Visual and Demographic Factors in Bioptic Driving

Training and Road Safety

DISSERTATION

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By

Bradley Edward Dougherty, OD, MS

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The Ohio State University

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Dissertation Committee:

Thomas W. Raasch, Advisor

G. Lynn Mitchell

Roanne E. Flom

Alison Norris

Mark A. Bullimore

Abstract

Bioptic telescopic spectacles (BTS) allow people with vision impairment to obtain driving licensure even when their visual acuity does not meet normal state standards. BTS are spectacles with a small telescope implanted in one or both of the lenses. The telescope is used for brief periods during driving to spot distant targets such as road signs and traffic signals. The study described in this dissertation examines visual and demographic associations among obtaining a bioptic driving license, training and road testing results, and motor vehicle collisions in patients with low vision. The study also compares the collision rate of bioptic drivers to that of a control group of non-bioptic drivers matched on age and sex. A retrospective study of medical records was completed for patients examined for entry into the Ohio bioptic driving program at the College of Optometry at The Ohio State University over a five year period. Data were collected on visual factors, documented driver training, licensure testing results, and post-licensure driving record.

No significant associations were found among visual and demographic factors and obtaining licensure after an initial vision examination. Several factors were significantly associated with the amount of training documented for

candidates for licensure, including age and previous non-bioptic driving experience. The amount of training documented was associated with road testing results, but not with driving safety after licensure. Previous driving experience was also significantly associated with occurrence of motor vehicle collisions (MVC) in bioptic drivers, with drivers without previous experience having approximately 2.5 times as many collisions per year of licensure than those with previous experience. Other significant associations with MVC in bioptic drivers included age and the number of non-collision related convictions. Nystagmus was independently associated with MVC, but no other patient visual factors were associated with MVC.

The rate of MVC per year for bioptic drivers was significantly greater than that of a group of control drivers matched on age and sex. This is consistent with past studies of bioptic collision rates. It is also consistent with past findings that groups with various medical restrictions have higher collision rates than control groups. This study does not address driving exposure in terms of actual mileage driven by bioptic drivers, and so no conclusions can be made regarding the rate of collision per mile driven for bioptic drivers, the visual or demographic associations with that figure, or how bioptic drivers compare to non-bioptic drivers in terms of collisions per mile driven.

This document is dedicated to Edward and Barbara Dougherty.

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I am so fortunate to have a big family and a lot of friends, who even when they couldn't quite determine how it was possible that I hadn't finished school yet, have done so much to make my life richer and happier and help me manage the various challenges I have faced. I would especially like to acknowledge my parents, brother, and sister for a lifetime of love and support. Finally, my wife Cynthia is a source of inexhaustible patience, love, and support; I could not have accomplished the things I have without her help.

Vita

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Field of Study

Major Field: Vision Science

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Introduction and Background

1.1 Description of Bioptic Driving

1.1.1 Design of Bioptic Telescopic Spectacles (BTS)

Bioptic telescopic spectacles (BTS) consist of either monocular or binocular telescopes mounted to an ordinary pair of spectacles. The telescope can be mounted to the bridge of the spectacle frame or in a drilled hole in one of the spectacle lenses (the "carrier lenses"). The telescope is generally mounted in a superior position such that a downward head tilt by the wearer results in a view through the telescope, but in straight ahead gaze the wearer views through the carrier lenses.

BTS are manufactured by only a few companies in the U.S.—Ocutech, Designs for Vision, and Conforma (BITA). There are a few different designs available. Designs for Vision and Conforma generally feature small Galilean or Keplerian telescopes mounted directly in the carrier lens, and Ocutech also offers larger Keplerian telescopes with a plastic housing that is mounted to the bridge of the spectacle frame and is positioned along the superior portion of the frame. Some of the most popular designs are shown in Figure 1.1.

1.1.2 Use in Driving

The primary use of BTS for driving is spotting distant targets. In this way, a person with sub-normal visual acuity may view and identify these distant targets sooner than would be possible without the use of a telescope. Examples of common distant targets include street signs, traffic signals, and other automobiles ahead of the driver. The driver uses a downward head tilt to achieve a view of the distant target and then returns to viewing through the carrier lens (Figure 1.2).

1.1.3 Role in Driving Licensure

BTS can be used for driving by people with visual acuity that is not sufficient to qualify them for a driver's license. BTS can be used in approximately 40 states for this purpose.[1-2] There is wide variation between states with respect to how BTS can be used to obtain a driver's license. Some states, like Ohio, maintain relatively strict control over the licensing of bioptic drivers, requiring a vision examination, mandated training sessions in the use of the BTS, and testing for licensure that is specific to bioptic use. Other states simply allow the use of BTS for the visual acuity testing for licensure.[1]
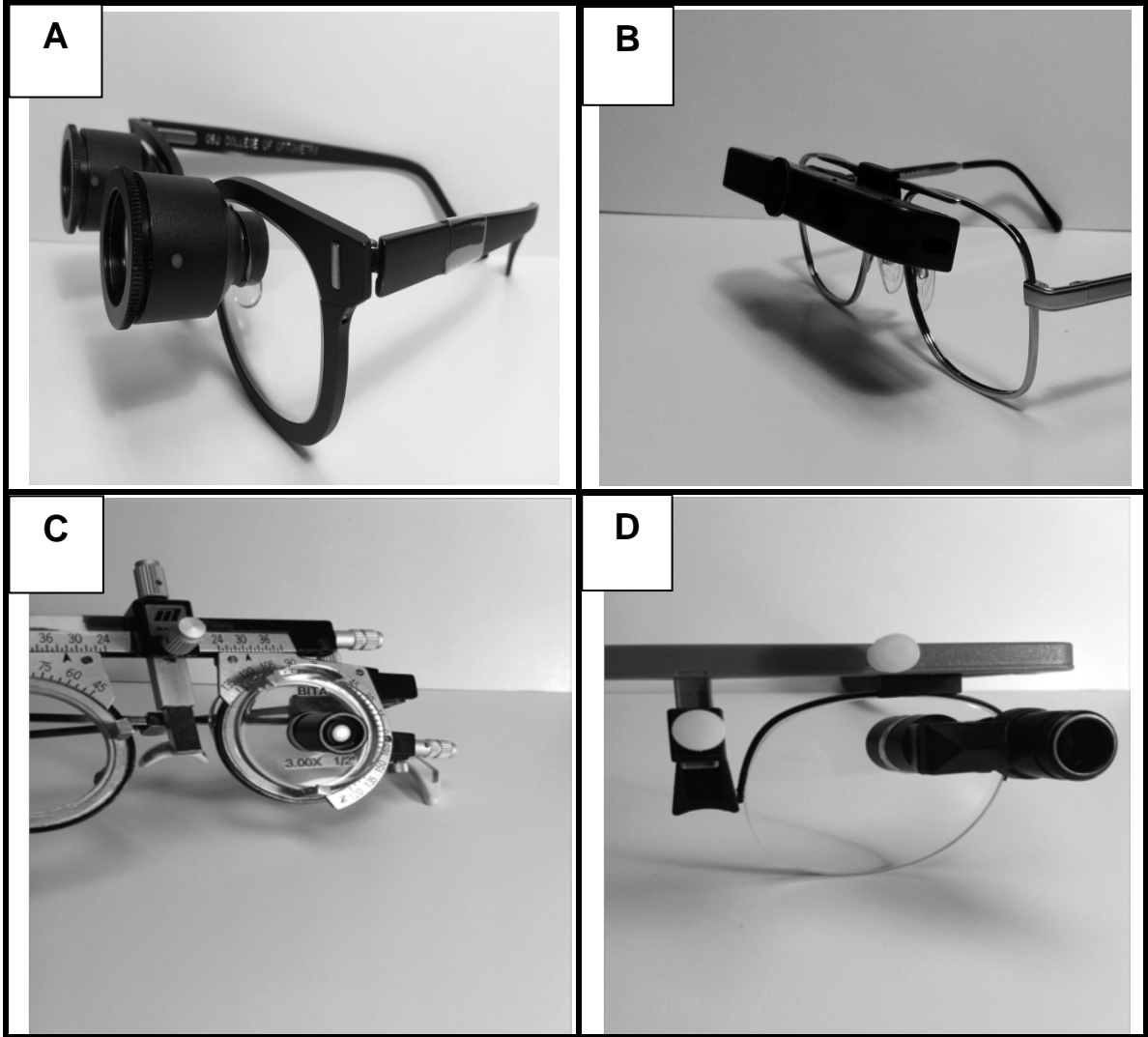
Figure 1.1: Bioptic Telescope Designs

A. Designs for Vision binocular BTS system **B.** Ocutech VES-K **C.** 3X BITA telescope in trial frame **D.** Ocutech Mini
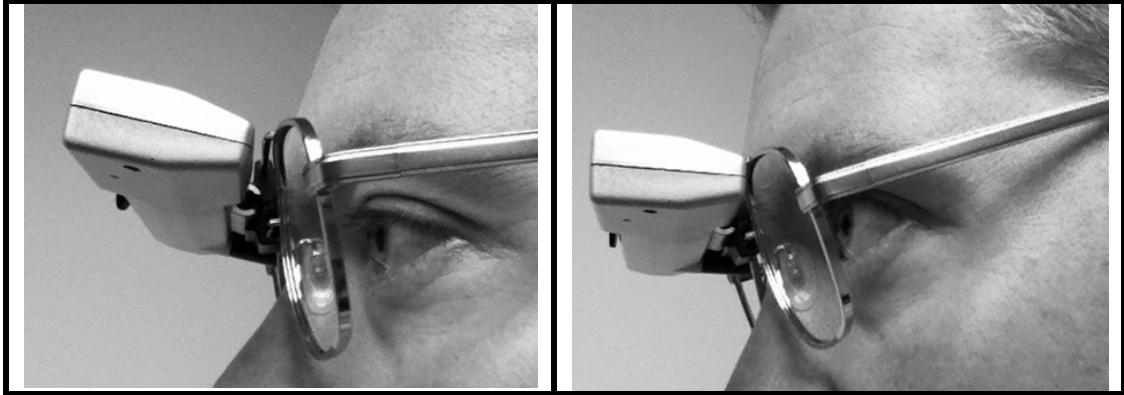
Figure1.2: Use of Bioptic Telescopic Spectacles

(Left panel) Straight Gaze (Viewing through Carrier Lenses) and (Right panel) with Downward Head Tilt to View through the Telescope

1.2 History and Controversy of Bioptic Driving

The introduction of the concept and term "bioptic telescopic spectacles" is generally credited to William Feinbloom in 1958.[3-5] It wasn't until later, [6] however, that Feinbloom published work on his experience with use of BTS by drivers with visual impairment. In the 1970s and 1980s, there was a considerable amount of published debate regarding the use of BTS for driving.

Perhaps the most commonly-cited opponent of driving with BTS was Gerald Fonda. In 1974 Fonda stated that the principal purpose of bioptic telescopes for driving was "… to pass the state driver's examination" while admitting some usefulness for spotting distant objects.[7] He also noted that, because the BTS was only used for brief spotting, drivers were essentially driving with low vision.[7] In the same paper Fonda listed six optical objections to driving with BTS, including limited field of view through a telescope, the presence of a ring scotoma when viewing through a telescope, the closer and larger appearance of objects viewed through telescopes, and the magnification of motion present when viewing through telescopes.[7]

In a later paper,[8] Fonda was even clearer about his objections. He had personally practiced driving using a BTS designed by Feinbloom, and he described it as "a frightening experience." He again pointed out the visual field limitations when viewing through a telescope and commented that "No training will make a driver safe who has such a large blind area in his field of vision."[8] He

also claimed that drivers frequently did not even wear the BTS after passing the test for licensure (although he did not cite any source for this claim).

Fonda noted that one of the reasons BTS were in use for people with low vision was the tremendous importance of driving for independence and employment. Interestingly, he did not argue that people with low vision should not be allowed to drive, but simply that it was hazardous to require the use of BTS for the task. He suggested "approach magnification" (driving more slowly until the words on a traffic sign subtend a large enough angle for the driver with low vision to read) as a safer alternative to use of BTS, and described a system of restricted licensing with examination by an optometrist or ophthalmologist and annual review of the driving record by the department of motor vehicles to be a superior alternative to the requirement by states for use of BTS for driving. Under this system, if a driver with low vision had a rate of crashes that exceeded the average rate of persons without visual impairment upon this annual review, the driver would lose his or her license.

In 1985, Bailey responded to several of Fonda's criticisms of BTS.[9] To Fonda's concern that BTS restricted the visual field in a way that was not consistent with safe driving, Bailey pointed out that the telescope in the BTS was generally only fitted in front of one eye and that the driver had both eyes open at all times. Therefore, a driver using BTS should be able to detect peripheral objects even when viewing through the telescope. To the criticism that the BTS is only used for very brief periods, Bailey countered that in fact those brief periods

spent reading a distant sign or viewing a traffic signal were all that was necessary to gain the needed information, and therefore the patient's visual acuity through the BTS was a useful indicator of whether a patient could use the BTS to safely drive. Korb also countered Fonda's assertion that driving with the use of a telescope was unsafe, noting that he would agree with Fonda if full-field, rather than bioptic telescopes were used but that bioptic systems do not have the same problems.[4] Indeed, many of Fonda's objections (including severe visual field constriction) seemed to assume the use of full field telescopes in front of both eyes, a situation which is certainly different than the actual setup for bioptic driving and not generally prescribed as a useful option for driving with visual impairment.

This debate introduced several topics that remain central to research on BTS for driving today. Some of these include the nature and importance of scotomas that result from use of BTS and whether drivers with low vision can reliably detect objects that fall within them, the amount of time that drivers actually view through the telescope, and the frequency with which drivers actually wear the BTS while driving. It also likely created more interest in studies of the crash rates of bioptic drivers.

Doherty et al.[10] recently investigated the role that the ring scotoma which is induced when viewing through the telescope portion of the BTS might play in the ability of drivers to detect important peripheral objects. Specifically, these authors investigated whether the fellow (non-telescope) eye could detect targets

during telescope viewing with a monocular BTS system, or if suppression and/or binocular rivalry might interfere with this process. While this questions had been investigated to some extent before,[11] this study used an experimental approach more likely to simulate the driving detection task than conventional perimeters. The study tested detection in passive viewing conditions as well as an active condition in which the subject had to read letters viewed through the telescope while identifying targets with the fellow eye.

Doherty and coauthors found that the fellow eye was generally able to detect targets presented within the ring scotoma during telescope use. These detection rates decreased when targets were presented on more complex backgrounds, during the active viewing conditions described, and with increasing age. Experienced bioptic users had generally higher detection rates than inexperienced subjects, but this difference did not reach statistical significance. The authors concluded that the results demonstrated that bioptic use does not result in an inability of the fellow eye to detect targets within the ring scotoma, and that the results were encouraging for those concerned about the issue with regard to bioptic driving safety. Future areas for research indicated by the authors included testing of the ability of strabismic fellow eyes to make these detections, and testing with even more complex background scenes, like videos of driving scenes.

1.3 Studies of Driver Behavior and Patient-reported Outcomes in Bioptic Driving

There are some studies that report on driver behavior and the self-reported usefulness of BTS. These studies provide context for examinations of driver safety and may suggest superior methods for selecting and preparing patients with low vision to drive using BTS. The most detailed report published on the experiences and feelings about driving with BTS of bioptic drivers was published by Bowers et al. in 2005.[12] The purpose of this study was to determine the frequency with which bioptic drivers use the BTS and how valuable bioptic drivers find the BTS to be for driving. Subjects for the study were recruited from four sources – a low vision clinic in Boston, a bioptic training program in West Virginia, a rural New Hampshire driving instruction practice, and a web site for bioptic drivers. The authors created a questionnaire that incorporated parts of the Driving Habits Questionnaire[13] and other items deemed relevant by practitioners experienced in working with bioptic drivers. Vision data were available for a portion of the sample, and self-reported vision data were obtained from subjects for whom examination data were not available. The vision data were used to investigate associations between visual factors and self-reported data. A total of 58 bioptic drivers were surveyed.

Almost all of the subjects used either a 3X or 4X monocular BTS, and 50% reported some form of in-car training in its use for driving. Sixty-two percent of subjects reported wearing the BTS at all times while driving and 10% reported using the BTS rarely or never. About three quarters of study participants rated

the BTS as "very helpful", and an additional 17% rated it as "moderately helpful" for driving. 90% of participants said that they would continue to use BTS for driving even if there was no requirement to use it for licensure. 88% of participants reported moderate or high driving confidence with BTS, 84% reported that they drove at the same speed as the flow of traffic, and 72% rated the quality of their driving as above average. Almost 8 in 10 participants said that bioptic driving improved their quality of life "a lot".

The Bowers et al. study also explored the situations in which bioptic drivers report using the BTS most frequently, and the situations in which they report experiencing the most difficulty. Approximately 90% of subjects reported using the BTS for road signs, 80% for traffic lights, and slightly more than half for overtaking other cars, viewing pedestrians ahead, and intersections without traffic lights. About 30% reported using BTS for judging car distance, and about 25% reported using BTS for seeing brake lights. The percentage of subjects reporting use of BTS for a specific task was fairly well correlated with the average difficulty rating for that task, such that a large percentage of bioptic drivers reported using the BTS for tasks that were generally rated as being difficult. The median percentage of time subjects estimated they viewed through the telescope portion of the BTS was 5%. Central visual field loss predicted the amount of time that bioptic drivers reported viewing through the telescope.

Bowers et al. also surveyed bioptic drivers on driving situations that they commonly avoid or find difficult. About half reported difficulty driving in the rain or

bright sun, and more than 60% said they either did not drive at night or found it difficult. About one third of drivers reported difficulty in high traffic situations, at rush hour, or with left turns. Less than 20% reported difficulty on the highway or when driving alone.

With regard to mileage driven by study participants, the mean ± SD miles driven in a week was 222 ± 211. Drivers reported a median of 6 driving days per week. They reported driving to a median of 4 different places in a week. The age of the driver predicted the number of miles driven per week in regression analyses, with increasing age associated with decreasing weekly mileage.

This study contributed a considerable amount of useful material to the body of knowledge regarding the experiences of bioptic drivers. Findings of note include that the vast majority of bioptic drivers feel that BTS are useful for driving, that they do not feel uncomfortable driving, and that they report driving about as much as non-bioptic drivers. The authors concluded that because of the relatively low number of bioptic drivers who report difficulty in situations in which BTS should not be particularly helpful, it is possible that use of BTS results in a false sense of confidence for drivers. They recommend further study in a number of areas, including monitoring of the actual time spent viewing through the telescope and actual tasks BTS are used for, and whether use of BTS results in better driving performance.

Bowers and colleagues have also investigated bioptic driving behaviors specifically in people with age-related macular degeneration (AMD) and other

causes of central visual field loss.[14] In a study of 115 bioptic drivers from 24 states, the authors found that bioptic drivers with AMD reported that they drove more miles and went more places than drivers with AMD from a previous study who did not use BTS, and also reported less difficulty in challenging driving situations than non-bioptic drivers with AMD. Drivers with central visual field loss from AMD and other causes reported viewing through the telescope for a greater percentage of total driving time than did drivers without central visual field loss (8% vs. 5%).

A series of studies from the Peli lab in Boston have made progress in answering several outstanding questions regarding biopic use, including how often drivers actually sight through the telescope and where they aim when they are using the telescope. The group has developed an in-car monitoring system that records the driver and the road scene and is equipped with a GPS system.[15-17] Using markers on the BTS frame and a near-infrared camera system, in combination with a novel calibration technique, the authors are able to map the position of the telescope aim during driving.[15]

Another study by these authors[16] found that, for two bioptic drivers who were recorded over relatively long periods of driving, actual use of the telescope portion of the BTS was not consistent with previous self-report studies. Both study participants overestimated the amount of time they used the telescope. One driver used the telescope only seven times over the course of about six hours of driving. The other driver used the telescope about once every minute

and a half. For instances of telescope use in which the authors could confidently identify the target for that driver, they found that 47% were for viewing vehicles in front of the driver, 40% were for viewing intersections ahead of the driver, and 13 % of the instances were for viewing road signs. They also found that the subject only used the telescope for road signs when in an unfamiliar area. The Peli group has also used a combination of this in-car observation system with automated techniques to enable analysis of the large amounts of data that are generated when many hours of driving are recorded and to detect such things as instances of telescope use, hard braking, and loss of lane position.[17]

1.4 Visual Factors in Driving Safety and Performance: Previous Research

There is a large body of research on the relationships among various aspects of vision and driving (though not *bioptic* driving). There are excellent reviews on the topic.[18-20] As bioptic drivers use impaired vision through carrier lenses for a large portion of their driving time, this research is relevant to questions regarding the effects of visual factors on bioptic driving. The purpose of this section is to provide a summary of what is known regarding the relationships among visual factors assessed for bioptic driving and measures of non-bioptic driving performance and safety.

