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Bioptic Telescope Use in Naturalistic Driving by People with Visual Impairment

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Purpose: The purpose of this study was to investigate the telescope use behaviors in natural daily driving of people with reduced visual acuity licensed to drive with a bioptic (a small spectacle-mounted telescope).

Methods: A large dataset (477 hours) of naturalistic driving was collected from 19 bioptic drivers (visual acuity 20/60 to 20/160 without the telescope). To reduce the data volume, a multiloss 50-layer deep residual neural network (ResNet-50) was used to detect potential bioptic telescope use events. Then, a total of 120 hours of selected video clips were reviewed and annotated in detail.

Results: The frequency of looking through their telescopes ranged from 4 to 308 times per hour (median: 27, interquartile range [IQR], 19–75), with each bioptic use lasting median 1.4 seconds (IQR, 1.2–1.8). Thus, participants spent only 1.6% (IQR, 0.7%–3.5%) driving time with their telescopes aiding their vision. Bioptic telescopes were used most often for checking the road ahead (84.8%), followed by looking at traffic lights (5.3%), and reading road signs (4.6%).

Conclusions: In daily driving, the bioptic drivers mostly (>98% of driving time) drove under low visual acuity conditions. The bioptic telescope was mainly used for observing road and traffic conditions in the distance for situational awareness. Only a small portion of usage was for road sign reading.

Translational Relevance: This study provides new insights into how the vision rehabilitation device—bioptic telescopes are used in daily driving. The findings may be helpful for designing bioptic driving training programs.

Introduction

In the United States alone, about 3.9 million visually impaired adults (>45 years old) are estimated to have corrected visual acuity worse than 20/40.[1] They may lose their driving privilege when their visual acuity falls below the requirement for an unrestricted license (typically 20/40 in many US states), which may significantly restrict their independence and mobility, especially for those living in rural and suburban areas.[2–5] However, those with moderately reduced visual acuity may be permitted to drive on a restricted license with the aid of a bioptic telescope in most states in the United States,[6,7] the province of Quebec in Canada,[8] the Netherlands,[9] and Australia.[10] The bioptic telescope is small and usually mounted at the top of the spectacle lens in front of one eye (Fig. 1). Regulations for bioptic driving vary widely across jurisdictions. For instance, special bioptic training and/or road tests are required in some jurisdictions, but not others.[7] Despite the legality of driving with bioptic telescopes, how they are used in daily driving is not well understood. This paper is the first step toward investigating the habitual bioptic use and daily driving behaviors of this unique group of people. How they compensate for their vision loss may provide insights into the vision factors critical for driving safety.

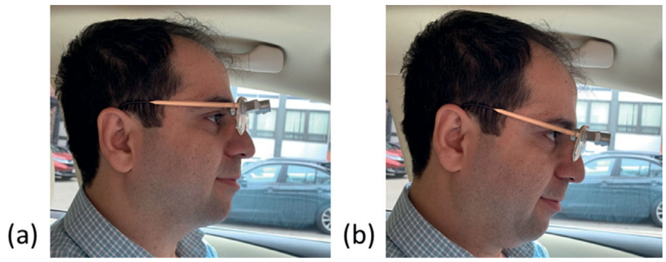

Figure 1. Illustration of bioptic telescope use. (a) Looking through the carrier lens (below the telescope) with unmagnified, low visual acuity vision. (b) Looking through the telescope with magnified vision.

Bioptic drivers normally use unmagnified vision through the carrier lens and magnified vision through the telescope in an alternating fashion. Although bioptic telescopes provide magnification, which may be helpful for viewing details of distant objects, the field of view through the telescope is relatively limited (e.g., 10° to 15° for a 3× telescope. The magnified image also blocks part of the visual field for the viewing eye, causing a ring-shaped scotoma. Our previous studies of bioptic telescopes in the controlled conditions of the laboratory, including simulated driving scenarios, have shown that the restricted visual field can affect detection of peripheral stimuli and hazards to some extent when looking through the telescope.[11–15] Thus, bioptic driving guidelines suggest that bioptic drivers should dip their head only briefly when needed to look through the telescope(s) to gain a magnified view of distant objects.[16]

However, how and when the bioptic is actually used in habitual driving is still not well understood. Some opponents of bioptic driving even suspect that bioptic telescopes might be used purely as a means for licensing and not used thereafter.[17] Prior studies of bioptic use behaviors mostly used self-report questionnaires. Park et al.[18] used a questionnaire to evaluate the training procedures experienced by bioptic drivers and their driving habits. Bowers et al. investigated bioptic telescope use patterns and driving patterns by telephone interview.[19,20] Owsley et al.[21] administered a questionnaire to examine whether the telescope was helpful in on-road situations. One limitation of these studies is that self-reports might not always be reliable. For example, estimating the amount of time spent using a bioptic telescope when driving is not straightforward. Typically, bioptic drivers report that they use the telescope most often for reading road signs and street names,[19–22] but these self-reports have never been verified by objective recordings of bioptic use behaviors during habitual driving.

