SURVEY OF OPHTHALMOLOGY VOLUME 43 • NUMBER 6 • MAY–JUNE 1999

PUBLIC HEALTH AND THE EYE

JOHANNA SEDDON AND DONALD FONG, EDITORS

Vision Impairment and Driving

CYNTHIA OWSLEY, PhD, MSPH,[1] AND GERALD McGWIN, JR, MS, PHD[2,3]

Departments of [1]Ophthalmology and [2]Surgery, School of Medicine, University of Alabama at Birmingham, Birmingham, Alabama, [3]Department of Epidemiology, School of Public Health, University of Alabama at Birmingham, Birmingham, Alabama, USA

Abstract. Driving is the primary mode of travel in many countries. It facilitates the performance of routine daily activities and is thus integral with the concept of quality of life. Vision is inarguably a fundamental component of safe driving. Drivers with certain eye conditions reduce their driving exposure and restrict their driving to the safest times, yet there is preliminary evidence that some eye conditions increase the risk of crashes. Visual acuity is only weakly related to crash involvement, whereas peripheral vision appears to play a more critical role. Color vision deficiency by itself is not a threat to safe driving. Based on the current literature, it is unclear whether other types of visual sensory impairment have a significant impact on driving safety and performance. Tests of visual attention and processing speed show great promise as methods of identifying high-risk drivers. There is a serious need for well-designed studies in key practical areas, such as the safety of low-vision drivers who use bioptic telescopes, the impact of monocular vision impairment on safety, and the effectiveness of vision rescreening policies after initial licensure. For ophthalmologists to guide patients about driving fitness, valid and reliable assessment tools must be developed and made widely available. (**Surv Ophthalmol 43**:535–550, 1999. © 1999 by Elsevier Science Inc. All rights reserved.)

Key words. automobile • contrast sensitivity • driving • eye disease • low vision • vision impairment • visual acuity • visual field

In 1996 there were 41,907 fatalities and 3,511,000 injuries caused by automobile crashes in the USA.[130] Approximately 6 million additional crashes resulted in property damage only. Research has demonstrated that these events are not random. Young and old drivers have higher accident rates than their middle-aged counterparts.[20,24,41,42,176,177,184] Furthermore, the nature of automobile crashes among these high-risk groups differs.[24,60] Alcohol and excessive speed are common causes of crashes among young drivers, yet they do not account for the large number of crashes among older drivers. Among older drivers, research has focused on medical conditions and impairments as risk factors for crash involvement,[76,129,138,176,177] including the role of vision impairment and eye disease.

The safe operation of an automobile requires the successful integration of human, vehicle, and environmental factors. A great deal of effort has focused on designing vehicles and roadways to reduce the likelihood of an automobile crash and injury during a crash. Attempts have also been made to restrict driving to those persons capable of operating an automobile safely. Laws designed to prohibit driving under the influence of alcohol or other drugs are an example. The restriction of driving privileges to only

0039-6257/99/$19.00
PII S0039-6257(99)00035-1

those persons who fulfill certain eligibility criteria is another. Some criteria (e.g., written tests) are designed to ensure a minimum level of knowledge. For other provisions (vision tests, for example), the rationale would appear to be an assessment of skills necessary for the safe operation of a motor vehicle. Although it is clear that vision is important for driving,[164] it is not at all clear that the vision tests used by licensing agencies assess the visual skills necessary to drive safely. The equivocal nature of the relationship between certain aspects of vision and driving, as indicated in the literature, supports this idea.

Driving is the primary mode of travel in many countries. It facilitates the performance of routine daily activities, employment, and opportunities for social interaction.[68] Possession of a driver's license in many societies is an important symbol of personal independence. Just as driving is frequently linked to autonomy, driving cessation is linked to social isolation and depression.[118] Thus, the ability to drive contributes strongly to the concept of health-related quality of life.[149] In addressing vision impairment and driving problems, clinicians must take into account the preservation of road safety, as well as the personal hardships of driving cessation in a society where the personal vehicle is the main mode of travel.

In this article we review what is known about how various eye diseases and conditions impact driving habits, performance, and safety. We then focus on the relationship between driving and specific types of vision impairment, regardless of cause, providing separate sections addressing drivers with low vision and commercial drivers. Finally, we discuss public policy issues and methodologic challenges for researchers interested in studying vision impairment and driving. A summary section highlights conclusions and needs.

Eye Diseases and Conditions

CATARACT

Cataract is a leading cause of vision impairment in adults over 60 years old.[84,175] Almost half of older adults by age 75 years have early cataract, and approximately one quarter have late cataract.[97] Typically bilateral in older adults, this condition compromises many aspects of vision, including acuity, contrast sensitivity, and visual field sensitivity, and increases disability glare. Although effective treatments for cataract are now available, many adults must cope for an extended period of time with vision impairment induced by cataract until the time when surgical removal of the cataract occurs, usually when functional limitations become serious. The implication is that there are many drivers on the road with cataract.

Older drivers with cataract more often report that they experience difficulty on the road than do those without cataract,[145] and they also report that they avoid challenging driving situations.[10] These challenges include driving at night, during inclement weather, on interstate highways, and in rush-hour traffic, and making left turns. Furthermore, drivers with cataract who report the most difficulty also report that they restrict their driving exposure, reducing the number of days they drive per week and restricting their "driving space" (i.e., the spatial extent of driving in their geographic area).[145] Cataract is also associated with driving cessation.[118] Although the studies reported do not permit inferences about cause and effect, it appears that many older drivers with cataract may self-regulate driving in response to their vision impairment. Cataract surgery with intraocular lens implantation is associated with decreases in driving difficulty as reported by patients. [7,115,126]

A question of interest is whether cataract places older drivers at an elevated risk for involvement in motor vehicle collisions. A recent study examined crash risk in older drivers with cataract, 97% of whom had bilateral cataract with at least one eye having best-corrected visual acuity of 20/40 or worse.[145] The comparison group consisted of older drivers free of cataract and other eye diseases. Older drivers with cataract were 2 ½ times more likely to have been involved in a crash during the previous 5 years, as compared to older drivers who were cataract free. This association was adjusted for driving exposure, age, comorbid medical conditions, other eye diseases, depression, and cognitive impairment. Two other studies failed to find an association between cataract and crash involvement. Foley et al relied on subjects' self-report that cataract was present and, in evaluating the association between cataract and crash involvement, did not adjust for driving exposure.[46] McCloskey et al also did not adjust for driving exposure, considered only injurious crashes, and used a sample derived from a health maintenance organization.[121]

GLAUCOMA

Glaucoma may soon be the second most common cause of blindness in the world. It has been projected that there will be 6.7 million cases of glaucoma worldwide by the year 2000,[153] and it is among the top four causes of vision impairment in older adults.[84,175] Persons with glaucoma and visual field impairment report more difficulty driving than do nonglaucomatous comparison groups, as assessed by vision-targeted health-related quality of life instruments.[59,113,148] However, no studies have addressed the driving habits of persons with glaucoma, or how their driving patterns may be influenced by their self-acknowledged driving difficulty.[140]

Studies of crash risk in older drivers have hinted that glaucoma may have a role in crash involvement among the elderly. A study of Washington State older drivers enrolled in a health maintenance organization indicated that those involved in an injurious crash were 50% more likely to have glaucoma than those who were not involved in a crash.[121] However, the confounding roles of other factors (comorbid medical conditions, driving exposure) were not evaluated. A prospective study by Foley et al on crashes regardless of injury in the Iowa Established Populations for Epidemiologic Studies of the Elderly cohort also found an unadjusted elevated crash risk among older drivers with glaucoma.[46] Hu et al, in a panel data analysis of the Iowa Established Populations for Epidemiologic Studies of the Elderly cohort from 1981 to 1993, found that male drivers with a self-reported history of glaucoma were 1.7 times more likely to be involved in a crash, but this association did not hold for women.[67] In a case-control study, Owsley et al evaluated visual risk factors for vehicle crashes that result in injury.[143] They found that older drivers involved in injurious crashes during the previous 5 years were 3.6 times more likely to have glaucoma than those who were crash free. Visual field impairment is a common functional manifestation in glaucoma. Johnson and Keltner reported that severe binocular field loss is associated with a history of crash involvement.[80] In their study, 35% of the drivers reporting that they had glaucoma exhibited a visual field deficit, although they did not report the severity of this deficit and whether it was associated with crash involvement.

It is interesting to point out that the use of topical eye medications in elderly patients with glaucoma increases their risk of another adverse mobility outcome, falling.[55] The possibility that medications to treat glaucoma may independently contribute to motor vehicle collisions has not been investigated, and, given the widespread use of pharmacologic treatments for this condition, it is an issue worthy of investigation.

DIABETIC RETINOPATHY

Diabetic retinopathy is a highly specific vascular complication of both type 1 and type 2 diabetes that poses a serious threat to vision. In the Wisconsin Epidemiologic Study of Diabetic Retinopathy, 3.6% of younger-onset patients (aged less than 30 years at diagnosis) and 1.6% of older-onset patients (aged 30 years or more at diagnosis) were legally blind.[1] In the younger-onset group, 86% of blindness was attributable to diabetic retinopathy. In the older-onset group, one third of the cases of legal blindness were attributable to diabetic retinopathy. Overall, diabetic retinopathy is estimated to be the most frequent cause of new cases of blindness among adults aged 20 to 74 years.