1.4.1 Visual Acuity

Visual acuity is certainly the most commonly-measured aspect of vision used for licensure purposes. Certainly the ability of a driver to read road signs at appropriate distances and identify other distant objects while driving should depend on his or her visual acuity. It is somewhat surprising, therefore, that there is not a particularly strong evidence base connecting it with driving safety. An early study by Hills and Burg in California found no significant relationship between visual acuity and motor vehicle collisions (MVC) in young or middle-aged drivers, and a weak correlation in older drivers.[20-22] Subsequent studies have consistently reported either weak[23-27] or no association.[28-34]

Studies of driving performance have suggested that there is a relationship between performance on certain driving tasks and visual acuity. Simulated visual impairment in normally-sighted drivers resulted in poor performance on a sign identification task and avoidance of hazards on a road course.[35-36] However, the authors of these studies have suggested that other tests of vision might be better predictors of performance.[37-38]

1.4.2 Visual Field

The second most commonly used vision test for driving licensure is some assessment of the visual field. Many U.S. states and other countries require some minimum visual field as a prerequisite for licensure. Several studies have found visual field loss to be a significant predictor of MVC. Johnson and Keltner,

in a study of 20,000 eyes in California, reported that people who had binocular visual field loss, as measured using automated perimetry, were approximately twice as likely as age- and sex-matched controls to experience an MVC.[39] Rubin et al. also found a higher incidence of MVC among people with binocular visual field loss.[29] Other studies have found that people with glaucoma, a disease which commonly results in visual field loss, are at higher risk for MVC.[33, 40-41] Visual field loss has also been demonstrated to negatively affect driving performance.[42-44] It should also be noted, however, that several studies have failed to find a relationship between visual field and driving performance or MVC, and this may be due to the fact that only more severe or binocular field loss results in negative effects.[20, 45]

1.4.3 Contrast Sensitivity

A number of studies have cited reduced contrast sensitivity as a significant predictor of MVC. Owsley et al. found that older drivers who had experienced an MVC in the five years prior to survey were eight times more likely to have poor contrast sensitivity than those who had not had an MVC.[34] Wood and colleagues have demonstrated that contrast sensitivity is related to performance on a number of driving tasks.[37-38, 46] Poor contrast sensitivity has also been linked to self-reported difficulty in certain driving situations, including making left turns and driving in heavy traffic.[47]

1.4.4 Glare Sensitivity and Recovery

Glare sensitivity was identified as a significant predictor of MVC involvement in a prospective study by Rubin et al., but interestingly only in participants with very poor glare sensitivity values.[29] In those with only mild or moderate increases in glare sensitivity, MVC risk was actually lower than for subjects with normal values.[29] Other studies have failed to find any association between disability glare and MVC involvement.[20, 34]

1.4.5 Low Luminance Visual Acuity

In theory, low luminance visual acuity may be an indicator of a driver's ability to view distant targets in low luminance driving situations. It has been suggested that the addition of a measure of low luminance visual acuity to the photopic visual tests typically used in driver vision screening may help identify drivers at risk for MVC.[38] This suggestion was based on prediction of performance measures on a closed road course.

1.4.6 Color Vision

Although it has been shown that people with color vision deficiency have difficulty with traffic signal recognition,[48] investigators have not generally found a relationship between color vision and MVC.[20]

1.4.8 Visual Attention

Visual attention testing is not a typical part of state licensing screening procedures, and is not included in the Ohio bioptic program vision test battery, but it warrants mention as a potentially useful screening tool. One test of visual attention, the Useful Field of View test,[49] requires patients to discriminate among stimuli presented centrally in the presence of distracters or while simultaneously completing peripheral vision tasks. The test has been demonstrated repeatedly to be a significant predictor of MVC involvement and driving performance.[29, 50-51]

1.5 Description of the Ohio Bioptic Driving Program

The Ohio bioptic driving program is overseen by the Ohio Bureau of Motor Vehicles, a division of the Department of Public Safety. The program is fairly centralized, with Central and Northern Ohio programs in Akron and Columbus, respectively, serving as the only two entry points for prospective bioptic drivers.

Figure 1.3 summarizes the steps a candidate in the Ohio bioptic program follows to obtain a license. Ohio requires prospective drivers to begin the program with a vision examination. At this examination, visual acuity, contrast sensitivity, peripheral visual field extent, color vision, glare sensitivity and recovery, and low luminance visual acuity are tested. Visual acuity and spotting efficiency with a telescope is also assessed at the exam. The examiner is asked to state the cause of vision impairment and whether the examination is consistent with that apparent cause, as well as any potential areas of concern.
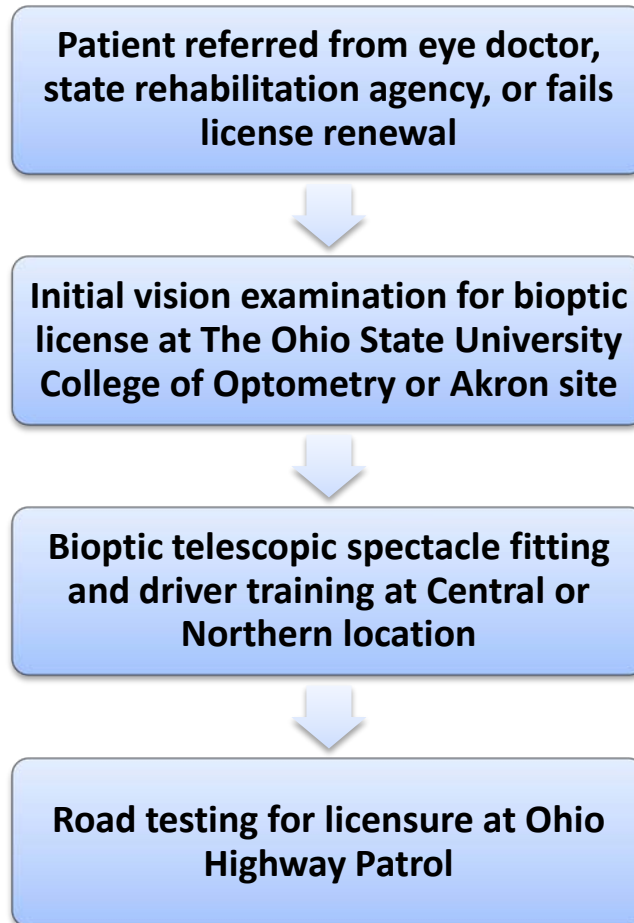
Figure 1.3: Process by which a Person with Visual Impairment Obtains a License to Drive with BTS in Ohio

The patient is required to meet usual Ohio visual acuity (the telescope is used for visual acuity testing) and visual field standards at a minimum. These standards for all drivers are visual acuity of 20/40 or better with both eyes (OU) (or 20/30 if the worse eye is worse than 20/200) for unrestricted driving and at least 20/70 (or 20/60 if the worse eye is worse than 20/200) for daylight-only driving, and a binocular visual field of at least 70 degrees to one side and 45 degrees to the other side. Bioptic drivers can meet the OU visual acuity standards using the telescope, and the visual field standard is exactly the same as for all other drivers. All bioptic drivers are also categorized at the initial exam and subsequent post-licensure follow up visits as either having a progressive visual condition or not. Table 1.1 summarizes the various licensure possibilities and their associated vision testing standards. As for all Ohio drivers, annual exams may be required for those deemed to have progressive visual deficiency. Otherwise, vision testing is required every four years after licensure for renewal. Of note, there is no minimum visual acuity through the carrier lenses of the BTS for Ohio bioptic drivers. Many states commonly require no worse than 20/200 through the carrier lenses. Unlike some other states, there is no limit on the magnification of the telescope in Ohio, though 6X is generally the highest power prescribed in the Ohio program.

Table 1.1: Summary of Possible License Types in Ohio and Visual and Examination Requirements

License Type	Vision Standard	Other Requirements
Unrestricted	20/40 or better using both eyes, plus 70 degrees VF to one side and 45 degrees to the opposite side	
Daylight Only	20/70 or better using both eyes, plus 70 degrees VF to one side and 45 degrees to the opposite side	No driving between sunset and sunrise
Bioptic Night + Daytime Without Bioptic	20/70 or better using both eyes, 70 degrees VF to one side and 45 degrees to the opposite side, and 20/40 or better using bioptic telescope	Must wear bioptic device between sunset and sunrise and must complete night bioptic training and testing program
Bioptic Full Time	20/40 or better using bioptic telescope, plus 70 degrees VF to one side and 45 degrees to the opposite side	Must wear bioptic device at all times and complete daylight and night bioptic training and testing programs Must have a year of violation-free driving after daylight licensure before night licensure

All other vision testing performed in the course of the bioptic vision examination is considered advisory. There are no Ohio standards, for example, for minimum contrast sensitivity required for bioptic licensure. In cases where there is a large deficit noted in one of these advisory vision tests, the potential consequences for driving can be noted by the examining optometrist in the "areas of concern" section of the letter which is forwarded to the Bureau of Motor Vehicles and the driving instructors.

Following successful completion of the vision examination, the next step in the Ohio program is BTS selection and fitting. This is performed by an optometrist and consists of determination of carrier lens prescription, ideal telescope magnification and type, ideal frame, sun filter needs, and other spectacle fitting issues. This step is generally completed by a different optometrist than performed the vision examination in the Central Ohio program, but is generally performed by the same optometrist in the Northern Ohio program.

Ohio mandates a training program in use of the BTS for driving before testing for licensure is allowed. The training program can vary—some trainees who lack previous driving experience are likely to require more training in the operation of a motor vehicle, which is not necessarily related to use of the BTS, whereas some who are experienced drivers would likely undergo training focused primarily on proper use and integration of the BTS. The driving instructor decides when the candidate is prepared to take a road test for licensure. This

results in wide variation in the total amount of training time that a potential bioptic driver receives.

When the driving instructor is satisfied that the potential bioptic driver is ready, the candidate proceeds to the road test, which is administered by the Ohio Highway Patrol. Examiners of the Highway Patrol are specially trained to administer the road test for bioptic driving. Candidates are evaluated on basic driving skills typical of road tests for normally-sighted drivers, as well as on use of the BTS system for driving.

In the event that a bioptic driving candidate fails a road test, the candidate must return to the driving instructor for additional training. Again, the driving instructor must approve the candidate for another road test. If the candidate fails three road tests, there is a mandatory one year waiting period before another test may be administered.

The Ohio bioptic program allows for licensure for daylight only, night only, or both daylight and night. A new bioptic driver may be licensed for daylight only driving for the first year after licensure and, if the driver completes a year of driving without any MVC or moving violations, he or she is eligible to begin the night driving program. The structure of the Ohio night bioptic program parallels that of the daylight program. Potential night drivers must undergo the same vision examination, a period of training, and a road test with the Highway Patrol. Training and testing are administered at night. Alternatively, a driver with relatively good visual acuity who qualifies for daylight-only (but not night) driving

without need for a bioptic (visual acuity of at least 20/70 but worse than 20/40) may apply for the night bioptic program and be licensed for daylight driving without BTS and night driving with a BTS. Over time, this type of driver may need to be licensed for both daylight and night with BTS if his or her visual acuity decreases to worse than 20/70. In this case, the driver would need to complete the daylight training program even though he or she already completed the night program.

1.6 Research Needed in Bioptic Driving

A recent publication[2] by Owsley called attention to the need for more research on bioptic driving and provided a detailed description of the specific areas requiring more study. The proposed research agenda (summarized in Table 1.2) included research on the characteristics of bioptic drivers, including demographics, nature of visual impairment, and previous driving experience, as well as the characteristics of the BTS in use. The agenda also included research on bioptic driving training, how many miles bioptic drivers actually drive (driving exposure), a variety of driving performance issues, and the safety of bioptic drivers. Owsley also suggested research into the effects that bioptic driving may have on employment and quality of life issues.

Table 1.2: Outstanding Questions in Bioptic Driving Research Addressed by this Study (adapted from Owsley[2])

Research Topic	Description	Questions
Characteristics of Bioptic Drivers	• Demographics • Nature of Visual Impairment • Previous Licensure Status • Age at Licensure	• What visual or other characteristics are associated with licensure, performance, or safety?
Training in Bioptic Driving	• Nature of training process • Amount of training	• Is training related to likelihood of licensure or driver safety?
Driving Skills and Performance of Bioptic Drivers	• Maintaining proper speed and lane position • Identifying traffic signals and signs	• Is vision related to on-road driving performance?
Safety of Bioptic Driving	• Motor vehicle collision rates	• What is the MVC rate for bioptic drivers? • How does the MVC rate compare to non-bioptic rate?
Driving Exposure	• Amount of driving performed in miles or years	• How does exposure in bioptic drivers compare with non-bioptic drivers?

1.7 Summary of Study and Research Questions

The study described in this dissertation is a retrospective study of bioptic drivers examined at The Ohio State University College of Optometry and another provider for the Central Ohio bioptic program (Vision and Vocational Services). The study patients were those who had initial vision examinations for entry into the Central Ohio bioptic program or had vision testing for renewal of a bioptic license at the College over a five year period. Several areas of needed research in bioptic driving are addressed in the study. Specific research questions addressed include:

- What are the relationships among patient vision and demographic characteristics and successful licensure and the amount of training received?

- What are the visual and demographic associations with motor vehicle collisions in bioptic drivers?

- How does the motor vehicle collision rate of bioptic drivers compare with that of a control group of drivers?

Chapter 2

Overview of Methods

2.1 Description of Study

The study described in this dissertation consists of three main parts: an analysis of potential predictors of achieving bioptic licensure for patients who applied for it in Ohio, an analysis of the associations among visual and demographic factors, driver training, and highway patrol testing results, and a study of the road safety of bioptic drivers including the relationships between visual factors and motor vehicle collisions. All study participants were patients at the Ohio State University College of Optometry. The study was approved by the Institutional Review Board of The Ohio State University.

2.2 Identification of Research Subjects

A preliminary review of patient records was conducted using a search of patient record databases for the procedural (CPT) code that is used at the College of Optometry for driving vision examinations (92499). The same code is used for several types of examinations. These include the initial bioptic program vision examinations described in the introduction. The code is also used for

vision examinations for renewal of bioptic licenses. A large portion of the examinations coded with this CPT code, however, are not related to bioptic driving but rather are for vision testing for other special cases including daytime driving only restricted licenses, licenses requiring yearly vision testing due to some progressive visual deficiency, commercial driver licenses, or cases in which the driver has some reduction in vision and prefers to be tested at the College as opposed to at the Bureau of Motor Vehicles. Occasionally, the code has also been used for ocular photography or other special testing associated with examinations unrelated to any type of driving. The implication of this varied use of the 92499 CPT code for identifying which patients were examined for bioptic driving purposes is that the percentage of these examinations relative to all of the exams coded 92499 is relatively small. However, this CPT code is the only way to use the patient record databases to identify patients who may have had an examination related to the bioptic driving program.

Computer patient records databases were searched using the 92499 code to identify all exams that may have been related to bioptic driving for a 5 year period, between 2004 and 2008. These searches combined produced a list of approximately 5000 patients with records coded 92499.

Of all patients with a 92499 CPT code whose records were examined, 500 were judged to have made application to participate in the Ohio bioptic program. This list of patients served as the master list of bioptic applicants and drivers for all analyses described in this dissertation, including the analyses of obtaining

bioptic licensure, testing and training results, and motor vehicle collisions that are described in later chapters. For the pilot study of licensure success of bioptic program applicants described in this chapter, the first 50 patients identified using the method described were analyzed. Figure 2.1 shows the distribution of participants for each part of the research described in this dissertation.

2.3 Record Review Process

Using the master list generated as described above, the records of all patients examined between 2004 and 2008 at the College of Optometry with an exam coded 92499 were accessed in order to identify all patients who had an initial vision examination for the Ohio bioptic driving program and made an application to participate. It should be noted that the method of search identified both patients who had an initial bioptic vision examination between 2004 and 2008 and patients who had an initial examination before this period and had a renewal visit between 2004 and 2008.

The following information was extracted from the medical records of all participants identified when present: age, gender, zip code, description of vision impairment, vision measures from the initial bioptic vision examination (described in the next section), notation of previous driving experience, date of bioptic licensure, and telescope type.

2.4 Vision Examination at the College of Optometry

The vision examination conducted at the College for all potential bioptic drivers in the Central Ohio program consists of vision testing that both determines eligibility for licensure according to Ohio law and serves as advisory information for determination of a potential bioptic driver's visual ability for driving. It is generally conducted within the Vision Rehabilitation Service by an attending optometrist and interns in their final year of optometry school. The examination procedures are summarized in Table 2.1.

Patients are generally tested with their habitual refractive correction in place. Visual acuity is usually tested using either an ETDRS[52] or a Bailey-Lovie[53] chart at a distance deemed appropriate by the tester, and is assessed for both eyes individually and together. Low luminance visual acuity is tested for both eyes together using the same charts with either reduced room lighting or a filter worn by the patient to reduce luminance. Contrast sensitivity is assessed for both eyes together using either a Pelli-Robson chart[54] at one meter or a Mars[55] chart at 50 cm. Horizontal visual field extent is assessed using either a Goldmann perimeter or an Arc perimeter. Color vision is assessed using the Farnsworth D-15 test, with abnormal color vision defined as two or more major errors. Glare testing is performed using the Brightness Acuity Tester. In the glare sensitivity test, the patient uses the better eye to read the visual acuity chart with the Brightness Acuity Tester on the "high" setting. In the glare recovery test, the patient's better eye is exposed to the "high" setting with the cap in for 30

Table 2.1: Summary of Vision Testing Procedures for Initial Vision Examination for Ohio Bioptic Driving Program

Vision Test	Description of Procedure
Visual Acuity	• Usually ETDRS or Bailey-Lovie Chart • Both eyes tested individually and together • Also tested through bioptic telescope
Contrast Sensitivity	• Pelli Robson or Mars Chart
Visual Field	• Arc Perimeter or Goldmann Perimeter
Glare Sensitivity	• Brightness Acuity Tester • Patient reads visual acuity chart using better eye with BAT on "high"
Glare Recovery	• Brightness Acuity Tester • Patient reads visual acuity chart using better eye without glare source after 30 seconds with BAT on "high" and cap in • Test result is time until one line above best VA is read
Color Vision	• Farnsworth D-15 • Abnormal defined as 2 or more major errors
Low Luminance Visual Acuity	• Usually ETDRS or Bailey-Lovie Chart • Low room luminance or a filter in place

seconds, after which he or she must read one line above the previous best visual acuity. The result for the glare recovery test is recorded as the time in seconds until the patient begins reading this line. Visual acuity is also tested using a telescope to ensure that the patient is able to achieve the necessary acuity to meet the Ohio standard.

For purposes of analysis, vision data were recorded from the most recent initial vision examination in cases where there were multiple examinations. The vision data were recorded from the summary letter sent from the College to the Ohio Bureau of Motor Vehicles whenever those data were contained in the letter. In cases in which the data were not contained in the letter, they were recorded from the examination record. In cases where multiple measurements were recorded in the record for the same vision test, the best recorded measurement was used for analysis.

2.5 Description of Training and Testing Records

Driver training and Ohio Highway Patrol testing records for this study came from Vision and Vocational Services, a non-profit organization that performed all driver training and most bioptic telescopic device fitting for patients in the Central Ohio bioptic program. Records may have included the number of hours of training a patient received, the date of Highway Patrol testing for licensure and the results of the testing (pass or fail), specific road testing errors, and the date of licensure.

