Previous Driving Experience, but Not Vision, Is Associated With Motor Vehicle Collision Rate in Bioptic Drivers

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PURPOSE. Bioptic telescopic spectacles (BTS) consist of a small telescope (or telescopes) mounted high in a pair of spectacle lenses. More than 40 states allow for some form of bioptic driving licensure for people with decreased central vision. The purpose of this study was to determine significant associations among previous driving experience, vision, and motor vehicle collisions (MVCs) for bioptic drivers in Ohio.

METHODS. We conducted a retrospective study of patients who received a vision examination and subsequently obtained bioptic licensure. We obtained driving records from the Ohio Bureau of Motor Vehicles in order to determine MVC involvement. Relationships among vision measures, age, sex, previous experience, and MVCs were investigated using time-to-event analysis and the Cox proportional hazards regression model.

RESULTS. We identified 237 bioptic drivers (65% male). Age at initial exam ranged from 16 to 81 years, and mean visual acuity was approximately 20/120. The number of MVCs per driver ranged from 0 to 11, with 124 (52%) drivers having had at least one MVC. Visual acuity and contrast sensitivity were not significant predictors of MVC. Drivers without previous driving experience were significantly more likely to have been involved in an MVC ($P < 0.001$), and this association remained significant after adjusting for age and sex ($P = 0.01$). The rate of MVC per year decreased steadily over a 10-year period for drivers without previous experience.

CONCLUSIONS. Previous nonbioptic driving experience, but not visual acuity or contrast sensitivity, was associated with yearly MVC rate in bioptic drivers.

Keywords: low vision, driving, bioptic telescopes

Biopic telescopic spectacles (BTS) consist of a small telescope (or telescopes) mounted high in a pair of spectacle lenses.¹ The spectacle lenses ("carrier lenses") contain any distance prescription. Using a downward head tilt, a biopic driver can access the telescope for a brief period to spot distant targets, such as road signs, traffic signals, and potential hazards. More than 40 states allow for some form of biopic driving licensure for people with decreased central vision.^{2,3} The loss of driving privileges, or the inability to obtain a license, is a common concern among patients with low vision. In a study of vision-related quality of life of people with age-related macular degeneration, those who did not drive reported lower vision-related quality of life on almost every subscale, even after the results were adjusted for visual acuity.⁴ The use of BTS allows some drivers with central visual acuity that does not meet state standards to obtain (or maintain) driving licensure and its associated benefits.

Since the introduction of biopic driving, there have been questions regarding its safety. There has been rather vigorous debate on the topic,^{5–8} which has often included discussions of patient rights and the optical limitations of telescopes for driving but which has largely occurred without mention of actual research on motor vehicle collisions (MVCs). This is likely at least partially due to the relative scarcity of biopic driving safety research. In the more than 40 years during which biopic driving has existed in the United States, there have been

only a few studies of road safety; they were conducted in only a few states, and the last large study was published in 1996. None of these studies reported on the relationships among visual and demographic factors and driver safety.

A summary of past studies of the road safety of biopic drivers is provided in Table 1. The first published study of road safety of biopic drivers, by Korb,⁹ appeared in 1970. Korb reported that none of 26 licensed biopic drivers experienced any MVC in a total of 32 person-years of driving. Feinbloom¹ reported in 1977 that, of 300 patients he fit with BTS for driving over the course of 18 years, none reported an MVC resulting in injury to any person or causing severe property damage. In 1988, Lippman et al.¹⁰ compared the MVC rate of 64 Texas biopic drivers to that of a control group of 64 drivers selected randomly by driver license number, based on the records of the Texas Department of Public Safety. The age- and sex-adjusted rate of MVC was 1.34 times greater for biopic drivers, and biopic drivers were at fault in 82% of the MVCs in which they were involved, compared to 40% of control drivers. A more recent study by Vincent et al.¹¹ involved 10 biopic drivers who had undergone extensive training, compared to control groups consisting of other medically restricted drivers and of normally sighted drivers. They found no increased risk of MVCs for biopic drivers over the first 2 years of licensure, though the small number of biopic drivers and MVCs documented makes the results difficult to interpret.