Despite its impact on vision, few studies have evaluated the association between diabetic retinopathy and driving. Only one published study has reported an association between this condition and crash involvement. McCloskey et al reported that older drivers with retinopathy had a nonsignificantly reduced risk of injurious crash involvement.[121] However, a number of studies have reported associations between diabetes and crash risk. Waller found that diabetics known to the California Department of Motor Vehicles had almost twice as many traffic crashes per mile driven as a reference group of nondiabetic drivers.[182] Similar studies conducted in Oklahoma and Washington State presented consistent results.[26,29] More recently, Hansotia and Broste reported that drivers with diabetes have slightly increased risks of traffic accidents than unaffected persons.[62] Koepsell et al reported that older drivers involved in injurious traffic crashes were 2.6 times more likely than control subjects to have a diagnosis of diabetes.[100] DeKlerk and Armstrong also reported a higher risk of hospital admissions for road trauma among young diabetic men.[33] Songer et al found no overall association between insulin-dependent diabetes mellitus (IDDM) and traffic crashes[165]; however, women with IDDM were at increased risk. A number of other publications have found no association between diabetes and crash involvement.[37,46,57,169,189] Unfortunately, none of these studies evaluated the role of diabetic eye disease in automobile crash involvement.

AGE-RELATED MACULAR DEGENERATION

Age-related macular degeneration (AMD) is the leading cause of untreatable vision impairment in older adults. Very few studies have addressed the impact of AMD on driving. It has been found that drivers with AMD report more difficulty driving,[114] more avoidance of challenging driving situations,[10] and less risk-taking behavior[173] than drivers without AMD. Greater scotopic sensitivity impairment in drivers with AMD is associated with more reported difficulty in night driving.[75]

Little is known about whether AMD elevates crash risk. The Washington State study of patients enrolled in a health maintenance organization[121] found no association between AMD and involvement in an injurious crash, but it did not take driving exposure into account. In a study of both simulated and on-road driving performance, drivers with AMD performed worse than age-matched normal subjects in a variety of driving maneuvers and situations.[173] They also had fewer crashes in prior years than did the controls. Given that drivers with AMD appear to restrict or limit their driving, it is possible that this counteracts any elevation in crash risk that may result from their vision impairment, an issue in need of clarification.

OTHER RETINAL DEGENERATIONS

There have been few studies on the driving characteristics of persons with retinal degenerations. Fishman et al found that drivers with retinitis pigmentosa (RP) were involved in more crashes in the previous 5 years than disease-free controls, an association that was mediated by a disproportionate number of female RP patients who were involved in crashes.[45] Those who were more visually impaired, either in central or peripheral vision, were not more likely to be crash-involved. The crash data were self-reports by study participants and were not based on state records. Szlyk et al similarly found an association between RP and self-reported crashes, as well as crashes in a driving simulator.[171] They further reported that this elevation in crash risk was related to restrictions in the horizontal extent of the visual field. In contrast, drivers with retinal degenerations primarily affecting central vision (Stargardt disease, cone-rod dystrophy) were not more likely than controls to be crash-involved, as assessed in a simulator, by self-report, and by state records.[172] Given that studies on driving and retinal degenerations are rare, have limited sample size, and cover broad case definitions, conclusions with respect to driving and crash risk in this area are not merited.

REFRACTIVE SURGERY

Several studies have indicated that after radial keratotomy (RK) or photorefractive keratectomy (PRK), some patients report increased difficulty with night vision while driving.[6,39,54,86,120,134–136] For example, up to 10% of patients who had PRK with an ablation zone of 4.00 mm in diameter indicated that halo problems interfered with night driving.[134–136] It is believed that these night vision problems most likely result from disturbances in the corneal aberration structure resulting from laser ablation. Martinez et al pointed out that at night and in other low-luminance conditions, when the pupil diameter can increase from 3 to 7 mm in diameter, the preoperative eye has a ninefold increased total aberration, whereas after PRK, there is a 100-fold increase in total aberration.[120] This raises the possibility that the use of large treatment zones in PRK to reduce visual problems such as halos and glare may reduce night driving difficulty, an area for further investigation. Analogously, after RK, under night conditions where the pupil diameter increases to 7 mm, aberrations are significantly increased, especially for smaller clear optical zones.[6] With both RK and PRK, self-reported night driving problems seem to lessen with the passage of time after surgery.[54]

There are some important issues that must be mentioned with respect to night driving and refractive surgery. First, it is important to point out that patients using other types of refractive correction, such as contact lenses and spectacles, report similar visual problems during night driving; thus, reported night driving difficulty is not a syndrome unique to patients who have had surgical treatment for their refractive error.[14] Second, the visual mechanisms underlying night driving complaints by patients after refractive surgery have not been clearly identified. Ghaith et al recently found that contrast sensitivity and disability glare deficits did not reflect patients' subjective assessments of their vision in everyday life.[54] Finally, it is unknown to what extent subjective night vision difficulty during driving in patients who have undergone refractive surgery is related to reduced driving exposure (e.g., avoidance of night driving) and unsafe driving at night (e.g., crashes).

Impairment of Visual Function

VISUAL ACUITY

Visual acuity is perhaps the most ubiquitous visual screening test used by licensing agencies for the determination of driving fitness. However, in the United States, the requirements are highly variable from state to state.[5] In Florida, drivers must have visual acuity of 20/70 in either eye with or without corrective lenses, whereas drivers in Connecticut must have 20/40 in the better eye, with or without corrective lenses. In some states, drivers who do not meet the vision requirement may be eligible for a restricted driver's license. For example, in Arkansas, drivers must have a minimum uncorrected visual acuity of 20/40 for an unrestricted license; persons with visual acuity of 20/60 will be restricted to daytime driving only. Finally, it should be noted that although these requirements apply for first-time license applicants, 12 states do not have mandatory periodic vision rescreening when drivers are older.[105,163]

The relationship between visual acuity and driving performance has been evaluated by a number of authors. Some of the most influential work was done by Burg[16,17] and reanalyzed by Hills and Burg.[66] The Burg studies analyzed data from 17,500 California drivers. These analyses indicated that for young and middle-aged drivers, there was no relationship between poor visual performance and crash rates. With respect to older drivers, visual acuity demonstrated significant relationships with crash rates. However, the authors noted that, despite statistical significance, the magnitude of the correlation was low, and they cautioned that the relationships found should not be taken to mean that poor vision is a causal factor in automobile crashes. A number of other studies have also reported positive associations between visual acuity and crash involvement.[9,30,64,66a,69,107,119] However, the magnitude of the associations typically observed in these studies is small. Several other studies of risk factors for automobile crashes among older drivers have also examined the role of visual acuity in crash risk but have reported no significant associations.[32,58,74,79,117,121,142] All in all, there is little support for a strong association between visual acuity and unsafe driving in the driving population in general, a conclusion expressed by several other authors.[21,66] For older drivers, there remains the possibility that an association between visual acuity and crash involvement exists but is, at best, weak. In terms of actual driving performance, simulated acuity impairment (from induced optical blur) has been associated with decrements in road sign recognition and road hazard avoidance, but was unrelated to clearance judgments about safe passage and slalom maneuvers.[65]

Given that visual acuity is the most commonly used visual screening test for licensure, it seems paradoxical that research generally does not support the conclusion that it can reliably identify high-risk drivers. It is not entirely clear why visual acuity was chosen as a screening test for driving. One possibility is that Snellen acuity was a clinically common and simple way of assessing visual function at the time licensing requirements were adopted. The existing variability with respect to acuity requirements for licensing is equally puzzling and may reflect arbitrary decisions as to what level of acuity a driver should possess in order to safely operate an automobile.

There are several possible reasons why studies have generally failed to find strong associations between visual acuity and crash risk. First, traditional visual sensory tests, such as letter acuity, were originally designed for the clinical diagnosis and monitoring of eye disease and do not by themselves reflect the visual complexity of the driving task. Guiding a vehicle along a roadway and through intersections involves the simultaneous use of central and peripheral vision and requires monitoring of primary and secondary tasks, all in the midst of a visually cluttered environment where critical events occur with little or no advance warning. Visual sensory tests do not typically include these stimulus features, and in fact seek to minimize distractions and secondary task demands. Thus, it is not surprising that traditional vision tests, such as acuity, contrast sensitivity, visual field sensitivity, and disability glare, are not strong predictors of crash involvement, a point also made in earlier studies.[9,121]

Second, the visual world of the driver is in motion, and in this sense, stationary test targets in screening tests are not very representative of the visual scene. Studies that have included both static and dynamic acuity measurements have generally found relatively stronger associations for dynamic than for static acuity.[16,17,66,161] However, the associations between dynamic visual acuity and driver safety are still weak. It has been noted that dynamic acuity deteriorates more rapidly with age and does not necessarily correspond to static acuity; that is, individuals with the same static acuity can have widely divergent dynamic acuity.[162] At the very least, tests of sensitivity for dynamic visual events require a closer look in terms of their association with driving problems.

Third, because of state licensing restrictions, it is possible that drivers with severe visual acuity impairment may not be driving, especially in states that have mandatory rescreening of visual acuity at certain yearly intervals. In this sense, visual acuity restrictions may in fact be successful in increasing public safety. Therefore, it would be impossible in many states to conduct the proper study to evaluate whether and to what extent visual acuity was associated with automobile crash involvement. Research also suggests that individuals with visual acuity and other vision impairments, especially older drivers, may elect to give up driving or simply limit their driving to familiar and low-risk situations.[10,18,52,118,170] All of these factors would mitigate against finding an association between acuity and crash involvement, even if one exists. However, many states (e.g., Alabama) do not require vision rescreening and, therefore, are likely to have drivers with visual acuities that would make them ineligible to drive in other states. Such situations represent opportunities to evaluate the impact of state visual acuity restrictions by providing estimates of crash risk among drivers who would have been screened out in other states. At least one such study found no significant association between visual acuity impairment (worse than 20/40) and crash risk.[141] Thus, had these individuals been removed from the road, the increase in public safety would likely have been negligible.

Finally, it may be that individuals with similar visual acuity may in fact differ with respect to other aspects of visual functioning critical for driving. Thus, vision screening protocols that address several domains of visual function may prove more useful in discriminating high- and low-risk drivers. Decina and Staplin provided some empiric support for this hypothesis.[32] They linked visual examination data from 12,400 drivers in Pennsylvania to drivers' crash histories and found that drivers who did not meet a combined vision screening criterion (including visual fields, acuity, and contrast sensitivity) had higher accident rates. Further, visual perception during driving is dependent not only on visual sensory function and physiologic optics, but also on central processing skills,[9,121,142] as will be discussed later.