2.6 Description of BMV Driving Records

Driving records from the Ohio Bureau of Motor Vehicles were obtained whenever possible for patients identified as having had an initial vision examination at the College of Optometry. These records contain information on license type and restrictions, as well as the last date of licensure. They do not contain the date of first licensure. They also contain information on motor vehicle collision (called "accidents" in the BMV record) involvement and convictions both related and not related to collisions (e.g. some speeding or seat belt violations). The records contain dates for motor vehicle collisions and convictions. For collisions, the driving record usually contains some notation regarding whether there were injuries involved and the severity of any injury. The Ohio BMV currently has a policy of not purging any driver data, but has previously purged at least some data. The analyses in this study of motor vehicle collisions and convictions used only data from 1997 forward due to prior purging of records. It should be noted that a number of the drivers studied were licensed before 1997, and so the data for those drivers' collision and conviction history is incomplete.

2.7 Description of Statistical Analyses

Regression models were used to identify significant associations between patient factors and outcome variables. Models were chosen based on the nature of the outcome variable of interest and the nature of the independent variables. Further description of the specific statistical approach employed for each analysis

is contained in subsequent chapters. SPSS version 19 (IBM, 2010) was used for all statistical analyses. Independent variables included in multivariate models all had score statistics with p values less than 0.05. In instances in which multivariate models were constructed for the prediction of an outcome, forward stepwise techniques were used. Decision for inclusion of independent variables was made using changes in -2 log likelihood, where each new variable was required to result in a significant change.
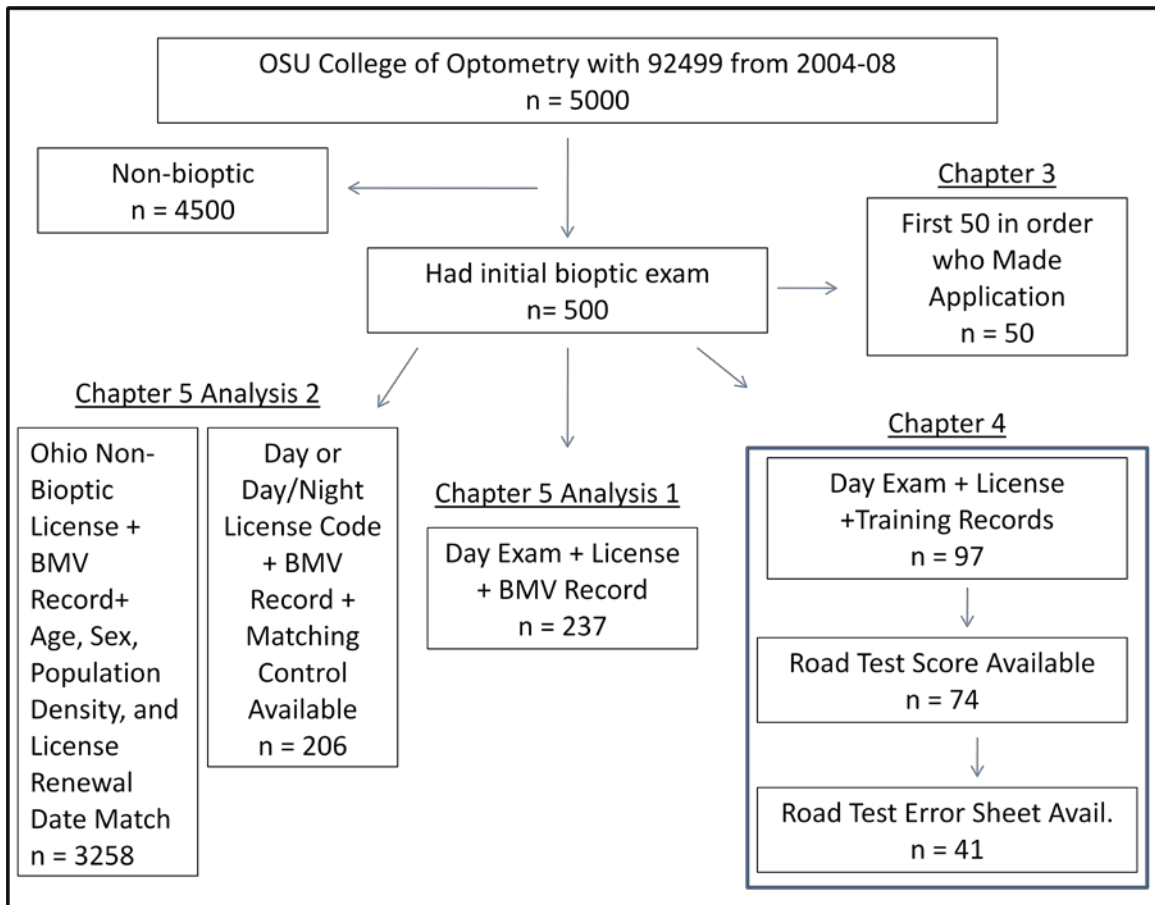
Figure 2.1: Flow Chart for Patient Inclusion in Studies

Chapter 3

Visual and Demographic Factors in Obtaining Bioptic Licensure

3.1 Introduction

In Ohio, an initial vision examination is the first step in becoming a bioptic driver. Though programs vary by state and country, it is likely that most potential bioptic drivers outside of Ohio are also likely to be examined by an optometrist or ophthalmologist early in the process. In Ohio, a range of vision testing is performed at this initial examination which includes visual acuity and visual field (which are vision testing requirements for all drivers in the state) as well as a number of other tests meant to be advisory (see Section 2.4 and Table 2.1).

Potential participants in the Ohio program vary widely with respect to a number of factors including age, previous (non-bioptic) driving experience, and ocular diagnosis and visual factors. There is a paucity of evidence regarding which factors might predict successful completion of a BTS driver training program and attainment of licensure. Knowledge of which of these factors might predict success in program completion would be of use to potential bioptic drivers, practitioners who examine these drivers, driving instructors who train drivers in the use of BTS, agencies that provide funding for bioptic driving

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candidates going through the program, and state departments of motor vehicles which license bioptic drivers.

For a potential bioptic driver, knowledge of his or her chance of successfully completing the program could be useful for a number of reasons. First, as bioptic driving is usually quite unfamiliar and may seem difficult to master, it may be helpful to know, on average, how often a person of similar demographic and visual characteristics makes it through the program and obtains licensure on average. The Ohio program requires a considerable time commitment and may require frequent travel to the training center and absence from work or other duties. In addition, there is often a significant financial cost for examinations, purchase of the BTS, and training. The decision by a potential bioptic driver about whether to commit a substantial amount of money and time to the program could certainly be influenced by prior knowledge of the chances for success. Similarly, for the eye care practitioner the ability to reasonably predict success in the program would be of tremendous use for counseling patients who are interested in the program.

Because of the high cost of both the BTS and training in its use, a high percentage of patients going through the program are funded by an outside source. In Ohio, this is most frequently the Bureau of Services for the Visually Impaired (BSVI). For many patients, almost the entire cost of the program is covered by this agency. A patient for whom BSVI purchases a BTS and many hours of training, but who does not ultimately pass the test for licensure

represents an inefficient use of resources for the Bureau. As resources are often quite limited, information on the chances for success in gaining licensure for a potential bioptic driver could be of use for BSVI and similar agencies when making funding decisions.

State departments of motor vehicles administer the tests for licensure of bioptic drivers. Some administer special tests for bioptic drivers and others simply allow the use of a BTS. It is possible that these departments could use information on success rates as a function of various visual or demographic factors in making program and testing decisions.

This chapter describes the results of a pilot study of the success rate of the first 50 Ohio bioptic driving program applicants identified by a record search at the College of Optometry. Demographic factors and the results of vision testing at the College were examined to determine whether any were associated with successful bioptic licensure.

3.2 Methods

3.2.1 Identification of Participants

A preliminary review of patient records was conducted using a search of patient record databases for the procedural (CPT) code that is used at the College of Optometry for driving vision examinations. Computer patient records databases were searched to identify all exams that may have been related to bioptic driving for a 5 year period, between 2004 and 2008. The records of all

patients identified were accessed in order to identify all patients who had an initial vision examination for the Ohio bioptic driving program and made an application to participate. The process used to identify bioptic drivers is described in more detail in section 2.3. For the pilot study of licensure success of bioptic program applicants described in this chapter, the first 50 patients (of the 500 determined to have had a vision examination for the program over a 5 year period) identified using the method described were analyzed. These 50 patients were the first 50, in order, on the list generated by CPT code search who had an initial vision examination and made application to the program.

3.2.2 Record Review and Determination of Licensure

Vision and demographic data were collected from the records of patients identified as having had an initial examination and made application to the bioptic program. Data were collected from the most recent initial vision examination in cases where more than one had been conducted. Age at the time of the initial examination, gender, logMAR visual acuity, log contrast sensitivity, nasal and temporal visual field (in degrees), glare sensitivity (logMAR visual acuity under glare condition), glare recovery (seconds until patient could read one line larger than threshold visual acuity after 30 seconds of glare exposure), color vision (Farnsworth D-15), and nature of ocular disease were recorded. Stability of the ocular disease and previous driving history were also recorded. Further information on vision testing is provided in Section 2.4 and Table 2.1.

The primary outcome measure for the pilot study, whether the patient ultimately received a driver's license with a bioptic restriction, was determined using two different sources—the College of Optometry medical record or the Vision and Vocational Services record. Notation in the College of Optometry record during a follow-up visit or an exam for vision testing for renewal of a bioptic license of a bioptic driver's license having been obtained by the patient was considered evidence of successful bioptic licensure. Likewise, notation in the Vision and Vocational Services record of successful testing for licensure was also accepted as evidence of licensure.

3.2.3 Statistical Analysis

Logistic regression was used to identify factors related to obtaining licensure. Univariate models were used to investigate associations between vision and demographic factors and licensure. P values less than 0.05 were considered significant in all analyses. Goodness of fit for final multivariate logistic regression models was checked using the Hosmer-Lemeshow test.[56-57] The statistical software SPPS 19 (IBM, 2010) was used for all analyses.

3.3 Results

Fifty patients (28 males) were identified as having completed an initial vision examination at the College of Optometry and made application to participate in the Ohio bioptic program. The mean logMAR visual acuity (±SD) for

these fifty patients was 0.69±0.19. (Snellen visual acuity equivalent mean = 20/98 OU). Mean log contrast sensitivity was 1.53±0.31. Age at initial examination ranged from 17 to 78 years (mean = 39 ±14 years). Figure 3.1 contains a summary of the age distribution of applicants.

Ocular conditions were categorized in order to analyze potential effects on obtaining licensure. The ocular condition category with the most patients was juvenile macular dystrophy (24%). Figure 3.2 shows the distribution of ocular diseases in the 50 patients examined.

Thirty-four patients reported some prior form of licensure. Of these, 18 had previously held unrestricted licenses, and 12 had previous daylight only (non-bioptic) licenses. Prior licensure status was not a significant predictor of receiving a bioptic license (p = 0.158).

Of the 50 patients, 34 (68%) were documented as having subsequently passed a road test and received a license to drive with BTS of the type for which they applied (daylight only or night). None of the visual, ocular, demographic, or other recorded factors were related to successful testing for licensure. Table 3.1 shows the values for visual and demographic factors for those patients who ultimately received the bioptic license applied for at the initial examination compared to those who were not documented as having obtained a bioptic license. Table 3.2 contains the logistic regression model statistics for the factors investigated. Because of the small number of participants, the power of the study to detect differences in patient characteristics between those who received a

license and those who did not was limited. With 50 participants, this study was only powered to detect a difference in odds ratio of 2.5 at one standard deviation from the mean of a covariate with power of 0.70.[58] The small number of patients is also reflected in the wide confidence intervals around some of the odds ratios.

Patients who did not ultimately obtain a license to drive with BTS (n = 16) exited the program at several different stages. Sixty-nine percent had no documented training, indicating that they exited the program immediately after the initial vision examination. Thirty-one percent received some training but had no documentation of road testing for licensure. All patients with documentation of a road test were ultimately licensed, though some required multiple attempts.
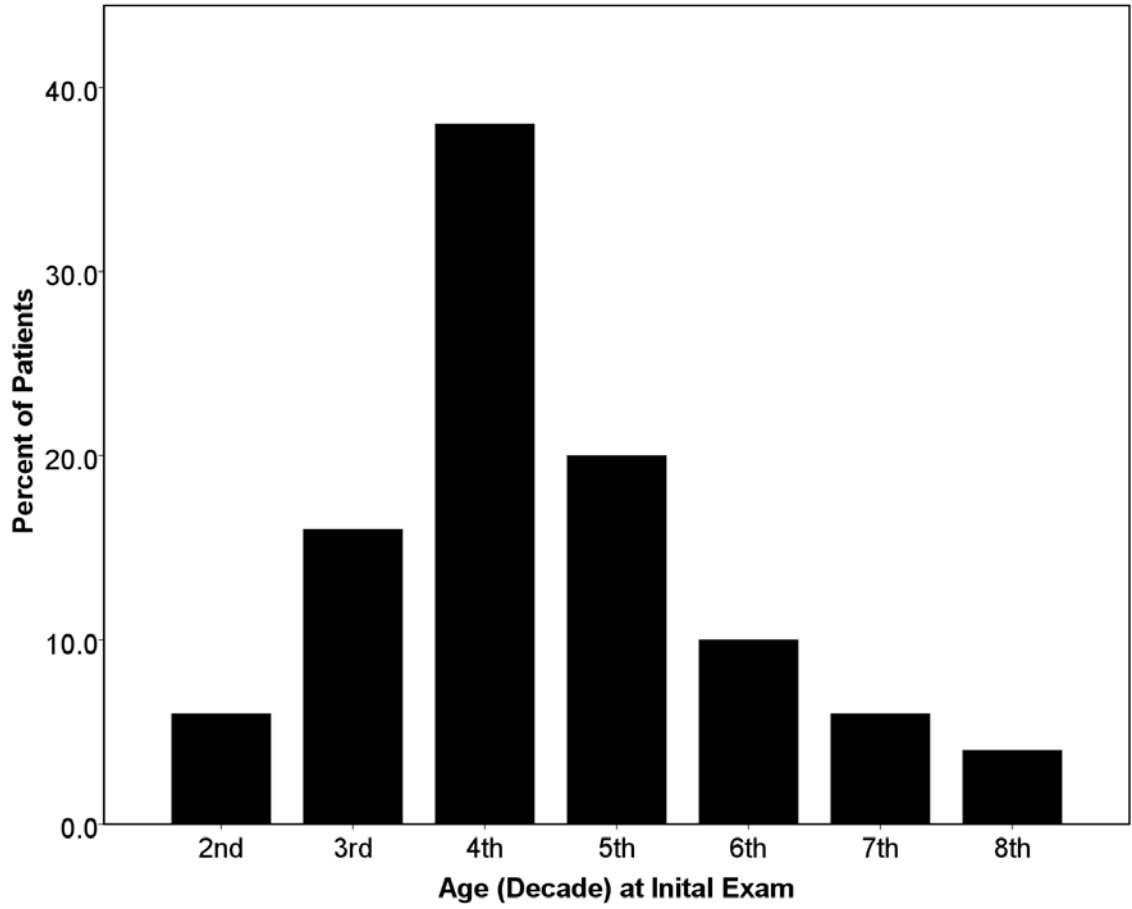
Figure 3.1: Summary of Age of Applicants by Decade (n=50)
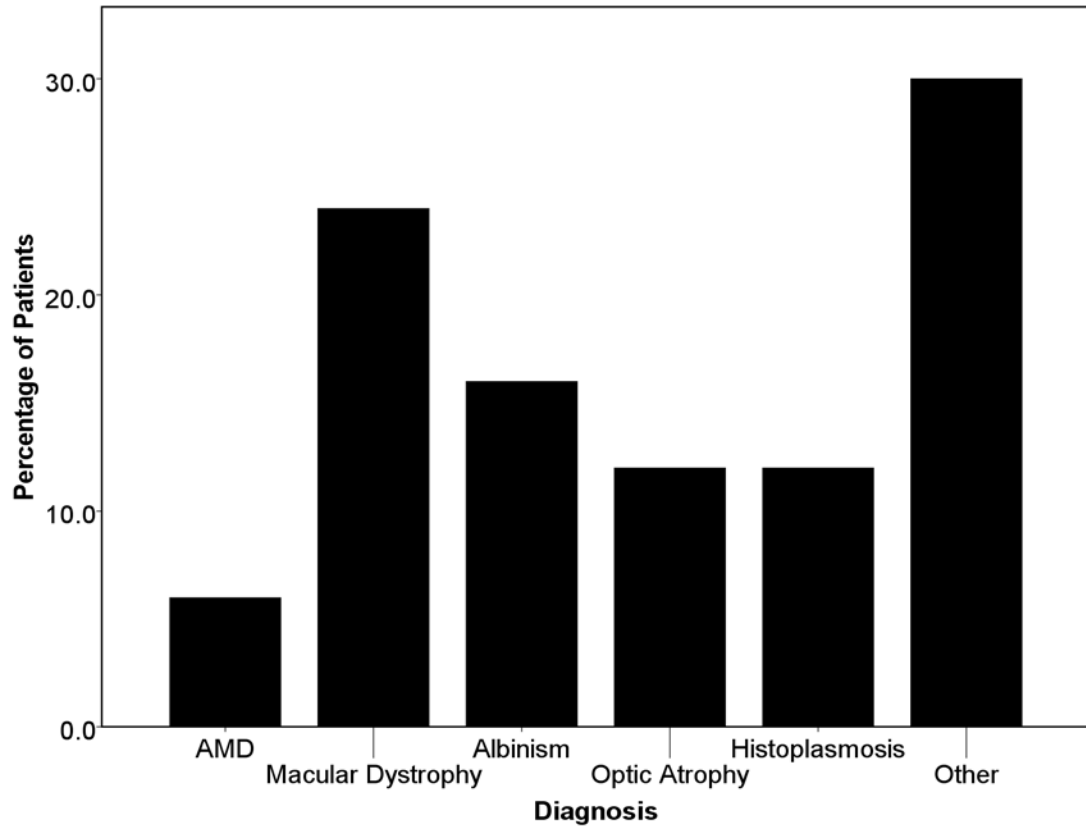
Figure 3.2: Distribution of Ocular Diseases in the 50 Patients Examined

Table 3.1: Visual and Demographic Characteristics of Patients Who Ultimately Received a Bioptic License Compared to Those Who Were Not Documented as Having Obtained a Bioptic License

	Total (n=50)	Licensed (n=34)	Not Licensed (n=16)
Age	39 ± 14	39 ± 14	40 ± 15
Male (percent)	60%	60%	50%
LogMAR Visual Acuity	0.69 ± 0.19	0.70 ± 0.17	0.68 ± 0.24
Contrast Sensitivity	1.53 ± 0.31	1.59 ± 0.22	1.42 ± 0.43
LogMAR Glare Sensitivity	0.86 ± 0.17	0.87 ± 0.17	0.83 ± 0.17
Glare Recovery (sec)	10 ±15	9 ± 9	14 ± 24
Horizontal Visual Field (degrees)	158 ± 14	158 ±14	158 ±12
Percent of Patients Color Defective	28%	26%	38%

Values are mean ± SD except gender (percent in each group that was male) and color vision (percent in each group that was color defective).

