Predictors of Driving Exposure in Bioptic Drivers and Implications for Motor Vehicle Collision Rates

THESIS

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Abstract

Purpose: For an individual not eligible for a regular driver’s license due to central visual impairment, 43 states allow for licensure with the aid of bioptic telescope spectacles (BTS). BTS consist of a small telescope lens mounted in the upper portion of a distance prescription lens. There is limited information regarding the driving exposure and road safety of bioptic drivers. The purpose of this study was to determine whether vision or demographic factors predict mileage driven in bioptic drivers and to determine a per mile motor vehicle collisions (MVC) rate.

Methods: Data on visual acuity (logMAR charts), contrast sensitivity (Pelli-Robson or Mars charts), age, sex, and previous driving experience were collected retrospectively from clinic records at the Ohio State University College of Optometry. MVC data was collected from the Bureau of Motor Vehicles database. A modified version of the Driving Habits Questionnaire (Owsley et al., 1999) was administered in person or by mail, and subjects were asked to estimate their yearly mileage. Spearman correlation and Mann-Whitney U tests were performed to determine predictors of driving exposure. Per mile MVC rate was calculated and used to compared to calculated MVC rates in the general population.
Results: 73 licensed Ohio bioptic drivers (48 male) were included. Mean (±SD) age was 51±16 years. Mean (min, max) binocular logMAR visual acuity was 0.66 (1.20, 0.18), or approximately 20/100. Median contrast sensitivity was 1.57 (1.00, 1.95). Reported annual mileage ranged from 100 to 90,000 miles per year, with a mean of 9,746. Age, gender, and previous (non-bioptic) driving experience were not significantly associated with estimated annual mileage. Visual acuity was inversely related to reported mileage (Spearman correlation = –0.286, P = 0.015). Contrast sensitivity was directly related to reported mileage (Spearman correlation = 0.308, P = 0.009). Glare acuity was inversely related to reported mileage (Spearman correlation = -0.261, P = 0.027). The per mile MVC rate was 15.3 MVC per 1,000,000 miles driven.

Conclusion: Visual acuity, contrast sensitivity, and glare acuity are significant predictors of driving exposure in BTS users, with drivers with poorer vision reporting less annual mileage. While older drivers and those with worse vision report driving shorter distances from home, on average BTS users drive a similar number of overall trips. When adjusting for exposure, BTS users may be at increased risk for MVC compared to the overall population.
This document is dedicated to John, Elsie, Mary, Floyd, Col. Bob, and the rest.

And to David, of course.
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Vita

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Field of Study

Major Field: Vision Science

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INTRODUCTION

1.1 BACKGROUND

1.1.1 BENEFITS OF DRIVING

Especially in places where there is limited widespread access to public transportation options, driving is often an important aspect of independence. For individuals who are no longer able to drive, the loss of driving privileges has been reported to result in an increased rate of depression and an increased feelings of isolation. 1-3

1.1.2 DRIVING IN A LOW VISION POPULATION

A recent study found that in the population of visually impaired patients surveyed who did not drive, 85% reported that they had stopped driving because of their impaired vision. 4 For people with low vision, those who could not drive reported lower quality of life regardless of their visual acuity. 5 For many with visual impairment, a bioptic license may be the only way to maintain driving privileges.
1.2 BIOPTIC TELESCOPE SPECTACLES

1.2.1 DESCRIPTION OF BIOPTIC TELESCOPE SPECTACLES

For an individual not eligible for a standard driver’s license due to central visual impairment, currently 43 U.S. states allow for licensure with the aid of bioptic telescope spectacles (BTS). BTS consist of a small telescope lens mounted in the upper portion of a distance prescription lens (the “carrier lens”) of a pair of glasses (Figure 1.1).

Figure 1.1 Use of Bioptic Telescope Spectacles.

Diagram of BTS demonstrating the upper positioning of the telescope which is accessed by the driver with a slight downward head tilt. Image from Ocutech.com.
While driving, the user most frequently uses the carrier lens portion of the device; however, for instances that require the driver to perform a specific distance visual task, the user can tilt her head downwards and briefly spot through the telescope portion of the device. Examples of these specific tasks include reading distant street signs and spotting traffic signals. Use of the BTS allows a driver with impaired vision to view distant objects much sooner than would be possible without the device.

1.2.2 BENEFITS OF BIOPTIC TELESCOPE SPECTACLES

Proponents of bioptic driving often point to its importance in maintaining independence, emotional health, and employment for people with vision impairment. This is especially important in a society that is heavily dependent on automobiles for transportation. A recent survey-based study of bioptic drivers argued for the importance of the devices to those who use them, reporting that about 75% of bioptic drivers surveyed rated the telescope device as “very helpful” and concluded that bioptic devices meet the needs of drivers with moderate vision impairment. For people with low vision, bioptic driving provides an important option to access all of the benefits of driving and avoid the negative outcomes of loss of driving privileges.

1.2.3 CONTROVERSY SURROUNDING BIOPTIC TELESCOPE SPECTACLES

The use of BTS for driving has been controversial since its introduction. Those opposed to bioptic devices for driving have argued that the devices are not useful in practice but rather only for passing the vision portion of the driving exam and that
bioptic drivers are a public safety hazard\textsuperscript{7,8}. There are several common concerns raised about the use of the devices for driving. First, when viewing through a telescope the visual field is reduced by a factor of the lens magnification. However, when used to drive, the vast majority of time is spent viewing through the carrier lenses and not the telescope. In this way, BTS are used in a similar fashion as car mirrors—routinely and briefly consulted for additional information by the driver. Also, BTS are usually fit monocularly, which may allow the fellow eye to detect peripheral hazards when spotting through the telescope.

Another potential concern arises as an optical consequence of the high magnification of telescopes—the ring scotoma. These telescopes work by magnifying a portion of space. When viewing this magnified space, a blind zone is created that encircles the central field of vision. It is important to distinguish that this effect is a direct consequence of magnification not the telescope housing unit. If the BTS is fit monocularly, however, the fellow eye may be able to detect peripheral objects that are obscured in the ring scotoma\textsuperscript{9}.

When using the BTS monocularly, there is an absence of binocular depth perception. This being said, there are still many monocular cues to depth perception that offer valuable information to a bioptic driver. In fact, driving without binocularity occurs anytime a person with monovision glasses or contact lenses operates a vehicle. Regardless of these facts, bioptic drivers only use their telescopes for brief spotting tasks.
1.3 HISTORY AND THE OHIO BIOPTIC DRIVING PROGRAM

1.3.1 HISTORY OF BIOPTIC DRIVING

The concept of using a bioptic device to assist in driving was introduced in the United States in the late 1950s by the optometrist William Feinbloom. Feinbloom reported that he first considered this when a patient he fit in bioptic telescope spectacles reported that he used the device to drive. The first reports of bioptic devices for driving originated in the 1970s. At this time several investigators reported that their patients did quite well driving with bioptic devices. Currently, forty-three US states including Ohio allow for the licensure with BTS. Additional countries involved in such programs are Canada and the Netherlands. No international or national standardization for license requirements yet exists.

