenty-one (21) other potential participants indicated initial interest and received a packet in the mail but either did not return the survey or chose to decline participation, for an overall response rate of 78%.

The mean ± SD age of enrolled bioptic drivers was 51 ± 16 years with a range of 20 to 88 years. Figure 1 shows the distribution of age of participants by decade. Twenty-five (25) of the subjects (34%) were female. Forty-nine (49) subjects (67%) reported previous non-bioptic driving licensure. The mean ± SD estimated length of licensure with bioptic privileges was 11 ± 6 years. Twenty-eight percent of participants had a retinal dystrophy affecting the macula. The most frequent single ocular diagnosis was albinism

(18% of drivers). Other frequent diagnoses included congenital nystagmus, presumed ocular histoplasmosis, and optic atrophy. Only about 5% of participants had age-related macular degeneration. Mean ± SD better-eye logMAR visual acuity of the subjects was 0.67 ± 0.18 (approximately 20/100). Mean ± SD log contrast sensitivity was 1.57 ± 0.23 (a near-normal[26] finding). The mean ± SD total horizontal visual field was 156° ± 15°, with a minimum of 115° and maximum of 195°.

The mean ± SD total number of trips typically taken within a week was 14 ± 10 with a range of 3 to 59 per week. The mean ± SD total number of destinations in a typical week was 6 ± 2, with a minimum of one and a maximum of 13. A summary of the proportion of bioptic drivers reporting trips to various locations is shown in Table 1. Neither age, visual acuity, horizontal visual field, nor contrast sensitivity was associated with the reported number of unique destinations or trips during a routine week when analyzed with Spearman correlation.

Bioptic drivers enrolled in the study reported a mean of 9,746 annual miles. The median (interquartile range) of these annual mileage estimates was 7,000 (2,500 to 12,000) miles. The minimum reported annual mileage was 100 miles, and the maximum was 90,000 miles. One participant failed to provide an annual mileage estimate. Poorer visual acuity, poorer contrast sensitivity, and less total horizontal visual field were each independently associated with less self-reported annual mileage, after adjustment for age (Table 2 and Figure 2).

Forty-two (58%) participants had at least one documented collision occurring after initial bioptic licensure. These 42 drivers were involved in a total of 95 reported collisions over the total time of bioptic licensure. Of these collisions, 66% were reported to involve no injuries, 15% were reported as possible injury, and 9% were reported as resulting in a non-incapacitating injury. Additionally, 10 (10%) collisions were recorded as reflecting that the reporting officer was unsure whether any personal injuries occurred. None of the collisions was reported to involve an incapacitating injury or fatality.

The mean yearly motor vehicle collision rate for individual participants was 0.14 per year. Aggregating data across the entire group of 73 study participants, we documented for this full cohort a total of 95 collisions in 8,464,522 total miles driven. This was based on the assumption that reported mileage for the previous year was representative of mileage each year since licensure. These findings equate to a rate of 11.2 collisions per million self-reported miles driven for this group of bioptic drivers.

Regression models adjusted for age showed that logMAR visual acuity (rate ratio = 4.08, 95% CI: 1.29 to 12.94, $P = .017$) and total horizontal visual field (rate ratio = 0.980, 95% CI: 0.967 to 0.994, $P = .005$) were each associated with per-mile collision rate. Drivers with worse visual acuity and less horizontal visual field had higher annual collision rates. We did not, however, find a statistically significant relationship between log contrast sensitivity (rate ratio = 0.57, 95% CI: 0.24 to 1.33, $P = .193$) and per-mile collision rate.

DISCUSSION

Visual acuity and contrast sensitivity had significant low-to-moderate correlations with self-reported mileage, adjusting for age, such that poorer vision was associated with fewer miles driven. This finding is consistent with past work in older drivers showing that visual acuity and contrast sensitivity predict greater self-reported difficulty with driving.[27] Neither poorer vision nor older age were, however, associated with fewer trips or locations visited.