Table 3.2: Unadjusted Odds Ratios for Patient Characteristics and Obtaining Bioptic Licensure (n=50)

Patient Characteristic	Odds Ratio	95% CI for Odds Ratio	P value
Age	1.00	(0.96,1.04)	0.893
Gender (female)	0.70	(0.22, 2.31)	0.558
Visual Acuity	1.57	(0.07, 35.78)	0.776
Contrast Sensitivity	6.44	(0.70, 59.48)	0.101
Color Vision Defective	0.58	(0.16, 2.11)	0.409
Visual Field	1.00	(0.96, 1.04)	0.968
Low Luminance VA	90.76	(0.59, 14006.54)	0.080
Glare Sensitivity	4.28	(0.97, 188.0)	0.452
Glare Recovery	0.98	(0.95, 1.02)	0.398
Previous Experience	0.35	(0.08, 1.50)	0.158
Diagnosis Category	0.98	(0.70, 1.39)	0.916
Progressive Disease	0.34	(0.10, 1.22)	0.099
Night Exam Type	0.52	(0.12, 2.27)	0.382

3.4 Discussion

This is the first study to investigate whether visual or demographic factors might predict successful completion of a bioptic driving training and testing program and obtain a license to drive with BTS. Approximately two thirds of patients identified as having presented for an initial bioptic vision examination in this pilot study eventually obtained a license to drive with BTS. No visual, ocular, demographic, or other factors were identified as being significantly related to eventual licensure.

There has not previously been any estimate of the rate of successful completion of the bioptic program for patients who make an application after the initial vision examination. This information should be of use to patients and clinicians as well as funding agencies. One important question is, for those patients who do not obtain licensure after entering the program, at what stage do they fail or leave the program? Possible points for exit or failure include immediately after the initial vision examination, during the training portion, or at the last stage—the road test. For potential bioptic drivers at the initial stage of application to the program, it should be useful to know how common it is for candidates to fail to make it through training or fail the testing portion before purchasing an expensive BTS and investing a great deal of time and effort in the training program. Similarly, for funding agencies supporting candidates the two major costs are the BTS itself and the driving instruction fees.

The results of this study indicate that there are two main stages at which candidates tend to exit the program. First, some candidates (n=11, 69% of those who did not receive licensure) appear to exit immediately after the initial vision examination and receive no training at all. Second, other candidates appear to exit after relatively few hours of training. In this study, the five patients who had some training but did not receive licensure had between 2.5 and 6 hours of training. Importantly, though, it appears that the vast majority of candidates who are approved by the driving instructor to take the road test with the Highway Patrol are eventually licensed. Even those who failed a road test in this study eventually passed a subsequent test and received a license to drive with BTS. So, the success rate for those candidates who are actually fit with BTS and receive training is higher than for all patients who have the initial vision examination.

One area for further study is why candidates who have an initial vision examination fail to proceed with the next steps of the program. Possibilities include inability to pay for the BTS and/or the training sessions and lack of confidence in one's ability to operate a motor vehicle successfully even with a BTS. Another area that warrants study is why candidates fail during the training portion of the program, and whether there are ways to correct the problems cited by the instructor or candidate during the training sessions and keep the candidate in the program.

The finding that no visual or demographic factors may be significant predictors of bioptic licensure is informative for clinicians managing patients with low vision interested in bioptic driving and others involved in bioptic programs. While many of these clinicians or other administrators of bioptic licensure programs would doubtlessly like to be able to make accurate assessments of individual patients' potential to finish the licensure process successfully given those patients' visual and demographic data, our findings indicate that this is a very difficult task. However, these findings are also indicative of the fact that potential bioptic candidates should not be excluded from bioptic driving programs out of hand based solely on vision. Rather, these findings suggest that it may be warranted for vision care providers to refer patients with relatively poor vision measurements on to the training portion of a bioptic program, or at least to an evaluation of the patient's ability to use a bioptic device for tasks related to driving.

These findings indicate that there are likely other important patient characteristics that we did not measure that are associated with whether or not a candidate receives bioptic licensure. Some of these factors could include the socioeconomic status of the patient, whether the patient has funding from an agency like the Bureau of Services for the Visually Impaired, the patient's ability to arrange transportation to and attend training sessions, and interactions between the patient and the driving instructor, who must approve the patient to proceed to Highway Patrol testing.

There are several limitations to this pilot study. First, the number of drivers studied was relatively small. Because of the limited power of the study to detect significant differences in patient characteristics between those who received licensure and those who did not, it is possible that there are real differences which this study failed to detect. The study was retrospective, which did not allow careful standardization of vision measurements or recording of demographic variables. Licensure was determined by notation in either the College of Optometry or Vision and Vocational Services record, and the possibility exists that this technique resulted in incorrect classification for some patients. Finally, the study sample was a mix of applicants to the daylight and nighttime program. There are some differences in the type of patient who applies to each of these programs, including their visual characteristics and driving history. There are also likely differences in the amount of training that patients generally receive in each of the programs because of these patient differences.

Chapter 4

Bioptic Training and Testing

4.1 Introduction

Driver training programs are a part of some, but not all, of U.S. states'

bioptic driving programs. A training program allows for potential bioptic drivers to

learn to use the BTS effectively for driving tasks, but may also include a good

deal of driving instruction that is not specifically related to use of the BTS. In Ohio

and other states, the training period also serves as an evaluation period. For a

potential bioptic driver to advance to the test for licensure, he or she must have

the approval of the driving instructor.

4.1.1 Previous Studies of Bioptic Training

Szlyk et al.[59] reported on the effectiveness of training in the use of bioptic

telescopes for driving and other tasks, and the effect of use of BTS on certain

visual skills as evaluated by trained therapists and clinicians. Driving skills in

particular were assessed using both a driving simulator and on a closed road

course. Bioptic drivers were assessed in a variety of ways, including number of

collisions in the simulator, speed maintenance, navigation of traffic situations,

braking, lane position, and location of signs and other objects. A primary

objective of the study was to evaluate the effectiveness of training in the use of

BTS. Driver training in the study was meant to teach bioptic drivers how to use

the BTS more effectively while driving, and training was given over eight

sessions on tasks such as sign location and recognition, maintaining lane

position, judging gap distances, and navigating complex traffic situations. Drivers

who received training in the use of BTS were compared on the driving skills

assessments to drivers who received BTS but no training. The study found that

subjects who received training in the use of BTS for driving performed statistically

significantly better on the driving assessment tests than subjects who received

BTS but no training. The authors also reported that, though the improvements

were less than for the training group, the non-training BTS group also

experienced significant gains on the assessments. Changes in performance on

specific driving skill assessments (e.g. lane keeping, sign recognition etc.) were

not reported.

Authors in the Netherlands, in collaboration with bioptic driving

researchers, trainers, and administrators in the United States, conducted a study

of a training program for bioptic licensure in that country.[5] The goal was to

determine whether people with moderate visual impairment could be trained to

drive safely enough to be licensed in the Netherlands, a country which had not

previously allowed for bioptic licensure. Nine of 36 (25%) people who underwent

training were eventually licensed after a road test. Interestingly, potential

candidates with nystagmus were excluded from the study. The reasoning for this criterion was that the study driving instructors felt that people with nystagmus had difficulty maintaining lane position, though they acknowledged that there was no published evidence of this, or that drivers with nystagmus generally require more training.

4.1.2 Previous Studies of On-road performance of Bioptic Drivers

There are very few studies of actual on-road performance of drivers using BTS. Wood and colleagues reported on a study of the on-road driving performance of 23 bioptic drivers and an equal number of control drivers in Alabama.[60] Drivers were rated by in-car observers for overall performance on a five point scale with respect to eight specific driving behaviors, including lane position, speed, scanning, and obeying traffic signals.

Twenty-two of the 23 bioptic drivers and all of the controls were rated as safe drivers overall. Bioptic drivers performed poorer than controls on several driving behaviors, including lane position, steering, and sign identification. However, for most rated behaviors, there were no differences between bioptic drivers and control drivers. The authors concluded that the study provided evidence that many bioptic drivers have the potential to operate vehicles on the road safely and that driving behaviors that were shown to be poorer in bioptic drivers might be points of emphasis in bioptic training programs.

We have previously conducted a pilot study of factors related to training and road testing in bioptic drivers.[61] In that study, we examined the training and Highway Patrol licensure testing records that were available for the first fifty patients identified as having had an examination for the bioptic program at the College of Optometry (the same group of patients described in Chapter 3). We found that the amount of training documented for candidates was inversely related to the total horizontal extent of the visual field (that is, people with reduced visual field had more documented hours of training before testing for licensure). We also found that increased age was associated with increased likelihood of failing a road test for licensure, a finding consistent with literature in non-bioptic driving.[62] The patients included in the pilot study were a mix of daylight and night program applicants, and there are differences in the amount of training typical of the two programs, namely night program applicants typically receive less training. This is likely due to the fact that night program applicants always have driving experience, and often already have experience driving with BTS. There are also differences in visual factors between the applicants of the two programs, with night program applicants having better vision generally. For these reasons, the larger study of training and testing described in this chapter included only candidates making application for daylight bioptic licenses.

In the study of bioptic driver training and testing for licensure with BTS described in this chapter, as in the pilot study, the patient records and driver training records of Vision and Vocational Services (VVS) were reviewed. Vision

and Vocational Services was the second location a prospective bioptic driver in the Central Ohio program would have reported to in the process of obtaining a license to drive with BTS (with the College of Optometry being the first). It was at VVS that BTS fitting and ordering were usually performed. This process includes examination by an optometrist for determination of the proper prescription for the spectacle carrier lenses of the BTS and determination of the type and magnification of the telescope to be used. Details such as the particular frame and frame size and which BTS company's design to order are also determined in the bioptic fitting process.

Vision and Vocational Services also operated the driving school at which all of the Central Ohio program's driver training occurred. Driving instructors at VVS who were certified in the instruction of drivers with impairments conducted training in driving, use of the BTS, and integration of BTS use into the driving task. Training in the program is personalized and so varies with each candidate, however, there are general practices that are followed for all candidates. Each driver generally begins with a session in which use of BTS is explained and the subject is evaluated on his or her ability to use the BTS to identify targets. A common exercise is to project images of road signs onto a wall for the candidate to identify using the BTS. Training may also include sessions in which the potential bioptic driver rides along in the passenger seat of a vehicle and completes certain tasks using the BTS like recognition of signs and traffic signals. It also includes sessions in which the candidate operates the vehicle and

the instructor rides in the passenger seat and provides instruction and evaluation on driving and use of the BTS.

Because the driving instructor who worked with the potential bioptic candidate usually accompanied the candidate to testing for licensure at the Highway Patrol, the VVS record frequently contained data regarding road testing results. The Highway Patrol test for bioptic licensure consists of three parts: Environmental, Road Test, and Maneuverability. The Environmental portion consists of a series of road signs that the candidate must identify correctly at an appropriate distance using the BTS while a passenger in a vehicle. The Road Test requires the candidate to drive a specified route in traffic with multiple examiners in the car. The examiners score the candidate on a number of driving tasks and skills. These include general driving habits like braking, steering, and maintaining proper speed as well as specific scoring on performing right and left turns, stopping, and using equipment properly. The scoring form used by the Highway Patrol for the Road Test portion of the examination is shown in Figure 4.1. Various point values are assigned to different items and a total score is given for each of the three portions of the test. A score of 26 or more points deducted from either the Road Test or Maneuverability portions results in failure of the test. For drivers who fail to obtain licensure at a testing session, portions passed on a previous test are not repeated in subsequent tests.

The purpose of this investigation was to examine visual and demographic factors and their relationship to daylight program training hours and road test results in

patients who completed the program and became licensed as bioptic drivers. This information may be of use for a number of reasons. Knowledge of the amount of training a potential bioptic driver is likely to help patients and program administrators plan time and budgets, and clinicians would be better able to counsel patients regarding what to expect at the beginning of the process of becoming licensed. The relationships among visual and demographic factors and Highway Patrol testing results may have interesting implications for the importance of these factors in actual driving performance.

4.2 Methods

A retrospective review of records of patients who completed an initial bioptic examination at the College of Optometry at the Ohio State University was completed. This review is described in more detail in Chapter 2. Data were collected on vision including visual acuity (logMAR charts), contrast sensitivity (Pelli Robson or Mars charts), visual field (arc perimeter or Goldmann), and glare sensitivity and recovery (Brightness Acuity Tester). The collection of data from medical records is also described in more detail in Chapter 2. Age, sex, ocular diagnosis, and previous licensure history were also recorded.

Figure 4.1: Ohio Highway Patrol Road Testing Form

STATE OF OHIO
DEPARTMENT OF PUBLIC SAFETY
ROAD TEST SCORING SHEET

STATE HIGHWAY PATROL
OHIO BUREAU OF MOTOR VEHICLES

DATE_____ CUSTOMER'S NAME_____ EXAMINER'S UNIT NO._____

VEHICLE INSPECTION
☒ PASSED   ☐ FAILED
DEFECTS_____

TEST RESULTS
ROAD— 20   MANEUV.— 12
FAILURE   SCORE OF -26 OR MORE

ROAD TEST

PTS. OFF -DRIVER-
☐☐☐ 2 A. Fails to use windshield wipers and/or defrosters.
☐☐☐ 2 B. Spends too much time starting engine.
☐☐☐ 2 C. Selects wrong gear.
☐☐☐ 2 D. Does not release emergency brake.

-GENERAL DRIVING-
☐☐☐ 2 A. Does not start/stop smoothly, or stalls vehicle.
☐☐☐ 2 B. Stays in same gear too long.
☐☐☐ 5 C. Fails to properly check traffic before pulling into traffic.
☐☐☐ 5 D. Straddles lanes or drives in center of road.
☒☐☐ 5 E. Changes lanes without properly checking traffic to rear. *Check your blind spot*
☐☐☐ 5 F. Makes unnecessary stops on roadway.
☐☐☐ 5 G. Improper steering – Erratic, weaving.
☐☐☐ 5 H. Improper braking – Too early/late, jerky.
☒☐☐ 5 I. Drives too fast/slow for conditions.
☒☐☐ 10 J. Follows too closely.
☐☐☐ 10 K. Violates speed limits – (_____).

-STOP STREETS *freeway*-
☐☐☐ 2 A. Hesitates too long for conditions.
☐☐☐ 5 B. Fails to stop in position to see in all directions.
☐☐☐ 5 C. Fails to look in all directions.
☐☐☐ 5 D. Improper observance of stop sign/traffic light.
☐☐☐ 15 E. Fails to yield to pedestrian.
☐☐☐ 15 F. Fails to yield to other traffic.

-SIGNALS-
☐☐☐ 5 A. Fails to signal change of lanes.
☐☐☐ 5 B. Fails to signal turns/stops.
☐☐☐ 5 C. Improper signals – Wrong, too soon/late.

-RIGHT TURNS-
☐☐☐ 5 A. Improper approach to turn.
☐☐☐ 5 B. Improper speed – Too fast/slow.
☐☐☐ 5 C. Drives into improper lane.
☐☐☐ 5 D. Turns too wide/short.
☐☐☐ 5 E. Improper vehicle position to turn.
☐☐☐ 15 F. Fails to yield to pedestrian.
☐☐☐ 15 G. Fails to yield to other traffic.

PTS. OFF -LEFT TURNS-
☐☐☐ 5 A. Improper approach to turn.
☐☐☐ 5 B. Improper speed – Too fast/slow.
☐☐☐ 5 C. Drives into improper lane.
☐☐☐ 5 D. Turns too wide/short.
☒☐☐ 5 E. Improper vehicle position to turn.
☐☐☐ 15 F. Fails to yield to pedestrian.
☐☐☐ 15 G. Fails to yield to other traffic.

MANEUVERABILITY TEST
☒☐☐ 2 A. Stopping to check progress.
☐☐☐ 5 B. Step 1 and 2 Stops – Not parallel with course.
☐☐☐ 5 C. Misjudging stopping points.
☒☐☐ 10 D. Striking marker.
☐☐☐ 26 E. Dangerous action – Knocking down a marker, bumping a marker off the painted square, traffic crash, or any other dangerous action.
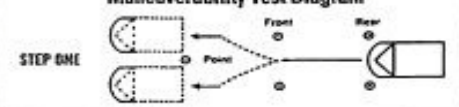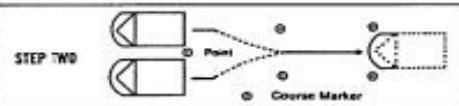
Maneuverability Test Diagram

STEP ONE

STEP TWO

Course Marker

IMMEDIATE FAILURE
☐ 1. Being involved in traffic crash.
☐ 2. Dangerous action – List in remarks.
☐ 3. Serious violation – Red light, stop sign, yield to traffic, and others.
☐ 4. Refusal to follow instructions.
☐ 5. Unable to follow instructions.

REMARKS *Watch your speed in residential areas. Stay at 25 mph*

TO CUSTOMER – THESE ARE YOUR TEST RESULTS. WE ARE PROVIDING YOU WITH THIS INFORMATION SO THAT YOU WILL BE AWARE OF ANY DRIVING ERRORS YOU MAY HAVE MADE.
BMV 5601 3/05

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Patients included in this study differed in several ways from those who were included in the pilot study described in Chapter 3. First, all of the patients included in this study were known to have completed the program and obtained a license to drive with BTS. Second, only daylight program training and testing were included in this study.

Information on the amount of documented training and specifics of BTS system fitting was collected from VVS records. For each new daylight bioptic driving candidate whose record contained both documentation of driver training and Highway Patrol testing results, the number of hours of documented training was recorded. This training may have included sessions of behind the wheel training, "ride-along" training in which the candidate occupied the passenger seat, and basic evaluation of and instruction on the use of the BTS. VVS records contain explicit notation of the hours of training received. Generally, the driving instructor notes in the patient's record the date and number of hours of training along with a report of the progress of the day's training.

All errors noted on any available Highway Patrol road testing forms were recorded, as was the total score on any road test and whether the candidate passed the test and received licensure. For the most common testing errors, potential visual and demographic associations were investigated.

4.2.1 Statistical Analysis

Relationships between potential demographic and visual predictors and hours of training before the driving instructor judged the patient ready for a road test were evaluated using linear regression. Independent associations between all potential predictor variables and hours of training were investigated first. A forward selection process was used to create a multivariate model for hours of training, with the first variable included based on the largest correlation and significance of the P value and subsequent additions based on partial correlations and P values.

Relationships between potential demographic and visual predictors and points missed on the first road test were also evaluated with linear regression. Independent associations of all potential predictor variables with points missed were investigated first. A forward selection process was used to create a multivariate model for points missed on the road test, with the first variable included based on the largest correlation and significance of the P value and subsequent additions based on partial correlations and P values. The relationship between hours of training and road test score was also evaluated using the correlation coefficient.

The relationships among visual and demographic factors and road testing results (passed first road test vs. failed first road test) were investigated using logistic regression. Independent associations between all potential predictor variables with road test results were investigated first. Then, a forward selection

process was used to create a multivariate model predicting road testing results.