To the best of our knowledge, only one on-road study, by Wood et al.,[23] has quantified telescope use of bioptic drivers. On-road driving was evaluated in an instrumented dual-brake vehicle along 14.6 miles of city, suburban, and controlled-access highways. Participants were instructed to provide a commentary of their driving observations, including calling out traffic light colors, traffic signs, and any pedestrians/cyclists/road workers encountered along the route. The route was chosen to have a high density of traffic lights and road signs. Bioptic use was determined from video recordings of the drivers and varied widely across participants (from a minimum of 0 to a maximum of 318 uses in the 45-minute drive). Although the study provided objective data on bioptic use behaviors in on-road driving, participants' behaviors might have been affected by the presence of the driving examiner in the dual-control car and the instruction to call out all road signs and traffic light colors. Thus, participants might have been more likely to use the bioptic than they would in habitual driving. The number of road signs and how often the telescope is used for reading road signs most likely varies in everyday driving dependent on the environment (city or rural) and how familiar the driver is with the route. In a familiar area, drivers probably do not have to use the bioptic telescope to read speed limit signs and road names, whereas in an unfamiliar area they might be more likely to use it.

We are interested in habitual bioptic use behaviors under naturalistic driving conditions. In a prior study, Luo et al.[24] recorded the telescope use of two bioptic drivers in their own cars for 5 and 10 days. That pilot naturalistic driving study demonstrated the feasibility of recording bioptic use behaviors during daily driving. However, the sample size was too small for any conclusions to be drawn about bioptic use behaviors. In the current study, we extended the prior work by utilizing much longer recordings of driving to examine bioptic telescope use of a larger sample of bioptic drivers. A major challenge of naturalistic driving studies is the large volume of data collected. To manually review this volume of data is not practically feasible. Given that our main aim was to quantify bioptic use, a multiloss 50-layer deep residual neural network (ResNet-50) for head pose tracking[25] was used to detect the bioptic telescope use events from the naturalistic driving videos. The detected events were then manually reviewed and annotated for investigation of the frequency and purpose of bioptic uses as well as examination of factors that might influence bioptic use behavior, such as the driving environment and level of vision impairment.

Figure 2. Digital Video Recording (DVR) system built as a rear view mirror. It is comprised of a front-scene view camera, a small in-car view camera on the far right side of the mirror, and a GPS recording device. The camera system did not impede participants' view through either the windshield or mirrors.

Methods

Participants

A total of 19 bioptic drivers (13 men and 6 women) participated in the study. They were recruited from two areas: in the United States ($n = 14$) by Schepens Eye Research Institute and Ohio State University, and in Canada ($n = 5$) by the Nazareth and Louis-Braille Institute.

The main inclusion criterion was that participants be active bioptic telescope drivers with a valid driving license that allowed them to drive with a bioptic telescope in the jurisdiction where they were residents. The visual acuity requirements for a bioptic license varied across the jurisdictions from which the participants were recruited (e.g., in Rhode Island, visual acuity without the telescope has to be between 20/100 and 20/40, and in Georgia between 20/200 and 20/60).

All participants provided informed consent in accordance with institutional review board approval at Schepens Eye Research Institute, Ohio State University, and Nazareth and Louis-Braille Institute. The study was conducted in accordance with the tenets of the Declaration of Helsinki.

Data Collection

A modified digital video recording device (Blackview HS950; Fig. 2) was installed in each participant's car. The recording device was made in the form of a rear view mirror, and was mounted over the existing rear view mirror. Thus, the video recording device did not occlude any field of view through the windshield. The device included two cameras, a front-scene view camera recording the road ahead, and an in-car view camera recording the participant's head. The video resolution was 1280 × 720 pixels with a field of view around 80° × 40°.

The recording device remained in participants' vehicles for between 4 and 8 weeks. The participants were instructed to drive as they would normally. The device automatically started recording from the moment that participants turned their car on until 10 seconds after the car was turned off.

Data Processing

A total of 477 hours of video data were collected (median 16.3 hours per subject, ranging from 2.7 to 57.0). Automated methods were developed to reduce the data volume by identifying bioptic telescope use events, which were then manually reviewed by trained evaluators.

Detection of Bioptic Telescope Use

When drivers use bioptic telescopes, they typically tilt their heads down to look through the bioptic telescope (Fig. 1). In this study, the change in head pose in the recorded driving videos was used to identify potential bioptic telescope use events. We detected head pose using a multiloss 50-layer deep residual neural network, ResNet-50,[25] trained on the large synthetic head pose 300W-LP dataset.[26] The synthetic 300W-LP dataset includes 122,450 samples of head poses in different orientations (yaw, pitch, and roll).