TABLE 1. Summary of Bioptic Driving Safety Studies

Study	Year	Number of Bioptic Drivers Studied	Method of MVC Determination	Summary of Findings
Korb ⁹	1970	26	Self-report	Bioptic drivers surveyed reported no MVCs in 32 person-years of driving
Feinbloom ¹	1977	300	Self-report	Bioptic drivers surveyed reported no "serious" MVCs with injury Average mileage reported by drivers was 12,500/y
Janke ¹²	1983	229	State records	7.4 MVCs per year for bioptic drivers Bioptic drivers have 1.9 times MVC rate of control group
Lippman et al. ¹⁰	1988	64	State records	Bioptic drivers have 1.34 times MVC rate of control group
Clarke ¹³	1996	609	State records	7.5 MVCs per year for bioptic drivers Bioptic drivers have 1.9 times MVC rate of control group
Vincent et al. ¹¹	2012	10	Insurance records	No increased MVC rate for bioptic drivers

The two largest studies of bioptic driving safety were both completed in California. In 1983, Janke¹² published the first report of bioptic driver safety that relied on state driving records. For 229 bioptic drivers over a 2-year study period, the MVC rate was 7.4 MVCs per 100 drivers per year. The rate for a large control group of California drivers was 3.98 per 100 drivers per year, which suggests approximately 1.9 times the crash risk for bioptic drivers. In 1996, Clarke¹³ reported a similar study conducted by the California Department of Motor Vehicles' Research and Development Branch. This study consisted of a 2-year observation of the driving records of 609 bioptic drivers and a control group of 28,109 nonbiptic drivers who were selected based on driver license number. The MVC rate for bioptic drivers after adjusting for age and sex was approximately 7.5 MVCs per 100 drivers per year, and the rate for control drivers was approximately 4 MVCs per 100 drivers per year, again suggesting approximately 1.9 times the crash risk for bioptic drivers.

Interestingly, none of the previous studies of the MVC risk has included a detailed analysis of the effects of the visual characteristics of bioptic drivers on safety. Licensed bioptic drivers would be expected to have a relatively wide range of visual acuities (from just worse than 20/40 to 20/200 or worse) and a relatively wide range of contrast sensitivities. The severity of the visual impairment might be expected to affect bioptic drivers both when looking through the carrier lenses and while sighting through the telescope. Currently, though, it is not possible to use evidence to make conclusions about the relative safety of bioptic drivers with different types or degrees of visual impairment.

Driving experience may also contribute to the relative safety of bioptic drivers. We have already reported that a lack of previous nonbiptic driving experience in candidates for licensure in Ohio is related to poorer scores on the Highway Patrol road test for licensure, which may serve as an indicator of a new bioptic driver's driving ability.¹⁴ People with adult-onset vision disorders often become bioptic drivers after many years of nonbiptic driving experience, while people with congenital or other early-onset vision disorders often enter the bioptic program without any previous driving experience. There is evidence from studies of normally sighted drivers that a lack of driving experience is a factor in increased risk of MVCs, yet there have been no studies on how previous nonbiptic driving experience is related to the road safety of bioptic drivers once they are licensed.

Knowledge of associations among vision, previous driving experience, and road safety could help clinicians and state or other public authorities make more informed decisions about which individuals are suitable candidates for bioptic licensure, and ultimately benefit the safety of those individuals and the general public. The purpose of this study was to determine significant associations among previous driving experience, vision, and MVCs for bioptic drivers in Ohio. We hypothesized that a lack of previous nonbiptic driving experience would be associated with an increased rate of MVCs, as would poorer visual acuity and contrast sensitivity.

METHODS

We conducted a retrospective study of patients who received a bioptic examination at the College of Optometry at the Ohio State University between 1991 and 2011 and who subsequently obtained daylight bioptic licensure. Data were collected from records of initial vision examinations, including visual acuity, contrast sensitivity, and horizontal visual field. Demographics, ocular diagnoses, and licensure history were also extracted from patient records. Subjects were classified as having previous nonbiptic driving experience if they reported any history of driving licensure (without a bioptic restriction) in Ohio or any other state.