In this study, bioptic drivers reported their estimated mileage for the previous one-year period, yielding a mean of 9,746 miles driven per year. By comparison, Bowers et al. interviewed 58 bioptic drivers via telephone and calculated an average self-reported yearly mileage of 11,544 miles per year.[6] In another study, Owsley et al. estimated an average self-reported yearly mileage for bioptic drivers of 13,000 miles through in-person interviews of 26 bioptic drivers.[16] Both of these studies used the Driving Habits Questionnaire and extrapolated from estimated weekly mileage driven for their annualized mileage estimates for their bioptic drivers. For comparison to drivers more broadly, the 2017 National Household Travel Survey reported an average of 13,806 miles per year for U.S. drivers 35 to 54 years of age.[28] That study extrapolated annual mileage estimates from travel logs that participants completed for a specific twenty-four hour period.

In this study, we calculated a mean yearly motor vehicle collision rate of 0.14 per year, which is relatively consistent with previous studies that report rates in the range of 0.074 to 0.13 collisions per year for bioptic drivers.[8, 10, 12] These studies also indicate that these collision rates are between 1.3 and 3 times the annual rates of control groups. To our knowledge this is the first study of bioptic drivers to calculate exposure-adjusted collision rates. Consideration of driving exposure may be especially important when studying bioptic drivers since they may have different driving habits than would typical comparison groups. Our finding that this group of bioptic drivers was involved in 11.2 collisions per million self-reported miles traveled can be compared to data from Massie et al. who calculated per mile crash rates using databases for the general U.S. population, although geographic variations in driving conditions may complicate comparisons.[25] They found that the collision rate per million miles varied by age group from approximately 4 to 20 collisions per million miles traveled, with teenagers having the highest rates. The bioptic collision rate per mile estimated for our study is greater than the rates reported by Massie et al. for all age groups except presumably fully-sighted young teenage drivers, and most comparable to the rates for drivers 20-24 and 75+. It should be noted, though, that any comparisons are complicated by the fact that bioptic drivers tend to have less experience than non-bioptic drivers of the same age, and also that the data from bioptic drivers in this study were collected over a number of years, rather than cross-sectionally at a specific age as in many studies of collision rates in fully-sighted drivers.

The higher calculated rate of collisions per million reported miles for this group of bioptic drivers as compared to fully-sighted drivers from other studies[25] highlights the need for further research on many aspects of bioptic driving performance and safety, including determination of patient characteristics that are collision risk factors and best driver training practices. However, when considering the elevated bioptic collision rate reported here, relevant context includes the likely importance of the trips undertaken by bioptic drivers, with 73% reporting trips to and from work. It should also be noted that none of the collisions in this study was reported to have resulted in a fatality or an incapacitating injury. Additionally, as a society we continue to tolerate some elevated risks, such as teen driving, despite their reported eight times increased risk for per-mile collisions versus middle-aged drivers, and such as cellular telephone use, which is reported to increase risk of collision by four times, even if used hands-free.[29,30]

While our past work[13] did not show a relationship between various measures of vision and annual motor vehicle collision rate, no data were available in that study to control for driving exposure. It was possible that poorer vision might actually have increased collision risk per mile traveled, but that this effect might have been masked by a compensatory reduction in driving exposure, such that the annual collision rate was not statistically related to poorer vision. The findings from this study (that bioptic drivers with poorer vision report driving fewer miles on average and that poorer visual acuity and visual field were associated with more collisions after adjusting for age and driving exposure) are generally consistent with that idea. We found an adjusted rate ratio indicative of an increase in collision rate of approximately four times with a one unit worsening of logMAR visual acuity (i.e. the difference between 20/20 and 20/200) or a 65 degree worsening of horizontal visual field (i.e. the difference between 180 degrees and the minimum allowable 115 degrees). While we did not find a significant association between contrast sensitivity and collision rate, it should be noted that the sample size is relatively small and this may have resulted in a lack of statistical power to do so. The number of years of licensure, and thus driving experience, varied for participants in this study. While previous studies[31, 32] have identified driving experience as related to motor vehicle collision rate in young drivers, particularly immediately after licensure, the fact that the effect of experience on crash rate decreases with increasing levels of experience likely reduced its influence on the findings in this study, in which most of the participants had relatively long driving histories. Additionally, about 2/3 of participants had previous, non-bioptic licensure prior to obtaining a bioptic license. Our previous work[13] with bioptic drivers showed that, while there was a higher rate of collisions per year in the first few years of bioptic licensure for drivers with no prior experience, for drivers with previous non-bioptic experience, there was no significant effect of years of bioptic licensure on collision rate.