First, the trained neural network was used to detect the head pose for each frame of the driving video. Second, possible bioptic telescope use events were identified by finding the head dipping movement. Finally, as the automatically detected events might include some false alarms, the detected bioptic telescope use events were manually reviewed to confirm real bioptic telescope use events. As a downward head movement for looking at the instrument panel or something else within the vehicle could be confused with bioptic use, we confirmed the true bioptic use events by checking whether the eye was aligned with the telescope.

Bioptic Telescope Use Examination

To assist the evaluator in interpreting what the participant was looking at through the telescope, the aiming point was depicted as a red box on the front-scene view images (Fig. 3). Because the in-car view camera was at an arbitrary position relative to the front-scene view camera, the registration of the aiming point in the scene image was calibrated by first finding a bioptic use event in which the target viewed through the telescope was not ambiguous, and then

Figure 3. Aiming point depicted based on the head pose. (a) Front-scene view channel with aiming point highlighted by red box (telescope is being used to view a car ahead on the road). (b) In-car view channel where the driver is dipping head to look through the bioptic telescope. The RBG axes representing the head pose are plotted according to the ResNet-50 results.

Table. Annotation Sheet for Recording Details of Each Bioptic Telescope Use

Targets	• Vehicle (with an informative behavior, such as rapid stop, turning, lane change, etc.) • Pedestrian • Traffic light • Road signs • Road ahead • Other
Intersection	• Yes • No
Subsequent maneuvers	• Driving straight • Turning • Curve driving • Changing lane • Braking • No action (stationary)
Traffic conditions	• Light (no more than one vehicle in 5 seconds headway in the same lane) • Heavy (moving, many cars around, normal speed) • Congested (moving slowly, stopping and starting often) • Not moving (not moving at all, or waiting at red light)
Road type	• Highway • Non-highway

determining the offset needed to align the head aiming point to the target.

Each confirmed bioptic telescope use event (total 2790 events in 120 hours of driving) was manually reviewed and annotated in terms of five main aspects (Table): *Targets*, *Intersection*, *Subsequent Maneuvers*, *Traffic Conditions*, and *Road Type*. Targets classified what the driver looked at through the bioptic telescope. Intersection indicated whether or not the bioptic telescope use was at an intersection (e.g., for checking traffic lights or road conditions at intersections). Subsequent Maneuvers categorized the maneuver the driver performed after the bioptic telescope use. Traffic Conditions described the traffic flow surrounding the participant's vehicle at the time of the telescope use. Road Type classified whether the bioptic use event occurred on the highway or not. For detailed subcategories of each aspect, please refer to the Table.

Three evaluators were trained to annotate the bioptic use events. During the training phase, they each annotated a set of events separately and then compared the results. When there was inconsistency in the annotations, the evaluators discussed those cases, explained their interpretations, and drew a common conclusion. Each evaluator then separately annotated 637 events. Cohen's kappa (>0.61) indicated substantial inter-rater agreement between the three evaluators' annotations of these events. The remaining 2153 events were evenly split into three groups (drawn randomly from events from each participant) and annotated by these three evaluators, respectively.

Bioptic Telescope Use Frequency Evaluation

Because the automated bioptic use detection might miss some true events, we manually reviewed some videos in order to accurately estimate the bioptic telescope use frequency. To prevent data loss due to file corruption, the video recording device split each period of continuous driving into multiple 5-minute long clips. For each bioptic driver, 1 hour of driving was selected, which included 12 randomly selected 5-minute video recordings. The 1 hour of videos was manually reviewed and all the bioptic telescope use events in these videos were visually identified. The bioptic telescope use frequency was computed as the number of events within the duration of these videos.

Statistical Analyses

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 11.5). A P value of 0.05 was used to define statistical significance. Because our data were not normally distributed, a Spearman's rank-order correlation was used to quantify the relationship between bioptic telescope use frequency and visual acuity, and the relationship between bioptic telescope use frequency and number of years of driving with a bioptic telescope.

Results

Sample Characteristics

The 19 participants (13 men) ranged in age from 22 to 90 years (median, 55.0; interquartile range, 35.5–64.0). The majority (n = 17) had congenital, childhood, or juvenile onset vision impairment, with the main cause being albinism (n = 7), followed by congenital cataracts (n = 2), congenital nystagmus (n = 2), and rod-cone dystrophy (n = 2). All participants, except one, used a monocular bioptic telescope. The magnification power ranged from 2.5 × to 6 ×. Experience of driving with a bioptic varied very widely from <1 to 44 years (median, 11; IQR, 1–16). Fifteen participants received bioptic driving training prior to obtaining their license. Participants' binocular visual acuity without the bioptic telescope ranged from 20/60 to 20/160 (0.47 to 0.90 LogMAR; median, 0.70; IQR,: 0.57–0.80) and with the bioptic from 20/20 to 20/63 (0.00 to 0.50 LogMAR; median, 0.18; IQR, 0.10–0.30). In reviewing the videos, we qualitatively confirmed that all bioptic drivers drove around their home areas based on observation of the recorded GPS data. So we assumed that they mostly drove in areas familiar to them.

