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Driving and Age-Related Macular Degeneration

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Abstract

This article reviews the research literature on driving and age-related macular degeneration, which is motivated by the link between driving and the quality of life of older adults and their increased collision rate. It addresses the risk of crashes, driving performance, driving difficulty, self-regulation, and interventions to enhance, safety, and considers directions for future research.

Driving, and the independence it affords, is strongly tied to the quality of life of older adults, particularly in the United States, where public transportation is not widespread. The literature on the characteristics that are associated with the cessation of driving is less extensive than that on the places where older drivers are at risk of involvement in motor vehicle collisions. An emerging body of research on the role of cognitive and visual impairment and health status has the potential to make significant strides in understanding driving cessation (Anstey, Windsor, Luszcz, & Andrews, 2006; Ragland, Satariano, & MacLeod, 2005). However, the negative impact of driving cessation, namely, a reduction in social activities and integration and an increase in depression, is less equivocal (Marottoli et al., 2000; Ragland et al., 2005). Although research on techniques to improve or maintain older persons' driving skills has been conducted for some time, there has been a paucity of research on strategies to reduce the negative consequences of the transition to the cessation of driving (Windsor & Anstey, 2006). The expansion of this research is critical because the maintenance of driving privileges cannot be justified for all individuals. This point is underscored by emerging demographic changes that, when coupled with the documented negative consequences of stopping driving, portend looming social, financial, and medical costs for a large number of older adults, their families, and caregivers.

Older adults and drivers' safety

In the United States, drivers aged 65 and older experience, in the aggregate, the fewest motor vehicle collisions of all the age groups (Lyman, Ferguson, Braver, & Williams, 2002). However, when driving volume is accounted for, older drivers have rates of motor vehicle collisions that exceed those of most other age groups except teenagers, reflecting their low volume of driving. The risk experienced by older drivers is magnified when injurious and fatal collisions are considered and their rates rival that of teenagers, since once they are involved in collisions, older drivers have an increased risk of death that can be attributed to their fragility (Li, Braver, & Chen, 2003). The risk of collision is a larger contributor to older drivers' rates of motor vehicle collision than is driving volume or fragility, accounting for 42% of older drivers' fatality rates from collisions (Dellinger, Langlois, & Li, 2002). Thus, identifying modifiable factors that are associated with that risk is vital. Most of the literature has focused on the role of chronic medical conditions, functional impairments (visual, cognitive, and

physical), and prescription medications. The general lack of agreement among studies regarding the characteristics that place older drivers at an increased risk can be partly attributed to methodological limitations. The impact of chronic medical conditions and visual and cognitive impairments on driving skills may be difficult to document because their functional consequences are heterogeneous. In addition, individuals with these conditions and impairments may modify their driving behavior, and failing to account for this possibility may obscure etiologically relevant relationships. The absence of consistent results from epidemiological studies partly explains the lack of evidenced-based educational, clinical, and legislative interventions.