At the initial vision examination, patients are generally tested with their habitual refractive correction in place. Visual acuity is tested using either an ETDRS¹⁵ or a Bailey-Lovie¹⁶ chart at a distance deemed appropriate by the tester, and is assessed for both eyes individually and together. Guessing is encouraged, and testing is stopped when three or more letters are missed on a given line. Contrast sensitivity is assessed for both eyes together using either a Pelli-Robson chart¹⁷ at 1 m or a Mars¹⁸ chart at 50 cm. Guessing is encouraged, and stopping rules of two of three letters missed in a triplet (Pelli-Robson) or of two consecutive letters missed (Mars) are used. Chart luminance for acuity and contrast testing is not assessed at every visit, but generally ranges from 100 to 160 cd/m². Horizontal visual field extent is assessed using either a Goldmann perimeter (typically with a V4e target) or an arc perimeter (typically with a 10-mm target).

We obtained driving records from the Ohio Bureau of Motor Vehicles in order to determine MVC involvement for the bioptic drivers examined at the College. The driving records contained information on MVC involvement, convictions,

TABLE 2. Ocular Condition for Included Participants, $n = 237$

Ocular Condition	Percent of Subjects
Albinism	16
Optic atrophy/other optic nerve disorder	16
Stargardt macular degeneration	15
Ocular histoplasmosis	13
Macular dystrophy/other macular disorder	8
Cone dystrophy/degeneration	7
Age-related macular degeneration	4
Congenital nystagmus	4
Myopic retinal degeneration	3
Retinoschisis	3
Diabetic retinopathy	3
Congenital cataract	3
Retinopathy of prematurity	2
All other causes	3

severity of MVC, date of last licensure, and license restrictions. Though the Bureau of Motor Vehicles driving records reported the date of last license renewal for each individual, they did not contain the dates of first bioptic licensure. To address this limitation in the dataset, we used two methods to estimate the date of initial licensure. The first method was to use dates included in medical or training records. That is, for all patients whose records contained such licensure date, that date was used in the analyses. We used a second method for subjects whose records did not contain a date of licensure. We used data from drivers with known licensure dates, and for those drivers the average time between vision examination and licensure was 7 months. Therefore, we estimated the licensure date for drivers without a documented first licensure date to be 7 months after the driver's initial vision examination. Fifty percent of subjects' records did not contain a licensure date and were thus estimated in this manner. Motor vehicle collision rates were calculated in terms of collisions per year of licensure. In order to determine whether MVC rates change over time after initial bioptic licensure, the mean MVC rate for bioptic drivers in each of the first 10 years of bioptic licensure was calculated. In this analysis, drivers with initial license dates prior to the 1997 purge date were included, but only years in which they were at risk for a collision were counted. For instance, a driver who was licensed 2 years prior to the purge date was included but only for the 8 years after the purge, and that driver entered the analysis as a third-year driver.

All study procedures were reviewed and approved by the Institutional Review Board of The Ohio State University and adhered to the tenets of the Declaration of Helsinki.

For statistical analysis, relationships among vision measures, age, sex, previous experience, and MVCs were investigated using time-to-event analysis and the Cox proportional hazards regression model.¹⁹ An event was defined as the first involvement in any MVC after the date of bioptic licensure was documented in the Bureau of Motor Vehicles record, and simple bivariate and multivariate Cox proportional hazards

FIGURE 1. Distribution of age (by decade) at initial examination ($n = 237$).

regression models were created to examine the effects of various patient characteristics on MVC involvement. For all time-to-event analyses, the start time was the date of bioptic licensure, and the censoring time, in the absence of an event, was the date of acquisition of the Bureau of Motor Vehicles driving record. In order to account for previous purging of the Bureau of Motor Vehicles records, a start time of January 1, 1997, was used for all cases (22%) in which the licensure date was prior to 1997. A P value of less than 0.05 was considered evidence of a significant association. The proportional hazards assumption for all covariates included in time-to-event regression models was checked graphically on log (-log[survival]) plots.^{20,21} Spearman correlation coefficients were used to examine the correlation between mean MVC rate and year of bioptic licensure over the first 10 years of licensure for both previously experienced and novice bioptic drivers. Tests for differences in various MVC indicators between experienced and novice bioptic drivers were conducted using χ^2 tests and analysis of variance. SPSS version 21 (IBM Corp., Armonk, NY, USA) was used for all statistical testing.