Time of Day When Driving Occurred

In this study, the time after sunrise and before sunset was defined as daytime and the time after sunset and before sunrise was defined as nighttime. Because the sunset time depended on geographic location and season, the time of driving occurrence was tallied according to the individual sunrise and sunset times for each participant. The percentage of driving occurrence time in each hour is depicted in Figure 4a. It can be seen that the driving occurrence decreased sharply after sunset, but participants #5 and #13 drove for a great amount of time before sunrise (early morning). For all participants, the median percentage of nighttime driving (relative to total driving time) was 5.7% (IQR, 0.2%–13.4%; Fig. 4b). Two participants did not drive at night at all, and for one participant (#5), 64.6% of driving occurred during nighttime. Note that nighttime driving was permitted for bioptic drivers in all the jurisdictions from which they were recruited, provided they met extra requirements.

Bioptic Telescope Use Frequency

Figure 5a presents the bioptic telescope use frequency, the number of times per hour the bioptic was used (median, 27; IQR, 19–75), quantified from the 1 hour of videos manually reviewed for each participant. The lowest frequency was 4/hours and the highest frequency was 308/hours. Bioptic telescope use frequency was not correlated with visual acuity (through carrier lenses: rho = 0.294; P = 0.221; through telescope: rho = 0.137; P = 0.573), or the number of years of bioptic driving (rho = 0.366; P = 0.135).

Time Looking Through Telescope

Almost all the bioptic telescope uses were brief, except for one participant (participant #3), who often looked through his telescope for a long duration in a single bioptic use event (the second most frequent user in Fig. 5a). For participant #3, the actual time looking through the telescope was manually determined for

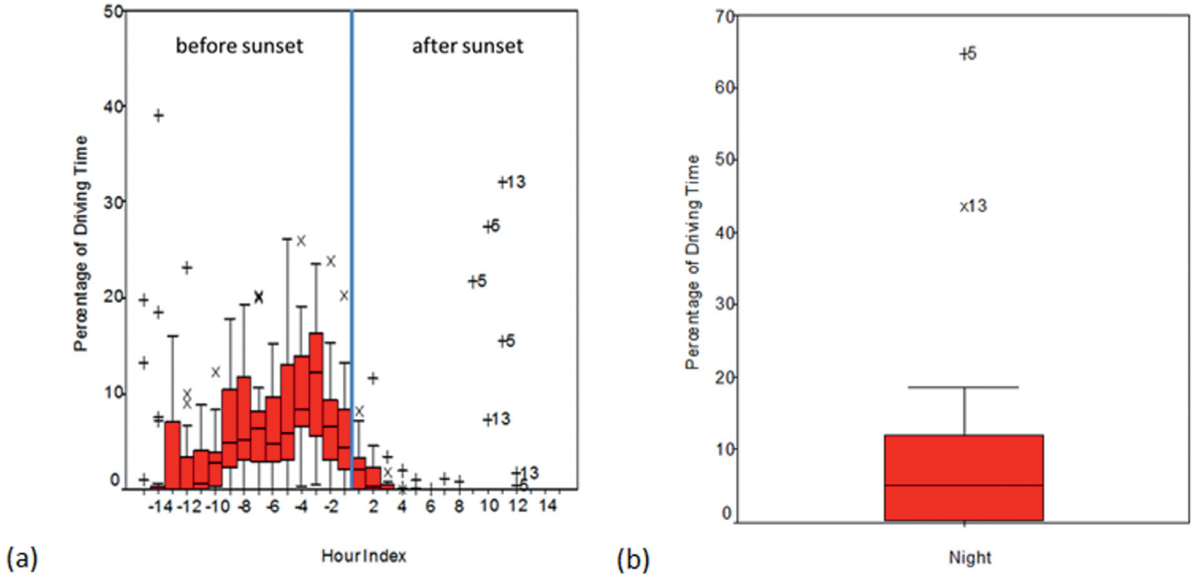

Figure 4. (a) Percentage of driving occurrence in each hour before and after sunset. (b) Percentage of total driving time spent driving at night. The blue vertical line marks the sunset time, which separates the day (on the left) and the night (on the right). The line within each box represents the median; box length represents the interquartile range (IQR); whiskers represent data within 1.5 × IQR. " × " indicates outliers (between 1.5× and 3× IQR) and "+" indicates extreme outliers (>3× IQR). Outliers discussed in the text are identified by participant number (here, #13 and #5).