Age-related macular degeneration: Considerations for driving

Much of the focus on age-related macular degeneration (AMD) in the field of visual rehabilitation is on the exudative form of AMD because it is the most visually disabling form. It causes severe impairment of acuity, which can strongly interfere with many important aspects of life, such as reading, passing the vision test for a driver's license, and recognizing faces. Yet AMD has a broad disease phenotype, in terms of both the types and severity of the structural lesions of the disease and of the severity and types of visual impairment that can be engendered (Age-related Eye Disease Study Research Group, 2005). Of the approximately 14 million persons in the United States who have AMD, 2 million have the exudative form, and the vast majority—12 million—have the nonexudative form (Klein, Klein, & Linton, 1992). In the earliest stages of AMD, which are clinically characterized by drusen or hyper- or hypopigmentation in the macula (or both), visual acuity typically remains good (about 20/40 or better). However, other functional symptoms, which are themselves visually disabling, can be present early. These early symptoms include visual difficulties under reduced illumination (Chen, Fitzke, Pauleikhoff, & Bird, 1992; Owsley et al., 2000; Scholl, Bellmann, Dandekar, Bird, & Fitzke, 2004), delays in adapting to the dark (Eisner, Fleming, Klein, & Mauldin, 1987; Owsley, Jackson, White, Feist, & Edwards, 2001; Owsley, McGwin, Jackson, Kallies, & Clark, 2007), delays in photo-stress recovery (Sandberg, Weiner, Miller, & Guadio, 1998), and deficits in spatial and temporal contrast sensitivity (Mayer et al., 1994; Midena, Angeli, Blarzino, Valenti, & Segato, 1997), all of which have been verified in psychophysics laboratories. It is also important to emphasize that the course of visual impairment in AMD is typically gradual, rather than having a sudden, acute onset, and thus that persons may have the opportunity to institute compensatory and coping strategies as they engage in the visual activities of daily living, including driving. Thus, with regard to AMD and driving, caution is desirable in making generalizations about the disease's implications for a specific individual's driving, both because AMD has such a broad functional spectrum and because persons with it can learn compensatory strategies for engaging in the tasks of everyday life.

AMD and driving difficulty

Many studies that have used questionnaires have shown that older adults who have AMD report greater difficulty driving than do older adults who do not have AMD. In response to health-related quality-of-life questionnaires, persons with AMD had lower scores (signifying more self-reported difficulty) on the driving subscales of the Activities of Daily Vision Scale (Mangione, Gutierrez, Lowe, Orav, & Seddon, 1999; Scilley et al., 2002) and the National Eye Institute Visual Function Questionnaire (Berdeaux, Nordmann, Colin, & Arnould, 2005; Clemons, Chew, Bressler, & McBree, 2003; Mangione et al., 2001; Mangione, Lee et al., 1998; Scilley, DeCarlo, Wells, & Owsley, 2004). Compared to subscales that address other domains, the driving subscale typically has one of the lowest scores. In general, driving difficulties are more accentuated with the greater severity of the disease. Even in the earliest stages of AMD, when acuity remains relatively good, driving at night is a frequent complaint. Studies have shown that the severity of AMD patients' night-driving difficulties are associated

with the severity of their scotopic (rod-mediated) visual dysfunction, as measured psychophysically (Owsley, McGwin, Scilley, & Kallies, 2006; Scilley et al., 2002), implying that the symptoms have a physiological basis. It is also noteworthy that in focus groups of persons with AMD (both those with early AMD and those with advanced AMD) whose purpose was to discuss the participants' vision, driving was by far the most commonly cited problem (Mangione, Berry et al., 1998; Owsley et al., 2006), underscoring its salience to personal well-being.

AMD and the self-regulation of driving behavior

It has been well established in the gerontology literature that many older adults tend to self-regulate their driving behavior to take their functional and medical problems into account (Ball et al., 1998; Owsley, 2004; Planek, Condon, & Fowler, 1968; Stutts, 1998). By "self-regulate," we mean make adjustments as to when, how much, and under what circumstances they drive. Most of what is known about self-regulation by older drivers is based on self-reports by older drivers themselves. One of the first ways that older adults self-regulate their driving is by avoiding or minimizing driving at night, and this is also true for those with impaired central vision, including those with AMD (Ball et al., 1998; De-Carlo, Scilley, Wells, & Owsley, 2003; Freeman, Muñoz, Turano, & West, 2006; Szlyk et al., 1995). Other self-regulatory behaviors used by persons with AMD include avoiding a variety of potentially challenging driving situations, such as rush-hour traffic, high-speed highways like interstates or expressways, driving alone, making left turns, and driving in the rain (Ball et al., 1998). A study of drivers with AMD using a driving simulator and on-road driving evaluation found evidence that they avoided driving in unfamiliar areas and changing lanes, and drove at slower speeds than drivers without AMD (Szlyk et al., 1995). In a more recent study (Moore & Miller, 2005), interviews were conducted with older drivers who had AMD, and the transcripts of the interviews were subjected to a content analysis whose purpose was to understand the driving strategies that these drivers used. The results revealed that the older drivers with AMD reported several strategies while driving, such as exercising extreme caution (for example, pulling over when another car was passing), relying on memory for the location of turn-offs and traffic-control devices (like knowing where all the stop signs are), using a "copilot" (a passenger who provided verbal cues about the roadway environment), and increased scanning of the road.