RESULTS

We identified 237 bioptic drivers (65% male) who had an initial vision examination for a daylight license at the College of Optometry and who also had a driving record from the Bureau of Motor Vehicles. The distribution of ocular conditions for participants is shown in Table 2. Visual and demographic characteristics of these drivers are shown in Table 3. Age at initial exam ranged from 16 to 81 years (median [interquartile range] = 38 [27, 50] years). Figure 1 shows the distribution of age at initial examination for study participants. Previous

TABLE 3. Visual, Demographic, and Testing Characteristics, $n = 237$

	Median	Minimum	Maximum	Interquartile Range
Age at exam, y	38	16	81	27, 50
Bioptic licensure, y	10	<1	21	7, 15
Visual acuity, logMAR	0.78	0.40	1.10	0.70, 0.86
Visual acuity, Snellen	20/120	20/50	20/250	20/100, 20/145
Contrast sensitivity, logCS	1.55	1.00	1.95	1.35, 1.65
Horizontal visual field, °	158	120	190	149, 170

FIGURE 2. Distribution of MVC by number per driver ($n = 237$).

nonbioptic driving experience (i.e., nonbioptic licensure) was reported for 137 (58%) of participants. Time since bioptic licensure ranged from 1 to 22 years (median = 10 [7, 15] years). Median logMAR visual acuity with both eyes (OU) was 0.78 (0.70, 0.86) (approximately 20/120), and median log contrast sensitivity OU was 1.55 (1.35, 1.65). The median binocular horizontal visual field was 158° (149°, 170°), and no participant had less than 120° horizontal visual field.

A total of 292 MVCs were reported in Bureau of Motor Vehicles records as having occurred after the documented or estimated bioptic licensure date for the 237 bioptic drivers. The number of MVCs per driver ranged from 0 to 11, with 124 drivers (52%) having had at least one MVC and 72 (30%) having had two or more. Correspondingly, just less than half (48%) of the drivers had no MVCs documented in the Bureau of Motor Vehicles record. The distribution of MVCs for all bioptic drivers is shown in Figure 2. The mean ($\pm$ SD) number of MVCs per year for all drivers was 0.13 ± 0.20 . Figure 3 shows the mean number of MVCs per year of licensure as a function of age.

Table 4 shows the results for the Cox proportional hazards simple bivariate regression models for visual and demographic factors using an event definition of first involvement in an

FIGURE 3. Mean MVC per year by age (decade) ($n = 237$).

TABLE 4. Cox Proportional Hazards Model Statistics for Simple Bivariate Associations Among Patient Characteristics and Involvement in an MVC, $n = 237$

Patient Characteristic	Hazard Ratio	95% CI for Hazard Ratio		P Value
		Lower	Upper	
Visual acuity	1.25	0.281	5.57	0.768
Contrast sensitivity	2.08	0.923	4.67	0.077
Visual field	1.01	0.993	1.01	0.536
Age	0.96	0.962	0.987	<0.001
Female sex	0.79	0.539	1.16	0.228
Previous experience	0.44	0.310	0.634	<0.001

MVC. Visual acuity and contrast sensitivity were not significant predictors of MVC in the Cox proportional hazards models. Sex was not associated with MVC ($P = 0.228$), but older age was significantly associated with lower risk of MVC ($P < 0.001$). Because age is correlated with previous driving experience (i.e., younger drivers are less likely to have been previously licensed), we tested a model that included both age and previous experience. When previous experience was included in the model, age was no longer a significant predictor of MVC. The relative risk of MVC for drivers with previous experience was 0.44 (95% confidence interval [CI] = 0.31, 0.63), indicating that having previously held a nonbioptic license was protective against MVC.