VISUAL FIELDS

Visual field assessment is another common screening procedure for driver licensing. In the USA approximately half of the individual states have requirements with respect to visual fields, and, as with visual acuity, requirements for visual fields are highly variable. In Arizona the field of vision must be 60°, plus 35° on the opposite side of the nose in at least one eye. The field of vision for Connecticut drivers must be 140° for a person with two eyes and 100° for a person with one eye. As with visual acuity, the rationale for one requirement over another is often not clear. Although some have suggested that an absolute visual field of less than 160° may prevent safe driving,[2] others propose that head and eye movements and use of mirrors can compensate for visual field defects.[133]

Numerous studies have assessed the relationship between visual field and driver safety, the most notable being that of Johnson and Keltner.[80] They reported that crash and violation rates were twice as high among those with binocular field loss than those without any loss. This study is noteworthy in that the rates took annual mileage into account. However, a number of other studies have also taken driving exposure into account and have not reported higher crash rates for those with visual field impairments.[16,17,32,66,141] An important consideration in comparing these results is that the definition of impairment differs among the studies. Johnson and Keltner defined impairment as very significant binocular field loss,[80] whereas most other studies defined it in a less extreme fashion.

Several other studies have also examined the association between visual fields and driving. In a series of articles, Wood et al evaluated the impact of simulated visual field restriction on driving performance on a closed course.[186–188] Taken together, the results of these studies suggest that simulated visual field impairment compromised some (e.g., identification of road signs, avoidance of obstacles, reaction time) but not all (e.g., speed estimation, stopping distance) aspects of driving performance. Lovsund and Hedin also reported that visual field defects impaired the detection of stimuli in the affected area in tests with a driving simulator.[111] The relevance of the findings from these studies to real-world driving is unclear. It is likely that the impact of sudden, simulated visual field restriction is different from that of naturally occurring restriction from eye disease, in which the driver may develop compensatory mechanisms over time. Further, closed-course or simulator driving is likely to be less complex and demanding than actual driving and may not allow observation of critical driving problems (e.g., crashes). In several studies in which real-world driving performance was assessed, drivers with visual field impairment were not at increased risk of driving problems.[19,25,28,119]

When interpreting the literature on visual fields and driving, it is important to consider measurement procedures. For example, in some studies only the extreme limits of the visual field were determined. Such screening techniques provide little information about the type or severity of visual field impairment (e.g., scotomas, central field defects). Another possible explanation for the differences among study results involves adaptation and compensatory strategies. Drivers with visual field defects may partly overcome them by eye and head movement, restricted driving, or both. In the future, studies should attempt to measure not only the extent of visual field defect but also the extent to which drivers accommodate. Drivers with visual field defects who successfully change their behaviors without a decrease in driving safety provide additional rationale for screening drivers for visual field defects. Such screening could identify impaired drivers and assist them in adopting accommodative strategies.

The visual field is restricted in drivers who are monocular or whose fellow eye is so severely impaired that they could be considered functionally monocular. Wood et al reported that simulated monocular vision did not affect closed-course driving performance.[186,188] The driving performance among drivers with real monocular vision has been assessed in a number of other studies.[38,80,90,96,107,123] In a study of 10,000 drivers, Johnson and Keltner reported that drivers with monocular visual field loss had a crash rate equal to that of a control group of drivers with both eyes.[80] Smaller studies by Edwards and Schachat[38] and McKnight et al[123] reported results consistent with these findings. However, not all studies support the conclusion that monocularity does not create a safety problem. From an unmarked police car, Liesmaa observed drivers' behavior during overtaking another car or entering a road junction. Drivers who were considered dangerous were stopped, and their vision was assessed.[107] A control group of nondangerous drivers was also stopped. The authors reported that there were three times as many one-eyed drivers among the dangerous drivers than among the control drivers. Keeney reported that monocularity was more common among a group of drivers with various driving transgressions than among patients in a general ophthalmologic practice.[90] Based on their review of the literature, Keeney and Garvey concluded that monocular drivers should not be licensed to drive commercial vehicles.[91]

In 1985 North reviewed the literature with respect to visual field status and driving performance and concluded that the literature is inconclusive.[133] He suggested that the inconsistency of findings may be attributed to differences in techniques used to measure visual fields and to the restricted driving habits of drivers with visual field defects, or both. North's conclusions reflect the findings of current research in this area. Most of the studies that have taken driving exposure into account have produced null results. The most prudent conclusion based on the literature may be that, although severe binocular visual field loss elevates crash risk, more subtle visual field impairment by itself is not likely to play a significant role in adverse driving events.

CONTRAST SENSITIVITY

Contrast sensitivity is not currently used as a licensing requirement in any state in the USA. A few studies have reported associations between contrast sensitivity and driving performance. Wood et al[186] and Wood and Troutbeck[188] simulated reduced contrast sensitivity and assessed subjects' driving performance on a closed road circuit. Overall driving scores were correlated with contrast sensitivity as measured by the Pelli-Robson chart in that better contrast sensitivity was associated with better driving skills. Similarly, Rubin et al reported that older drivers who reported difficulties with day and evening driving had worse contrast sensitivity.[157] Greater impairment in contrast sensitivity has been linked to a higher number of at-fault crashes in the previous 5 years[9] and in the subsequent 3 years,[141] although these associations were not adjusted for confounding factors. Marottoli et al also reported a positive univariate association between adverse driving events among older drivers and impaired contrast sensitivity.[119] Contrast sensitivity, as well as visual acuity, is linked to road sign recognition.[40,99,144] On the other hand, Owsley et al found that impairment of contrast sensitivity in a sample of older Alabama drivers was not related to future crash involvement when the relationship was adjusted for exposure and other independent predictors.[141] Given the scarcity of studies on contrast sensitivity and driving and the importance of image contrast in pattern vision, this is an area deserving of further study.

USEFUL FIELD OF VIEW

Because driving is a complex visual and cognitive task, it is unlikely that an assessment of visual sensory impairment and the diagnosis of eye disease would alone be sufficient to identify those at elevated risk for crash involvement. Visual information processing skills, not only visual sensory thresholds, have a great deal of face validity to the execution of safe driving practices. One such skill that appears to be relevant is visual attention. Several studies from the early 1970s implied that impaired visual attention abilities were linked to crash involvement,[12,85,125] but this finding was not further explored until recently.

Ball and colleagues[8,11,159] developed a task called the useful field of view test (Visual Resources, Inc., Chicago, IL) that assesses the visual field area over which one can use rapidly presented information (see also Sanders[158]). Unlike conventional measures of visual field, which assess visual sensory sensitivity, the useful field of view test additionally relies on higher-order processing skills, such as selective and divided attention and rapid visual processing speed. Reduction in the useful field of view in older drivers is associated with a history of at-fault crash involvement[9,139,141] and injurious crash involvement.[143] Those drivers with the most severe restrictions tended to have the highest number of crashes during the previous 5 years.[9] In a prospective follow-up study, Owsley et al found that older drivers with a 40% or greater impairment in the useful field of view were 2.2 times more likely to have a crash during the 3 years of follow-up, after adjusting for age, sex, race, chronic medical conditions, mental status, and driving exposure.[141] This association was primarily mediated by difficulty in dividing attention under brief target durations. It is noteworthy that in this study useful field of view impairment was the only type of visual deficit that was related to future crash involvement; deficits in acuity, contrast sensitivity, and visual field sensitivity were unrelated to future crashes. The useful field of view test has also been used to study crash proneness in the Alzheimer disease population. Studies indicate that in drivers with Alzheimer disease, useful field of view reduction is one of the best predictors of crash involvement in a simulator and poor on-road performance in a driving test, as compared to other cognitive tests.[27,36,70,155] These studies imply that visual attention and visual processing speed are critical considerations in the evaluation of safe driving skills and may be better screening tests than visual sensory tests for crash-prone older drivers.

Impaired performance on other tests of higher-order visual processing abilities have also been related to crash involvement and impaired driving performance, underscoring the importance of assessing visual skills beyond basic sensory capabilities. Studies have reported associations between unsafe driving and deficits in visual search and sequencing abilities,[34,56] selective attention tasks,[36,119] spatial memory,[137,155] and the perception of three-dimensional structure from motion.[155]

OTHER VISION IMPAIRMENTS

A number of other aspects of visual function have been considered with respect to driving. Color vision is tested at license application in 42 states in the

USA, and the ability to respond properly to color traffic signals is a requirement for a commercial vehicle license.[31] The reason for testing color vision in both personal and commercial licensing is not because color vision deficiency is a major risk factor for crash involvement; rather, color vision screening is simply meant to ensure that drivers can obey color traffic control devices.[63] The critical cues on the road can typically be obtained through multiple sources of information (e.g., luminance, position, pattern), so drivers with color vision anomalies do not experience serious difficulty in traffic signal recognition. Vingrys and Cole's comprehensive review of this literature indicates that the vast majority of studies on color vision and road safety support this conclusion, finding no association between color deficiencies and vehicle crash involvement or impaired driving performance.[179] One exception is a study by Verriest et al, who reported that drivers with color vision defects were more likely to have rear-end collisions.[179] However, because of the overwhelming wealth of evidence to the contrary, it is reasonable to conclude that color vision deficiency by itself does not increase crash risk in personal or commercial drivers.