A common form of self-regulation used by older drivers, in general, is reducing their exposure to driving, that is, the amount of driving done in terms of miles on the road. This is a strategy that drivers with AMD also use. For example, DeCarlo et al. (2003) found that 24% of the clients with AMD who sought services at a low vision rehabilitation clinic were still active drivers. Instead of giving up driving altogether, they had drastically reduced their exposure, traveling only to destinations in their everyday lives that they deemed the most necessary. They continued to drive even though most of them did not meet the visual acuity standard for having a driver's license in their state of residence.

Self-regulation by older drivers, either by reducing exposure to driving or by avoiding challenging driving situations, seems like it may theoretically reduce the risk of crashing in populations with functional impairments that are relevant to driving, since it would reduce these drivers' exposure to the risks of the road. However, self-regulation of driving by functionally compromised older adults has never been proved to be an effective strategy for enhancing their safety. Although the research is clear that many older drivers, including those with AMD, avoid challenging driving situations, institute strategies for driving at the safest times, and reduce their exposure to driving, the research is also clear that, as a group, older drivers with various medical problems and functional impairments have an elevated risk of crashes. Thus, the findings suggest that self-regulatory strategies, on their own, may not be effective enough to improve safety or that many functionally compromised drivers do not self-

regulate their driving. These are practical issues that are worthy of further investigation. Since much of the data on self-regulation is based on self-reports, there is also a need for research to verify the findings with measures of actual driving behaviors using technologies and instrumentation that track the actual movement of vehicles through the driving environment in real time. There has been some work in this area (Dingus et al., 2006; Murakami & Wagner, 1997; Wouters & Bos, 2000), but much more is needed to determine the extent to which the functional and medical characteristics of older drivers are related to self-regulatory behaviors on the road.

Stopping driving altogether can be viewed as the most extreme form of self-regulation. Research has indicated that compared to drivers with good eye health, older drivers with eye diseases that cause significant visual impairment are more likely to cease driving (Forrest, Bunker, Songer, Coben, & Cauley, 1997; Marottoli et al., 1993; Stutts, 1998), and this is also true for drivers with advanced AMD (Campbell, Bush, & Hale, 1993; DeCarlo et al., 2003). It remains to be determined the extent to which drivers with AMD voluntarily stop driving or have their licenses revoked by the state and the extent to which family members, friends, and health care providers influence their decision to stop driving. Another important issue for consideration is that although the cessation of driving removes a driver who is at a high risk of being involved in a crash on the road, how persons who stop driving continue to be mobile in their communities still needs to be addressed. In recent years, there has been increased attention to the creation of alternative transportation options for elderly people who do not drive (Freund, 2004; Suen & Sen, 2004), yet there are many communities in the United States where driving one's automobile or depending on family members and friends are still the only viable options. Prospective studies have demonstrated that driving cessation by older adults is associated with depression (Fonda, Wallace, & Herzog, 2001; Marottoli et al., 1997; Ragland et al., 2005) and an increased risk of entry into long-term care (Freeman, Gange, Muñoz, & West, 2006), findings that emphasize the importance of driving and access to community transportation for health and well-being.