Drivers without previous experience were significantly more likely to have been involved in an MVC ($P < 0.001$), and this association remained significant after adjusting for age and sex ($P = 0.01$). Table 5 compares drivers with and without previous experience in terms of years of bioptic licensure and various MVC indicators. The mean $\pm$ SD number of years of bioptic driving for those with previous driving experience was 10 ± 5 vs. 11 ± 5 years for drivers without previous experience. Forty-one percent of drivers with previous licensure were involved in an MVC versus 68% of drivers without previous licensure.

In order to investigate changes in MVC rate over time, mean rates were calculated for each of the first 10 years of bioptic licensure for drivers with and without previous nonbioptic driving experience (Fig. 4). The MVC rate of experienced drivers was relatively stable over all 10 years, while the mean MVC rate for drivers without previous experience was highest in the first year of licensure and showed a decreasing trend over subsequent years. The Spearman correlation coefficient for mean MVC rate versus year of licensure was -0.19 for previously experienced drivers ($P = 0.612$) and -0.94 for novice drivers ($P < 0.001$).

DISCUSSION

We have performed a study of the road safety of bioptic drivers in Ohio and the visual, demographic, and driving experience characteristics of these drivers that are associated with road safety. This is the first study known to us that has investigated the relationships among various patient visual factors, previous driving experience, and risk of MVCs for bioptic drivers. In summary, a time-to-event model for MVC involvement showed a significant association between MVCs and lack of previous nonbioptic licensure. That is, bioptic drivers without previous driving experience had an increased risk for MVC. The collision rate of bioptic drivers without previous nonbioptic driving experience dropped in successive years of bioptic

TABLE 5. Comparison of MVC Data Between Drivers With and Without Previous Driving Experience, $n = 237$

	Previous Driving Experience, $n = 138$	No Previous Driving Experience, $n = 99$	<i>P</i> Value
Years bioptic licensure, mean $\pm$ SD	10 $\pm$ 5	11 $\pm$ 5	0.137
Any MVC, %	40.9	67.7	<0.001
Multiple MVCs, %	18.2	46.5	<0.001
Number MVCs, mean $\pm$ SD	0.78 $\pm$ 1.39	1.85 $\pm$ 2.00	<0.001
MVC/y of licensure, mean $\pm$ SD	0.077 $\pm$ 0.14	0.20 $\pm$ 0.25	<0.001

licensure. We did not find a significant relationship between visual acuity or contrast sensitivity and collisions.

We found a mean rate of approximately 0.13 MVCs per year for our bioptic drivers, with previously experienced bioptic drivers having a rate of 0.077 MVCs per year and novice bioptic drivers having a rate of 0.20 MVCs per year. In other studies, Janke¹² found a rate of approximately 0.074 MVCs per year in California, and Clarke,¹³ also in California, reported a similar MVC rate for bioptic drivers of 0.077 MVCs per year. It is difficult to compare the rates from the California studies to the rates from the present study because driving conditions may vary between states, as may methods of record keeping for crashes and the characteristics of each state's bioptic drivers.

There was wide variation in the driving records of bioptic drivers studied. For instance, the range for MVC involvement was 0 to 11, and approximately half of the drivers studied were not involved in any MVC at all (Fig. 2). This variation in MVC occurrence in the bioptic drivers studied suggests that it would be desirable to devise a system that better identifies bioptic drivers most prone to MVC. Our data suggest that this is likely not possible based solely on vision testing, as visual acuity and contrast sensitivity were not associated with MVC risk. However, our data do suggest that knowledge of a new bioptic driver's previous driving experience may be useful in predicting collision risk.