1.3.2 HISTORY OF THE BIOPTIC PROGRAM IN OHIO

The bioptic program first began in Ohio as a pilot program in 1990. The current program was initiated in April of 1996. These guidelines established the visual requirements for entry into the bioptic program. To obtain an Ohio license, regardless of whether the driver plans to use a BTS, he or she must pass the same vision standards. Visual acuity and visual field requirements are the same; however, a bioptic driver may qualify by using his or her BTS. Daytime and nighttime driving privileges are handled separately and require different training experiences.
1.3.3 STEPS TO OBTAIN AN OHIO DRIVERS LICENSE WITH BIOPTIC TELESCOPE

SPECTACLES

Entry into the Ohio bioptic driving program occurs through one of three routes (Figure 1.1). A potential candidate can be referred from his or her optometrist or ophthalmologist or through a state agency. Additionally, if a person fails the vision portion of his driver’s license renewal at the Bureau of Motor Vehicles, she can be referred from there. Self-referral for consideration in the bioptic program is also permissible.

In Ohio, the majority of potential bioptic drivers have an initial vision examination at the College of Optometry at The Ohio State University. The vision examination at the College of Optometry includes testing of visual acuity, contrast sensitivity, peripheral visual fields, glare acuity and recovery, low luminance visual acuity, and color vision. Candidates can also be evaluated at another center in Akron.

If at the end of a series of testing the optometrist determines that the candidate visually qualifies, the candidate will be sent to be fit for a BTS and trained on its use. Then the potential drivers must receive on-road training conducted by a certified driving rehabilitation specialist. After an average of 20 to 50 hours of training,¹²,¹³ the driver must pass an on-road examination conducted by the Ohio Highway Patrol in order to become licensed.

Licensed bioptic drivers are required to return for additional vision testing every one or four years depending on the initial vision examiner’s recommendation. A recommendation for one year renewal requirements is usually made in the instances in
which a visual condition is determined to be progressive or unstable. Drivers with non-
progressive visual conditions typically warrant a four year renewal schedule.

Initial licensure permits daytime only driving with BTS. After one year, the driver
can be eligible for nighttime privileges if he or she has not had any driving convictions
or at-fault MVC within the previous 12 months. The candidate must also have her
vision reassessed to determine if the vision with the telescope is adequate to meet the
more stringent night-time visual acuity requirements. After additional nighttime driving
training hours, the driver will be required to pass an additional on-road night driving
test through the Ohio Highway Patrol.
Figure 1.2 Flow chart of process for Ohio licensure and renewal with bioptic telescopic lenses.
1.3.4 Visual Requirements for Ohio Driving Licensure Eligibility

Visual requirements for licensure in the state of Ohio are defined by the Bureau of Motor Vehicles (BMV) as stated by the Ohio Administrative Code. Within this document, visual acuity and visual field are set as the primary visual restrictive benchmarks for licensure.

1.3.4.1 Visual Acuity

For a binocular applicant, a combined visual acuity of 20/40 or better is required for unrestricted driving privileges. If visual acuity is worse than 20/40 but at least 20/70, then the applicant can qualify for a day-time only restricted license. Corrective eyewear, such as contact lenses or spectacles, may be worn during testing; however, the corrective eyewear will be required for driving if needed to meet the standards for visual acuity. Applicants with visual acuity worse than 20/70 are denied licensure.

An applicant in Ohio is considered monocular if his or her visual acuity is worse than 20/200 in the worse eye. For these monocular applicants, a visual acuity of 20/30 or better is required for unrestricted driving privileges. For applicants with acuities worse than 20/30 but at least 20/60, a day-time only restricted license may be granted. If visual acuity is worse than 20/60, licensure will be denied.

1.3.4.2 Visual Field

To qualify for an unrestricted driver’s license, the applicant must have at least 70 degrees of visual field on both sides of the fixation point. If the applicant has at least
45 degrees to one side of fixation, he may still qualify if the other side has at least a visual field of 70 degrees. In this case, the applicant would be required to have an outside mirror on his vehicle on the side with the more limited visual field. Anyone who does not possess a visual field of at least 70 degrees to one side and 45 degrees on the other side will be denied licensure. 14

1.3.4.3 ADDITIONAL TESTING

If an applicant fails to pass the vision requirements at the BMV, he will be referred to an optometrist or ophthalmologist. Additional testing at this visit could include history, Bailey-Lovie acuity, refraction, contrast sensitivity, low luminance acuity, glare acuity, glare recovery, color vision, and an ocular health examination. 14 This additional testing is characteristic of bioptic intake examinations and does not characterize testing at all other sites.

1.3.4.4 VISUAL REQUIREMENTS FOR NON-BIOPTIC DRIVERS AND BIOPTIC DRIVERS

The visual requirements for an Ohio driver’s license are the same regardless of whether the applicant plans to use BTS or not. However, an applicant wishing to enter into the Ohio bioptic driving program may use a BTS in addition to any necessary corrective eyewear in order to meet the visual requirements.
1.4 Driving Exposure

1.4.1 Previous Studies Evaluating Driving Exposure in the General Population

In 2000 the United States Department of Transportation Federal Highway Administration estimated that the average annual mileage driven was 13,476 miles per person per year. For males the average annual mileage was 16,550 miles per person per year compared to 10,142 miles per person per year for females. When considering yearly mileage based on age, drivers between the ages of 35 and 54 drove the most miles at 15,291 miles per person per year. Young drivers between the ages of 16 and 19 and older drivers over the age of 65 drove the fewest number of yearly miles at 7,624 miles per person per year and 7,646 miles per person per year respectively. Drivers between the ages of 20 and 34 drove an average of 15,098 miles per person per year while drivers between the ages of 55 and 64 drove an average of 11,972 miles per person per year.  

1.4.2 Previous Studies Evaluating Driving Exposure in the Bioptic Driving Population

There has been limited research published on driving exposure in the bioptic driving population. In Feinbloom’s 1977 survey of 300 bioptic drivers he determined that the self-reported yearly mileage average was 12,500 miles per person per year. The range of self-reported yearly mileage was 4,000 to 45,000 miles per person per year.  

More recently, Bowers estimated an average self-reported annual exposure of 11,544
miles per person per year. Owsley estimated that bioptic drivers drove an average of 13,000 miles per person per year, also by self-report. Both of these more recent studies estimated mileage using the Driving Habits Questionnaire, a validated survey of driving behavior.

1.5 Driving Safety

1.5.1 Previous Studies Evaluating Driving Safety in the Presence of Vision Impairment

When comparing older drivers who had been involved in a car crash within the past five year period to older drivers not involved in a crash, restricted visual field and glaucoma were found to be significant crash predictors. Older drivers with restricted visual fields were more likely to be involved in a crash compared to older drivers with a normal visual field.

When considering drivers with central vision loss, Szlyk et al. compared driving skills of ten older subjects with macular degeneration (average visual acuity of 20/70) to eleven similarly aged drivers with normal vision. Both groups underwent a series of cognitive and visual tests, a driving simulator program, and an on-road driving evaluation. The macular degeneration group was found to have poorer simulator and on-road driving performance compared to the normal vision group. This included delayed braking response times to stop signs, slower driving speeds, poor lane positioning, and increased simulator accidents. Interestingly, the macular degeneration group was involved in fewer self-reported collisions and was convicted of fewer traffic
offenses than the normal vision group. Subjects with macular degeneration reported compensating for their reduced vision by taking fewer driving risks, such as driving only in familiar areas and self-restricting driving to daytime only. The authors concluded that risk taking while driving was the most significant predictor of accidents and traffic offenses.