Disabling glare problems are discussed as a serious threat to the safety of older road users,[185] but one is hard-pressed to identify actual studies that scientifically confirm this notion. This failure to find an association between glare and road safety may be attributed to methodologic difficulties in defining "glare" and in measuring a multifaceted phenomenon, as well as to a poor understanding of what people mean when they say they have "glare" problems. The role of eye movement disorders in driving is largely an unexplored area of research. Previous research on normally sighted drivers indicates that experienced drivers continuously scan the road scene for useful information.[127] Older drivers with restricted ability to turn their heads are limited in the distances at which approaching traffic can be brought into the central visual field for visual inspection.[73] Motion perception and optical flow phenomena, such as "heading," have a great deal of face validity to the driving task, but little research has addressed how impairments in motion processing may affect driving performance and safety. Shinar found that performance in a motion perception task was one of the best correlates of self-reported crash involvement among a large battery of vision tests, but the relationship was still weak.[161] Similarly, he found that acuity under low illumination was related to nighttime crash involvement, but again the link was weak. Leibowitz and colleagues have suggested that drivers' errors and crashes at night may stem from their lack of awareness of perceptual limitations that occur in low light.[103,104] There have been reports that the crashes of commercial drivers with poor or no stereoacuity are more severe and occur at a higher rate than those of drivers with normal stereoacuity.[69,101,112] Yet the extent to which these findings extend to noncommercial drivers is unclear. The importance of binocular vision disorders to driving is another area in need of clarification.

Low Vision

Licensing policies for low-vision drivers using bioptic telescopic spectacles (BTS) have received a great deal of attention. Bioptic telescopic spectacles used for driving have telescopes mounted in the superior portion of a regular lens (often referred to as a "carrier lens"), which incorporates the refractive correction as does the telescope. The most common telescope magnifications are between 2X and 4X and provide a field of view between 6° and 16°. As with other vision requirements, there is considerable variability in laws governing the use of BTS by drivers.[5] In the USA, more than half of the states allow drivers to use these devices when operating a motor vehicle; some have a special license category for such drivers. A number of authors have discussed the use of BTS and training programs for drivers who wish to use such devices.[5,13,23,44,71,72,81–83,87,88,92,93,95,101,146,147,150,166–168,174,180,183]

Despite this large body of literature, there have been few controlled studies of crash risk among drivers who use BTS. Four studies, from California,[78] New York,[132] Maine,[34] and Texas,[110] have reported that users of BTS have higher crash rates than control groups. An additional study from Texas found crash rates of visually impaired drivers to be similar to those of drivers with cardiovascular and neurologic impairments.[109] A study of drivers using BTS in Massachusetts reported crash rates lower than those of the general population.[101] Unfortunately, firm conclusions cannot be made on the basis of these studies for several reasons. Many of the studies used the general population of drivers as the control group. It is not clear whether the BTS itself and its "side effects" (e.g., reduced field of view) or severely impaired visual function or both are responsible for the elevated crash rates. Furthermore, it is likely that drivers using BTS restrict their driving (e.g., avoid night driving), and failure by investigators to account for such self-regulation in etiologic studies may lead to invalid results. As the design of low-vision assistive devices and training programs improve and become more popular, it is unclear whether the above studies will apply to future bioptic drivers.

Although most would agree that severely visually impaired individuals (e.g., those having visual acuity worse than 20/200, or less than a 20° visual field in the better eye) should not drive, controversy remains regarding drivers with moderate visual impairment. It has been recommended that the use of BTS for such drivers should be considered on an individual basis and should not be mandatory for obtaining a driver's license.[13] Other recommendations include a mandated use of BTS in conjunction with strict licensing requirements, including annual vision examinations and special training in the use of BTS.[92] Bioptic telescopic spectacle training programs already exist in a number of states.[5,183] Fonda has argued that low-vision drivers can drive safely without BTS and that such individuals should be issued restricted licenses.[47–51] He argues that the use of BTS while driving may, in fact, increase rather than reduce the risk of crash involvement. According to Fonda, restrictions placed on low-vision drivers should be determined by eye care professionals who should consider a driver's vision, previous driving record, and cognitive capabilities. This approach assumes that ophthalmologists can accurately judge what degree of vision is a threat to safe driving. As this literature review indicates, they may not have valid screening tools for making these recommendations.

Commercial Driving

In many countries, including the USA, licensing requirements for drivers of commercial vehicles differ from those for private vehicles. In fact, requirements for commercial drivers of heavy vehicles in the USA are governed by federal regulations. The federal regulation states that a person is physically qualified to drive a commercial motor vehicle if that person has distant visual acuity of at least 20/40 (Snellen) in each eye without corrective lenses or visual acuity separately corrected to 20/40 (Snellen) or better with corrective lenses, distant binocular acuity of at least 20/40 (Snellen) in both eyes with or without corrective lenses, field of vision of at least 70° (horizontal) in each eye, and the ability to recognize the colors of traffic signals and devices showing standard red, green, and amber. Monocular individuals are also prohibited from operating a commercial vehicle in the United States. These vision requirements are more restrictive than those for private vehicles in most states. It should be noted that there are many other medical conditions (e.g., insulin-requiring diabetes) that also prevent individuals from commercial driving. In the United States, physicians are reminded that when they perform the Department of Transportation (DOT) medical certification examination, their primary responsibility is to the public, not to the patient.[151] The legal issues surrounding failure to properly apply DOT regulatory criteria are beyond the scope of this article. However, the reader is directed to a recent article by Pommerenke et al for more information on DOT examinations.[151]

The question of whether monocular drivers should be granted commercial licenses is controversial. The term "monocular" is typically used quite broadly in the research literature on this topic and denotes drivers who have a total absence of function in one eye and, also, those who have visual function in one eye below the minimum level for commercial licensing. Keeney and Garvey argued that monocular drivers should not be licensed to drive commercial vehicles, but at the time of their review, little empiric work had been conducted.[91] Since that time, only a few studies have provided data to examine the question. Laberge-Nadeau et al[102] and Dionne et al[35] reported that commercial motor vehicle drivers with binocular vision problems (operationalized as no or poor stereoacuity) had more severe crashes (as measured by the total number of crash-related victims) than did those with normal stereoacuity, but their crash rate was not higher. Maag et al reported that problems with binocular vision (assessed by stereoacuity) were associated with higher crash rates among taxi drivers.[112] A study in California examined the 2-year crash and conviction rates of 16,465 heavy-vehicle operators, including a subgroup of 1,202 drivers who were visually impaired.[156] Visually impaired drivers (those with 20/40 visual acuity or worse in the worse eye) had significantly more total crashes and convictions than did nonimpaired drivers. Driving exposure did not differ in the two groups.

On the other hand, McKnight et al measured the visual and driving performances of 40 monocular and 40 binocular commercial drivers and found no differences with respect to visual search, lane placement, clearance judgment, gap judgment, hazard detection, and information recognition.[123] Monocular drivers were less adept than binocular drivers in sign-reading distance in both daytime and nighttime driving. The authors concluded that monocular drivers have some significant reductions in selected visual capabilities and in certain driving functions compared with binocular drivers. However, differences in the safety for most day-to-day driving functions were not apparent. A problem with this study is that the definitions of monocular versus binocular drivers were not clearly stated. The importance of good vision in both eyes for commercial drivers of heavy trucks may also be called into question by a study of commercial vehicle drivers who received waivers of the federal vision requirements.[43] The severity of the vision impairment and the extent to which it involved both eyes or a single eye was not described in the report. The crash rates of the 2,234 drivers in the waiver program as of 1995, adjusted for self-reported miles traveled, were compared to the crash rates of heavy trucks provided by the 1994 General Estimates System of the National Highway Traffic Safety Administration. The waiver group's crash rate was not higher than the national reference group, nor were their crashes more severe.[43]

Public Policy

It has long been recognized that visual acuity testing is not a good technique for identifying unsafe, i.e., crash-prone, drivers.[15–17] Possible reasons for visual acuity's lack of association with problem drivers, especially at-risk older drivers, was discussed in the section on visual acuity. If we were to change the policy for vision screening, what should it be changed to? The answer is not readily available, because adequate studies relevant to this issue have not been performed. The proper design for such studies is elusive. First, it is difficult to evaluate the effectiveness of current visual acuity requirements, because if an applicant fails the acuity test, then he or she is (presumably) removed from the road, and there is no further information about his or her driving outcomes (e.g., crashes, violations). Because the criteria for failing visual acuity tests vary among states, crash and violation rates from state to state could be examined according to their visual acuity requirements. However, such studies have a number of serious challenges, such as valid adjustments for climate, road quality, geography, and demographics, and interpretation limitations with respect to individuals. Another approach is to evaluate the association between different visual abilities, including acuity, and prior crash involvement, with the goal of comparing the magnitudes of associations among the various vision tests and crashing. This is a popular study design. A problem is that visual acuity impairment is correlated with other types of vision impairment (e.g., contrast sensitivity, stereoacuity) and, thus, because of the visual acuity criterion for licensing, those at highest risk for crash involvement may already be removed from the road. States in which drivers are not rescreened for visual acuity after their initial license application may provide the most appropriate settings for the comparison of various vision tests as screening tools. These studies should have prospective, population-based designs.

Even if a valid screening tool or battery were developed, the practical issue of implementation would be complex. Changing policy would be expensive, as it would require retraining of personnel and reinstrumentation at every licensing site, as well as a public education campaign. The political process to support and implement a change in policy could take years, and it would need to take place in each state separately.

Research indicates that periodic vision rescreening of drivers may have benefit in terms of saving lives,[105,131,163] although there are still many unanswered questions in this regard. What visual abilities should be rescreened for? Are there measures of visual function that have a stronger relationship to driver safety than does the weakly related visual acuity test? What is the optimal time interval for rescreening? At what age should rescreening requirements be applied? What level of impairment at the previous test should trigger a subsequent rescreening? There are personal freedom issues interwoven into considerations of rescreening. For example, is it fair to target older adults for rescreening simply on the basis of age?