The fact that previous nonbioptic driving experience was strongly associated with collisions is consistent with our previous finding that those with previous experience had

better bioptic training and road testing outcomes.¹⁴ It is also consistent with studies of collision rates of normally sighted drivers, with new teenage drivers having been shown to have collision rates three to four times those of older drivers.^{22–24} Another important finding is that the MVC rate of bioptic drivers who did not have previous driving experience at the time of licensure decreased significantly with successive years of bioptic licensure. After 10 years of bioptic licensure, the difference in mean collision rate between these drivers and those who had previous nonbioptic driving experience at the time of licensure was considerably smaller than at the beginning of the 10-year period. This relatively rapid decrease in MVC rate is comparable to that observed in newly licensed normally sighted drivers,²⁵ and suggests that they make adaptations that decrease their MVC risk. It also highlights the importance of considering previous driving experience when studying the road safety of bioptic drivers. Our results suggest that programs that decrease the collision risk of novice bioptic drivers would be desirable, though it is not clear what specific strategies might be most effective. Further research could investigate what specific attributes and driving skills previously experienced bioptic drivers might possess that result in fewer MVCs, and whether there are interventions that could aid novice drivers in attaining these attributes more quickly.

Though we found no relationship between vision and collisions per year of licensure, it is certainly possible that vision is related to the per mile MVC rate. For instance, a

FIGURE 4. MVC rate by year since initial licensure for drivers with and without previous nonbioptic driving experience. *Closed circles* are novice drivers; *open circles* represent previously licensed bioptic drivers.

driver's poor vision may make the individual less confident in his or her ability to drive safely and more likely to restrict mileage. This would, in turn, result in less exposure to collisions and could obscure a real relationship between vision and collisions per mile. In interpreting crash rates, the issue of driving exposure in terms of miles driven is a crucial one. As Owsley^{2,26} has pointed out, the lack of knowledge regarding how many miles bioptic drivers travel each year is a key limitation in each of the few existing studies of collisions in bioptic drivers, the present study included. Exposure data would allow for calculations of MVC rate per mile driven. These data could elucidate other relationships that are important for driving safety, such as any evidence that drivers with relatively poor vision drive fewer miles per year and thus may actually be at higher risk of MVCs per mile even though they do not have higher collision rates per year. To date, the only reports of mileage driven by bioptic drivers come from self-report surveys, and none of these studies obtained information on the number of collisions. The results of these survey studies have been mixed, with some reporting that miles driven per year for bioptic drivers are similar to those for nonbioptic drivers,^{1,27} and others reporting that bioptic drivers drive fewer miles.²⁸ We are currently conducting research in which we are surveying bioptic drivers regarding their mileage and driving habits. Other systems using Global Positioning System (GPS) and video recording have been developed,²⁹ and should also be of use in answering these questions.

Strengths of this study include that it is the first to examine the relationship between vision and MVCs in bioptic drivers, that the number of bioptic drivers studied was relatively large, and that the time period over which state driving records were available was relatively long. The study also has several limitations. The data were collected retrospectively, which did not allow the level of standardization of vision and other measurements that would be possible in a prospective study. Vision changes may have occurred in some drivers during the observed licensure time, but our analysis used only the vision data obtained at the initial vision examination. It is unlikely that visual acuity or visual field would have changed a great deal, as such changes would have been detected at the repeat vision testing (usually at our clinic) that is required at least every 4 years, and would have resulted in loss of licensure. This may limit our ability to draw conclusions about the importance of vision as a predictor of MVC. The lack of driving exposure data meant that we were unable to determine collision rates per mile. Additionally, the state driving records did not allow for determination of date of first bioptic licensure or fault for MVCs.

There are a number of areas of need for research in bioptic driving,² including exposure, training, and driving performance and the relationship that vision has to these. Future studies should also attempt to ascertain fault more precisely for all MVCs by examining individual police reports, which typically contain detailed descriptions of collisions and information on which drivers may have been cited. Such report review is particularly important given previous small studies showing that bioptic drivers may be at greater risk for being assigned fault in a collision than nonbioptic drivers.¹⁰ Together, advances in these areas should help clinicians, patients, and relevant licensing authorities make more informed decisions about bioptic driving.

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