Logistic regression was also used to investigate relationships among

independent variables and specific road testing errors. Goodness of fit for final

multivariate logistic regression models was checked using the Hosmer-

Lemeshow test.[56-57] SPSS version 19 was used for all analyses. Figure 4.2

shows a concept map of potential relationships between patient characteristics

and training and testing outcomes, as well as the potential relationships with

MVC. The correlation between hours of training and road test failure was also

investigated.
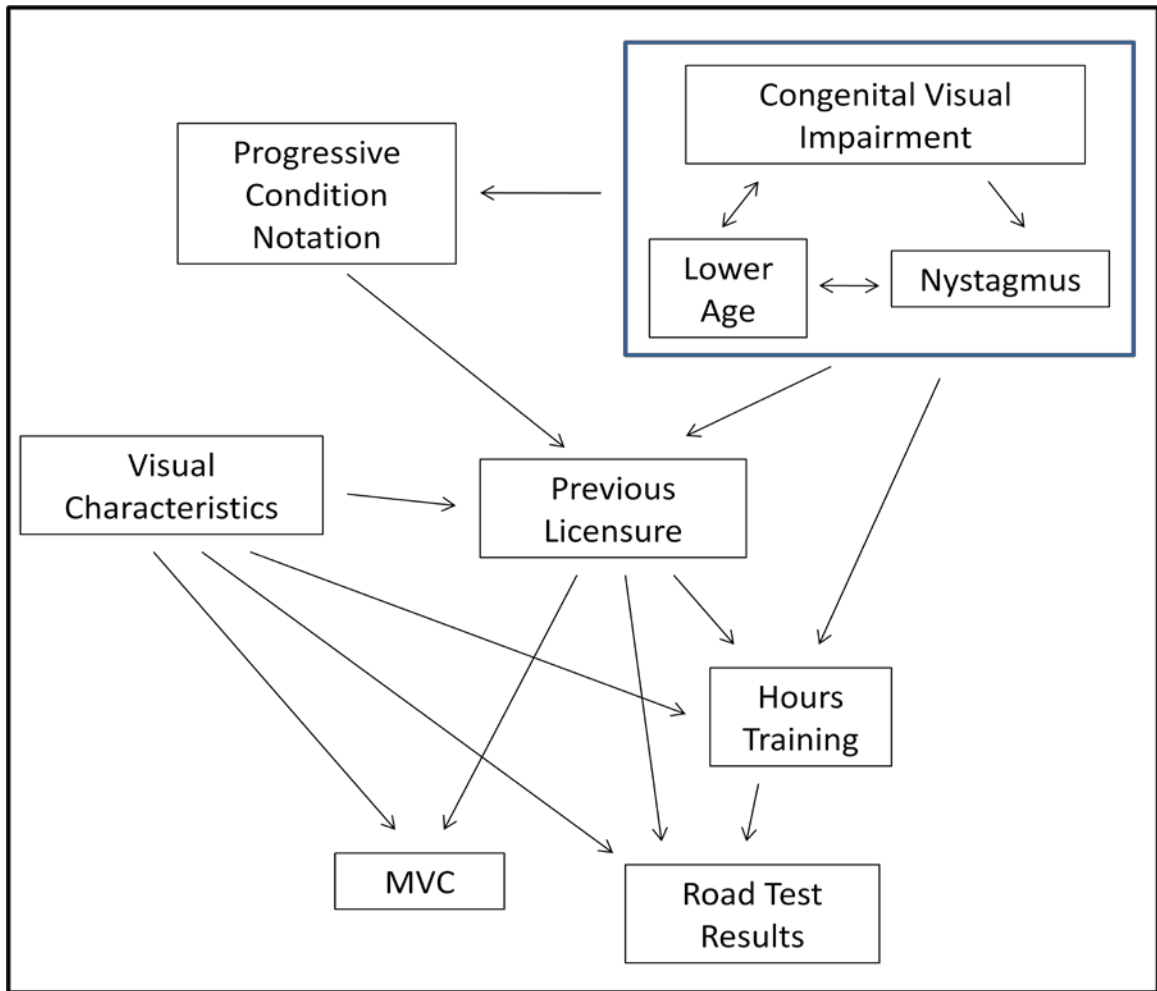
Figure 4.2: Concept Map of Potential Relationships among Patient
Characteristics and Outcomes

4.3 Results

Ninety-seven patients were included in this portion of the study. None of these patients were included in the initial pilot study of training and testing. They were identified as having completed an initial vision examination at the College of Optometry, received a license to drive with BTS, and also as having a record at Vision and Vocational Services. In addition, for all included patients, there was an indication in the VVS record that they had passed the road test for daylight licensure with BTS. Documentation of training hours was available for 95 of the 97 patients. The number of points missed on the first Highway Patrol road test was available for 74 of the patients. Copies of the actual road testing scoring form containing specific testing errors were available for 41 patients. Participants for whom predictor data were not available were not included in analyses using those data.

Age at initial exam for patients studied ranged from 16 to 81 years (mean = 40±16 years). Mean logMAR visual acuity was 0.76±0.13 (Snellen equivalent = 20/115). Mean log contrast sensitivity was 1.52±0.23, and mean horizontal visual field extent was 157±15 degrees. Table 4.1 contains a summary of visual and demographic characteristics of patients included in the study.

4.3.1 Documented Training Hours

The mean (±SD) number of hours of training prior to road testing was 26±15, with a range of 9 to 75 hours. Candidates who had not previously had a

driver's license received a mean of 36±16 hours of training, while those with a history of previous licensure received 19±10. Table 4.2 contains model coefficients from simple bivariate linear regression models for all potential predictors of the number of documented hours of training. Lack of previous licensure was independently associated with greater total documented hours of training ($p< 0.001$). Younger age was also associated with more training ($p = 0.003$). A multivariate model for hours training contained only previous experience.

4.3.2 Road Testing

Table 4.3 contains the model coefficients from simple bivariate linear regression models for all examined potential predictors of the number of points deducted on the first Highway Patrol road test. Notation of a progressive visual condition was the only visual or demographic patient characteristic associated with the number of points deducted on the first Highway Patrol Road Test ($p = 0.025$).

Lack of previous licensure, lack of notation of a progressive visual condition, and nystagmus were all independently significantly associated with having failed a portion of the Highway Patrol licensure test. Table 4.4 contains bivariate logistic regression model coefficients and odds ratios for predictors of failing any part of the road test at least once. An attempt at creating a multivariate logistic regression model using a forward selection procedure resulted in a model

that contained only previous experience (p<0.001), likely reflecting the interrelationships among previous experience, nystagmus, and visual condition stability shown in Figure 4.2.

We also investigated the relationship between the number of hours of training a person received and his or her road test results. There was a significant association between hours of training and both points deducted on the first Road Test portion of the Highway Patrol licensure test ($p < 0.001$), and having failed any portion of the Highway Patrol test ($p< 0.001$). Figure 4.3 shows the relationship between points deducted on the road test and hours of documented training for all patients for whom this information was available, and indicates that there is a trend for candidates with more hours of training to have more points deducted on the Road Test portion of the exam. Figure 4.4 shows hours training for candidates who passed the Highway Patrol exam on the first try vs. candidates who failed at least one portion of the exam. The mean hours of training for those who passed on the first attempt was 20±10 vs. 37±17 for those who failed at least one portion of the exam. Attempts to use a forward selection process to create a multivariate model for prediction of points deducted on the road test or failure of the road test using hours of training in addition to visual and demographic independent variables resulted in models for both containing only documented training hours, demonstrating the strength of the association between the amount of training received and testing results.

Table 4.1: Summary of Visual and Demographic Factors of Patients Included in Study of Training and Testing, and Training and Road Testing Data (n=97)

	Range	Mean	SD
Age	16-81	40	16
LogMAR Visual Acuity	0.4 - 1.1	0.76	0.13
Contrast Sensitivity	1.05 - 1.95	1.52	.23
Visual Field	120 - 190	156.8	14.7
Low Luminance VA	0. 6- 1.2	0.86	0.14
Glare Sensitivity	0. 6- 5	0.96	0.47
Glare Recovery	1 - 35	5.77	5.38
Training Hours	9-75	26.1	15.4
Points Deducted on Road Test	0-148	17	20
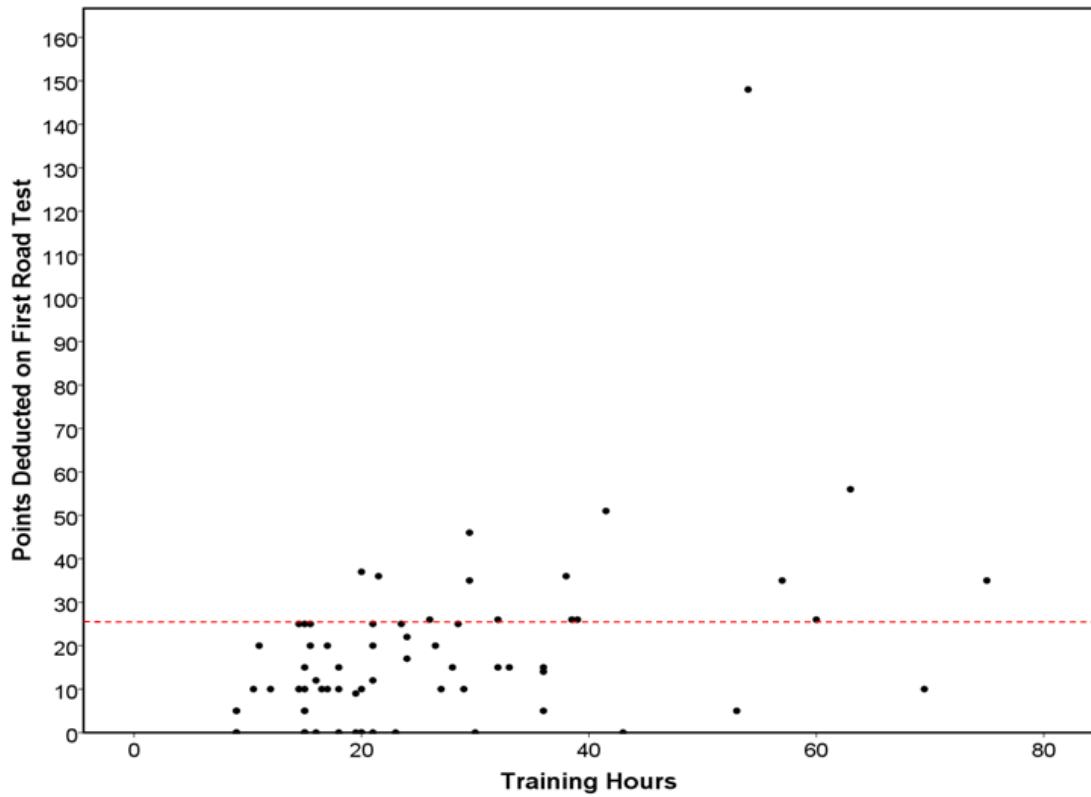
Figure 4.3: The Relationship between Points Deducted on the Road Test and Hours of Documented Training (n=73)

The dashed line indicates a failing score on road test, with all points above the line being failing scores.
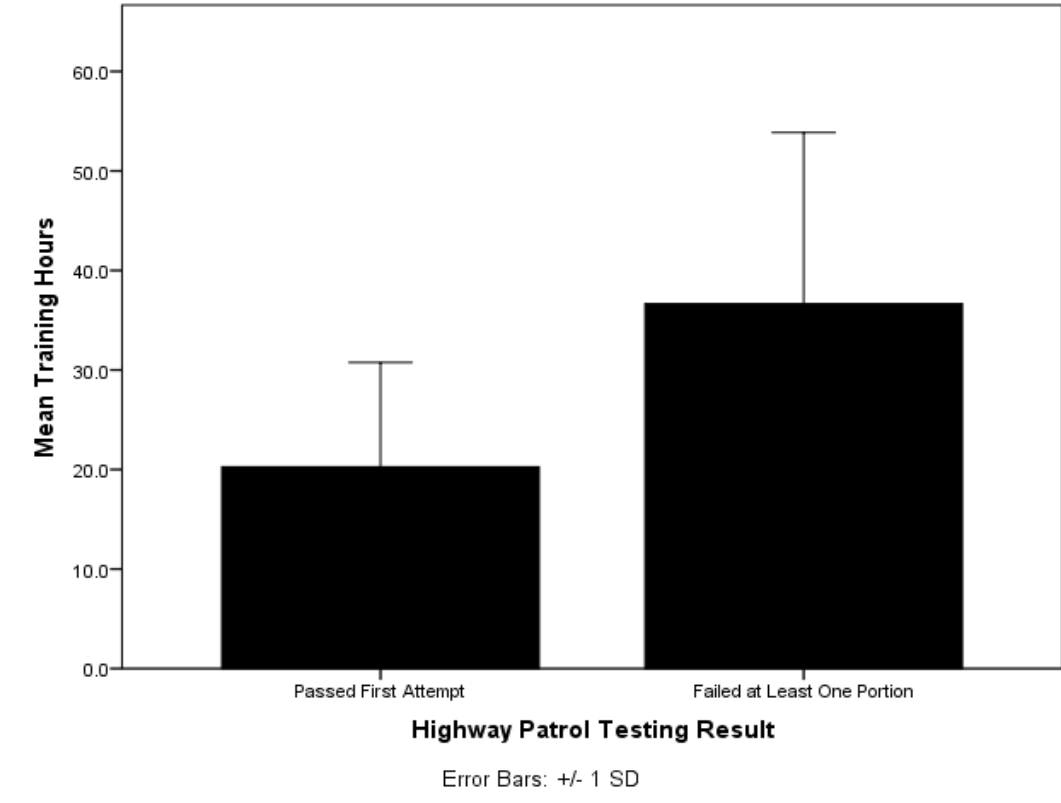
Figure 4.4: Hours Training for Candidates who Passed the Highway Patrol Exam on the First Attempt vs. Candidates who Failed at Least One Portion of the Exam

Table 4.2: Unadjusted Associations between Patient Characteristics and Hours of Documented Training (n=95)

Patient Characteristic	β	SE	t Statistic	P value
Age (years)	-0.302	0.100	-3.01	**0.003**
Previous Experience	-17.08	2.69	-6.35	**<0.001**
Female Gender	3.75	3.54	1.06	0.293
Visual Acuity (logMAR)	-0.254	12.26	-0.021	0.983
Log Contrast Sensitivity	5.90	6.88	0.858	0.393
Color Vision Defect	-5.20	3.72	-1.40	0.166
Visual Field Extent (deg)	-0.119	0.109	-1.01	0.277
Low Luminance VA (logMAR)	0.098	11.54	0.009	0.993
Glare Sensitivity (logMAR)	0.564	3.36	0.168	0.867
Glare Recovery (sec)	-0.454	0.290	-1.56	0.121

Table 4.3: Unadjusted Associations between Patient Characteristics and Predictors of Points Missed on the Ohio Highway Patrol Road Test (n=74)

Patient Characteristic	β	SE	t Statistic	P value
Age	0.034	0.160	0.215	0.830
Female Gender	-2.05	5.23	-0.392	0.696
Previous Experience	-8.53	4.75	-1.80	0.077
Progressive Visual Condition	-11.0	4.80	-2.29	**0.025**
Visual Acuity	24.62	19.76	1.25	0.217
Contrast Sensitivity	9.08	10.89	0.834	0.407
Color Vision	3.178	6.09	0.522	0.603
Nystagmus	7.56	4.98	1.52	0.133
Visual Field	-0.157	0.160	-0.985	0.328
Low Luminance VA	11.64	16.66	0.699	0.487
Glare Sensitivity	-0.614	4.66	-0.132	0.896
Glare Recovery	-0.166	0.431	-0.385	0.701
Hours Training	0.652	0.146	4.48	**<0.001**

Table 4.4: Unadjusted Odds Ratios for Patient Characteristics and Failure of a Portion of the Road Test for Licensure (n=74)

Patient Characteristic	Odds Ratio	95% CI for Odds Ratio		P value
		Lower	Upper	
Age	0.533	0.020	13.97	0.706
Female Gender	2.078	0.834	5.18	0.117
Previous Experience	0.161	0.064	0.406	**<0.001**
Visual Acuity	0.533	0.020	13.97	.706
Contrast Sensitivity	1.151	0.176	7.55	0.883
Color Vision	1.033	0.383	2.79	0.949
Visual Field	0.984	0.956	1.01	0.284
Low Luminance VA	1.157	0.051	26.03	0.927
Glare Sensitivity	0.604	0.138	2.65	0.504
Glare Recovery	0.999	0.921	1.08	0.975
Nystagmus	3.529	1.400	8.90	**0.008**
Progressive Visual Condition	0.203	0.069	0.595	**0.004**
Hours Training	1.093	1.047	1.14	**<0.001**

The most common error marked on available (n=41) scoring forms from the Road Test portion of the Highway Patrol exam was "drives too fast/slow for conditions" (46% of patients with available road test scoring forms). Other common errors on road testing included "improper steering - erratic, weaving" (29% of patients with available road test scoring forms), "straddles lanes or drives in center of the road" (24%), "improper braking—too early/late, jerky" (22%), and "turns too wide/short, left turns" (17%). Figure 4.4 shows the frequency of common road testing errors.

There were several significant associations between patient characteristics and the most common road testing errors. The number of documented training hours was associated with the errors "straddles lanes or drives in center of road" (p = 0.022) and "improper steering—erratic, weaving" (p = 0.048), with drivers who committed these errors on the road test having more training hours on average than those who did not commit the error (41 hours vs. 25 hours for a straddle error and 38 hours vs. 25 hours for a steering error). Presence of nystagmus, visual acuity, and low luminance visual acuity were associated with the "drives too fast/slow for conditions" error. In a multivariate logistic regression, only nystagmus was significantly associated with this error. Color vision deficiency was associated with "turns too wide/short, left turn" (p = 0.010). There were no visual or demographic factors significantly associated with braking errors.
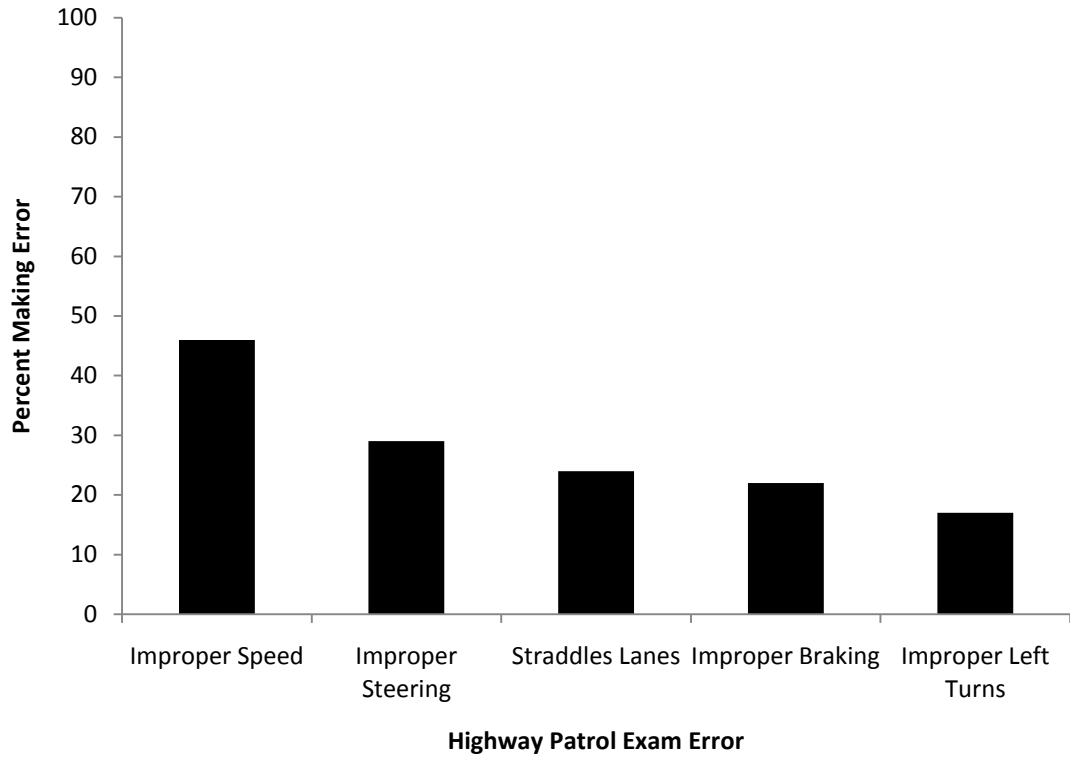
Figure 4.5: Frequency of Most Common Road Testing Errors (n=41)

4.4 Discussion

Age and previous experience were related to the amount of training patients received before testing for licensure. Specifically, patients who had not previously been licensed received more training than those who had previously been licensed. This is logical, as the training program consists of a mixture of training in basic driving skills and use of the bioptic device for driving. Candidates for bioptic licensure who have previous experience with driving an automobile without the use of BTS are likely to require less training in basic driving skills than those without this experience. Training for these patients is likely to focus primarily on integration of BTS use into the driving task and result in a shorter duration before the driving instructor deems the patient ready to attempt the Highway patrol test for licensure.

There was also a significant association between the number of hours of documented training and the number of points deducted on the Road Test portion of the Highway Patrol licensure exam. Candidates with more documented training had more points deducted during the Road Test portion of the exam. One possible interpretation of this fact, given the finding that lack of driving experience was also associated with more training hours, is that candidates with more training missed more points on the road test because of a lack of driving experience. However, the relationship between training hours and road test point deductions remains significant even after adjusting for previous driving experience. Because of the nature of the Ohio bioptic program, where candidates

are only allowed to take the Highway Patrol exam after the driving instructor decides that they are ready to do so, candidates with more training hours are people who have taken a greater amount of time to convince the instructor of their readiness. Based on road testing results, it appears that Highway Patrol examiners judge these candidates to be poorer drivers during the road test.