The profession of ophthalmology has had a strong commitment to promoting driver safety, as evidenced by professional policy statements and editorial essays published on this topic over the years.[3,4,15,28,89,94,98,106,160] One issue subject to intense debate is the physician's responsibility with regard to reporting drivers—noncommercial as well as commercial—with serious vision impairments to the licensing authorities. Some states have mandatory reporting laws, whereas others have mechanisms for reporting but do not require reporting. Failure to appropriately perform the DOT examination for commercial drivers can result in physician liability.[151] There is evidence that some physicians do not clearly understand the reporting laws or recommendations in the jurisdiction in which they practice.[152] There have been cases in which a physician has been held legally responsible for a crash incurred by his or her patient because there was evidence that the physician knew about a functional impairment that rendered driving unsafe and did not report it to the authorities. How does this relate to the concept of physician-patient confidentiality, and is the confidential trust violated if the physician reports the patient's medical condition and functional impairment to the licensing authorities without the patient's awareness and consent? This is a growing and complex area of case law.[22,53,154] With respect to examinations that require pupillary dilation, some have raised concerns about whether driving home after dilation is safe, and guidelines are needed in this area.[182]

A related issue is whether an ophthalmologist, with the clinical and diagnostic tools presently available, has the appropriate means to make sound recommendations to patients about the appropriateness of their driving. As our literature survey has indicated, visual acuity is at best weakly related to crash involvement, and what type and severity of visual field impairment makes driving dangerous is arguable. There is a serious need for research to develop a battery of tests with proved sensitivity and specificity for identifying high-risk drivers, so that ophthalmologists can provide guidance to their patients, and also to medical advisory boards working with licensing offices.[61] Physicians can refer visually impaired drivers to driver reeducation programs that are designed to reinforce safe driving practices and caution on the road, especially for older drivers. Although these programs effectively enhance knowledge about how to be a safe driver, they as yet have no proved safety benefit.[77,124]

Research Challenges

TAKING DRIVING EXPOSURE INTO ACCOUNT

It has long been recognized by the insurance industry that driving exposure—how much, where, and under what circumstances someone drives—is linked to crash risk. Drivers with vision impairments and eye conditions often reduce their time on the road and avoid night driving and other challenging driving situations, and this composes an important element in the evaluation of whether vision impairment elevates crash risk. However, many studies have failed to adjust for driving exposure when evaluating the role of vision impairment in driving, and this calls into question the validity of conclusions. Driving exposure information can be obtained in an interview, and valid and reliable methods of asking about when and where one drives have been developed.[128,145] For example, a recent study by the Federal Highway Administration found that self-reported travel distance validly reflected actual travel distance as measured by a global positioning satellite system.[128]

CLASSIFYING AND DEFINING OUTCOMES

Previous research has used an array of sources to identify poor driving, including crashes, violations, performance in on-road tests, performance in driving simulators, and self-reported driving habits, including driving cessation. It has never been established that risk factors for one type of "adverse" driving outcome automatically apply to other adverse outcomes, thus making comparison across studies difficult. Studies focusing on crashes as the outcome of interest have relied on a variety of crash definitions and sources, including state records, self-reports, and injurious, fatal, and at-fault crashes. Particular caution should be used when relying on self-reported crashes as the outcome of interest. This is because concordance between self-reported crashes and actual state records is only moderate, and risk factor analyses for self-reported crashes do not provide results equivalent to those of analyses relying on state records.[116,122]

Driving performance studies using simulators typically quantitate a variety of driving maneuvers and component behaviors, such as reaction time and lane deviation. The issue of simulator validity is central; to what extent does poor driving performance in the simulator reflect poor on-road performance? Simulator studies must grapple with this issue if results are intended to be generalizable to actual driving.

Measuring actual on-road performance has grown in popularity. Several studies have used observers who apply rating scales to specific components of the subject's driving. The issue of interrater reliability and examiner bias if the examiner is aware of the subject's vision impairment are obvious concerns. These issues taken together require that researchers carefully consider the strengths and limitations of their outcome measures, and be cautious about generalizing results.

EFFECT OF AGE

Vision impairment is more prevalent in older adults,[84,175] and given that crash rates increase with age,[129] it is possible that observed associations between visual function and driving performance are confounded by age.

DEFINITION AND EFFECTS OF OCULAR DISEASE

Interpreting and comparing results across studies are complicated by inconsistencies in the ways in which ocular disease is measured. At least one study has demonstrated poor agreement between clinical and self-reported eye disease diagnoses.[108] However, the lack of perfect agreement between physician diagnosis and self-report is not a fatal flaw. For it to impact a study's results, subjects who invalidly report the presence or absence of an eye condition or who are misdiagnosed must also have an increased or decreased risk of crash involvement. Nevertheless, given that any degree of misclassification will impact measures of association, the use of valid definitions of eye disease is critical in studies on the role of eye disease in driver safety.

Researchers often categorize measures of visual function (often called setting "cutpoints") in an attempt to define impaired versus nonimpaired drivers. These categorizations are often dissimilar across studies, hindering comparisons of study results. Even more problematic is that the categories appear to be arbitrarily chosen or are dictated by conventions from the literature and/or clinic, which also seem to have no stated rationale. Researchers should provide firm reasons for defining impairment levels. Furthermore, they should consider multiple categories to allow for issues of dose-response patterns (e.g., the greater the impairment, the greater the risk of crash involvement) to be evaluated. When categories are not used, visual function data are often analyzed in their raw form; these distributions are rarely normal. However, in many studies on vision impairment and driving, statistical analysis techniques for normally distributed data (e.g., analysis of variance) are frequently applied to the data. This is particularly problematic when automobile crash rates or counts that are also not normally distributed are compared. Finally, few studies have attempted to identify the independent association between vision impairment and driving performance. Many factors may confound or modify such associations and should be accounted for when conducting analyses. In addition, when several types of visual function are analyzed within the same study, issues of collinearity need to be carefully considered.

Future research must move beyond small-scale studies presenting results for a limited number of vision or ocular measures. Such studies only provide restricted conclusions with respect to vision and driving because they fail to fully characterize eye health and visual function. Therefore, for example, a study demonstrating a positive association between glaucoma and crash involvement is incomplete unless one can determine the role of visual function, particularly visual fields, as well as other factors (e.g., glaucoma medications). This additional information would aid physicians in assessing glaucoma patients with respect to driving competence by means of measures other than diagnosis of the disease itself. It should be noted that such studies require the appropriate application of multivariable data analysis techniques as well as a large sample size to increase the precision of the study results.

DEVELOPMENT OF TESTS TO IDENTIFY UNSAFE DRIVERS

There is growing consensus among the public, government officials, physicians, and researchers that the vision tests and instruments used at driver licensing sites do not effectively identify unsafe drivers, and there is also a great deal of consensus that ophthalmologists and other physicians do not have the appropriate tools to identify problem drivers in the clinical setting. These issues have been discussed widely and frequently in the print and broadcast media, indicating their public urgency. Not only does research have the challenge of developing tests of high sensitivity and specificity for identifying unsafe drivers, but these tests must also be cost-effective and acceptable to the public.

Summary

Vision is inarguably a fundamental component of safe motor vehicle operation. Certain eye conditions and diseases, such as cataract and glaucoma, may elevate crash risk, although the literature in this area is sparse and, thus, conclusions are preliminary. Although demonstrating that certain eye diseases increase crash risk is noteworthy, the ultimate question is what visual functional impairments stemming from these conditions engender driving problems. Several studies have converged on the finding that drivers with eye conditions and diseases tend to reduce their driving exposure and modify their driving habits. To what extent this reduced exposure and changed driving pattern "protects" them from crash involvement remains to be determined.

There is remarkable agreement among studies that visual acuity is only weakly associated with crash involvement and unsafe driving performance. There are undoubtedly a number of reasons for this weak link. Current practices of visual acuity screening at driver licensing sites should not be viewed as an effective means of identifying those with vision impairments that elevate crash risk. There is stronger evidence of the critical role of peripheral vision for safe driving, although previous studies have used assorted definitions of visual field impairment, making straightforward conclusions difficult. Color vision deficiency by itself is not a threat to good driving performance. Other aspects of visual sensory impairment have high face validity to the driving task (contrast sensitivity, motion perception, eye movements, binocular vision disorders) but have not been sufficiently examined to permit firm conclusions about their roles. Visual attention skills and visual processing speed as assessed by the useful field of view paradigm show great promise as ways to identify high-risk older drivers.

A chronic problem in much of the literature on this topic is the failure to take driving exposure into account when associations between vision impairment, eye disease, and crash risk are evaluated. The failure to do so may mask associations and/or lead to erroneous conclusions. Studies focused on a history of crash involvement as the outcome measure are instructive in the early stages of investigation. Ultimately, though, prospective designs must be implemented in order to understand causes. Three areas in serious need of well-designed studies are the safety of low-vision drivers using bioptic telescopes, the impact of monocular vision impairment or blindness on driver safety, and the effectiveness of vision rescreening after initial licensure.

The role of the ophthalmologist in driver safety has been widely discussed over the years, but it needs to be clarified. Most importantly, if ophthalmologists are expected to provide guidance about driving fitness to visually impaired patients, families, and licensing agencies, they will require valid and reliable assessment tools on which to base recommendations.

Method of Literature Search

Literature for this review was based on a MEDLINE search using the terms *vision*, *ocular*, *vision impairment*, *driving*, *accident*, and *crash*, for the period 1966 to the present. Additionally, references contained within those articles and not listed in MEDLINE were gathered. Articles and reports from the authors' reprint collections were also included. Published abstracts that were not accompanied by full-length articles were not included.