1.5.2 Previous Studies Evaluating Driving Safety in the Bioptic Population

There is limited information available regarding the road safety of bioptic drivers. A few studies have shown MVC rates 1.34 to 3 times higher in bioptic drivers than control groups.\textsuperscript{20,21} These rates are comparable to the rates of drivers with other medical restrictions.\textsuperscript{21} In Feinbloom’s published study of 300 low vision bioptic drivers, he reported that none of these drivers suffered an accident causing bodily harm or severe property damage. The drivers in this sample had between one and ten years of bioptic driving experience, and reported that they tended to self-restrict their driving to avoid hazardous situations.\textsuperscript{10} Dougherty et al. recently published the first study of how visual and demographic factors were related to collisions in bioptic drivers.\textsuperscript{22} They found no relationship between vision or demographic factors and annual crash rate. There has not been a published study, however, of how visual or demographic factors affect mileage driven. \textit{Table 1.1} summarizes the results of major published studies on driving safety in the bioptic driving population.
Table 1.1  Summary of Bioptic Safety Studies. (Adapted from Dougherty et al. 22)

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Bioptic Drivers Studied</th>
<th>Method of MVC Determination</th>
<th>Summary of Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korb 11</td>
<td>26</td>
<td>Survey</td>
<td>No bioptic drivers reported any MVC in 32 person-years of driving.</td>
</tr>
<tr>
<td>Feinbloom 10</td>
<td>300</td>
<td>Survey</td>
<td>Average self-reported yearly mileage by drivers was 12,500 miles/years (4,000 to 45,000). No bioptic drivers self-reported any “serious” MVC with injury.</td>
</tr>
<tr>
<td>Janke 21</td>
<td>229</td>
<td>Survey</td>
<td>Bioptic drivers had 1.5x total yearly MVC rate and 2.2x fatal/injury yearly MVC rate than controls. MVC rate for bioptic drivers was 7.4 MVC/100 drivers/year.</td>
</tr>
<tr>
<td>Lippman et al. 20</td>
<td>64</td>
<td>State Records</td>
<td>Bioptic drivers had 1.34x total yearly MVC rate than controls. Bioptic drivers not more likely than controls to have MVC, but if had one were more likely to have more. At fault 82% of time. 22 total MVC self-reported over 10 years.</td>
</tr>
<tr>
<td>Clarke 23</td>
<td>609</td>
<td>State Records</td>
<td>Bioptic drivers had 1.9x total yearly MVC rate and 1.7x fatal/injury yearly MVC rate than controls. MVC rate for bioptic drivers was 7.5 MVC/100 drivers/year.</td>
</tr>
<tr>
<td>Dougherty et al. 22</td>
<td>237</td>
<td>State Records</td>
<td>MVC rate for bioptic drivers was 1.3 MVC/100 drivers/year of bioptic licensure. Previous driving experience predicted driving outcomes for bioptic drivers but visual factors did not.</td>
</tr>
</tbody>
</table>
1.6 RESEARCH NEEDED AND PURPOSE

There have been recent calls for more research on a number of aspects of bioptic driving that are still poorly understood. The characteristics of bioptic drivers can be better categorized through demographics, the nature of their individual visual impairment, previous licensure status, and age at licensure. Training in bioptic driving can be studied by understanding the nature of the training process and the amount of training each bioptic driver receives. Driving skills and performance can be assessed by measuring bioptic driver’s ability to maintain proper speed and lane position as well as by measuring ability to identify traffic signals and signs.

Perhaps the most important remaining questions involve driving safety. This is usually measured by motor vehicle collision rates. A major limitation in all of the published safety studies has been a lack of knowledge about driving exposure (mileage). Driving exposure as determined by the amount of driving performed within a given time period allows researchers to compare exposure rates to the overall driving population. Without information on the driving exposure of bioptic drivers and how it compares to the general population, it is very difficult to interpret studies of the number of collisions in which they are involved over a period of time. If there are large differences in exposure, two drivers with the same absolute number of collisions will in fact have very different crash rates per mile. Also, differences in driving exposure may obscure relationships between visual or demographic factors and collision rates. The purpose of this study was to better describe the driving exposure of bioptic drivers, including mileage traveled, places visited, and number of trips. Additionally, the study
seeks to investigate how vision or demographic factors may influence the mileage driven by bioptic drivers.
METHODS

2.1 RESEARCH DESIGN OVERVIEW

A single-center study was designed to assess the self-reported driving exposure of licensed bioptic drivers in the Central Ohio bioptic Driving Program.

2.2 PERMISSION FOR RESEARCH ON HUMAN SUBJECTS

This study was conducted in accordance with the tenets of the Declaration of Helsinki and the study protocol was approved by the Biomedical Sciences Institutional Review Board (IRB) at The Ohio State University. All subjects granted informed consent and HIPAA research authorization prior to participation in any study procedures.

2.3 INCLUSION AND EXCLUSION CRITERIA

In order to be eligible to participate in the study, participants were required to be established bioptic drivers with valid Ohio driver’s licenses with bioptic restrictions. Participants who were no longer driving but who had previously been licensed to drive using a bioptic telescopic device were also eligible to participate. Potential subjects who used a bioptic telescopic device for visual enhancement but did not complete either day or night training through the Ohio bioptic training program were deemed ineligible for participation.
2.4 Patient Recruitment

Potential participants were identified as candidates for participation by review of clinic schedules at The Ohio State University College of Optometry’s Vision Rehabilitation Service. Vision Rehabilitation schedules were reviewed and bioptic drivers with future appointments for license renewal were identified. Records were reviewed to make determination of eligibility, and eligible potential participants were marked for contact during their renewal examination.

Immediately following the renewal examination (after determination of whether the driver qualified for renewal of licensure), potential participants were given a brief description of the study and asked whether they might be interested in participating by the attending optometrist or study staff. Patients who indicated interest in the study completed it in one of two ways: either they completed the consent process and survey in the examination room immediately following the renewal appointment, or they were sent a packet containing the survey in the mail and were asked to complete it at home and send it back to the investigators.

2.5 Procedures

2.5.1 Mileage Estimation

Each subject completed a modified version of the Driving Habits Questionnaire (see Appendix A) in 16 point font. All questions regarding mileage referred to the previous year. The survey asks participants to specify when they initially became licensed with a bioptic device, and this date was used to determine years of bioptic
driving experience for each participant. Participants were additionally asked whether or not they still drive with a bioptic device. Next, the survey asked participants to approximate how frequently they drive in a typical week to common locations such as the store, an appointment, or a family member’s house. Space was also provided for participants to list any additional locations that they drive to in a typical week. This information, combined with a participant-provided estimate of one-way mileage for each typical trip location, can be used to produce a calculated yearly mileage estimation for each participant. As a second measure of annual mileage, subjects were also asked simply to estimate their mileage driven over the past year.

2.5.2 DEMOGRAPHIC DATA

Retrospective demographic data were obtained from the examination summary letter written after the initial bioptic intake examination. This letter is written by the attending optometrist to the Bureau of Motor Vehicles and the driving trainer as one of the initial steps in the Ohio bioptic program, and includes age, previous license history, vision data, an indication of whether the patient meets the vision standards for the program, and any concerns that the optometrist might have regarding potential licensure of the patient. For the select instances when this letter was unavailable, data were obtained from the earliest available examination record.