This fact is also suggested by the significant association between training hours and failure of any portion of the Highway Patrol exam. Candidates who failed some portion of the test had more documented training hours than those who passed on the first attempt. It should be noted that some of the difference in the amount of training between those who passed on the first attempt and those who did not is likely related to the fact that candidates often return to the driving instructor for more training following a failure on the exam. Any extra training received after a failure was counted in the determination of total hours of training. However, the number of hours of training received after a Highway Patrol Exam failure is generally quite small relative to the total number of hours for a candidate, and there is sometimes no extra training documented at all after a failure. Therefore, it seems likely that the difference in training hours cannot be explained solely by extra hours received after a failure.

In contrast to our previous finding in a pilot study of training and testing in bioptic drivers that the extent of the horizontal visual field was inversely related to the number of hours of training received, the extent of the horizontal field was not associated with the amount of training received. The extent of visual field was

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also not associated with failure on the Highway Patrol exam. Although visual field extent has been shown to be related to driving performance and driving safety, the requirement for Ohio licensure (including bioptic licensure) of at least 70 degrees visual field to one side and 45 degrees to the opposite side has the consequence that drivers with significant peripheral visual field loss are not included in this study. Drivers in this study have generally normal peripheral visual field and do not have ocular diseases which result in restricted peripheral visual field, thus limiting our ability to make conclusions on the possible effects of reduced visual field on bioptic driving performance.

The only visual factors predictive of failure of a portion of the Highway Patrol exam in bivariate models were the presence of nystagmus and lack of notation of a progressive visual condition. Whether nystagmus may be detrimental to driving ability has been a subject of interest for some time among those interested in vision and driving.[5] Because of the nature of nystagmus, it is reasonable to wonder whether the lateral movement of the eyes might cause difficulty accessing the telescope in BTS. We have previously shown that nystagmus was independently associated with a greater number of training hours, but that the association was no longer significant if we controlled for previous driving experience.[63] Those with nystagmus have congenital visual impairments, and therefore have never had visual acuity sufficient to meet state standards for non-bioptic licensure and do not have prior driving experience when they enter the bioptic program. The relationship between nystagmus and

failure on a portion of the Highway Patrol exam in this study is similar, with a statistically significant simple bivariate association but no significant association in a multivariate model. In this case, when the number of hours of training is accounted for, the association between nystagmus and Highway Patrol exam failure is no longer significant.

Study of the driving performance of bioptic drivers is an area of research which is in its early stages. Analysis of road testing results and specific road testing errors by bioptic driving candidates on the Highway Patrol exam in this study may be informative with regard to the driving performance of bioptic drivers. We found that the most common errors committed by drivers in this study involved improper steering, straddling lanes, controlling speed appropriately, and making turns. Wood et al., in studies of bioptic driving performance, have found that common errors in road testing included losing lane position and improper steering.[60] Of course, the performance of drivers on the Highway Patrol road test in this study may not be indicative of their bioptic driving performance in the years following the test.

As with the study of patient characteristics of obtaining bioptic licensure presented in Chapter 3, many of the patient visual factors were not associated with the amount of training received or licensure testing results. This is indicative of the fact that there are likely many factors that influence the amount of training received and testing results, and that patients with a wide range of visual profiles appear to be able to perform the tasks associated with training and testing for

bioptic driving licensure. This will continue to make it difficult for patients,

clinicians, and bioptic programs to predict the amount of time likely to be needed

for driver training or the likely results of testing for licensure based on the visual

or demographic characteristics of patients.

Chapter 5

Visual and Demographic Factors in the Road Safety of Bioptic Drivers and Comparison with a Control Group of Non-Bioptic Drivers

5.1 Introduction

Since the introduction of bioptic driving, a central question has existed regarding its safety. There has been rather vigorous debate on the topic 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 (MVC). This is at least partially because of the relative scarcity of bioptic driving safety research.

5.1.1 Previous Studies of Bioptic Driving Safety and Driving Experience

The first published study of road safety of bioptic drivers, by Korb, appeared in 1970.[4] Study participants had minimum visual acuity through the bioptic telescope of 20/40, normal visual field and color vision, visual impairment that resulted from either a congenital condition or had remained stable for at least two years, and "satisfactory results with subjective testing and initial training procedures with bioptic systems".[4] Subjects were fit with bioptic telescopes with power ranging from 1.7 to 3X and were given three months to adapt to use of the system. Of 67 people initially examined for the study, 26 (39%) were eventually

licensed. Reasons for failure to obtain a license included unstable visual condition, failure to demonstrate proficiency with the BTS, failure to obtain 20/40 with the BTS, and various attitudes deemed inappropriate for continuing with the process of becoming licensed. The majority of those licensed using BTS were licensed in Massachusetts, with a few obtaining licenses in other states or in Canada.

Of the 26 patients who were licensed, Korb reported that none of them experienced any motor vehicle collision (MVC) in a total of 32 person-years of driving. It is not clear whether assessment of MVC was accomplished via patient interview or review of state records in this study. Interviews were conducted with all participants, but there is no mention of accessing the records of any state department of motor vehicles. Other findings from patient interviews included that patients reported the BTS being useful for spotting signs, traffic signals, and road hazards, as well as for identifying exits on the highway. Interestingly, this study has been cited several times in the literature as reporting on a greater number of study participants (128) and driving years (six year study period) than it actually does , and it is cited for reporting a lower frequency of MVC in bioptic drivers than for the general population.[6, 64]

William Feinbloom, the developer of BTS, reported in 1977 on 300 patients he fit with BTS for driving over the course of 18 years.[6] The paper contains some description of the visual ability Feinbloom deemed important for successful bioptic driving. He noted that the ability to perceive motion, visual

acuity (including dynamic visual acuity), depth perception, head and eye movements, color vision, and figure identity ("the ability to keep the identities of objects separate despite the intersection of their retinal images") all played some role in the ability to drive. Of note, Feinbloom stated that visual acuity was primarily only necessary for tasks like reading distant signs, and that visual acuity of about 20/200 was likely to be sufficient for bioptic driving. This opinion was based on a small experiment in which he used plus lenses to blur the vision of drivers and then asked them to report on the difficulties they experienced. He noted that dynamic visual acuity may in fact be better correlated with successful driving than static visual acuity, and that nystagmus may negatively impact dynamic visual acuity.

He also reported that driving experience for patients in the study ranged from one to ten years, and that self-reported yearly mileage ranged from 4,000 to 45,000 with an average of 12,500 miles driven per year. Assessment of MVC for these drivers appears to have been made using self-report in patient interviews. Feinbloom reported that none of the patients in the study had an MVC resulting in injury to any person or severe property damage. The paper does not contain a detailed analysis including the total number or severity of reported MVC. Feinbloom concluded with a list of recommendations for bioptic driving program administration, which included minimum visual acuity through the telescope of 20/40 and through the carrier lenses of 20/160, a horizontal visual field of 130

degrees, stable visual loss, annual reexamination of vision and road skills, and a program of driver training and testing specific to bioptic drivers.

Janke published the first report of bioptic driver safety that relied on state driving records in 1983.[65] This study of 229 bioptic drivers in California is also notable for its use of a large control group for comparison of MVC rate. The author used California Department of Motor Vehicles records to create a control group of 21,064 drivers selected because they had a license number ending in101. For the 229 drivers in the BTS group over a two year study period, the MVC rate was 7.4 MVC per 100 drivers per year. The rate for the control group was 3.98 per 100 drivers per year. These rates were interpreted as evidence that bioptic drivers had 1.9 times the accident rate as controls, which was significantly different by T-test.

A few aspects of the methods of the study are worth noting when considering these MVC comparisons. First, one-sided T-tests were used for all analyses, which the authors noted made it statistically easier to conclude that there were significant differences between bioptic drivers and controls. The authors state that they used one-sided tests because the Department of Motor Vehicles were concerned about whether bioptic drivers were more, not less, dangerous than normally-sighted drivers. Second, when differences in age and sex between the BTS group and the control group were accounted for, the difference in MVC rate was smaller. The MVC rate of bioptic drivers was 1.5 times that of controls after adjusting for age and sex. It was reported as

significant at the p < 0.05 level on a one-sided T-test, which means it may not have been significantly different using a two-sided test. Also, a second analysis which excluded all drivers from both the BTS and control groups who had invalid licenses or licenses which had been revoked did not demonstrate any difference between groups with respect to crash rate.

The Janke study also compared the severity of MVC between bioptic drivers and controls. The age and sex-adjusted rate of MVC with injuries or fatalities for bioptic drivers was about 2.2 times that of the control group. The rate for bioptic drivers was about 2.5 MVC with injury or fatality per 100 drivers per year. In a similar fashion to the comparison of all crashes, the authors also compared injurious MVC for only validly-licensed drivers from both groups and found no significant difference between bioptic drivers and controls.

Another interesting aspect of the Janke study was an analysis of the records of a smaller group of bioptic drivers comparing the year before they were licensed with BTS to the following year (the first year with BTS). The purpose of this analysis was to investigate whether BTS made drivers more safe or whether, as Fonda had suggested years earlier, BTS might be a hazard for drivers with low vision. The full details of this analysis are not presented, but the author did state that 62 subjects were analyzed in this way, and that there was a "tendency" for MVC rate to be greater in the first year of BTS wear than the year prior. No statistical analysis of this statement was presented, and the author called for more study of the topic.

Other recommendations made by the author include consideration of restriction of bioptic licenses to daytime only and restricting the area in which drivers with BTS are permitted to drive. She also pointed out that the MVC rate of bioptic drivers in the study, while higher than that of the control group, should be considered relative to drivers with other medical conditions and other groups of drivers who are high risk. These other groups, the author stated, had higher MVC rates in similar studies in California than the bioptic drivers did.

The MVC rate of bioptic drivers in Texas was examined in 1988 by Lippman, Corn, and Lewis.[11] The first author described himself in the introduction as an opponent of bioptic driving. The study compared the MVC rate of 64 Texas bioptic drivers to that of a control group of 64 drivers selected randomly by driver license number. The 64 bioptic drivers were all of the drivers licensed in Texas to drive with BTS with more than one year of driving experience. The number of years of driving experience for these drivers appears to have ranged from 1 to about 10 years. MVC statistics were based on the records of the Texas Department of Public Safety.

The authors reported that 18 of the 64 bioptic drivers had a documented MVC, and that these drivers had a total of 22 documented MVC. 14 of the control group drivers had a documented MVC, and these drivers had a total of 15 MVC. From these data, the authors concluded that bioptic drivers are not more likely to have an MVC than control drivers, but that the age and sex-adjusted rate of MVC is 1.34 times greater for bioptic drivers. Therefore, they concluded that a bioptic

driver who has an MVC is more likely to have multiple MVC. Other findings of the study included that bioptic drivers were at fault in 82% of the MVC they were involved in, compared to 40% of control drivers.

This study also made an attempt to explore the relationship between visual factors and bioptic driving safety. Twenty-six of the bioptic drivers had some eye examination documentation available. However, the information was not complete enough to make any real conclusions. The authors reported that 38.5% of the drivers with eye examination records had documented visual acuity of 20/200 or less, and that 9 of the 26 were using binocular telescopic systems. For the six bioptic drivers who had both an MVC and eye examination data, an ophthalmologist reviewer judged that visual factors played a role in half of the MVC. It is not clear what criteria were used to make these determinations, and the authors acknowledge the difficulties with making these determinations.

The study is also notable for its exploration of the ability of BTS wearers to detect peripheral targets, a subject that remains a topic of interest today. The question was investigated for a small number of subjects using a combination of perimetry techniques and both monocular and binocular BTS. The conclusion that the authors reached is that subjects did have the ability to detect peripheral objects that fell within the ring scotoma of the eye viewing through the telescope by using the fellow eye, but that use of a binocular BTS system eliminated this ability. The authors cautioned against the use of binocular telescopic systems for driving based on these findings.

This study relied on a relatively small number of drivers and MVC for its conclusions. The authors noted that overall bioptic drivers have more MVC than control drivers in the discussion, but failed to mention that the study found that bioptic drivers individually are not more likely than control drivers to have any MVC in the same discussion section. None of the MVC statistics were reported relative to driving exposure. It is not clear whether years of driving exposure were accounted for when tabulating the number of MVC for either group. Also, the paper mentioned that MVC reports are expunged from Texas records after 5 years, but made no reference to whether or how this fact was taken into account.

The largest and most complete study of bioptic driving safety completed was reported by the California Department of Motor Vehicles' Research and Development Branch in 1996.[66] This is essentially the same group as conducted the Janke study in 1983[65] and used similar methods as that study, including a 2 year observation period, adjustment for age and sex differences between comparison groups, and a large (28,109) control group. One notable difference between this report and the 1983 Janke report was that the statistical analysis in this report is considerably more detailed and analysis of covariance (ANCOVA), rather than T-test, was used to determine whether there were differences in MVC rate between groups.

This study consisted of a two year observation of the driving records of 609 bioptic drivers and a control group of 28,109 non-bioptic drivers who were selected based on driver license number. MVC, including MVC with injury, and

other citations were recorded for both groups and ANCOVA was used to test for significant differences in these variables. Adjustment was made for age and sex. The MVC rate for bioptic drivers after adjusting for age and sex was approximately 7.5 MVC per 100 drivers per year, and the rate for control drivers was approximately 4 MVC per 100 drivers per year, which suggests approximately 1.9 times the crash risk for bioptic drivers. The rates for MVC with injury or fatality were approximately 2 per 100 drivers per year for bioptic drivers and 1.2 per 100 drivers per year in the control group. Bioptic drivers had fewer citations per year than drivers in the control group. Unlike the previous study by Janke, all of the relationships between MVC rates and citations held when only those drivers with valid licenses were analyzed.

Interestingly, a portion of this paper discussed the fate of the recommendation from the 1983 study that all bioptic drivers be limited to daytime-only driving. This recommendation became the official policy of the California DMV after the 1983 study was published. However, this study's check of daytime-only restrictions on the licenses of bioptic drivers found that only 35% of them had been restricted to daytime only. The author recommended an investigation into how this occurred, and it is illustrative of the difficulty that departments of motor vehicles can have in enforcing the policies of bioptic driving programs.

In repeating the methods of the 1983 study with a larger group of California bioptic drivers, the authors of this study essentially confirmed that

earlier study's findings that bioptic drivers have a higher MVC rate than controls. It also demonstrated that bioptic drivers had a smaller number of citations than controls. The authors interpreted this as evidence that bioptic drivers are likely exercising greater caution while driving than normally-sighted drivers, and yet are still experiencing more MVC. They conclude by recommending that the state reconsider whether licensing bioptic drivers is appropriate given their higher MVC rate and "reformulate vision standards and guidelines to make them more fail-safe, so that problem (bioptic) drivers cannot avoid appropriate treatment."

5.1.2 Summary of studies of bioptic driving safety

In the more than 40 years that driving with BTS has existed in the United States, there have been very few studies of its safety. The results of these studies are variable, with some reporting that bioptic drivers almost never are involved in motor vehicle collisions and others suggesting that bioptic drivers are at significantly higher risk for collisions.

The published work suggesting that bioptic drivers are safer than normally-sighted drivers appears to be primarily based on self report. There are no studies that use the records of state departments of motor vehicles that have found that the MVC rate is less in bioptic drivers than in normally-sighted drivers. The studies that did use state driving record data have found higher MVC rates for bioptic drivers, ranging from 1.34 to approximately 2.3 times the rate of control drivers depending on the method of analysis.[11, 65-66] There are few of

these studies, however, they were conducted in only a few states, and the last of them was published approximately 17 years ago. None of these studies reported on the relationships among visual and demographic factors and driver safety.

The purpose of this study was to use a combination of the data contained in the College of Optometry medical records for patients examined for participation in the Central Ohio bioptic driving program, training and testing data from the program's driving trainers and the Ohio Highway Patrol, and the driving records of these patients from the Ohio Bureau of Motor Vehicles to determine MVC rates for bioptic drivers in Ohio and the associations between visual and demographic factors and MVC. Another purpose was to compare the MVC rate of bioptic drivers to that of a control group of non-bioptic drivers.

Table 5.1: Summary of Bioptic Driving Safety Studies

Study	Number of Bioptic Drivers Studied	Method of MVC Determination	Summary of Findings
Korb[4]	26	survey	• All bioptic drivers surveyed reported no MVC in 32 person-years of driving
Feinbloom[6]	300	survey	• All bioptic drivers surveyed reported no "serious" MVC with injury • Average mileage reported by drivers was 12,500/yr
Janke[65]	229	state records	• 7.4 MVC per year for bioptic drivers • Bioptic drivers have 1.9 times MVC rate as control group for those with valid licenses
Lippman et al.[11]	64	state records	• Bioptic drivers have 1.34 times the MVC rate as control group
Clarke[66]	609	state records	• 7.5 MVC per year for bioptic drivers • Bioptic drivers have 1.9 times MVC rate as control group

5.2 Methods

A retrospective study of patients identified as having received an initial daylight bioptic examination at the College of Optometry at the Ohio State University was conducted. Data were collected on vision, including visual acuity (logMAR charts), contrast sensitivity (Pelli Robson or Mars charts) and visual field (arc or Goldmann perimeter). Demographics, ocular diagnoses, and licensure history were also recorded from patient records. The medical record review and vision examination processes are described in further detail in Chapter 2.

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. A request was made for the driving records of all patients identified as having made application for a daylight license using BTS. The driving records contain information on MVC involvement, convictions for MVC, severity of MVC, other violations and convictions, date of last licensure, and license restrictions. A more detailed description of the contents of the Bureau of Motor Vehicles driving record is contained in Chapter 2.

Though the Bureau of Motor Vehicles driving record reports the date of last license renewal, it does not contain the date of first licensure. For analyses involving the number of years a driver was licensed, we used one of two dates as the date of licensure. The first method was to use dates obtained from Vision and Vocational Services or College of Optometry records. Often, the training and

testing notes from VVS contain the date of licensure. For some patients, a copy

of the first driver's license or other notation of the date of licensure was included

in the College of Optometry medical record. For all patients whose records

contained a licensure date, that date was used for analyses. For patients whose

records did not contain a date of licensure, we used the mean time from the initial

vision examination to licensure for drivers with known licensure dates (7 months)

in order to estimate a licensure date. Therefore, the estimated licensure date for

drivers without a documented licensure date was 7 months after the initial

examination.

We used convictions noted in the driving record in an attempt to determine

whether the driver was cited for the MVC in which he or she was involved. There

is no explicit documentation of fault for an MVC in the BMV record or connection

between a particular MVC and a particular conviction. However, there is

commonly notation of a conviction that is likely to be associated with MVC (e.g.

failure to yield right of way) either on the same day or in the period immediately

following an MVC. A conviction was counted as being associated with a

particular MVC if the date associated with the conviction was within two months

of the date of the MVC and if it was consistent with a conviction type that could

be associated with an MVC.

In order to compare the MVC rates of bioptic drivers to those of non-

bioptic drivers, we created a control group of non-bioptic drivers. For each bioptic

driver, we searched the Bureau of Motor Vehicles database for age-, sex-, and

population density category-matched control drivers who had similar last license renewal dates. The age match criterion used was a birth date within ± 12 months of the bioptic driver's birth date. The license renewal date criterion was a last license renewal date within ± 4 months of the bioptic driver's last renewal. For each bioptic driver, all non-bioptic drivers meeting these matching criteria were analyzed as control drivers. A composite control driver was created for each bioptic driver whose MVC rate was the average of all matches for that particular bioptic driver. Study procedures were reviewed and approved by the Institutional Review Board of The Ohio State University. Waivers of consent and HIPAA authorization were granted for the study.