AMD and the risk of crashes

Despite the prevalence of AMD, little epidemiologic research has focused on the association between AMD and involvement in motor vehicle crashes. To date, no study has explicitly focused on the association between AMD and involvement in crashes, as has been the case for other common eye conditions (such as cataract and glaucoma) (McGwin et al., 2004; Owsley, Stalvey, Wells, & Sloane, 1999). There have been studies in which AMD has been included among a host of other medical and eye conditions whose association with involvement in motor vehicle crashes was evaluated (McCloskey, Koepsell, Wolf, & Buchner, 1994; Owsley, McGwin, & Ball, 1998; Sims, McGwin, Allman, Ball, & Owsley, 2000). None of these studies reported significant associations for AMD, but it would be inappropriate to conclude that no such association exists. Although there is a well-documented increase in visual impairment with the progression of AMD, among a group of individuals with AMD, the distribution and types of impairment are likely to be diverse. Failing to account for this heterogeneity may lead to associations that perhaps fail to recognize the elevated risk of motor vehicle crashes among a smaller group of severely impaired drivers because it is overwhelmed by the lack of an elevated risk among a larger group of drivers with minimal to moderate visual impairment. In addition, should individuals with AMD modify their driving behavior (for example, reduce their mileage and avoid night driving), the failure to account for such exposure to risk may also lead to biased associations. Finally, some of the research to date has defined AMD on the basis of self-reported information (Sims et al., 2000), which may not be a valid and reliable method of identifying individuals with this condition.

While research on AMD and involvement in motor vehicle crashes has been limited, a larger body of literature has evaluated the common deficits in visual function and their relationship with safe driving. As we noted earlier, impairments in visual acuity and contrast sensitivity are the hallmarks of AMD. Owsley and McGwin's (1999) review of the literature with respect to these impairments concluded that despite evidence for an association between impaired visual acuity and involvement in motor vehicle crashes, this association is likely to be small. However, the authors described several potential limitations of the research that may explain why strong associations have been missed and, alternatively, how the small, albeit significant, associations can be explained by methodological limitations. With respect to contrast sensitivity, the research has been much less extensive than that for visual acuity; however, it has generally been supportive of an association. Yet drawing firm conclusions from this research is also hampered by methodological limitations, including the lack of objective measures of involvement in motor vehicle crashes and data on exposure to driving (Slade, Dunne, & Miles, 2002). Since the 1999 review, there has been little new research on visual acuity and contrast sensitivity and involvement in motor vehicle crashes. One recent prospective study with objective measures of involvement in motor vehicle crashes and proper accounting for exposure to driving found no evidence of a significant association between either visual acuity or contrast sensitivity and involvement in motor vehicle crashes (Rubin et al., 2007). Finally, it is perhaps important to note that AMD is also associated with other forms of visual impairment (such as a delay in adapting to the dark) for which there is no research either to support or to refute their association with involvement in motor vehicle crashes.

AMD and driving performance

Few studies have examined the relationship between AMD and driving performance on the basis of simulated driving or controlled driving. The limited findings that are available suggest worse performance among persons with AMD, as measured by braking response time, slower speed, lane crossings, and simulator accidents (Szlyk et al., 1995). However, the same persons were involved in fewer self-reported accidents and had fewer convictions for traffic violations. Furthermore, research on AMD-related visual impairments (such as on visual acuity and contrast sensitivity) and on-road or simulated driving performance has used simulated visual impairment in healthy young volunteers and closed-road courses, which may not accurately reflect the complexities of real-world driving (Brooks, Tyrrell, & Frank, 2005; Higgins & Wood, 2005; Wood, 2002). The relevance of this work to drivers with AMD remains to be determined.