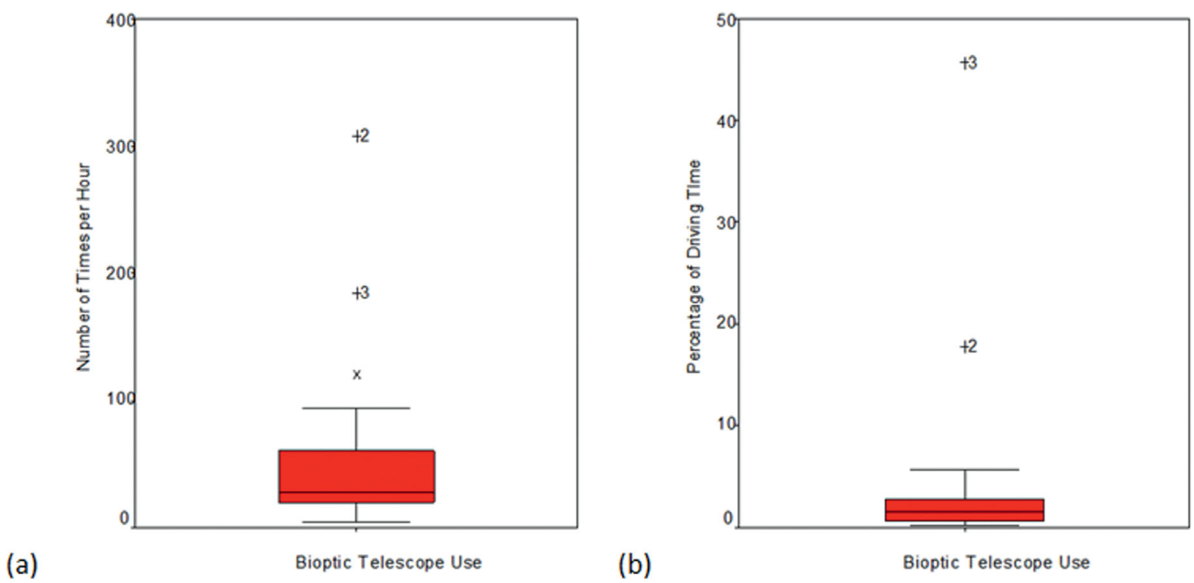

Figure 5. (a) Distribution of bioptic telescope use frequency (number of times used per hour). (b) Distribution of the driving time (percentage) spent in using bioptic telescope.

each detected event from the start of the downward head tilt to the end of the upward head movement at the end of the bioptic use. The median duration was 4.0 seconds (IQR, 1.0–12.5). For each of the other 18 participants, we manually counted the number of video frames in each of 180 randomly selected bioptic use events. The median duration of the bioptic use events for these 18 participants was 1.4 seconds (IQR, 1.2–1.8). Using this representative bioptic use duration, the percentage of time looking through the telescope was estimated, which was 1.6% (median) with IQR between 0.7% and 3.5% (Fig. 5b).

The participant (participant #3) who often used the bioptic in a prolonged fashion spent about 46% of driving time looking through his telescope. The distribution of this participant's bioptic telescope use

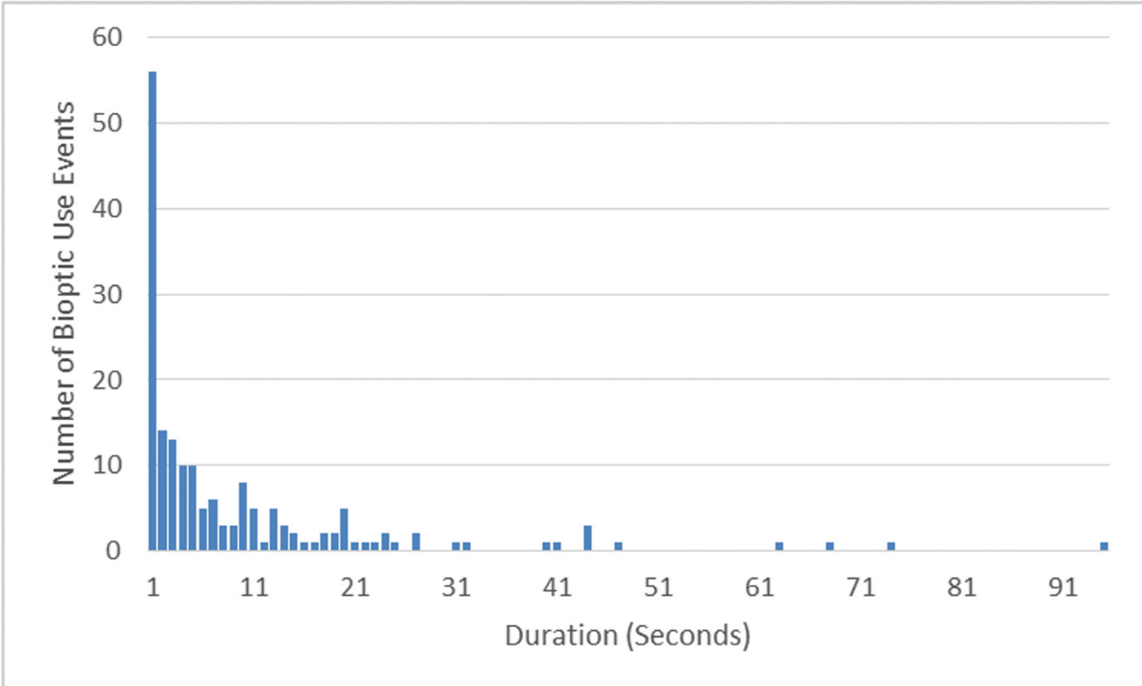

Figure 6. Histogram of biopic telescope use duration for participant #3, who often looked through his telescope for a long time.