Knowledge about the increasing risk of collision in bioptic drivers as visual acuity and visual field worsen may be useful to a number of parties, including clinicians, driving instructors, those establishing licensing standards, and indeed bioptic drivers themselves. Further study would be required to determine what effect reduced visual acuity might have on specific aspects of driving performance that lead to more collisions in bioptic drivers, and driving simulator or naturalistic recording studies could be of use in making that determination. It should also be noted that we did not have access to data on potential confounders of the relationship between vision and collision rate, such as cognitive status, depression, or general health.

Limitations

One limitation of this study is that yearly mileage was estimated by self-report of drivers, as compared to approaches which measure actual mileage driven with in-car devices. Previous work comparing self-report to recorded mileage has found that drivers frequently misestimate their mileage. A recent study[33] using data from the SHRP2 Naturalistic Driving

Study found that the median self-reported annual mileage was about 2,900 miles more than the recorded median annual mileage and that drivers with lower exposure overestimated more than other drivers. Unfortunately, it is unlikely that any simple correction factor could be applied to improve the validity of self-reported mileage since, as Langford et al indicated, "[t]here are contradictory research findings about the extent and direction of differences between odometer-derived and self-reported driving distances."[34] These findings support the use of naturalistic recording or other methods that provide objective measures of mileage for future studies of driving safety.

Another limitation of this study might be our choice to use a simple yearly mileage estimate rather than an estimate derived from a structured questionnaire, as can be done with the Driving Habits Questionnaire.[24] We made this decision based on the difficulties inherent in completion of a mailed questionnaire as compared with the relative clarity of an annual mileage estimate, as well as to facilitate comparisons with past studies[14, 35] that used a simple yearly mileage estimate. Additionally, while participants made mileage estimates only for the past year, we assumed that this estimate was reflective of their driving practices throughout the period of their licensure for bioptic driving, which would be flawed if driving habits changed significantly over the course of licensure. A further limitation is that we used vision data only from the last vision examination without consideration for vision changes that some participants may have experienced over the course of their driving histories. There may have also been self-selection bias; potential participants with a history of collisions may have been less likely to agree to participate due to a concern that revealing that history could negatively influence their licensure renewal. Additionally, we only enrolled drivers from the clinic at Ohio State, and this could be a source of bias. Also, focusing only on bioptic drivers in the state of Ohio may limit generalizability to other geographic regions and jurisdictions, especially if traffic conditions and rules and practices for selecting, equipping, and training bioptic drivers were to differ substantially.