References

1. Aiello LP, Gardner TW, King GL: Diabetic retinopathy. Diabetes Care 21:143–156, 1998
2. Allen MJ: Vision and driving. Traff Safe Res 3:8–11, 1969
3. American Academy of Ophthalmology: Vision Requirements for Driving: Policy Statement. San Francisco, American Academy of Ophthalmology Board of Directors, 1995
4. American Medical Association, Committee on Medical Aspects of Automotive Safety: Visual factors in automobile driving, and provisional standards. Arch Ophthalmol 81: 865–871, 1969
5. Appel SD, Brilliant RL, Reich LN: Driving with visual impairment: facts and issues. J Vis Rehabil 4:19–31, 1990
6. Applegate RA, Howland HC, Sharp RP: Corneal aberrations and visual performance after radial keratotomy. J Refract Surg 14:397–407, 1998
7. Applegate WB, Miller ST, Elam JT: Impact of cataract surgery with lens implantation on vision and physical function in elderly patients. JAMA 257:1064–1066, 1987
8. Ball K, Beard B, Roenker D: Age and visual search: Expanding the useful field of view. J Opt Soc Am 5:2210–2219, 1988
9. Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR: Visual attention problems as a predictor of vehicle crashes in older drivers. Invest Ophthalmol Vis Sci 34:3110–3123, 1993
10. Ball K, Owsley C, Stalvey B: Driving avoidance and functional impairment in older drivers. Accid Anal Prev 30: 313–322, 1998
11. Ball K, Roenker D, Bruni J: Developmental changes in attention and visual search throughout adulthood, in Enns J (ed): The Development of Attention: Research and Theory. North Holland, Elsevier Science Publishers, 1990, pp. 489–508
12. Barrett GV, Mihal WL, Panek PE: Information-processing skills predictive of accident involvement for younger and older commercial drivers. Industr Gerontol 4:173–182, 1977
13. Barron C: Bioptic telescopic spectacles for motor vehicle driving. J Am Optom Assoc 61:37–41, 1991
14. Belin MW: Evaluating refractive surgery: What is the appropriate baseline? Arch Ophthalmol 116:1104–1105, 1998
15. Brody L: The role of vision in motor vehicle operation: A review. Int Record Med Gen Pract Clin 167:365–377, 1954
16. Burg A: The Relationship Between Vision Test Scores and Driving Record: General Findings, Report 67–24. Los Angeles, UCLA Department of Engineering, 1967
17. Burg A: The Relationship Between Vision Test Scores and Driving Record: Additional Findings, Report 68–27. Los Angeles, UCLA Department of Engineering, 1968
18. Campbell MK, Bush TL, Hale WE: Medical conditions associated with driving cessation in community-dwelling, ambulatory elders. J Gerontol 48:S230–S234, 1993
19. Cashell GTW: Visual function in relation to road accidents. Injury 2:9–10, 1970
20. Cerrelli E: Older Drivers: The Age Factor in Traffic Safety. National Highway Traffic Safety Administration Technical Report. HS 807 402. Washington, DC, Department of Transportation, 1989
21. Charman WN: Vision and driving—a literature review and commentary. Ophthalmic Physiol Opt 17:371–391, 1997
22. Classe JG: Clinicolegal aspects of practice. South J Optom 4:65–69, 1986
23. Colenbrander A, Fletcher DC: Low vision rehabilitation: vision requirements for driving. J Ophthalmol Nurs Tech 11: 111–115, 1992
24. Cooper PJ: Differences in accident characteristics among elderly drivers and between elderly and middle-aged drivers. Accid Anal Prev 22:499–508, 1990
25. Council FM, Allen JA: A Study of the Visual Fields of North Carolina Drivers and Their Relationship to Accidents. Chapel Hill, University of North Carolina Highway Safety Research Center, 1974
26. Crancer JA, McMurray L: Accident and violation rates of Washington's medically restricted drivers. JAMA 205:272–276, 1968
27. Cushman LA: Cognitive capacity and concurrent driving performance in older drivers. IATSS Res 20:38–45, 1996
28. Danielson RW: The relationship of fields of vision and safety in driving, with a report of 680 drivers examined by various screening methods. Am J Ophthalmol 44:657–680, 1957
29. Davis TG, Wehling EH, Carpenter RL: Oklahoma's medically restricted drivers. A study of selected medical conditions. Oklahoma State Med J 66:322–327, 1973
30. Davison PA: Inter-relationships between British drivers' visual abilities, age and road accident histories. Ophthalmic Physiol Opt 5:195–204, 1985
31. Decina LE, Breton ME, Staplin L: Visual Disorders and Commercial Drivers. Report Number DTFH61-90-C-0093. Washington, DC, Office of Motor Carriers, Federal Highway Administration, US Department of Transportation, 1991
32. Decina LE, Staplin L: Retrospective evaluation of alternative vision screening criteria for older and younger drivers. Accid Anal Prev 25:267–275, 1993
33. DeKlerk NH, Armstrong BK: Admission to hospital for road trauma in patients with diabetes mellitus. J Epidemiol Community Health 37:232–237, 1983
34. Department of State, Motor Vehicle Division, State of Maine: Study: Bioptic Lens Driver, 1976–1982. Augusta, Maine, 1983
35. Dionne G, Desjardins D, Laberge-Nadeau C, Maag U: Medical conditions, risk exposure, and truck drivers' accidents: an analysis with count data regression models. Accid Anal Prev 27:295–305, 1995
36. Duchek JM, Hunt L, Ball K: Attention and driving performance in Alzheimer's disease. J Gerontol 53B:P130-P141, 1998
37. Eadington DW, Frier BM: Type 1 diabetes and driving experience: An eight year cohort study. Diabetic Med 6:137–141, 1989
38. Edwards MG, Schachat AP: Impact of enucleation for choroidal melanoma on the performance of vision-dependent activities. Arch Ophthalmol 109:519–521, 1991
39. Eggink FA, Houdijn Beekhuis W, Trokel SL, den Boon JM: Enlargement of the photorefractive keratectomy optical zone. J Cataract Refract Surg 22:1159–1164, 1996
40. Evans DW, Ginsburg AP: Contrast sensitivity predicts age-related differences in highway-sign discriminability. Hum Factors 25:637–642, 1985
41. Evans L: Older driver involvement in fatal and severe traffic crashes. J Gerontol 43:S186–S193, 1988
42. Evans L: Risk of fatality from physical trauma versus sex and age. J Trauma 28:368–378, 1988
43. Federal Highway Administration, Office of Motor Carrier Standards: The Seventh Monitoring Report on the Drivers of Commercial Motor Vehicles Who Receive Vision Waivers. Washington, DC, US Department of Transportation, 1996
44. Feinbloom W: Driving with bioptic telescopic spectacles (BTS). Am J Optom Physiol Opt 54:35–42, 1977
45. Fishman GA, Anderson RJ, Stinson L, Haque A: Driving performance of retinitis pigmentosa patients. Br J Ophthalmol 65:122–126, 1981