Interventions to enhance safety and performance in drivers with AMD

The cessation of driving is certainly an appropriate step for drivers with AMD who are experiencing severe visual impairment. However, it comes with serious personal costs to the individual who lives in a society where the primary mode of travel is an automobile (Fonda et al., 2001; Freeman, Gange et al., 2006; Marottoli et al., 1997; Ragland et al., 2005). Older adults, like younger adults, prefer driving over other modes of travel in their communities (Hu & Young, 1999; Jette & Branch, 1992), and driving is associated with a better quality of life (DeCarlo et al., 2003; Mangione et al., 2001). In response to these well-established facts, there have been significant efforts over the past two decades to develop interventions to reduce the risk of crashes among older drivers with functional impairments, so that they can remain drivers as long as it is safely possible to do so. Two types of interventions are relevant to drivers with AMD, namely, educational programs that are designed to promote safe driving skills among elderly people who may have functional and medical impairments and training in the use of bioptic telescopes for driving.

Educational interventions

Educational programs to promote safe driving practices among elderly people have been developed by several organizations and have gained widespread popularity throughout the United States (AAA, 2008b; AARP, 2008; Janke, 1994b; National Safety Council, 2008). For example, since its inception in 1979, millions of Americans have participated in the AARP Driver Safety Program (formerly called 55-Alive). Programs for older drivers have several delivery designs, including classroom educational programs, videos, web-based programs, CD-ROMs, and workbooks. The effectiveness of two of these programs on the safety of drivers (that is, on reducing the crash rate) have been evaluated (Janke, 1994b; McKnight, Simone, & Weidman, 1982). The evaluations demonstrated that the enrollees gained knowledge about safe driving and how aging affects skills that are important for driving. Neither program reduced the crash rate compared with nonintervention groups; that is, the programs demonstrated no safety benefit. Two recent studies (Bedard et al., 2008; Marottoli et al., 2007), which evaluated the impact of a classroom educational program on older drivers' knowledge and on-road driving skills, showed improvements in knowledge and some aspects of driving skills. However, neither study evaluated whether the program had a safety benefit.

A driver education program for elderly drivers with visual impairments, called Knowledge Enhances Your Safety (KEYS) (Stalvey & Owsley, 2003), was evaluated (Owsley, McGwin, Phillips, McNeal, and Stalvey, 2004). The curriculum, based on models of change in and the promotion of health behavior (Bandura, 1986; Prochaska & DiClemente, 1992; Rosenstock, 1990), was designed to be led by a health educator and delivered to individual drivers in two one-on-one sessions, and was individually tailored to the drivers' driving needs, lifestyles, and types of visual impairment. The curriculum emphasized self-awareness of how the driver's visual impairment affected safe driving, driving maneuvers that the driver found particularly challenging, and strategies for addressing these challenges on the road (such as avoiding night driving, planning routes ahead of time to minimize the number of trips, and staying on highly familiar routes). In the evaluation of the program, drivers were randomized according to whether they had received either usual care, which consisted of a comprehensive eye examination, or usual care plus the KEYS educational program. The evaluation found that KEYS imparted knowledge about safe driving practices, such as self-regulatory strategies, yet did not enhance safety in the two years following the educational program—that is, it did not reduce the motor vehicle collision rate for the participants compared to the group who did not participate in KEYS. The findings of that study agreed with those of others (Janke, 1994b; McKnight et al., 1982) that there is no empirical support for the idea that educational programs enhance the safety of older drivers. Involvement in motor vehicle collisions is influenced by a multiplicity of factors (including the driver's functional and medical characteristics, fatigue, and personality; the design of highways; other vehicles; and weather), and thus it may be simplistic to expect that educational programs, however thorough and individualized, would affect the collision rate.