Information recorded from the initial letter included gender, age at initial bioptic examination, and whether the patient had previously held a non-bioptic driver’s license. An estimation of the date of initial bioptic licensure was also produced from the date of
the initial intake exam using a method devised for previous studies.\textsuperscript{22} This initial licensure date was calculated as 7 months after the intake exam date, as seven months has previously been determined to be the average amount of time from intake to licensure for Ohio bioptic drivers.

2.5.3 \textbf{VISUAL DATA FROM BIOPTIC EXAMINATION}

Retrospective visual data were also obtained from the examination summary letter written after the initial bioptic intake examination. For the select instances when this letter was unavailable, data were obtained from the earliest available examination file. Information obtained included monocular and binocular visual acuity through the carrier lenses (Bailey-Lovie or ETDRS logMAR chart), visual acuity through the bioptic telescope (Bailey-Lovie or ETDRS logMAR chart), low luminance visual acuity (Bailey-Lovie or ETDRS logMAR chart), contrast sensitivity (Pelli Robson or Mars chart), temporal and nasal visual field (Arc perimeter or Goldmann perimeter), glare acuity (brightness acuity tester), glare recovery (brightness acuity tester), and color vision (Farnsworth D-15). Stability of the vision (stable or potentially progressive) as specified by the examining optometrist was also recorded.

2.5.3.1 \textbf{VISUAL ACUITY PROTOCOL}

Visual acuity is measured during the initial examination with either an Early Treatment Diabetic Retinopathy Study (ETDRS) logMAR chart or Bailey-Lovie chart. Both charts allow for high-contrast visual acuity testing. Larger letters are presented at
the top of the chart and each subsequent row decreases in size logarithmically. Each row contains five letters of the same size with constant spacing between every letter and row.

The charts are sometimes retro-illuminated and sometimes lighting is provided by a directed stand lamp and over-head lighting. The charts are contained within a moveable stand. The subject sits at a distance from the chart determined by the examiner, typically 10 feet or two meters. This distance can be adjusted as necessary to obtain the equivalent Snellen acuity required for licensure. Visual acuity is typically measured binocularly before monocularly. While testing, the subject is asked to start at the top of the chart and read every letter until he or she reaches the threshold of their visual acuity. Guessing is encouraged. The subject will be stopped once he or she incorrectly identifies three out of five letters within one row (less than fifty percent correct).

Low luminance visual acuity testing is also performed with either the ETDRS or Bailey-Lovie chart. To reduce the illumination, room lighting is dimmed, or a filter is placed over the patient’s eyes. Visual acuity is then measured in a similar fashion.

2.5.3.2 CONTRAST SENSITIVITY PROTOCOL

Contrast sensitivity testing measures the subject’s ability to discern targets of similar size while changing the relative luminance between the background and the target. Both testing methods used for licensure in the state of Ohio use Sloan letters as a target. The Pelli Robson chart uses Sloan letters approximately equivalent to 2.5
cycles per degree at a distance of 3 meters. The contrast is highest at the top of the chart. Throughout the chart letters of similar contrast are grouped in sets of three with each subsequent grouping decreasing in contrast by 0.15 log units. There are six letters on each row. Testing is generally performed at 1 meter during bioptic examinations. Starting at the top of the chart, the subject binocularly reads each letter until he or she incorrectly names at least two out of three letters within a similar contrast grouping. Subjects are scored based on the contrast of the last triad in which two out of three were read correctly or based on a “letter by letter” scoring system which assigns 0.05 log CS per letter.

A similar testing method is used with the Mars Contrast Sensitivity chart. This chart uses Sloan letters equivalent to 0.8 cycles per degree at a distance of 0.5 meters. The Mars chart has the advantage over the Pelli Robson chart of being more durable and more portable due to its compact size. The subject wears appropriate reading correction during testing. Each subsequent letter within the Mars chart decreases in contrast by 0.04 log units. The subject starts at the top of the chart and binocularly reads each letter until he or she incorrectly names two consecutive letters. Subjects are scored based on the contrast of the last letter correctly read.

2.5.3.3 VISUAL FIELD PROTOCOL

Visual field testing determines the peripheral limits of a subject’s field of view. Testing devices used include the arc perimeter and the Goldmann perimeter. In the state of Ohio, only horizontal visual field requirements are specified for licensure; therefore,
testing often occurs only along the horizontal meridian, though frequently at least eight meridians are measured at the initial examination.

The arc perimeter consists of a semicircular metal track with a 0.33 meter radius. A chin rest at the center of the semi-circle allows for the subject to be positioned within the device. The subject is monocularly occluded and asked to look straight ahead. A small high-contrast target (generally a round, white, 10mm spot) is then slowly shifted from the extreme edge of the perimeter inward into the subject’s field of view. Once detected, the target is re-introduced from the other side of the perimeter. Both nasal and temporal fields of view are recorded in degrees for each eye.

The Goldmann perimeter consists of a three-dimensional hemisphere with a chin rest positioned in the center of the bowl. The size and relative intensity of the target can be modulated by the examiner. The largest and brightest target (a V4e target) is generally used in the bioptic exam. Similar to the arc perimeter, the subject is monocularly occluded and directed to look at a central target. The subject then signals when she can first detect the moving peripheral target as it becomes visible along the tested meridian.

2.5.3.4 GLARE ACUITY AND RECOVERY PROTOCOL

Both glare acuity and recovery are measured with the brightness acuity tester (BAT). The BAT is an illuminated white hemisphere with a small central occludable aperture. Once the aperture is aligned with the subject’s eye, the subject can view a distant acuity chart with variable levels of glare. 27 In the instance of glare acuity, the
distance visual acuity is measured while the subject views through the BAT. The 
brightness setting is set to a maximum value. During the glare recovery test, the subject 
aligns his or her better eye with the BAT and allows the light to bleach the 
photoreceptors. After thirty seconds, the glare source is removed, and the subject reads 
the visual acuity chart. The time it takes the subject to read his or her threshold visual 
acuity is recorded as the glare recovery time.

2.5.3.5 COLOR VISION PROTOCOL

The Farnsworth D-15 test allows subjects to be distinguished between color-
normal and color-abnormal. Both acquired and congenital color abnormalities can be 
detected in this test. The Farnsworth D-15 test consists of fifteen color samples 
attached to circular tiles. One circular tile is fixed to the wooden testing board while the 
additional samples are moveable. The subject is asked to find the closest match to the 
fixed sample and subsequently place all the samples in color order. By quickly plotting 
the results, the examiner can determine the subject’s color vision status—normal or 
abnormal. A standard of two or more major errors is used for classification as abnormal.

2.5.4 DRIVING RECORDS

Driving records and motor vehicle collision reports were obtained through the 
Ohio Bureau of Motor Vehicles/Ohio Department of Public Safety. The driving record 
included a list of all reported collisions and citations in Ohio ordered by date and Ohio 
county number. Each report included an indication of the violation category. This file
was downloaded from the Bureau of Motor Vehicles onto a secure computer and processed to allow for relevant data extraction based on Ohio driver’s license number. Police reports of collisions were obtained via the Department of Public Safety web site. Through this public access resource, all reports for collisions in Ohio within the previous five years were available. These reports included a scanned copy of the original incident report filed by the police officer.