duration is shown in Figure 6. In general, this driver used the bioptic telescope briefly (1 second or less) for 32% of all the bioptic telescope use events, and he used the bioptic telescope for >2 seconds for 60% of the events. The longest bioptic telescope use duration was 95 seconds. This participant looked through the bioptic telescope for long durations only when driving outside the city with a clear road, light or no oncoming traffic, and no side roads. The driver (participant #2) who used the telescope most frequently spent 17.8% of the driving time using his bioptic telescope, and all bioptic uses were brief.

Bioptic Telescope Use Annotation

The distributions of the maneuvers after the bioptic telescope use, the types of targets viewed through the bioptic, intersection, types of roads, and traffic conditions are presented in Figure 7 through Figure 10, respectively.

More than 60.0% of maneuvers after the bioptic telescope use were driving straight (Fig. 7). For the other maneuvers after the bioptic telescope use, 13.1% were stationary (the bioptic was used while the vehicle was stopped), 11.2% were driving on curved roads, 7.1% were turning, 5.9% were braking, and 1.1% were lane changes.

As for the targets being observed (Fig. 8), the bioptic telescopes were used most often for checking the road

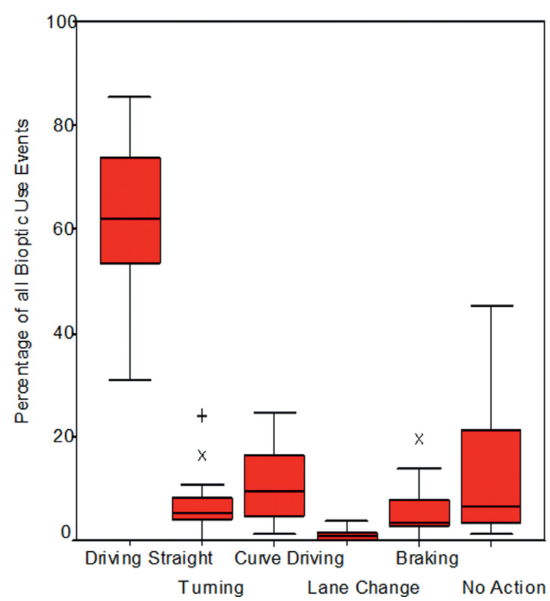

Figure 7. Distribution of bioptic telescope use with respect to maneuvers after each bioptic use event.

ahead (84.8%), followed by looking at traffic lights (5.3%), and reading road signs (4.6%).

Approximately 40% of the bioptic telescope use events occurred for checking intersections (Fig. 9), and the rest (60%) were not associated with intersections. Overall, we observed substantially more bioptic telescope uses (82.1%) during non-highway driving,

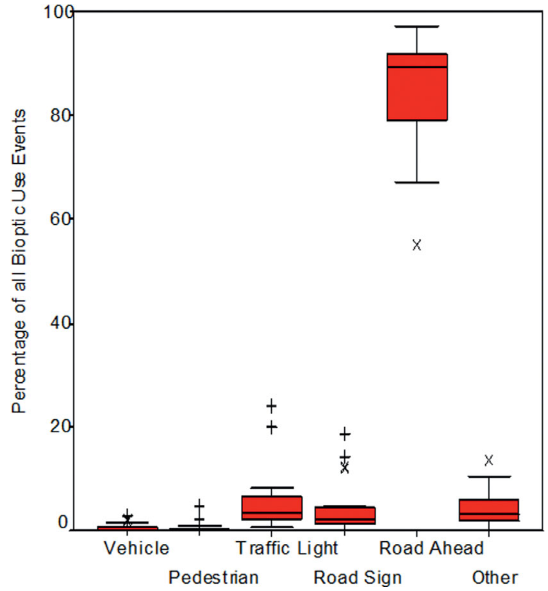

Figure 8. Distribution of bioptic telescope use with respect to the types of targets viewed through the bioptic.