46. Foley DJ, Wallace RB, Eberhard J: Risk factors for motor vehicle crashes among older drivers in a rural community. J Am Geriatr Soc 43:776–781, 1995
47. Fonda G: Legal blindness can be compatible with safe driving [see comments]. Ophthalmology 96:1457–1459, 1989
48. Fonda G: Training in use of the bioptic telescopic spectacle (BTS) for driving is unreasonable. Trans Pa Acad Ophthalmol Otolaryngol 40:716–718, 1988
49. Fonda G: Suggested vision standards for drivers in the United States with vision ranging from 20/175 (6/52) to 20/50 (6/15). Ann Ophthalmol 18:76–79, 1986
50. Fonda G: Bioptic telescopic spectacle is a hazard for operating a motor vehicle. Arch Ophthalmol 101:1907–1908, 1983
51. Fonda G: Approach magnification is safer than bioptic telescopic spectacles for operating a motor vehicle. Trans Pa Acad Ophthalmol Otolaryngol 35:137–140, 1982
52. Forrest KY, Bunker CH, Songer TJ, et al: Driving patterns and medical conditions in older women. J Am Geriatr Soc 45:1214–1218, 1997
53. Garfinkel PE, Shlensky R: Should you be required to report potentially hazardous drivers? Leg Aspects Med Pract 8:17–19, 1980
54. Ghaith AA, Daniel J, Stulting RD: Contrast sensitivity and glare disability after radial keratotomy and photorefractive keratectomy. Arch Ophthalmol 116:12–18, 1998
55. Glynn RJ, Seddon JM, Krug JH Jr, et al: Falls in elderly patients with glaucoma. Arch Ophthalmol 109:205–210, 1991
56. Goode KT, Ball KK, Sloane M: Useful field of view and other neurocognitive indicators of crash risk in older adults. J Clin Psychol Med Settings 5:425–440, 1998
57. Gresset JA, Meyer FM: Risk of accidents among elderly car drivers with visual acuity equal to 6/12 or 6/15 and lack of binocular vision. Ophthalmic Physiol Opt 14:33–37, 1994
58. Gresset J, Meyer F: Risk of automobile accidents among elderly drivers with impairments or chronic diseases. Can J Public Health 85:282–285, 1994
59. Gutierrez P, Wilson MR, Johnson C: Influence of glaucomatous visual field loss on health-related quality of life. Arch Ophthalmol 115:777–784, 1997
60. Hakamies-Blomqvist LE: Fatal accidents of older drivers. Accid Anal Prev 25:19–27, 1993
61. Hales RH: Functional ability profiles for driver licensing: Exemplification by visual profile. Arch Ophthalmol 100: 1780–1783, 1982
62. Hansotia P, Broste SK: The effect of epilepsy or diabetes mellitus on the risk of automobile accidents. N Engl J Med 324:22–26, 1991
63. Health GG, Schmidt I: Signal color recognition in color defective observers. Am J Optom Arch Am Acad Optom 36: 421–437, 1959
64. Henderson L, Burg A: Vision and Audition in Driving: Final Report, HS-81 265. Washington, DC, Federal Highway Administration, 1974
65. Higgins KE, Wood J, Tait A: Vision and driving: Selective effect of optical blur on different driving tasks. Hum Factors 41:224–232, 1998
66. Hills BL, Burg A: A reanalysis of California driver vision data: general findings. Report No. LR 768. Transport and Road Research Laboratories, Crowthorne, Berkshire
66a. Hofstetter HW: Visual acuity and highway accidents. J Am Optom Assoc 47:887–893, 1976
67. Hu PS, Trumble D, Lu A: Statistical Relationships Between Vehicle Crashes, Driving Cessation, and Age-Related Physical or Mental Limitations: Final Summary Report. Washington, DC, US Dept of Transportation, National Highway Traffic Safety Administration, 1997. Contract DTNH22-92-X-0547 (report available through National Technical Information Service, Springfield, VA 22161)
68. Hu PS, Young J: Nationwide Personal Transportation Survey: Demographic Special Reports. Report FHWA-PL-94-019. Oak Ridge, TN, Oak Ridge Laboratories, 1994
69. Humphriss D: Three South African studies on relation between road accidents and driver's vision. Ophthalmic Physiol Opt 7:73–79, 1987
70. Hunt L, Morris JC, Edwards D, Wilson BS: Driving performance in persons with mild senile dementia of the Alzheimer type. J Am Geriatr Soc 41:747–752, 1993
71. Huss CP: Model approach: low vision driver's training and assessment. J Vis Rehabil 2:31–44, 1988
72. Huss CP: Multidisciplinary approach to driving for the visually handicapped. Rehabil Optom 2:10–11, 1984
73. Isler RB, Parsonson BS, Hansson GJ: Age related effects of restricted head movements on the useful field of view of drivers. Accid Anal Prev 29:793–801, 1997
74. Ivers RQ, Mitchell P, Cumming RG: Sensory impairment and driving: The Blue Mountains Eye Study. Am J Public Health 89:85–87, 1999
75. Jackson GR, Owsley C, Cideciyan AV: Rod vs cone sensitivity loss in age-related macular degeneration. Invest Ophthalmol Vis Sci (Suppl) 38:S354, 1997
76. Janke MK: Mature driver improvement program in California. Transportation Res Rec 1483:77–83, 1994
77. Janke MK: Accident rates of drivers with bioptic telescopic lenses. J Safety Res 14:159–165, 1983
78. Janke MK: Age-Related Disabilities That May Impair Driving and Their Assessment. Sacramento, California Department of Motor Vehicles, 1994
79. Johansson K, Bronge L, Lundberg C: Can a physician recognize an older driver with increased crash risk potential? J Am Geriatr Soc 44:1198–1204, 1996
80. Johnson CA, Keltner JL: Incidence of visual field loss in 20, 000 eyes and its relationship to driving performance. Arch Ophthalmol 101:371–375, 1983
81. Jose R, Carter K, Carter C: A training program for clients considering the use of bioptic telescopes for driving. J Vis Impair Blind 77:425–428, 1983
82. Jose RT, Butler JH: Training a patient to drive with telescopic lenses. Am J Optom Physiol Opt 52:340–346, 1975
83. Jose RT, Ousley B: The visually handicapped, driving and bioptics: some new facts. Rehab Optom 2:2–5, 1984
84. Kahn HA, Leibowitz HM, Ganley JP: The Framingham Eye Study. I. Outline and major prevalence findings. Am J Epidemiol 106:17–32, 1977
85. Kahneman D, Ben-Ishai R, Lotan M: Relation of a test of attention to road accidents. J Appl Psychol 58:113–115, 1973
86. Katlun T, Wieband W: Change in twilight vision and glare sensitivity after PRK (English translation). Ophthalmologe 95:420–426, 1998
87. Katz A: The use of bioptic telescopic systems for driving, in Gale AG (ed): Vision in Vehicles. North Holland, Elsevier Science, 1991
88. Keeney AH: Driving at high risk. Sightsaving Rev 48:167–174, 1979
89. Keeney AH: The visually impaired driver and physician responsibilities. Am J Ophthalmol 82:799–801, 1976
90. Keeney AH: Relationship of ocular pathology and driving impairment. Trans Am Acad Ophthalmol Otolaryngol 72: 737–740, 1968
91. Keeney AH, Garvey J: The dilemma of the monocular driver. Am J Ophthalmol 91:801–803, 1981
92. Kelleher DK: Driving with low vision. J Vis Impair Blind 11: 345–350, 1979
93. Kelleher DK, Mehr EB, Hirsch MJ: Motor vehicle operation by a patient with low vision: a case report. Am J Optom 48: 773–776, 1971
94. Keltner JL, Johnson CA: Visual function and driving safety. Arch Ophthalmol 110:1697–1698, 1992
95. Keverline-Walls M, Molenda M: Training procedures for more cosmetically appealing miniaturized telescopes. J Vis Rehabil 5:11–16, 1991
96. Kite CR, King JN: A survey of the factors limiting the visual fields of motor vehicle drivers in relation to minimum visual fields and visibility standards. Br J Physiol Opt 18:85–107, 1961
97. Klein BEK, Klein R, Linton KLP: Prevalence of age-related lens opacities in a population. Ophthalmology 99:546–552, 1992
98. Klein R: Age-related eye disease, visual impairment, and driving in the elderly. Hum Factors 33:521–525, 1991
99. Kline TJB, Ghali LM, Kline DW, Brown S: Visibility distance

of highway signs among young, middle-aged, and older observers: Icons are better than text. Hum Factors 32:609–619, 1990
100. Koepsell TD, Wolf ME, McCloskey L, et al: Medical conditions and motor vehicle collision injuries in older drivers. J Am Geriatr Soc 42:695–700, 1994
101. Korb DR: Preparing the visually handicapped person for motor vehicle operation. Am J Optom 47:619–628, 1970
102. Laberge-Nadeau C, Dionne G, Maag U, et al: Medical conditions and the severity of commercial motor vehicle drivers' road accidents. Accid Anal Prev 28:43–51, 1996
103. Leibowitz HW, Owens DA: Nighttime driving accidents and selective degradation. Science 197:422–423, 1977
104. Leibowitz HW, Owens DA, Tyrrell RA: The assured clear distance ahead rule: implications for nighttime traffic safety and the law. Accid Anal Prev 30:93–99, 1998
105. Levy DT, Vernick JS, Howard KA: Relationship between driver's license renewal policies and fatal crashes involving drivers 70 years or older. JAMA 274:1026–1030, 1995
106. Lichter PR: The ophthalmologist's role in licensing drivers. Ophthalmology 96:1455–1456, 1989
107. Liesmaa M: The influence of driver's vision in relation to his driving ability. Optician 166:10–13, 1973
108. Linton KL, Klein BE, Klein R: The validity of self-reported and surrogate-reported cataract and age-related macular degeneration in the Beaver Dam Eye Study. Am J Epidemiol 134:1438–1446, 1991
109. Lippman O: The effect of the Texas medical advisory board for driver licensing on driving performance. Proc Am Assoc Auto Med 23:204–216, 1979
110. Lippman O, Corn AL, Lewis MC: Bioptic telescopic spectacles and driving performance: a study in Texas. J Vis Impair Blind 82:182–187, 1988
111. Lovsund P, Hedin A: Effects on driving performance of visual field defects, in Gale A, Freeman MH, Haslegrave CM, et al (eds): Vision in Vehicles. Amsterdam, Elsevier, 1989
112. Maag U, Vanasse C, Dionne-Nadeau C: Taxi drivers' accidents: how binocular vision problems are related to their rate and severity in terms of the number of victims. Accid Anal Prev 29:217–224, 1997
113. MacKean JM, Elkington AR: Glaucoma and driving. Br Med J 285:777–778, 1982
114. Mangione CM, Ajani UA, Padan A: Impact of age-related macular degeneration on visual functioning (abstract). J Am Geriatr Soc 42:SA73, 1994
115. Mangione CM, Phillips RS, Lawrence MG: Improved visual function and attenuation of declines in health-related quality of life after cataract extraction. Arch Ophthalmol 112: 1419–1425, 1994
116. Marottoli RA, Cooney LM, Tinetti ME: Self-report versus state records for identifying crashes among older drivers. J Gerontol 52A:M184–M187, 1997
117. Marottoli RA, Cooney LM Jr, Wagner R, et al: Predictors of automobile crashes and moving violations among elderly drivers. Ann Intern Med 121:842–846, 1994
118. Marottoli RA, Ostfeld AM, Merrill SS: Driving cessation and changes in mileage driven among elderly individuals. J Gerontol 48:S255–S260, 1993
119. Marottoli RA, Richardson ED, Stowe MH, et al: Development of a test battery to identify older drivers at risk for self-reported adverse driving events. J Am Geriatr Soc 46: 562–568, 1998
120. Martinez CE, Applegate RA, Klyce SD, et al: Effect of pupillary dilation on corneal optical aberrations after photorefractive keratectomy. Arch Ophthalmol 116:1053–1062, 1998
121. McCloskey LW, Koepsell TD, Wolf ME, Buchner DM: Motor vehicle collision injuries and sensory impairments of older drivers. Age Aging 23:267–272, 1994
122. McGwin G Jr, Owsley C, Ball K: Identifying crash involvement among older drivers: Agreement between self-report and state-records. Accid Anal Prev 30:781–791, 1998
123. McKnight AJ, Shinar D, Hilburn B: The visual and driving performance of monocular and binocular heavy-truck drivers. Accid Anal Prev 23:225–237, 1991
124. McKnight AJ, Simone GA, Weidman JR: Elderly Driver Retraining. Washington, DC, US Department of Transportation, 1982. Report number DOT HS-806-336
125. Mihal WL, Barrett GV: Individual differences in perceptual information processing and their relation to automobile accident involvement. J Appl Psychol 61:229–233, 1976
126. Monestam E, Wachmeister L: Impact of cataract surgery on car driving: a population based study in Sweden. Br J Ophthalmol 81:16–22, 1997
127. Mourant RR, Rockwell TH: Strategies of visual search by novice and experienced drivers. Hum Factors 14:325–335, 1972
128. Murakami E, Wagner DP: Comparison Between Computer-Assisted Self-interviewing Using GPS With Retrospective Trip Reporting Using Telephone Interviews. Washington, DC, FHWA, US Department of Transportation, 1997
129. National Highway Traffic Safety Administration: Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers. Washington, DC, US Department of Transportation, 1989
130. National Highway Traffic Safety Administration: Traffic Safety Facts 1996. Washington, DC, US Department of Transportation, 1996
131. Nelson DE, Sacks JJ, Chorba TL: Required vision testing for older drivers. N Engl J Med 326:1784–1785, 1992
132. New York State Department of Motor Vehicles, Division of Research and Evaluation, 1989
133. North RV: The relationship between the extent of visual field and driving performance: a review. Ophthalmic Physiol Opt 5:205–210, 1985
134. O'Brart DPS, Gartry DS, Lohmann CP: Excimer laser photorefractive keratectomy for myopia: comparison of 4.00- and 5.00-millimeter ablation zones. J Refract Corneal Surg 10:87–94, 1994
135. O'Brart DPS, Lohmann CP, Fitzke FW: Disturbances in night vision after excimer laser photorefractive keratectomy. Eye 8:46–51, 1994
136. O'Brart DPS, Lohmann CP, Fitzke FW: Night vision after excimer laser photorefractive keratectomy: haze and halos. Eur J Ophthalmol 4:43–51, 1994
137. Odenheimer GL, Beaudet M, Jette AM: Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. J Gerontol 49:M153–M159, 1994
138. Owsley C: Clinical and research issues on older drivers: Future directions. Alzheimer Dis Related Disord 11:3–7, 1997
139. Owsley C: Vision and driving in the elderly. Optom Vis Sci 71:727–735, 1994
140. Owsley C: Quality of life and vision impairment: Driving, in Anderson DR, Drance SM (eds): Encounters in Glaucoma Research 3: How to Ascertain Progression and Outcome. Amsterdam, Kugler, 1996, pp 37–44
141. Owsley C, Ball K, McGwin G Jr: Visual processing impairment and risk of motor vehicle crash among older adults. JAMA 279:1083–1088, 1998
142. Owsley C, Ball K, Sloane ME: Visual/cognitive correlates of vehicle accidents in older drivers. Psychol Aging 6:403–415, 1991
143. Owsley C, McGwin G Jr, Ball K: Vision impairment, eye disease, and injurious motor vehicle crashes in the elderly. Ophthalmic Epidemiol 5:101–113, 1998
144. Owsley C, Sloane ME: Contrast sensitivity and the perception of real-world targets. Br J Ophthalmol 71:791–796, 1987
145. Owsley C, Stalvey B, Wells J, Sloane ME: Older drivers and cataract: Driving habits and crash risk. J Gerontol Medical Sciences, 54A:M203–M211, 1990
146. Park WL, Unatin JH, Hebert A: A driving program for the visually impaired. J Am Optom Assoc 63:54–59, 1992
147. Park WL, Unatin J, Park JM: A profile of the demographics, training and driving history of telescopic drivers in the state of Michigan. J Am Optom Assoc 66:274–280, 1995
148. Parrish RK II, Gedde SJ, Scott IU, et al: Visual function and quality of life among patients with glaucoma. Arch Ophthalmol 115:1447–1455, 1997
149. Patrick DL, Deyo RA: Generic and disease-specific measures in assessing health status and quality of life. Med Care 27:S217–S232, 1989