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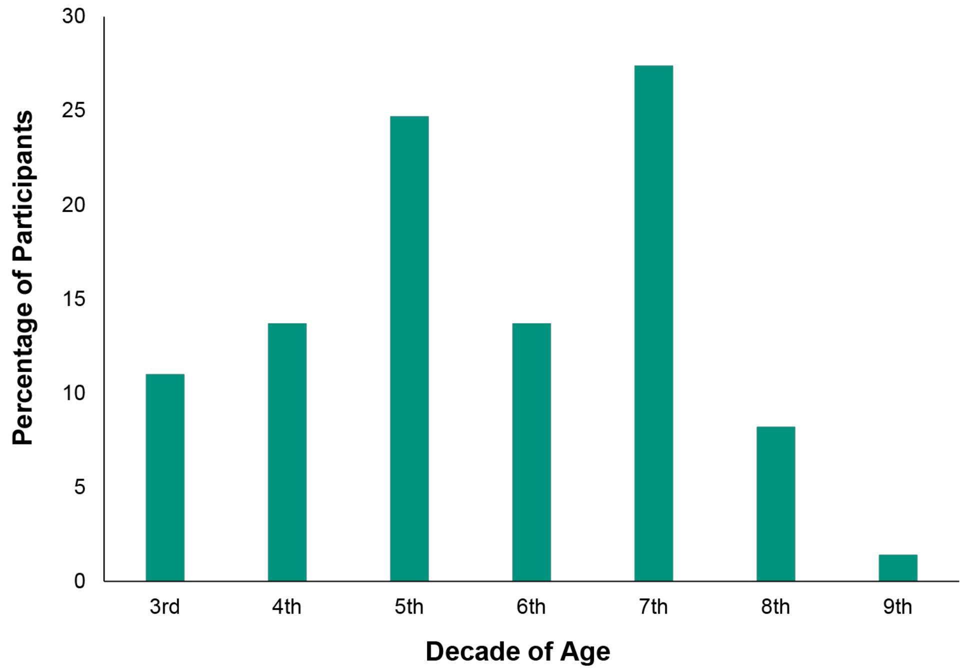

Figure 1.
Distribution of age of subjects.

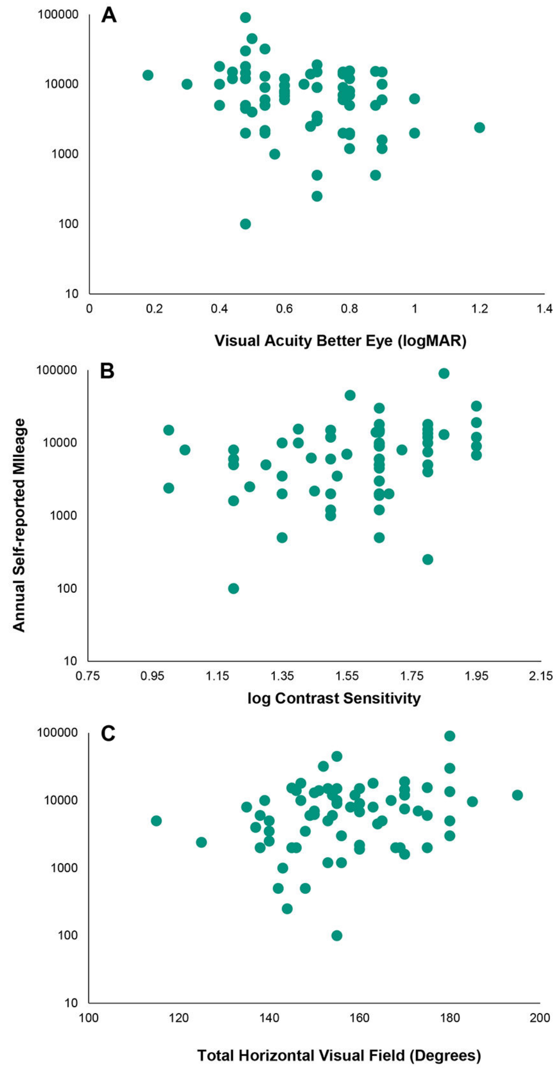

Figure 2.
Annual mileage by visual acuity, contrast sensitivity, and horizontal visual field.

Table 1.

Proportion of Drivers Reporting Trips to Common Locations

Destination	# Participants (%)
Work	53 (73)
Stores	67 (92)
Church	37 (50)
Visit Relatives	42 (58)
Visit Friends	43 (59)
Restaurants	55 (75)
Appointments	52 (71)
Other	39 (53)

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Table 2.

Relationships of Vision Measures with Self-reported Mileage, Adjusted for Age.

Vision Measure	Correlation Coefficient	*P*-value
Visual Acuity (logMAR)	−.275	.020
Contrast Sensitivity (logCS)	.300	.012
Horizontal Visual Field (degrees)	.280	.019