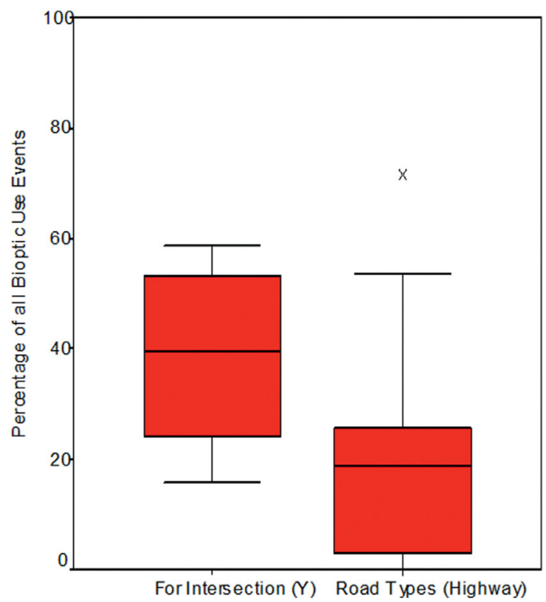

Figure 9. Distribution of bioptic telescope use with respect to intersection (yes) and road type (highway). Since intersection (yes or no) and road type (highway or non-highway) were binary-choice questions, the figure only presents data for one choice for each of them for simplicity.

and only 17.9% during highway driving (Fig. 9), except for two participants who used their bioptic more on the highway (53.5% and 71.4%). It should be noted that the percentages were not normalized for driving exposure on each road type. Therefore, the percentage may reflect both the driving exposure and the frequency of bioptic use events for each road type.

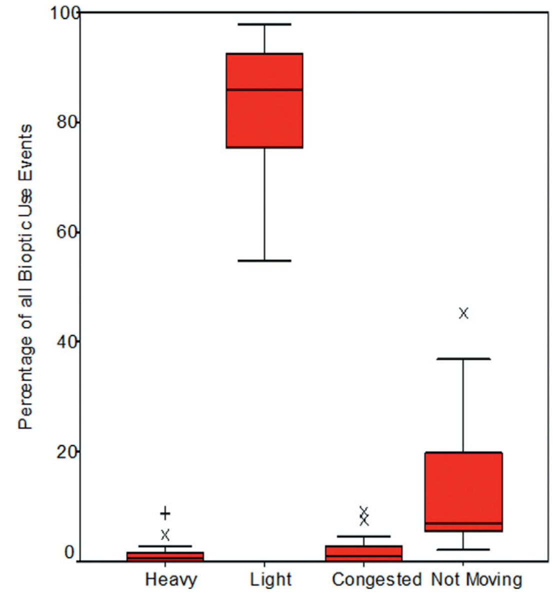

Figure 10. Distribution of bioptic telescope use with respect to traffic conditions.

More than 80% of bioptic telescope uses were carried out when surrounding traffic was light (Fig. 10). Very few occurred when traffic was heavy (1.3%) or congested (2.1%).

Discussion

Our sample of bioptic drivers varied in age, bioptic driving experience, and geographic location, representative of a wide cross section of the bioptic driving population. We found that the frequency of bioptic use varied widely across subjects, ranging from 4 to 308 uses per hour. Similarly, Wood et al.'s study[23] found wide variability in bioptic telescope use frequency among participants (0 to 318 uses) in a 45-minute on-road driving evaluation. The median frequency of use was 27 times per hour in the current study compared to an average of 103 times per hour in Wood et al.'s study.[23] This difference in usage frequency was likely due to different driving situations: habitual daily driving in the current study compared to designated sign-reading tasks during the road test in the Wood et al. study.

Most (18 of 19) participants used the telescope briefly with a median duration of 1.4 seconds between the start and end of each telescope use. This observation is in good agreement with recommended bioptic use guidelines.[16] In general, participants spent only 1.6% of total driving time using their bioptic telescope, which is lower than the median estimate of 5% based on bioptic drivers' self-reports in a previous questionnaire study.[20] However, we found that two drivers spent a much higher percentage of driving time (46.1% and 17.8%) using their bioptic telescope. One of these drivers used the telescope briefly but very frequently whereas the other used the telescope less frequently but many bioptic uses were long (median 4.0 seconds). These two drivers did not differ from the rest of cohort in age, years of bioptic driving experience, or vision impairment. Rather, the main factor that may have accounted for their different bioptic use habits was the fact that they had never received any bioptic driving training. As our previous studies showed, detection of peripheral hazards may be impaired to some extent when looking through a bioptic.[13–15] So it is a concern when a bioptic driver uses a telescope for a very long time, even under light traffic conditions. We suggest that training in how to use a bioptic when driving is necessary for all bioptic drivers before they receive a license.