2.6 STATISTICAL METHODS

Means with standard deviations, medians, and counts were calculated for demographic data for the purposes of summarizing these data. Spearman correlation coefficients were used to characterize the relationships between continuous variables such as logMAR visual acuity and annual mileage. For testing of relationships between categorical variables, such as gender, and continuous outcome variables we used Mann-Whitney U tests.

In order to calculate a collision rate adjusted for mileage, we used a similar method to the one that Massie et al. used to calculate a crash rate for the general U.S. population. First, the total number of MVC for each driver was divided by the total years of bioptic licensure to generate an average number of MVC per year for each driver. We then took the sum of those averages for all drivers to get the average number of MVC experienced by the entire group of subjects. We divided that sum by the total number of self-reported miles driven by all subjects in a year, and then calculated how
many collision on average the group of subjects would experience per million miles driven. All statistical testing was performed using IBM SPSS software version 21.
RESULTS

3.1 PARTICIPANTS

3.1.1 VISION AND DEMOGRAPHICS

A total of 73 subjects enrolled in the study. Of these subjects, 49 completed the Driving Habits Questionnaire (DHQ) survey in person after their vision examination at the college of optometry. An additional 24 subjects completed the DHQ survey via mail. Twenty-one other potential subjects were identified, indicated initial interest, and received a packet in the mail but either did not return the survey or chose to decline participation.

The mean ± SD age of enrolled bioptic drivers was 51 ± 16 years (Table 3.1, Figure 3.1). The minimum age was 16 years and the maximum age was 71 years. Twenty-five of the subjects (34%) were female. Forty nine subjects (67%) reported previous driving experience before driving with a BTS. The average length of licensure with BTS was 11 ± 6 years.

The most frequent ocular diagnosis for enrolled bioptic drivers was albinism with 13 participants (Figure 3.2). Other frequent diagnoses included congenital nystagmus, optic atrophy, and Stargardt’s macular degeneration.

The average logMAR visual acuity of the subjects was 0.66 ± 0.18, or approximately Snellen 20/100 (Table 3.2).
Table 3.1  Summary of Subject Visual Factors. (n=73)

<table>
<thead>
<tr>
<th>Visual Factor</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Acuity (logMAR)</td>
<td>1.20 (20/320)</td>
<td>0.18 (20/32)</td>
<td>0.66</td>
<td>0.18</td>
</tr>
<tr>
<td>Contrast Sensitivity (logCS)</td>
<td>1.00</td>
<td>1.95</td>
<td>1.57</td>
<td>0.23</td>
</tr>
<tr>
<td>Horizontal Visual Field (deg)</td>
<td>115</td>
<td>195</td>
<td>156</td>
<td>15</td>
</tr>
<tr>
<td>Low Luminance Visual Acuity (logMAR)</td>
<td>1.60 (20/800)</td>
<td>0.40 (20/50)</td>
<td>0.79</td>
<td>0.21</td>
</tr>
<tr>
<td>Glare Acuity (logMAR)</td>
<td>1.38 (20/500)</td>
<td>0.40 (20/50)</td>
<td>0.79</td>
<td>0.20</td>
</tr>
<tr>
<td>Glare Recovery (sec)</td>
<td>0</td>
<td>18</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Abnormal Color Vision</td>
<td>18% (13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Progressive Condition</td>
<td>29% (21)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.1 Frequency of Decade of Age amongst Subjects.
Figure 3.2  Frequency of Subjects’ Ocular Diagnoses.

Other causes of vision loss include toxoplasmosis, white dot syndromes, posterior uveitis, and cortical loss.

Table 3.2  Summary of Subject Demographics. (n=73)

<table>
<thead>
<tr>
<th>Subject Demographic</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>51 ± 16</td>
</tr>
<tr>
<td>Length of Licensure (years)</td>
<td>11 ± 6</td>
</tr>
<tr>
<td>Female Gender</td>
<td>34% (25)</td>
</tr>
<tr>
<td>Previous Experience</td>
<td>67% (49)</td>
</tr>
</tbody>
</table>
The poorest logMAR visual acuity was 1.20 with a best value of 0.18. The average contrast sensitivity was $1.57 \pm 0.23$ with a minimum value of 1.00 and a maximum value of 1.95. The average total horizontal visual field was $156^\circ \pm 15^\circ$ with a minimum value of $115^\circ$ and maximum value of $195^\circ$. The average low luminance visual acuity was $0.79 \pm 0.20$ (approximately 20/125). The poorest value was 1.60 and the maximum value was 0.40. The average glare acuity was a logMAR acuity of $0.79 \pm 0.20$ with a minimum value of 0.40 and a maximum value of 1.38. The average glare recovery was 6 $\pm$ 4 seconds. The minimum value was 0 seconds and the maximum value was 18 seconds. A total of 13 subjects (18%) were identified as having abnormal color vision. A total of 21 subjects (29%) were identified as having a progressive visual condition.

3.2 RESULTS OF DRIVING HABITS QUESTIONNAIRE SURVEY

3.2.1 DRIVING DESTINATIONS AND TRIPS

A total of 53 subjects (73%) reported using their BTS to drive to work (Table 3.3). The total number of people using their BTS to drive to a store was 67 (92%), while 37 (50%) reported driving to church. Many subjects also reported using their BTS to drive to visit other people. Forty-two reported (58%) driving to visit relatives and 43 (59%) reported driving to visit friends. BTS also self-reportedly used by 55 (75%) subjects drive to restaurants. Forty (71%) subjects reported using their BTS to drive to appointments. In addition to these destinations, 40 (53%) subjects reported driving to other non-specified locations with their BTS.
Table 3.3  Self-Reported Frequency of Driving Destinations amongst Subjects. (n=73)

<table>
<thead>
<tr>
<th>Destination</th>
<th>Percent Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Store</td>
<td>92% (67)</td>
</tr>
<tr>
<td>Restaurant</td>
<td>75% (55)</td>
</tr>
<tr>
<td>Work</td>
<td>73% (53)</td>
</tr>
<tr>
<td>Appointment</td>
<td>71% (52)</td>
</tr>
<tr>
<td>Friend</td>
<td>59% (43)</td>
</tr>
<tr>
<td>Relative</td>
<td>58% (42)</td>
</tr>
<tr>
<td>Church</td>
<td>50% (37)</td>
</tr>
<tr>
<td>Other</td>
<td>53% (40)</td>
</tr>
</tbody>
</table>
Total number of trips typically taken within a week was determined to be an average of 14 ± 10 with a minimum of 3 and a maximum of 59 weekly trips (Table 3.4). On average during a typical week, the total number of destinations was 6 ± 2 with a minimum of 1 and a maximum of 13 weekly destinations. The farthest destination from home was determined to be an average of 25 ± 29 miles with a minimum of 2 and a maximum of 200 miles.

3.2.2 SELF-REPORTED MILEAGE ESTIMATES

Average self-reported yearly mileage via the simple yearly estimation method was determined to be 9,746 ± 13,000 miles/person/year (Table 3.5). The minimum value was 100 miles per person per year. The maximum value was 90,000 miles per person per year. Average self-reported yearly mileage via the calculated composite method was determined to be 13,597 ± 12,316 miles per person per year. The minimum value was 866 miles per person per year. The maximum value was 70,200 miles per person per year. One subject failed to provide a simple yearly mileage estimate.