Two “self-assessment” tools, consisting of a set of exercises or questions, are designed to reveal older drivers' functional problems or medical issues that could contribute to unsafe driving and inadequate driving performance. The Driving Decisions Workbook (Eby, Molnar, Shope, Vivoda, & Fordyce, 2003) contains items in 37 assessment areas that address issues that are relevant for safe driving from three domains of health; driving abilities; and experiences, attitudes, and behaviors. Items addressing vision are included in the driving abilities domain. The items were designed so that they would prompt a self-appraisal of one's driving ability. As the driver goes through the items, response-contingent feedback is provided to increase self-awareness and general knowledge about driving, suggestions for further driving or medical evaluations are given, and compensatory strategies when driving are offered. Following the administration of the workbook to a group of older drivers, 75% indicated that the workbook

increased their knowledge of changes related to aging that can affect driving, and almost half reported that the workbook led them to consider taking a driving refresher course or to have a physician check their vision, cognition, and psychomotor abilities. There was no comparison of these postworkbook attitudes to attitudes prior to completing the workbook that would have determined if the workbook led to changes in self-awareness. The workbook items did demonstrate construct validity in that drivers whose responses indicated potential driving problems were more likely to demonstrate problems with driving performance on an actual road test. The efficacy of the workbook in terms of enhancing drivers' safety is not known.

Roadwise Review (AAA, 2008a), a screening tool on a CD-ROM, allows older drivers to estimate eight functional abilities, including vision, that previous research has demonstrated are relevant for safe driving. The tool is designed to be used in the privacy of an older driver's home, and at the end of the screening tasks, feedback is provided to inform the older driver about potential driving problems and recommendations about referrals to relevant health care providers (such as a physician, occupational therapist, certified driving rehabilitation specialist, and optometrist) to address functional impairments (Staplin & Dinh-Zarr, 2006). Although the functional abilities selected for inclusion in Roadwise Review are evidence based in that they are associated with involvement in motor vehicle collisions by older drivers (Staplin, Lococo, Gish, & Decina, 2003), the evaluation of Roadwise Review as a screening tool with respect to performance or safety outcomes has not been reported.

Bioptic driver training

Bioptic driving refers to the process of operating a vehicle with the assistance of specialized bioptic telescopic spectacles, often called bioptics. These devices allow some drivers with low vision, including those with AMD, to meet the minimum acuity standards for licensing. During driving, bioptic devices are typically used briefly to see details, such as road signs, or to "spot" specific landmarks. Most of the vision that is used while driving is through the person's regular eyewear, sometimes called the "carrier lens." Although bioptic eyewear may improve visual acuity, a driver's visual field is reduced while looking through the bioptic device. It is important to point out that using bioptics to obtain a driver's license and to drive is legal in only some jurisdictions in the United States and around the world (Peli & Peli, 2002), and even among the jurisdictions where bioptics are permitted, there is considerable variability in the details of the laws governing the use of bioptics.

As Owsley and McGwin (1999) noted, many authors have discussed the use of bioptics by persons with impaired central vision and training programs for persons who want to use them for driving. Despite this large and growing literature, there have been few controlled studies of the risk of crashes among drivers who use bioptics. Two studies (Janke, 1994a; Lippman, Corn, & Lewis, 1988) have reported that users of bioptic telescopes have higher crash rates than do control groups. Another study, from Texas, found similar crash rates for drivers who are visually impaired and drivers with cardiovascular and neurological impairments (Lippman, 1979). A study in Massachusetts reported lower crash rates for bioptic drivers than drivers in the general population (Korb, 1970). Unfortunately, a number of methodological issues prevent firm conclusions based on these studies. First, many of the studies have used the general population of drivers as the control group. Second, it is not clear whether the bioptic itself and its "side effects" (such as a reduced field of view) or severely impaired visual function or both is responsible for the elevated crash rates. Third, as the designs of low vision assistive devices and training programs improve and become more popular, it is unclear whether the studies would apply to current and future bioptic drivers. Previous research had found that drivers who are visually impaired tend to restrict their driving (for instance, avoid night driving and use familiar routes) (Ball et al., 1998; Freeman, Muñoz et al., 2006), and thus failure to account for such self-regulation in etiological studies may lead to invalid conclusions. Ultimately,

whether bioptic telescopes improve drivers' safety (or perhaps worsen it) cannot be gleaned from the current literature.