5.2.1 Statistical Analysis

Relationships among vision, demographic factors, and BMV data including MVC were investigated using time-to-event analysis and the Cox proportional hazards regression model.[67] For this study, an event was defined in multiple ways. First, any involvement in an MVC after the date of bioptic licensure was defined as an event and simple bivariate and multivariate Cox proportional hazards regression were created to examine the effects of various patient characteristics on MVC involvement. Variables with significant P values in bivariate models were considered for inclusion in multivariate models, and addition of variables to multivariate models was made if it resulted in a significant change in -2 log likelihood. Alternatively, we also performed these analyses using

an event definition of an MVC with an associated conviction. The relationship between non-MVC convictions per year of licensure and MVC per year of licensure was evaluated using Spearman correlation.

For all time-to-event analyses, the start time was the known or estimated 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 BMV records, a start time of January 1, 1997 was assumed for all cases where the licensure date was prior to 1997. A P value of less than 0.05 was considered evidence of a significant association for all regression models. The proportional hazards assumption for all covariates included in final multivariate time-to-event regression models was checked graphically on log (-log(survival)) plots.[68-69]

For the comparison of MVC rates between bioptic drivers and control non-bioptic drivers, the number of MVC per year was calculated for the period since the last license renewal only for each bioptic driver. The mean MVC per year was then calculated for each of the composite control drivers for each bioptic driver over the same period.

5.3 Results

5.3.1 Visual and Demographic Associations with MVC in Bioptic Drivers

237 bioptic drivers (65% male) were identified as having had an initial vision examination for a daylight license at the College of Optometry and also

having a driving record from the Bureau of Motor Vehicles. Visual and

demographic characteristics of these drivers are shown in Table 5.2. Age at initial

exam ranged from 16 to 81 years (mean = 39±15 years). Figure 5.1 shows the

distribution of age at initial examination for study participants. Time since bioptic

licensure ranged from 1 to 22 years (mean = 10±5 years). Mean logMAR visual

acuity OU was 0.76±0.12 (approximately 20/115) and mean log contrast

sensitivity was 1.53±0.23.

A total of 292 MVC after the documented or estimated bioptic licensure

date were reported in the BMV records for the 237 bioptic drivers in this analysis.

The number of MVC per driver ranged from 0 to 11, with 124 (52%) drivers

having had at least one MVC and 72 (30%) having had two or more. The

distribution of MVC for all bioptic drivers is shown in Figure 5.2.

The mean number of years since bioptic licensure (or since the estimated

date of licensure) for this sample of bioptic drivers was 10±5. The mean number

of MVC per year was 0.129±0.20. Figure 5.3 shows the Kaplan Meier cumulative

hazard function for involvement in an MVC for all drivers. Figure 5.4 shows the

mean number of MVC per year of licensure as a function of age.

Table 5.2: Visual, Demographic, and Testing Characteristics (n=237)

	Minimum	Maximum	Mean	SD
Age at Exam	16	81	39	15
Hours Training	9.0	75.0	26.6	15.5
Years Bioptic Licensure	0	21	10	5
Visual Acuity	0.40	1.10	0.76	0.12
Contrast Sensitivity	1.00	1.95	1.53	0.23
Horizontal VF	0	190	157	18
Low Luminance VA	0.50	1.20	0.84	0.13
Glare Recovery (sec)	0	40	7	6
Number MVC	0	11	1.23	1.75
Points Deducted on First Road Test	0	148	17.14	20.66
Glare Sensitivity (logMAR)	0.48	5.00	0.91	0.33
Number of MVC Convictions	0	8	0.63	1.17
Number of Non-MVC Convictions	0	10	0.95	1.68
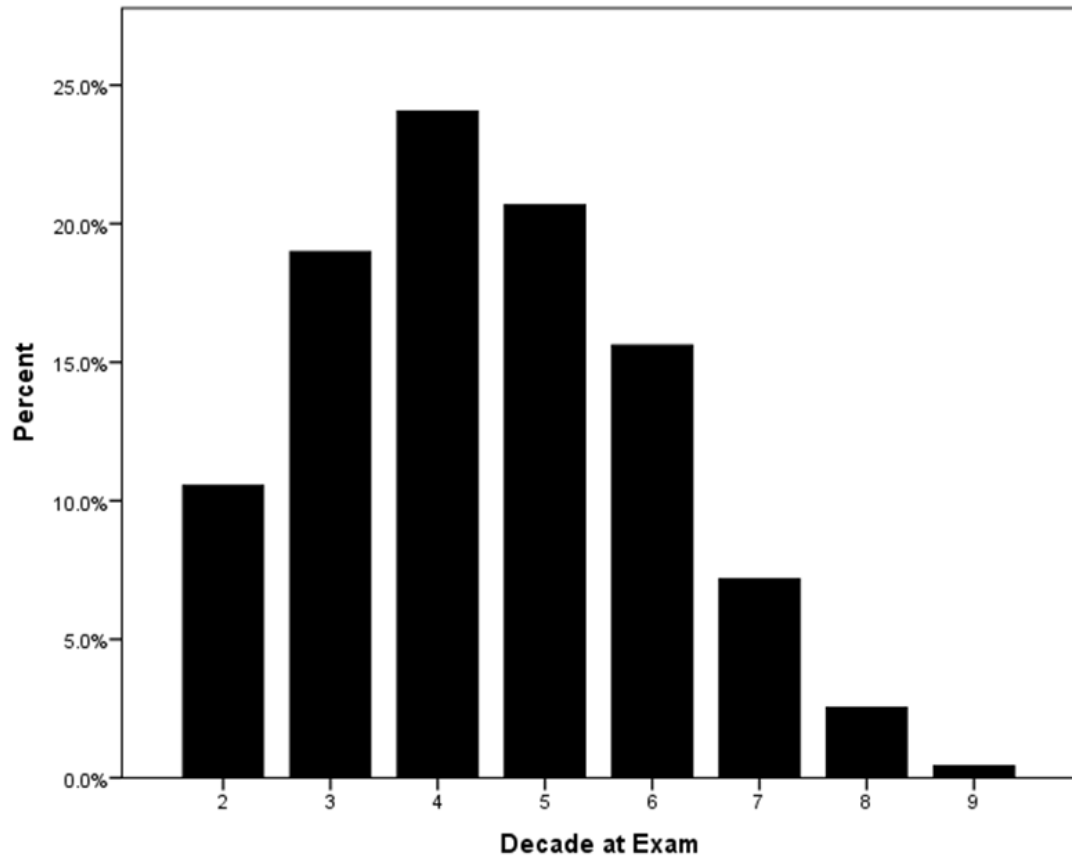
Figure 5.1: Distribution of Age (by Decade) at Initial Examination (n=237)

The mean number of years of bioptic driving for those with previous driving experience was 10±5 vs. 11±5 for drivers without previous experience. Drivers without previous experience were significantly more likely to have been involved in an MVC ($p < 0.001$), have a conviction associated with an MVC ($p = 0.008$), have multiple MVC ($p < 0.001$), and have multiple MVC-related convictions ($p = 0.007$). Table 5.3 contains a comparison of drivers with and without previous experience on these various MVC indicators. Table 5.4 shows the MVC rate for drivers by years of bioptic licensure.

Table 5.5 shows the results for the Cox proportional hazards simple bivariate regression models for visual factors using an event definition of involvement in an MVC. Notation of a progressive visual condition at the initial vision examination and documented nystagmus were significantly associated with involvement in an MVC. It should be noted that there were significant relationships between these two factors and previous driving experience. Only approximately 8.1% of drivers who did not have previous experience had notation of a progressive visual deficiency, compared with 53.3% of drivers who did have previous experience. Likewise, drivers without previous experience were more likely to have nystagmus. Visual acuity, contrast sensitivity, horizontal visual field, and all other measured visual factors were not significant predictors of MVC in the Cox models.
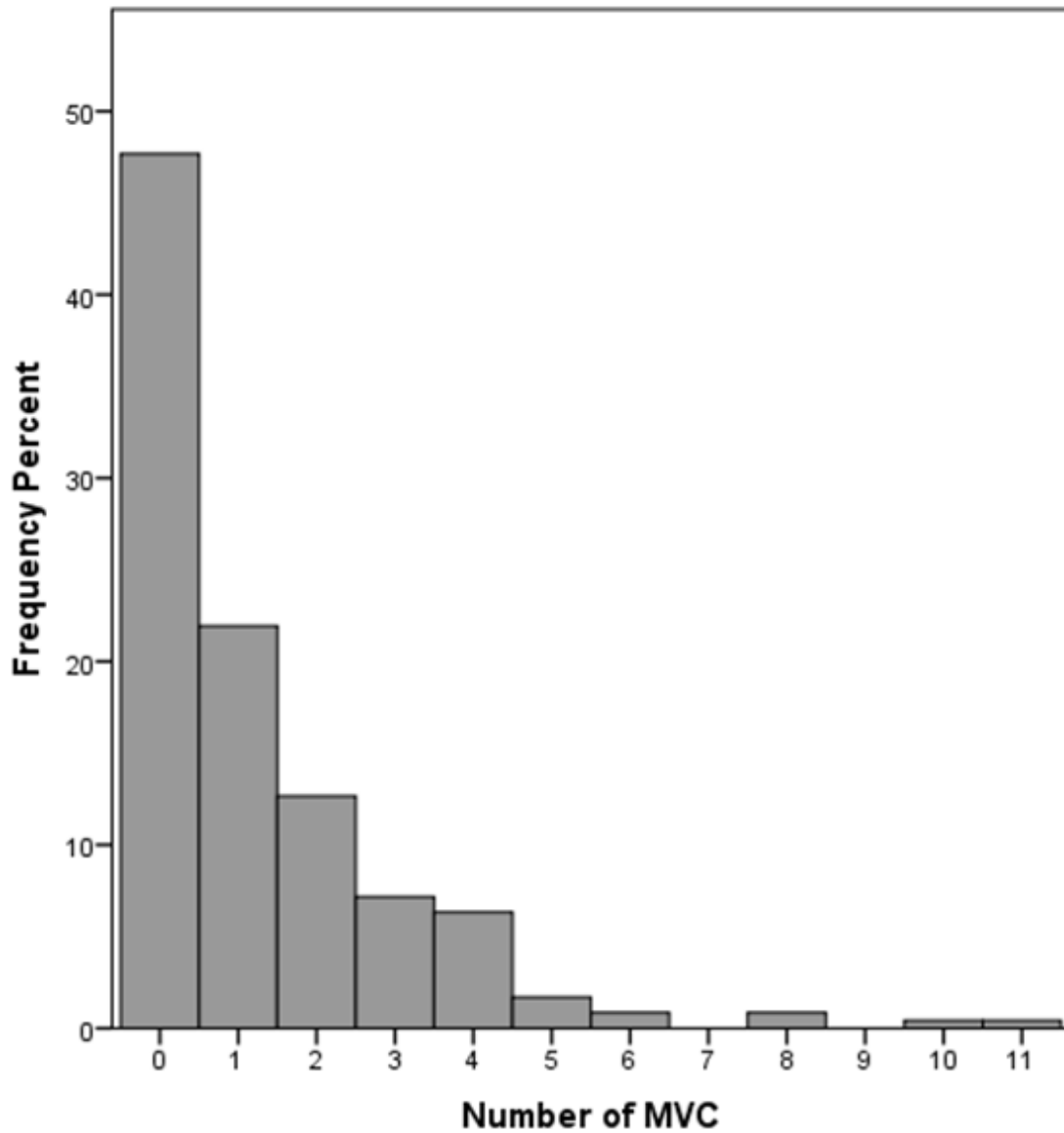
Figure 5.2: Distribution of MVC by Number per Driver (n=237)
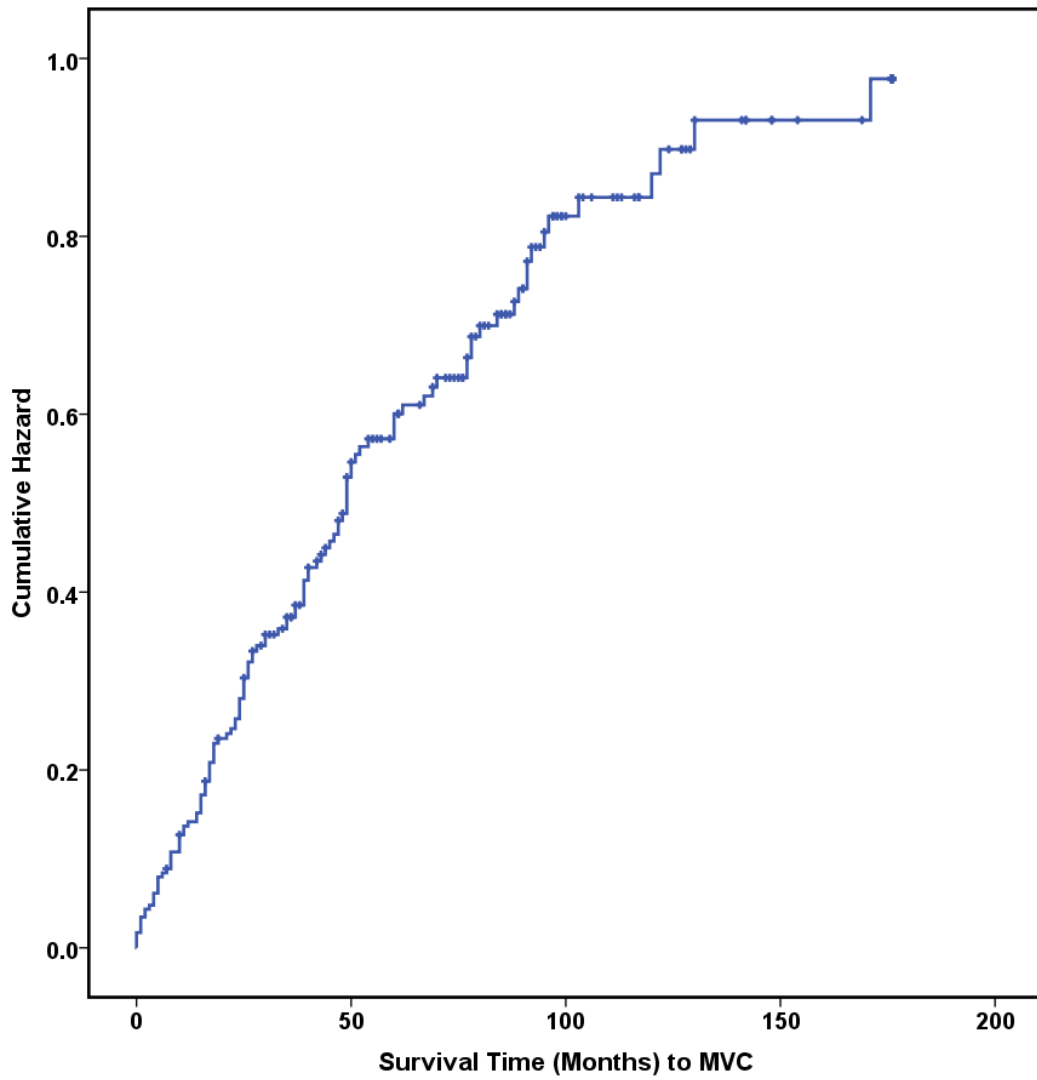
Figure 5.3: Cumulative Hazard Plot for MVC Involvement (n=237)
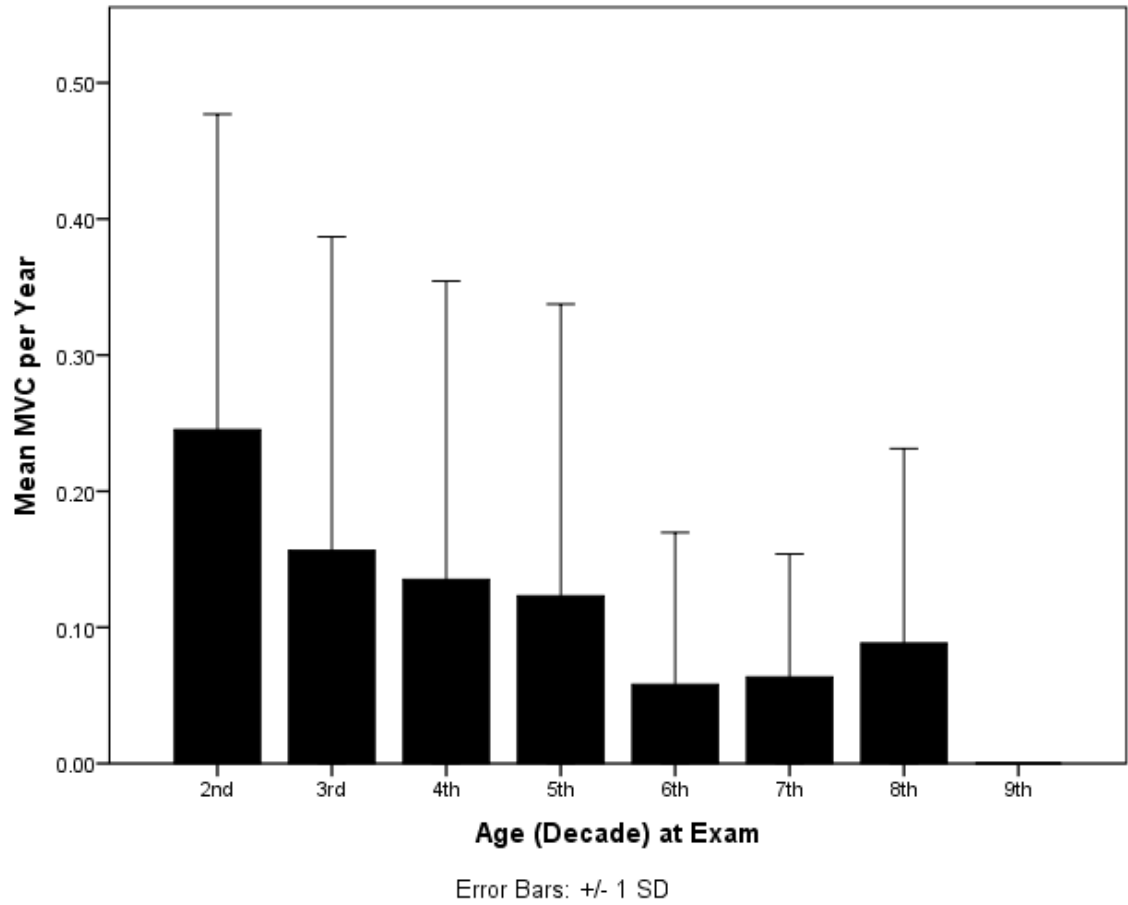
Figure 5.4: Mean MVC per Year by Age (Decade) (n=237)

Table 5.3: Comparison of MVC Data between Drivers With and Without Previous Driving Experience (n=237)

P values are from Chi-squared or median tests

	Previous Driving Experience	No Previous Driving Experience	P Value
Years Bioptic Licensure (mean ± SD)	10±5	11±5	0.137
Any MVC (%)	40.9	67.7	**< 0.001**
Any MVC Conviction (%)	27.7	44.4	**0.008**
Multiple MVC (%)	18.2	46.5	**< 0.001**
Multiple MVC Conviction (%)	9.5	22.2	**0.007**
Number MVC (mean ± SD)	0.78±1.39	1.85±2.00	**< 0.001**
MVC/Years of Licensure (mean ± SD)	0.077±0.14	0.20±0.25	**< 0.001**

Table 5.4: MVC per Year by Years of Bioptic Driving Experience Category (n=237)

Years of Bioptic Licensure	MVC per Year of Licensure (mean ± SD)
0-5 years	0.14±0.30
6-10 years	0.14±0.23
11+ years	0.12±0.13

Table 5.6 shows the results for the Cox proportional hazards simple bivariate regression models for demographic, training, and testing factors using an event definition of involvement in an MVC. Gender was not associated with MVC (p=0.228), but older age was significantly associated with lower risk of MVC (p < 0.001). Previous (without-bioptic) licensure status was associated with lower risk of MVC (p < 0.001), with 41% of drivers with previous licensure involved in an MVC versus 67% of drivers without previous licensure. The relative risk of MVC for drivers with previous experience was 0.444. Figure 5.5 shows the cumulative hazard functions for drivers with previous experience and drivers who had not previously been licensed. The number of non-MVC related convictions per year was significantly correlated with the number of MVC per year of licensure (Spearman rho = 0.46, p < 0.001). Construction of a multivariate model for MVC involvement produced a model containing previous driving experience and notation of a progressive visual condition. As in creation of multivariate models in Chapter 4, the fact that variables like age and nystagmus were not included in multivariate models is likely related to the interrelationships of these variables with previous experience and notation of progressive condition (see figure 4.2).