When considering the difference between simple yearly and calculated composite estimations, it was determined that for 52 (72%) subjects the calculated composite value was larger than the simple yearly estimate (Figure 3.4). One possible reason for this discrepancy is that when calculating a mileage for a typical week, subjects can include infrequent destinations that can cause the yearly calculated composite mileage to be over-estimated when extrapolated over 52 weeks.
Table 3.4  Self-Reported Typical Weekly Driving Trips, Destinations, and Distances.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Total Trips</td>
<td>3</td>
<td>59</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Number of Total Destinations</td>
<td>1</td>
<td>13</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Farthest Typical Destination from Home (miles)</td>
<td>2</td>
<td>200</td>
<td>25</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 3.5  Self-Reported Yearly Mileage Estimates.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean (miles/person/year)</th>
<th>Range (miles/person/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Yearly Estimate</td>
<td>9,746</td>
<td>100 – 90,000</td>
</tr>
<tr>
<td>Calculated Composite</td>
<td>13,597</td>
<td>866 – 70,200</td>
</tr>
</tbody>
</table>
**Figure 3.3** Comparison of Simple Yearly and Calculated Composite Mileage Estimate.

The estimates are further separated by survey completion method – by mail or in person. Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
The traveling salesman who reported driving 90,000 miles per year versus the veterinarian who only drives 900 miles per year to and from her horse barn are very different people. Whether or not they are estimating their exact yearly mileage, it was felt that these subjects were both giving valuable information about his or her driving habits.

Overall, estimating how many miles driven in a year seemed easier to understand and less abstract for most subjects; therefore, we felt it would be the more accurate of the two estimation methods. No significant difference between yearly mileage estimates was determined between subjects who completed the survey in person or via mail (P = 0.425, see Figure 3.4). For these reasons all further calculations were made using only the simple yearly estimation method.

### 3.3 Predictors of Number of Trips and Farthest Distance Traveled

#### 3.3.1 Self-Reported Number of Trips

Self-reported number of trips during a typical week was not determined to be significantly correlated with age (Spearman rho = 0.043, p = 0.719) (Figures 3.5, 3.6). Number of trips was also not significantly correlated with gender (p = 0.305) (Figure 3.7).

Additionally, neither better eye visual acuity (Spearman rho = -0.227, p = 0.053) nor contrast sensitivity (Spearman rho = 0.003, p = 0.982) were found to be significantly correlated with total trips in a typical week, though there was a trend toward fewer trips for subjects with poorer visual acuity (Figures 3.8, 3.9).
Figure 3.4  Self-Reported Yearly Mileage Estimates by Survey Completion Method.

Line shown displays 1:1 comparison.
Figure 3.5 Self-Reported Number of Trips by Age.
Figure 3.6  Self-Reported Number of Trips by Decade of Age.

Only one subject was in the 9th decade and therefore was not included in the figure. Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
Figure 3.7  Self-Reported Number of Trips by Gender.

Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
Figure 3.8  Self-Reported Number of Trips by Visual Acuity.
Figure 3.9  Self-Reported Number of Trips by Contrast Sensitivity.
The self-reported number of trips was also not found to be significantly correlated with the number of years of bioptic licensure (Spearman rho = 0.064, p = 0.591) (Figure 3.10).

3.3.2 Self-Reported Farthest Destination from Home

Increasing age was found to have a slight inverse correlation with the farthest destination from home (Spearman rho = -0.28, p = 0.018). Therefore older subjects self-reported that during a typical week the farthest destination was closer to home compared to younger subjects (Figure 3.11). Gender (p = 0.45) and years of bioptic licensure (Spearman rho = 0.19, p = 0.108) were not found to be significantly associated with farthest self-reported distance from home (Figures 3.12, 3.13).

Visual acuity was determined to have a slight inverse correlation with the farthest distance typically traveled from home (Spearman rho = -0.25, p = 0.03). Subjects with poorer visual acuity self-reported that during a typical week the farthest destination was closer to home than subjects with better visual acuity (Figure 3.14). Additionally, contrast sensitivity was found to have a moderate direct correlation with the farthest distance typically traveled from home (Spearman rho = 0.42, p < 0.001). Subjects with poorer contrast sensitivity reported that during a typical week the farthest destination was closer to home than subjects with better contrast sensitivity (Figure 3.15).
Figure 3.10  Self-Reported Number of Trips by Number of Years of Bioptic Licensure.
Figure 3.11  Self-Reported Farthest Destination from Home by Decade of Age.

Only one subject was in the 9th decade and therefore was not included in the figure. Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
Figure 3.12  Self-Reported Farthest Destination from Home by Gender.

Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
Figure 3.13  Self-Reported Farthest Destination from Home by Number of Years of Bioptic Licensure.
Figure 3.14  Self-Reported Farthest Destination from Home by Visual Acuity.
Figure 3.15  Self-Reported Farthest Destination from Home by Contrast Sensitivity.
3.4 PREDICTORS OF ANNUAL ESTIMATED MILEAGE

3.4.1 VISUAL AND DEMOGRAPHIC ASSOCIATIONS WITH SELF-REPORTED MILEAGE ESTIMATES

Self-reported yearly mileage was found to have no significant correlation with gender (p = 0.293), previous non-bioptic driving experience (p = 0.425), age (p = 0.481), or years of licensure (p = 0.074) (Tables 3.6, 3.7 and Figures 3.16, 3.17, 3.18, and 3.19). Visual factors found to have no significant correlation to self-reported yearly mileage included telescope visual acuity (p = 0.179), low luminance visual acuity (p = 0.112), glare recovery (0.611), and abnormal color vision (p = 0.439).

Self-reported yearly mileage was found to have a slight inverse correlation to glare acuity (Spearman rho = -0.261, p = 0.027). Subjects with worse glare acuity were more likely to self-report driving fewer miles in a year than subjects with a quicker glare recovery. Additionally, self-reported yearly mileage was determined to have a slight inverse correlation to visual acuity (Spearman rho = -0.286, p = 0.015). Subjects with poorer visual acuity were more likely to self-report driving fewer miles in a year than subjects with better visual acuity (Figure 3.20). Finally, contrast sensitivity was found to have a moderate direct correlation with self-reported yearly mileage (Spearman rho = 0.308, p = 0.009). Subjects with poorer contrast sensitivity were more likely to self-report driving fewer miles in a year than subjects with better contrast sensitivity (Figure 3.21 and Table 3.7).
Table 3.6  Visual and Demographic Associations with Self-Reported Mileage Estimates

(Double asterisk signifies $p < 0.05$)

<table>
<thead>
<tr>
<th>Patient Characteristic</th>
<th>Spearman Correlation</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Acuity (logMAR)</td>
<td>-0.286</td>
<td>0.015**</td>
</tr>
<tr>
<td>Contrast Sensitivity (logCS)</td>
<td>0.308</td>
<td>0.009**</td>
</tr>
<tr>
<td>Telescope Visual Acuity (logMAR)</td>
<td>-0.160</td>
<td>0.179</td>
</tr>
<tr>
<td>Low Luminance VA (logMAR)</td>
<td>-0.190</td>
<td>0.112</td>
</tr>
<tr>
<td>Glare Recovery (sec)</td>
<td>-0.061</td>
<td>0.611</td>
</tr>
<tr>
<td>Glare Acuity (logMAR)</td>
<td>-0.261</td>
<td>0.027**</td>
</tr>
<tr>
<td>Age (years)</td>
<td>-0.084</td>
<td>0.481</td>
</tr>
<tr>
<td>Years of Licensure (years)</td>
<td>0.212</td>
<td>0.074</td>
</tr>
<tr>
<td>MVC per Year</td>
<td>0.157</td>
<td>0.231</td>
</tr>
</tbody>
</table>

Table 3.7  Visual and Demographic Associations with Self-Reported Mileage Estimates

<table>
<thead>
<tr>
<th>Patient Characteristic</th>
<th>t Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal Color Vision</td>
<td>-0.779</td>
<td>0.439</td>
</tr>
<tr>
<td>Progressive Condition</td>
<td>-1.758</td>
<td>0.083</td>
</tr>
<tr>
<td>Female Gender</td>
<td>1.061</td>
<td>0.293</td>
</tr>
<tr>
<td>Previous Driving Experience</td>
<td>1.112</td>
<td>0.270</td>
</tr>
</tbody>
</table>
Figure 3.16  Self-Reported Yearly Mileage by Gender.

Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
**Figure 3.17** Self-Reported Yearly Mileage by Previous Driving Experience.

Box signifies first and third quartile values with median. Whiskers signify minimum and maximum values.
**Figure 3.18** Self-Reported Yearly Mileage by Age.

Only one subject was in the 9th decade and therefore was not included in the figure.

Box signifies first and third quartile values with median. Whiskers signfiy minimum and maximum values.
Figure 3.19  Self-Reported Yearly Mileage by Years Licensed.
Figure 3.20 Self-Reported Yearly Mileage by Visual Acuity.
Figure 3.21  Self-Reported Yearly Mileage by Contrast Sensitivity.
3.5 MOTOR VEHICLE COLLISIONS

3.5.2 MOTOR VEHICLE COLLISIONS FREQUENCY AND RATE

A total of 42 (58%) subjects were involved in reported collisions in the state of Ohio. These 42 bioptic drivers were involved in a total of 101 collisions. Forty-six (63%) subjects had a history of convictions for traffic offenses in Ohio. A total of 20 (27%) subjects were not involved in any collisions or convictions (Table 3.8). The range total number of collisions on record per subject was 0 to 6.

The median yearly MVC rate was found to be 0.09 MVC per year (Figure 3.22). In an average year, the 73 participants as a group experienced 10.8 collisions and drove 703,910 miles. This equates to a calculated estimate of 15.3 MVC per 1,000,000 miles driven for the entire group of bioptic drivers. Self-reported yearly mileage was not determined to be statistically significantly correlated to motor vehicular collisions per year (rho = 0.157, p = 0.231) (Tables 3.6, 3.7).

3.5.2 MOTOR VEHICLE COLLISION SEVERITY AND VARIATION BY TIME OF YEAR

A total of 67 (66%) collisions were given a level 5 severity rating, which means the MVC involved no injuries (Figure 3.23). Fifteen (15%) collisions were given a level 4 severity rating, which means that possible injuries occurs. Nine (9%) collisions were given a level 3 severity rating, which means that a non-incapacitating injury occurred. Additionally, 10 (10%) collisions were given a severity rating of 9. This means that when the accident record was filed, the reporting officer was unsure if any
personal injuries occurred. No collisions with a rating more serious than 3 were recorded.

Compared to all other months, most MVC occurred during the month of October. A total of 14 subjects were involved in MVC during that month (Figure 3.24). The second most MVC occurred during January with 13 total collisions. The months with the fewest MVC were May with 4 collisions and November with 5 collisions. The Ohio Department of Public Safety reports the highest numbers of recorded MVC involving deer during the months of October and November.30

When considering only MVC with moderate severity—those either causing non-incapacitating injury or potential injury—none occurred during the months of November or December (Figure 3.25). Two collisions with non-incapacitating injuries occurred during August, which was the most of any month. The most collisions with potential injury occurred during the months of January and March with 2 collisions each month. When looking at the relative number of MVC by season, each season was similar (Figure 3.26). Twenty-eight (28%) MVC occurred during the winter while 26 (26%) occurred during both the summer and fall. Twenty-one (21%) occurred during the spring.
Table 3.8 Frequency of Bioptic Drivers with Record of Collisions, Convictions, or None Since First Bioptic Licensure. (n=73)

<table>
<thead>
<tr>
<th></th>
<th>Collisions</th>
<th>Convictions</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Involvement</td>
<td>58% (42)</td>
<td>63% (46)</td>
<td>27% (20)</td>
</tr>
</tbody>
</table>

Figure 3.22 Frequency of MVC per Year.
Severity was determined by the rating given on the 101 total MVC reports.

Figure 3.23 Relative Frequency of MVC Severity.
Figure 3.24 Frequency of MVC by Month.
Figure 3.25 Frequency of MVC with Moderate Severity by Month.

Moderate severity MVC are characterized as those causing non-incapacitating injury or potential injury.
Figure 3.26  Relative Frequency of MVC by Season.

Winter includes the months of December through February. Spring includes the months of March through May. Summer includes the months of June through August. Fall includes the months of September through November.
4.1 DRIVING EXPOSURE

The average self-reported yearly mileage for bioptic drivers was found to be 9,746 miles per person per year. By comparison, Bowers et al. interviewed 58 bioptic drivers via telephone and calculated an average self-reported yearly mileage of 11,544 miles per person per year. Similarly, Owsley et al. determined that the average self-reported yearly mileage of bioptic drivers is 13,000 miles per person per year. These interviews were done through an in-person interview of 26 bioptic drivers. Both previous studies used a modified version of the Driving Habits Questionnaire in which they asked subjects to estimate weekly mileage driven. In each study, bioptic drivers reported driving less miles than the average overall population. This study determined a self-reported yearly mileage estimate that is even smaller in magnitude than results of these previous bioptic driving exposure studies.

Previous research has suggested that the rate of MVC per year in the bioptic driving population is between 0.074 and 0.13 MVC per year, and that on average bioptic drivers are involved in MVC between 1.3 and 3 times the rate of control groups. In this study, we calculated a median yearly MVC rate of 0.09 MVC per year, which is consistent with previous studies. If bioptic drivers have higher yearly MVC rates compared to control groups and also have reduced driving exposure, then the ratio
of collisions per mile for bioptic drivers compared to controls may be even greater. However, a direct comparison cannot be made based on this study because there was no control group.

One limitation of this study is that yearly mileage was subjectively determined, as compared to some approaches which measure mileage with an in-car device. Mileage was estimated via two methods – a simple yearly estimate and a calculated composite using the Driving Habits Questionnaire. When looking at the difference between the mean self-reported yearly mileages, the calculated composite method tended to be higher. This could be a result of the complexity of estimating how far destinations are from home and how frequently during a week a person drives to that location. When determining weekly mileage driven, it can also be easy to overlook or include infrequent destinations. The fact that the two estimation methods are so different suggests some possible misunderstanding of the task by the participants. A total of 21 participants (29%) completed the survey via mail. These participants were individually called and instructed on the purpose of the survey; however, the survey itself was completed without the direct supervision of a researcher. By comparison, subjects who completed the survey in person answered the questions in the presence of a researcher. For the instances where a participant was confused or wanted further clarification, he or she could readily ask the researcher (though he or she could also have misunderstood and not asked as well). In future studies of subjective measures of driving exposure, consideration should be given to conducting the survey in the presence of a researcher.
or verbally over the phone so as to limit the misunderstanding and confusion inherent to this complex estimation.