150. Politzer MR: Vision rehabilitation therapy for the bioptic driver. J Am Optom Assoc 66:18–24, 1995
151. Pommerenke F, Hegmann K, Hartenbaum NP: DOT examinations: practical aspects and regulatory review. Am Fam Phys 58:415–426, 1998
152. Potamitis T, Aggarwal RK, Tsaloumas M: Driving, glaucoma, and the law. BMJ 309:1057–1058, 1994
153. Quigley HA, Vitale S: Models of open-angle glaucoma prevalence and incidence in the United States. Invest Ophthalmol Vis Sci 38:83–91, 1997
154. Reuben DB, Silliman RA, Traines M: The aging driver: Medicine, policy, and ethics. J Am Geriatr Soc 36:1135–1142, 1988
155. Rizzo M, Reinach S, McGehee D, Dawson J: Simulated car crashes and crash predictors in drivers with Alzheimer disease. Arch Neurol 54:545–551, 1997
156. Roger PN, Ratz M, Janke MK: Accident and Conviction Rates of Visually Impaired Heavy-Vehicle Operators. Sacramento, State of California Department of Motor Vehicles, Research and Development Office, 1987
157. Rubin GS, Roche KB, Prasada-Rao P, Fried LP: Visual impairment and disability in older adults. Clin Vis Sci 71:750–756, 1994
158. Sanders AF: Some aspects of the selective process in the functional field of view. Ergonomics 13:101–117, 1970
159. Sekuler R, Ball K: Visual localization: Age and practice. J Opt Soc Am 3:864–867, 1986
160. Selling LS: Ophthalmologist's place in prevention of traffic accidents. Trans Am Med Assoc (Ophthalmol) 120:261, 1942
161. Shinar D: Driver Visual Limitations, Diagnosis, and Treatment. Bloomington, Indiana University 1977. Report No. DOT-HS-5-01275
162. Shinar D, Schieber F: Visual requirements for safety and mobility of older drivers. Hum Factors 33:507–519, 1991
163. Shipp MD: Potential human and economic cost-savings attributable to vision testing policies for driver license renewal, 1989–1991. Optom Bis Sci 75:103–118, 1998
164. Sivak M: The information that drivers use: is it indeed 90% visual? Perception 25:1081–1089, 1996
165. Songer TJ, LaPorte RE, Dorman JS: Motor vehicle accidents and IDDM. Diabetes Care 11:701–707, 1988
166. Spitzberg LA: A patient's experience on driving with a bioptic. J Vis Rehabil 5:17–20, 1991
167. Spitzberg LA, Jose RT, Kuether CL: Behind-the-lens telescope. Prob Optom 3:504–509, 1991
168. Spitzberg LA, Jose RT, Kuether CL: Behind the lens telescope: a new concept in biotpics. Optom Vis Sci 66:616–620, 1989
169. Stevens AB, Roberts M, McKane R: Motor vehicle driving among diabetics taking insulin and non-diabetics. BJM 299: 591–595, 1989
170. Stutts JC: Do older drivers with visual and cognitive impairments drive less? J Am Geriatr Soc 46:854–861, 1998
171. Szlyk JP, Alexander KR, Severing K, Fishman GA: Assessment of driving performance in patients with retinitis pigmentosa. Arch Ophthalmol 110:1709–1713, 1992
172. Szlyk JP, Fishman GA, Severing K: Evaluation of driving performance in patients with juvenile macular dystrophies. Arch Ophthalmol 111:207–212, 1993
173. Szlyk JP, Pizzimenti CE, Fishman GA: A comparison of driving in older subjects with and without age-related macular degeneration. Arch Ophthalmol 113:1033–1040, 1995
174. Taylor DG: Telescopic spectacles for driving: user data satisfaction, preferences and effects in vocational, educational, and personal tasks: a study in Illinois. J Vis Rehabil 4:29–59, 1990
175. Tielsch JM, Sommer A, Witt K, et al: The Baltimore Eye Survey. Blindness and visual impairment in an American urban population. Arch Ophthalmol 108:286–290, 1990
176. Transportation Research Board: Transportation in an Aging Society. Vol. 2. Washington, DC, National Research Council, 1989
177. Transportation Research Board: Transportation in an Aging Society. Vol 1. Washington, DC, National Research Council, 1989
178. Verriest G, Naubauer O, Marre M, Uvijls A: New investigations concerning the relationships between congenital colour vision defects and road traffic security. Int Ophthalmol 2:887–899,1980
179. Vingrys AJ, Cole BL: Are colour vision standards justified in the transport industry? Ophthalmic Physiol Opt 8:257–274, 1988
180. Vogel GL: Training the bioptic telescopic wearer for driving. J Am Optom Assoc 62:288–293, 1991
181. Waller JA: Chronic medical conditions and traffic safety. N Engl J Med 273:1413–1420, 1965
182. Watts P, O'Duffy D, Riddell C: Can I drive after those drops, doctor? Eye 12:963–966, 1995
183. Weiss NJ: The visually impaired driver in New York state. J Vis Impair Blind 6:228–232, 1979
184. Williams CF, Carsten O: Driver age versus crash involvement. Am J Public Health 79:326–327, 1989
185. Wolbarsht ML: Tests for glare sensitivity and peripheral vision in driver applicants. J Safety Res 9:128–139, 1977
186. Wood JM, Dique T, Troutbeck R: The effect of artificial visual impairment on functional visual fields and driving performance. Clin Vis Sci 8:563–575, 1993
187. Wood JM, Troutbeck R: Elderly drivers and simulated visual impairment. Optom Vis Sci 72:115–124, 1995
188. Wood JM, Troutbeck R: Effect of restriction of the binocular visual field on driving performance. Ophthalmic Physiol Opt 12:291–298, 1992
189. Ysander L: The safety of drivers with chronic disease. Br J Industr Med 23:28–36, 1966

Supported in part by National Institutes of Health grants R01-AG14684 and P50-AG11684, an unrestricted grant from Research to Prevent Blindness, Inc., and a grant pursuant to an agreement between General Motors and the U.S. Department of Transportation. Facilities provided by the Alabama Eye Institute. The authors have no commercial or proprietary interests in any of the products, tests, or devices in this article.

Reprint address: Cynthia Owsley, PhD, Clinical Research Unit, Department of Ophthalmology, School of Medicine, University of Alabama at Birmingham, Eye Foundation Hospital, 700 S. 18th St., Suite 609, Birmingham, AL 35294-0009, USA. E-mail: owsley@eyes.uab.edu.