Table 5.7 shows the results for the Cox proportional hazards bivariate regression models for visual factors using an event definition of involvement in an MVC and an associated conviction. In contrast to the models using an event definition of any involvement in an MVC, no visual factors were significantly

associated with an MVC conviction. There were, however, trends in associations for notation of progressive visual condition and color vision status.

Table 5.8 shows the results for the Cox proportional hazards bivariate regression models for demographic, training, and testing factors using an event definition of involvement in an MVC and an associated conviction. Gender was not associated with an MVC conviction (p = 0.47). Age was significantly associated with MVC conviction (p =0.003). Previous licensure status was significantly associated with MVC conviction (p = 0.006). A multivariate model contained only age.

5.3.2 Comparison of MVC Rate of Bioptic Drivers and Non-Bioptic Drivers

Between 1 and 42 non-bioptic control drivers were identified for each of 231 bioptic drivers with daytime or fulltime bioptic licenses, for a total of 3553 control drivers. For 8 bioptic drivers, no control drivers matching on the age, sex, population density, and last license renewal criteria were found, and so these drivers were not included in the analysis. Bioptic drivers with time since last licensure of less than 2 months or more than 48 months (indicative of the fact that the last license was not renewed before expiration) were also eliminated from the analysis, leaving a total of 206 bioptic drivers and 3285 matching control drivers.

Table 5.5: Cox Regression Model Statistics for Simple Bivariate Associations among Patient Visual Characteristics and Involvement in an MVC (n=237)

Patient Characteristic	Hazard Ratio	95% CI for Hazard Ratio		P Value
		Lower	Upper	
Progressive Condition	0.489	0.324	0.739	**0.001**
Visual Acuity	1.25	0.281	5.57	0.768
Contrast Sensitivity	2.08	0.923	4.67	0.077
Color Vision	1.33	0.886	1.99	0.170
Nystagmus	1.56	1.07	2.29	**0.021**
Visual Field	1.01	0.993	1.01	0.536
Low Luminance VA	0.477	0.116	1.97	0.306
Glare Sensitivity	0.765	0.361	1.62	0.483
Glare Recovery	0.993	0.965	1.02	0.610

Table 5.6: Cox Regression Model Statistics for Bivariate Associations among Patient Demographic Characteristics, Training, and Highway Patrol Testing Results and Involvement in an MVC (n=237)

Patient Characteristic	Hazard Ratio	95% CI for Hazard Ratio		P Value
		Lower	Upper	
Age	0.975	0.962	0.987	**<0.001**
Female Gender	0.790	0.539	1.16	0.228
Prev. Experience	0.444	0.310	0.634	**<0.001**
Hrs. Training	1.01	0.988	1.03	0.438
Road Test Failure	1.47	0.779	2.77	0.235
Road Test Points Deducted	1.01	0.996	1.02	0.182
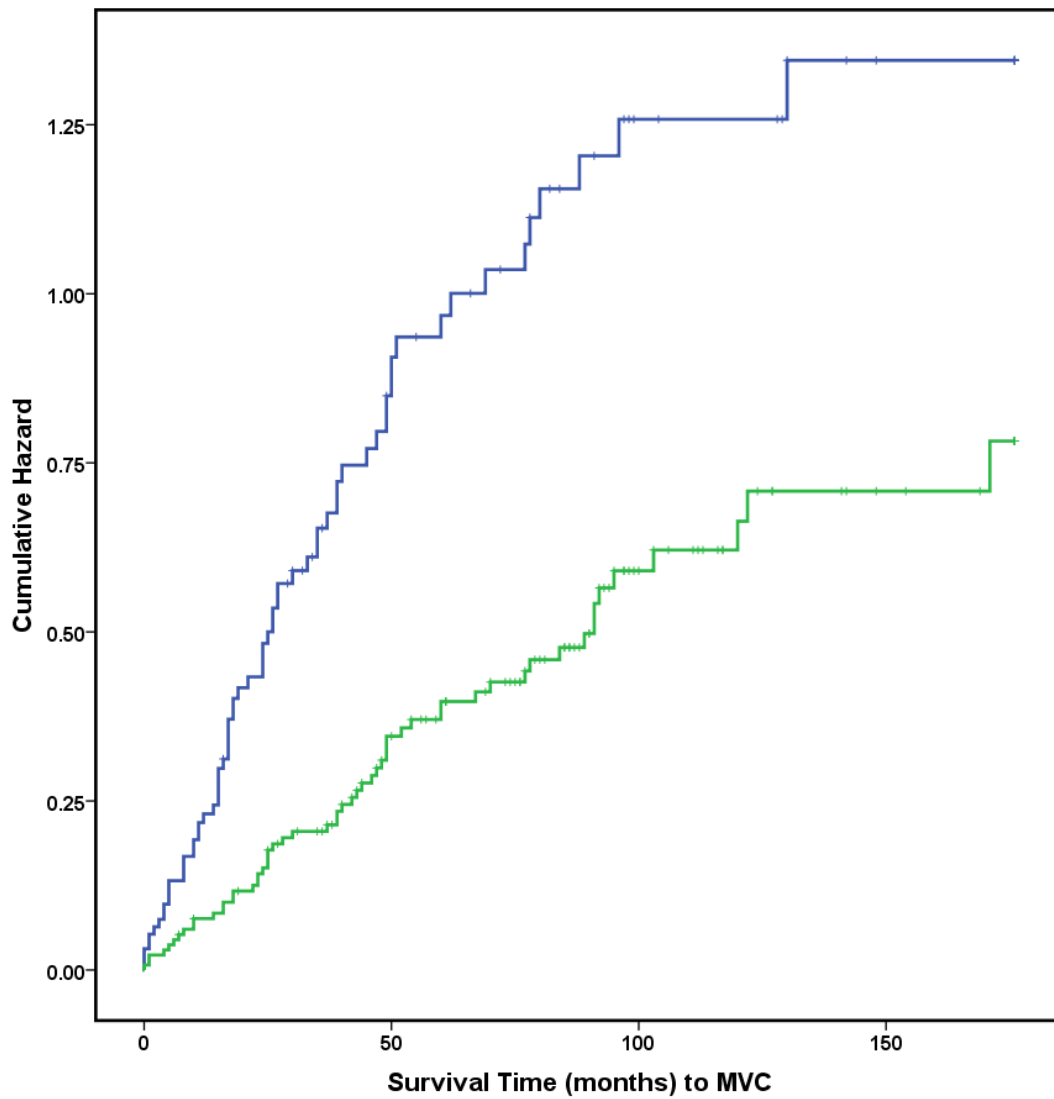
Figure 5.5: Cumulative Hazard Plot for MVC Involvement by Previous Driving Experience (n=237)

The upper line represents drivers who had never previously been licensed and the lower line represents drivers with previous experience.

16% of the bioptic drivers analyzed were involved in an MVC since the last license renewal (mean licensure time = 23.5 months). The mean number of MVC for bioptic drivers was 0.113 ± 0.32 per year since last licensure and 0.0322 ± 0.045 for "composite" non-bioptic control drivers (a ratio of 3.5 times more for bioptic drivers than controls). The ratio of total convictions per year for bioptic drivers compared to non-bioptic composite control drivers was 1.5.

Table 5.7: Cox Regression Model Statistics for Bivariate Associations among Patient Visual Characteristics and MVC with an Associated Conviction (n=237)

Patient Characteristic	Hazard Ratio	95% CI for Hazard Ratio		P Value
		Lower	Upper	
Progressive Condition	0.633	0.385	1.04	0.072
Visual Acuity	0.992	0.153	6.42	0.993
Contrast Sensitivity	1.26	0.500	3.18	0.625
Color Vision	1.50	0.928	2.41	0.098
Nystagmus	1.24	0.779	1.98	0.362
Visual Field	1.01	0.989	1.01	0.835
Low Luminance VA	0.257	0.042	1.57	0.141
Glare Sensitivity	0.616	0.194	1.96	0.413
Glare Recovery	1.01	0.967	1.04	0.924

Table 5.8: Cox Regression Model Statistics for Unadjusted Associations among Patient Demographic Characteristics, Training, and Highway Patrol Testing Results and MVC with an Associated Conviction (n=237)

Patient Characteristic	Hazard Ratio	95% CI for Hazard Ratio		P Value
		Lower	Upper	
Age	0.977	0.962	0.992	**0.003**
Gender	0.842	0.529	1.34	0.470
Prev. Experience	0.544	0.352	0.840	**0.006**
Hrs. Training	0.993	0.963	1.03	0.639
Road Test Failure	1.90	0.838	4.30	0.124
Road Test Pts.	1.01	0.978	1.03	0.722

5.4 Discussion

We have performed a study of the safety of bioptic drivers in Ohio, and the visual and demographic characteristics of these drivers that are associated with safety. We found a motor vehicle collision (MVC) rate of 0.13 MVC per year of bioptic licensure. In construction of a multivariate time-to-event model for MVC involvement, we found a significant association between MVC and lack of previous driving licensure.

We attempted to determine whether drivers involved in MVC were cited for those collisions by assessing whether a conviction was noted in the driving record that corresponded to the MVC in question. We found that approximately 35% of the bioptic drivers studied had one or more convictions related to an MVC. This method for determining fault in MVC is certainly imperfect, as there is not a direct link between convictions and MVC in the driving record. In the future we will attempt to ascertain fault for all MVCs more precisely by examining individual police reports. These reports contain more detailed descriptions of the collisions and whether each driver was cited. As previous studies have found that bioptic drivers may be at greater risk for fault in an MVC than non-bioptic drivers[11], this is an important area of study.

This is the first study we are aware of that has investigated the relationships among various patient visual factors and risk of motor vehicle collisions for bioptic drivers. Though nystagmus and the notation of a progressive visual deficiency were associated with MVC, both of these associations were no

longer significant after accounting for previous driving experience. Other commonly-measured visual factors, such as visual acuity, contrast sensitivity, and horizontal visual field were not associated with MVC in univariate or multivariate models. As in the previous chapter on training and testing, it appears that previous driving experience is an important predictor of driving outcomes in bioptic drivers. This suggests there may be some other intervention or training strategy which may help bioptic drivers without previous experience achieve similar MVC rates as those with previous experience. It also must be noted, however, that the rates we have reported are MVC per year of licensure. It is possible that there are differences in the actual number of miles driven between experienced and inexperienced drivers that explain at least some of the difference in MVC rates.

The issue of driving exposure in miles driven is a crucial one. As Owsley has pointed out previously,[2, 20] the lack of knowledge regarding how many miles bioptic drivers drive each year is a key weakness in the few existing studies of MVC in bioptic drivers, the present study included. To date, the only reports of mileage driven by bioptic drivers come from self report studies,[6, 42] and none of these studies obtained information on the number of MVC. These survey studies have reported that miles driven per year for bioptic drivers are similar to non-bioptic drivers. A future goal of our research is to survey drivers included in this study regarding their mileage in order to produce MVC rates per mile driven, rather than per year. Certainly other technologies being used to study bioptic

driving, such as GPS systems in cars, could be of use in answering these questions as well.

In Chapter 4, we found that the number of hours of training that a bioptic driver received was associated with poorer scores on the Highway Patrol road test and an increased likelihood of failure of some portion of the licensure test. However, we did not find any associations between hours of training received or Highway Patrol test failure or score and risk of MVC involvement. The relationship between road testing and driver safety is relevant because road testing is frequently suggested as an alternative to rigid vision standards for people with visual impairments seeking licensure. In fact, in some U.S. states, people are allowed to prove their driving ability on a road test for licensure without meeting the vision standard of that state. The ability to make conclusions of the usefulness of road testing in predicting MVC is obviously limited by the fact that all participants in the present study passed the licensure test. Therefore, we may only conclude that neither having failed the test at least once before passing it nor the score on the first road test are associated with MVC.

There are several previous studies of driving safety that estimated the rate of MVC for bioptic drivers. Lippman, Corn, and Lewis[11] found 22 MVC for 64 bioptic drivers over a ten year study period in Texas, but did not report an adjustment for number of years of licensure. Janke[65] found a rate of approximately 0.074 MVC per year over a two-year study period in California. Clarke,[66] also in California, reported a very similar MVC rate for bioptic drivers of

0.077 per year. In the present study, we found rates for bioptic drivers of approximately 0.13 MVC per year in our study of visual and demographic associations with MVC and 0.11 per year in our comparison of MVC rates with non-bioptic drivers. The average driver in our study of visual and demographic associations had approximately 10 years of bioptic licensure, which is considerably longer than for drivers in both California studies. It is difficult to compare the rates from the California studies to the rate from the present study because driving conditions may vary between states, as may methods of record keeping for crashes. However, one can consider other statistics from non-bioptic driving samples to aid in comparisons. The rate of fatal MVC per mile driven in Ohio has historically been similar (and perhaps slightly lower) to that of California.[70] These statistics suggest that the traffic conditions in the two states may not be dissimilar. Also, in our comparison study of MVC rates we found an MVC rate for a control group of non-bioptic drivers who were matched on age, sex, population density, and last license renewal date of the bioptic drivers studied of 0.032 MVC per year of licensure. The rate in the California study by Clarke for non-bioptic control drivers was 0.039 per year,[66] which suggests that the traffic conditions may be comparable. However, in 2010 there were 416,490 MVC in California and 300,164 MVC in Ohio (1.4 to 1 ratio), though California has approximately 2.6 times as many licensed drivers.[71-72] This suggests that the number of MVC reported per driver is lower in California. Therefore, it is not

entirely clear how driving conditions in each state affect bioptic drivers and caution must be exercised in comparing the MVC rates.

Another way to put the MVC rate for bioptic drivers in Ohio in context is to compare it to the MVC rate of a control group of non-bioptic drivers in Ohio. The group of bioptic drivers had an MVC rate of 0.113 MVC per year compared to 0.032 MVC per year in the control group. Previous studies have found bioptic drivers to have generally higher rates, ranging from 1.3 to 2.3 times the rate of non-bioptic control groups. In the present study, the rate of MVC per year for bioptic drivers was approximately 3.5 times that of the control group. To put this in context, it is useful to consider the MVC rates of other groups. For instance, a California study reported that the MVC rates of drivers with other medical restrictions ranged from 2.3 to 4.8 times those of control drivers.[65] A recent study reported that use of a cellular telephone while driving, even if used hands-free, resulted in a four-fold increase in collision rate.[73] A study of teenage drivers reported a per-mile MVC risk eight times that of middle aged drivers.[74] These examples indicate that there are other groups of licensed drivers with known elevated risks. These groups are also ones that have been subject to extra regulations for obtaining and maintaining licensure, and may provide useful examples when considering programs to improve road safety.

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. The predictors of

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involvement in multiple MVC included a lack of prior licensure and the number of

non-MVC convictions. The combination of higher MVC rates for bioptic drivers

and the wide variation in MVC occurrence within this group 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 we found very few visual factors to be associated with MVC

occurrence. One patient factor that was strongly associated with MVC

occurrence was previous, non-bioptic, driving experience. Further work could

investigate what specific attributes might be present in experienced drivers that

result in fewer MVC and whether there are training or education programs that

could aid novice drivers in attaining these attributes. The significant correlation

between the rate of non MVC-related convictions (e.g. speeding) and the MVC

rate suggests that monitoring of this type of conviction post-licensure may be

useful in identifying at-risk drivers.

Another area of potential future research is testing for licensure. Though

this study only examined drivers who had already passed the Ohio Highway

Patrol test for licensure, having failed a portion of the test at least once and the

score on the first road test were not predictive of future MVC. It is possible that

there might be enhanced road testing techniques that would better identify bioptic

drivers at risk for MVC. It is also possible that a combination of more rigorous

testing for licensure and directed training for candidates that fail portions of the

testing could result in better MVC rates. A report by the National Highway

Transportation Safety Administration recently pointed out that other countries often have more difficult tests for licensure than the United States does, and have shown a trend toward increasing the difficulty of their licensure testing and instituting graduated licenses in an effort to reduce fatalities in young, novice drivers.[75] There are also some examples of graduated licensing program in U.S. states that appear to be effective for this purpose.[75-76] It is possible that there are useful lessons in these efforts to increase safety in new, normally-sighted drivers that may be of use for bioptic driving programs.

There has been debate about what the requirements for licensure for bioptic drivers should be since bioptic drivers first began to be licensed. Several suggestions that came from the initial debates regarding bioptic driving and driving with vision impairment generally may be useful to consider again now. For instance, Feinbloom suggested that bioptic drivers have yearly vision and road tests.[6] Fonda, though against bioptic driving, thought that drivers with low vision should be allowed to drive with a license subject to revocation if annual reviews of the driver's MVC rate showed the rate to be above that of the average driver.[8] In considering how best to allow safe bioptic drivers to continue to enjoy the tremendous quality of life, employment, and other benefits associated with driving while reducing possible hazards to the public, it may be that more post-licensure monitoring of the driving skills and driving records of bioptic drivers is warranted.

The study described in this chapter has several limitations. The data collection was retrospective, which did not allow the level of standardization of vision and other measurement that would be possible in a prospective study. The driving record does not attribute fault in cases of MVC, and so it was necessary to approximate whether bioptic drivers were at fault in each MVC using convictions listed in the driving record. Future studies will investigate police reports in order to more definitely determine fault. Though the control group of non-bioptic drivers was matched within ± 4 months of the date of last licensure, the exact time from last licensure to the date of the driving record was not known for each control driver. For this reason, the MVC rate for control drivers presented in the study is an estimate that assumes that, on average, the time since last licensure was the same for control drivers as for bioptic drivers.

Chapter 6

Conclusions and Future Research

6.1 Conclusions

In the study described in this dissertation, we examined visual and demographic associations among obtaining a bioptic driving license, training and road testing results, and motor vehicle collisions in patients with low vision. We also compared the collision rate of bioptic drivers to that of a control group of non-bioptic drivers matched on age and sex. We did not identify any significant associations between visual and demographic factors and obtaining licensure after an initial vision examination.

Several factors were significantly associated with the amount of training documented for candidates for licensure, including age and previous non-bioptic driving experience. The amount of training documented was associated with road testing results, but not with driving safety after licensure. Previous driving experience was also significantly associated with occurrence of motor vehicle collisions in bioptic drivers, with drivers without previous experience having approximately 2.5 times as many collisions per year of licensure as those with previous experience. Other significant independent associations with motor vehicle collisions in bioptic drivers included younger age and the number of non-

collision related convictions. Nystagmus was independently associated with MVC, but no other patient visual factors were associated. The patient characteristics with significant associations with MVC are interrelated. Patients with congenital conditions are more likely to be younger, have stable conditions, have nystagmus, and lack previous experience. Previous experience was shown to be a particularly strong predictor of a number of bioptic driving outcomes.

The rate of motor vehicle collisions per year since the last date of licensure for bioptic drivers was approximately 3.5 times that of a group of control drivers matched on age and sex. This is consistent with the few past studies of bioptic collision rates, which have found rates that were higher than those of control groups. It is also consistent with past findings that groups with various medical restrictions have higher collision rates than control groups. This study did not address the actual mileage driven by bioptic drivers, and so no conclusion can be made regarding the rate of collisions per mile driven for bioptic drivers, the visual or demographic associations with that figure, or how bioptic drivers compare to non-bioptic drivers in terms of collisions per mile driven.

6.2 Future Research

There are several areas of research in bioptic driving that should be pursued in the future. One of these is driving exposure in terms of miles driven, which will allow for better comparisons of the safety of bioptic drivers compared to normally-sighted drivers. Another is whether specific training programs or post-

license control programs (e.g. post-licensure road testing or annual review of driving record) can reduce the rate of motor vehicle collisions for bioptic drivers. Other relevant topics for future study include the impact of bioptic licensure on employment, quality of life, and socio-emotional status in people with vision impairment, and on-road driving performance with bioptic devices.

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