Several bioptic training programs for drivers with visual impairments have been outlined by clinicians and rehabilitation professionals (Huss, 1988; Huss & Corn, 2004; Jose & Butler, 1975; Kelleher, 1974; Park, Unatin, & Hebert, 1992; Politzer, 1995; Vogel, 1991), but most have not been evaluated for their impact on visual skills during driving or on the driving status, exposure, habits, or safety of persons who have completed the programs. Thus, little evidence-based guidance is available about how to structure bioptic training programs for persons who want to drive, but whose visual acuity does not meet the visual acuity licensing standard in their states of residence. One evaluation study examined the impact of an extensive training period in the use of bioptics in everyday tasks, including on-road driving, versus the prescription of bioptics without training (Szlyk et al., 2000). Seven of the 25 participants had macular degeneration, and 2 of the 7 were in their 40s, so the extent to which the study widely applies to persons with AMD is uncertain. The results supported the efficacy of bioptic training, rather than the prescription of bioptics alone without training. There was a greater improvement in the performance of tasks, including visual tasks that are relevant to driving (as assessed in a driving simulator), by persons who received the training program than by those who did not.

Clinicians and motor vehicle administrators have been concerned that drivers with serious impairments of visual acuity may use bioptic telescopes for driving, so as to pass the visual acuity screening test for licensure, but once licensed, may not use, or only minimally use, the bioptics for driving. To address this issue, Bowers, Apfelbaum, & Peli (2005) surveyed a convenience sample of 58 bioptic drivers with moderately reduced visual acuity about their use of bioptics when driving. The majority of those who were surveyed, 62%, indicated that they always used bioptics when driving. What remains to be determined is whether behavioral data would verify this high rate of self-reported use of bioptics when driving.

Although data on the ages of those who use bioptics for driving are limited, the surveys that have been conducted (Bowers et al., 2005; Park, Unatin, & Park, 1995) have suggested that the vast majority of bioptic drivers are not older adults with AMD, but young and middle-aged adults with early-onset retinal degenerations. Clinical anecdotes are consistent with this finding. There are many issues that have not been addressed about bioptic telescopes and drivers with AMD. For example, to what extent are older drivers with AMD offered bioptic telescopes as a rehabilitation option when their visual acuity is severely impaired? Are these drivers less interested in bioptic telescopes because they have driven for many decades without using assistive devices? How effective are bioptic training programs for older adults who often have medical and functional comorbidities? Questions such as these need to be addressed before bioptic telescopes can be offered as a practical rehabilitation option for drivers with AMD.

Finally, it is important to point out that these devices may be a solution for which there is no driving-related problem. For individuals with less than severely impaired vision, the use of bioptics may not be necessary because there is a lack of research suggesting that such individuals have significantly elevated crash rates. And for those with severe visual impairments, there is little debate that they should not be allowed to drive (with or without assistive devices).

Directions for future research

The most obvious need for future research is a well-designed study to assess the relationship between AMD and involvement in motor vehicle collisions. Such a study should include individuals with clinically diagnosed AMD that has been well characterized both functionally and pathologically. A study of this type is vital to understanding driver safety in persons with

AMD since characterizing the risk of motor vehicle collisions with respect to these features will serve both etiological and clinical needs. Moreover, evaluating this relationship within the context of a longitudinal study would provide additional valuable insights into how the natural history of AMD relates to changes in the risk of collisions over time. Another high-priority research area is bioptic telescopes. A number of questions on this topic need to be addressed through well-designed studies: To what extent do bioptic telescopes improve the safety of drivers with AMD? How do the bioptics affect the driving performance of this population, if at all? Under what circumstances do drivers with AMD use bioptic telescopes? How should rehabilitation programs be designed for drivers with AMD who are learning to use bioptic telescopes on the road? Are these programs effective in enhancing the safety and performance of drivers with AMD? The answers to such questions from well-designed studies are important, since they will serve to inform both clinical and policy audiences about the safety of bioptics for driving.

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