Another interesting finding in this study was that age, gender and vision were not found to be correlated to the typical number of trips taken in a week. In regards to farthest distance typically driven in a week, however, older drivers and those with worse visual acuity and contrast sensitivity were more likely to report staying closer to home when driving. This would suggest that older drivers and those with worse vision are adjusting their driving exposure in regards to location but not frequency of driving.

4.2 Vision and Mileage

Visual acuity and contrast sensitivity had significant low to moderate correlations with self-reported mileage such that those with poorer vision were more likely to self-report driving fewer miles in a year. This finding seems consistent with past work in older drivers showing that these factors predict greater self-reported difficulty with driving.  

In this study, all vision data were gathered retrospectively from the initial bioptic intake examination record. In the few instances when this record was unavailable, vision data was taken from the first record available after licensure. Since none of the vision data used in our analysis were collected prospectively, this could limit our ability to draw conclusions from these results. That being said while vision could have changed from the time of initial licensure and enrollment in the study, it is unlikely these changes were large. Visual field and acuity are measured at each
licensure renewal examination every one to four years; therefore, anyone who had significant visual declines would have likely lost his or her licensure privileges.

4.3 **MOTOR VEHICLE COLLISIONS PER MILE**

To our knowledge this is the first study on bioptic drivers to calculate an MVC-per-mile rate. We found that bioptic drivers had a mean rate of 15.3 MVC per 1,000,000 self-reported miles driven. Therefore when adjusting for decreased driving exposure it becomes more suggestive that bioptic drivers are at an increased risk of MVC compared to the overall population. Though geographic differences and variations in MVC crash reporting practices vary and complicate comparison, Massie et al. have calculated per mile crash rates using national databases in the general population. They found that the rate per million miles of any MVC was approximately 6, but varied by age group from approximately 4 to 20 MVC per million miles traveled, with teenagers having the highest rate.

Other licensed populations have been reported to be at an increased risk of MVC. For example a study reported that use of cellular telephone devices, even if used hands-free, increases risk of MVC by four times. It has also been reported that teenagers are at eight times increased risk for per-mile MVC than middle aged drivers. Both of these higher risk groups are the focus of increased regulation and legislation in an effort to improve overall driving safety. This leads us to suggest that although bioptic drivers seem to have an increased risk of MVC, there is a need for further research into potential training strategies and screening protocols to identify individuals who may be
at an increased risk for MVC and help provide appropriate training necessary for safe driving.

4.4 Vision and Safety

The relationship between driving safety and vision is not completely understood. One recent study of Ohio bioptic drivers reported that visual acuity and contrast sensitivity do not predict the collision rate per year in the bioptic driving population. However, age and previous experience did, such that younger bioptic drivers and those with less experience were more likely to have an elevated yearly MVC rate. That study suggests that people with poorer visual acuity and contrast sensitivity drive less and so have less exposure to crash risk. So, it is possible that the relationship between vision and driving exposure could obscure an actual relationship between vision and MVC. It should be noted, however, that although we found a trend toward greater collision rates per mile in people with poorer vision, the correlations did not reach statistical significance, nor did the correlation between MVC rate and exposure.

When considering safety, we found that 20 (27%) of participants were not involved in any collisions and had no traffic convictions. Forty-two (58%) participants were involved in one or more MVC since gaining bioptic licensure. The severity of 66% of the MVC was rated as occurring with no injuries. This would suggest that although many bioptic drivers are involved in a collision at some point, the relative severity of these collisions is often mild.
Ohio weather varies throughout the year with four distinct seasons; therefore, Ohio drivers face changing road conditions throughout the year in a way that is not comparable to the driving situations of drivers in states like California and Texas. This limits our ability to directly compare our results with the work of previous researchers. Interestingly, when comparing the relative frequency of MVC involvement in each season we found that each season was similar. This could suggest that although driving conditions are more hazardous during the winter, bioptic drivers are self-limiting their exposure. Future research should consider evaluating the driving exposure of bioptic drivers in different seasonal and weather-related driving conditions.

4.5 LIMITATIONS AND FUTURE RESEARCH

While this study examined visual and demographic predictors of driving exposure, we still have limited knowledge of why bioptic drivers are involved in more MVC than controls. Work on this matter is currently being done with driving simulators and also in-car monitoring devices. Bioptic drivers and controls can be monitored in a driving simulator to determine whether driving performance differs. Because driving simulators are limited in their ability to recreate real-world driving situations, it is also important to conduct naturalistic driving studies, such as those that use GPS devices and video recordings to obtain an objective measure of driving exposure. Additionally, these studies can also record lane positioning, reaction time, and driving pattern data. Comparisons should be made between self-reported and objective measurements of exposure in the future. Ultimately, we hope to better understand how the safety of
bioptic drivers is related to visual and demographic factors as well as driving behavior so as to better predict successful BTS candidates and train people deficient in the skills necessary to be a safe driver.
CONCLUSION

Visual acuity, contrast sensitivity, and glare acuity are significant predictors of driving exposure in BTS users such that drivers with poorer vision report less annual mileage. Additionally, while older drivers and those with worse vision report driving shorter maximum trip distances, on average these drivers take a similar number of overall trips. This study found average reported annual mileage that is lower than the general population and the subjects in other bioptic studies. These findings are significant when considering driving safety and risk. Low driving exposure in bioptic drivers has important implications for consideration of their per-mile risk of motor vehicle collisions.
APPENDIX A

MODIFIED DRIVING HABITS QUESTIONNAIRE

The questions below are about your driving history. Please answer as best as you can about if and when you got a bioptic driver’s license, whether you still drive, and how far and to which places you drive.

1. Do you currently drive? (circle one) YES NO

   If you do not currently drive, when was the last time you drove?
   Month: _____ Year: ______

2. Did you ever get a BIOPTIC driver’s license? YES NO

   If yes, when did you first get your BIOPTIC driver’s license?
   Approximate Month: ______
   Approximate Year: ______

3. How many miles would you say you drive each year? (If you no longer drive, answer with the number of miles you think you drove in the year before you stopped driving)
**Miles Driven Per Year:** ________________

In the table below, put a check next to the places you go and give your best estimate of how many miles those places are from your home and how often you go to them in a typical **WEEK**.

*(If you no longer drive, answer the questions based on where you used to drive when you were still driving.)*

<table>
<thead>
<tr>
<th>Check If You Drive To Each Place</th>
<th>Place</th>
<th>How Many Times Per WEEK?</th>
<th>Estimated Miles From Home (one way)</th>
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<tbody>
<tr>
<td>Work</td>
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<td>Stores</td>
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<td>Church</td>
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<td>Relative’s Houses</td>
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<tr>
<td>Friend’s Houses</td>
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<tr>
<td>Out to Eat (restaurants)</td>
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<td></td>
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<tr>
<td>Appointments (doctor, hair etc.)</td>
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</tbody>
</table>
Now, are there any other places you go in a typical **WEEK**?

<table>
<thead>
<tr>
<th>List Other Places Below</th>
<th>How Many Times Per WEEK?</th>
<th>Estimated Miles From Home (one way)</th>
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**END**
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