In the survey study by Bowers et al.,[19] 100% of bioptic drivers reported that they used their telescope for reading road signs and 60% for checking the road ahead; however, the frequency of telescope use for those tasks was not quantified. Wood et al.[23] noted in their on-road driving study that road signs were the most frequently viewed target (46.2%), followed by traffic lights (39.6%), pedestrians (6.7%), the vehicle ahead (5.1%), and the roadway at intersections (2.4%). The findings of Wood et al.'s study are likely related to the number and type of potential targets along the unfamiliar driving route as well as the requirement to call out all traffic signs and traffic lights. We observed different behaviors in this study – the bioptic was used mostly for looking at the road ahead. We think this is probably because in natural daily driving, the participants drove mostly in familiar areas, and they usually knew the directions, routes, and road signs. It was the traffic conditions and the mobile objects (traffic and pedestrians) in the environment that varied when driving along familiar routes. Therefore, checking the road ahead at a far distance was what the bioptic was used for most often. This may be a proactive strategy to gain awareness of the road situation ahead in the distance (not necessarily knowing whether or not there are hazards), which otherwise the bioptic driver would not be able to see. This strategy is sensible for maximizing the extent of the scene visible within the restricted field of view of the telescope. Far distances are usually where the bioptic drivers have difficulty in seeing details and they are also the distances at which the small telescopic visual field can cover a relatively large area of the scene. By comparison, at shorter distances, the telescope field of view covers only a small area of the scene. Thus, at shorter distances, the ability to perceive a wide field of view through the carrier lens (despite the low visual acuity) presumably would be relatively more important than high resolution vision (through magnification) with a small field of view through the telescope, because the need for high resolution vision is reduced for short distances.

The majority of driving was undertaken during the day. However, almost all of the participants ($n = 17$) did also drive at nighttime, and one even drove more in the nighttime than the daytime. We contacted the two participants with the highest percentage of nighttime driving, 64.6% and 43.6% of their total driving duration, and asked about the reason for their long hours of driving at night. Nighttime driving is allowed in the jurisdiction in which these two participants are licensed to drive. One participant needed to drive at night to work whereas the other participant chose to drive at night because there were not many cars on the road.

It might be expected that there would be some relationship between the level of vision impairment and bioptic use frequency. However, we found no significant correlation between visual acuity (with or without bioptic) and bioptic telescope use frequency. In other words, drivers with worse visual acuity were not more likely to use the telescope than those with better visual acuity. This might seem a surprising result; however, there are many other factors that might also affect telescope use frequency, such as familiarity with the driving route, and whether driving on the highway or in a city. There are many factors that may affect bioptic use frequency. We previously reported a case in which cell phone use caused a large reduction in bioptic use frequency.[24] In addition, passenger presence may affect drivers' behaviors,[27] possibly including bioptic use too, for instance, when the driver had conversation with the passenger during driving. Because only 8 of the 19 bioptic drivers occasionally drove with passengers present, the limited sample could not support robust analysis in this paper. The high prevalence of GPS navigation systems may also reduce the need for reading street signs. Because we found most bioptic uses were for looking at the road ahead in the distance, which was presumably beyond the visual capability of all the participants no matter what visual acuity they had, it is not unreasonable that there might be no relationship between visual acuity and bioptic use frequency.

Despite the legality of driving with a bioptic, the safety of such driving still remains controversial. Poor understanding of bioptic driving safety is also reflected in the very different regulations across jurisdictions. Because our findings confirmed that the majority of participants spent most of their driving time looking through the carrier lens (i.e., driving under low vision conditions with moderately reduced visual acuity), a critical question that needs to be answered is whether it is safe to drive under low vision conditions for the majority (>98%) of driving time. Further analysis of the naturalistic driving data collected in the current study will be carried out to address this question.

In addition to addressing questions about the safety of bioptic driving, investigating this unique population of drivers can contribute to improved understanding of the role of vision in driving in general. Due to the visual acuity requirements for driving licensure, there is an ethical barrier preventing researchers from studying driving safety in naturalistic settings in drivers with visual acuity far below the licensure thresholds. As bioptic drivers spend most of their driving time not looking through their telescopes, they can be a cohort for researchers to ethically and legally study driving safety in the natural real-world environments. It has been shown in a standardized road test that most already-licensed bioptic drivers (22 out of 23) were rated safe.[23] Recent studies also found that bioptic drivers' collisions rates were correlated neither with visual acuity[28] nor road test performance.[29] In a case report, an early bioptic adopter received his license in 1971 had 20/100 vision at that time,[30] and according to a report acquired from California Department of Motor Vehicles, his vision still remained 20/100 in 2017. His vision specialist made a comment on the report that he "has been driving since 1971 with excellent safety record." This is just an individual case that might represent many bioptic drivers with clean safety records too. Dougherty[28] found 48% of bioptic drivers (whose median bioptic driving experience was 10 years) in Ohio had zero motor vehicle collisions. This compelling body of facts suggests that it might be possible to drive safely with low visual acuity. If we can further confirm the safety of driving with reduced visual acuity with solid evidence from naturalistic driving studies, significant implications and new questions would arise as to the role of visual function in driving.

Conclusions

This is, to the best of our knowledge, the first report about bioptic telescope use patterns based on natural daily driving. Our results suggest that visually impaired drivers drove for most of the time (>98%) under unassisted low vision conditions (corrected only with the distance spectacle prescription provided by the carrier lenses of the bioptic device), even in night driving. The bioptic telescopes were used most often for checking the road ahead for distant situation awareness, and only a small percentage was for sign reading. Further studies are required to investigate the causal relationship between driving safety and human factors, such as bioptic use habits and visual acuity, in habitual naturalistic driving conditions.

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