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ASSESSING VISUAL FUNCTION IN THE OLDER DRIVER

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Safe driving depends critically upon vision. Because visual functional problems and eye disease are more prevalent in the older adult population,[34] a natural hypothesis is that visual disorders are the major cause of driving difficulty in elderly individuals. This expectation is reflected by the fact that of all the psychomotor functions that could be evaluated at the driver licensing site (besides the road test), the only one routinely assessed is vision. Despite the intuitive appeal of a link between vision and driving ability, studies have found only weak correlations between visual deficits (e.g., visual acuity, visual field loss) and vehicle crashes.[26,27,54] These correlations were often statistically significant due to very large sample sizes but accounted for less than 5% of the crash variance in these studies. Thus, these data are insignificant in reaching the practical goal of successfully identifying which older drivers are seriously at risk for crash involvement. Despite earlier failures to identify potent visual risk factors, the search continues.

STRUCTURAL AND PHYSIOLOGIC CHANGES IN THE VISUAL SYSTEM DURING AGING

There are many structural and physiologic changes in the visual system during later adulthood.[42,51,62,63] These changes in their minor forms are considered "normal" accompaniments to growing old, but in their more advanced stages they cause serious vision impairment and conse-

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quently are designated as *diseases*. For example, during adulthood the crystalline lens undergoes increased density or opacification. When this increased density progresses to where it causes significant functional problems, it is generally termed a *cataract*. A similar point can be made for the macular changes that typify virtually all older retinas, such as pigmentary mottling and the appearance of drusen. When these changes become more serious and co-occur with decreased acuity, a diagnosis of age-related maculopathy is usually made. Thus, the ocular changes considered to be normal accompaniments to growing old actually lie on the same continuum as changes attributed to age-related disease processes, and thus sharp distinctions between normal eye health and eye disease are difficult to make and are often quite arbitrary.

The four leading causes of vision impairment in older adults in the United States according to the Framingham Eye Study are age-related maculopathy, cataract, glaucoma, and diabetic retinopathy.[34] All these conditions can affect central vision severely (e.g., acuity, contrast sensitivity, color discrimination), peripheral vision (e.g., light sensitivity in various areas of the visual field), or both, thus interfering with the performance of the visual activities of daily living. It has been estimated that 19% of adults between the ages of 65 and 75 have at least one of these conditions. The prevalence increases among the *oldest old*, reaching almost 50% in the over 75 age group. When uncorrectable vision impairment progresses to the point where it significantly interferes with the performance of daily activities, the individual is said to have *low vision*.[22] Elderly individuals are disproportionately represented among the low vision population, with one estimate indicating that they constitute 70% of this group.[33]

Optical Changes

There are several optical changes in the older eye that have deleterious effects on retinal image formation and thus can impair vision. The first change is the *decreased retinal illuminance* of the older eye compared with the young eye. There is an increased light absorption by ocular structures along the visual axis, which reduces the absolute light level reaching the photoreceptors.[12,47] These structures include the crystalline lens, and to a lesser extent, the cornea and the vitreous. Because more light is absorbed by the structures along the visual axis, the retinal illuminance of the aged eye is reduced relative to the young eye. Weale has estimated that the 60-year-old retina receives about one third the light of the 21-year-old retina.[62] This essentially means that older adults are operating at a lower light adaptation level than young adults. Pupillary miosis also contributes to reduced retinal illuminance. This refers to the tendency of the older adult's pupil to remain at a relatively small fixed size despite decreases in ambient illumination.[35] Whereas a young adult's pupil becomes larger in the dark (thus permitting more light to enter the eye), the older adult's pupil remains at a small diameter. A reduction in retinal illuminance may be especially detrimental to night driving, because spatial (pattern) vision is especially degraded under low light levels.

A second major change in the optics of the older eye is its *increased light scattering* properties due to the increased opacity of the crystalline lens and other parts of the optical media.[3,66] Increased light scatter essentially reduces the contrast of the retinal image. Contrast is the physical characteristic of images that allows for the detection of pattern and is a main building block of vision. Reduced contrast sensitivity hampers pattern perception, a well-documented problem among elderly individuals.[19,41] Increased light scatter in the older eye also is believed to be responsible for increased susceptibility to glare,[3,23] which older adults report as a particular problem when driving.[46]

A third major optical problem in the older eye is the reduced amplitude of accommodation, a condition referred to as *presbyopia*. By ages 60 to 70, very little accommodative (*focusing*) ability of the eye remains, and most older adults require corrective lenses to see optimally at near distances.[28] The corrective lenses prescribed for near distances are usually targeted to optimize vision for the routine reading distance, usually about 40 cm; however, the dashboard of a car, which displays numerous control devices for successfully operating a vehicle, is typically at greater than 40 cm, which means these dashboard controls are not in clear focus for many older drivers.

Neuroanatomic and Physiologic Changes

The pathways of the central nervous system involved in the processing of visual pattern also undergo changes during adulthood. Studies have reported photoreceptor loss in the older retina,[17,24,36] although the loss of rods (photoreceptors specialized for night vision) is more dramatic than the loss of cones (those specialized for daylight and color vision).[17,24] There is also a loss of retinal ganglion cells, the neurons that carry information about visual pattern to higher brain centers,[4,18] and a loss of visual cortical cells.[20,58,65] Other aging-associated cortical changes include neurofibrillary degeneration, shrinkage of dendritic arbors, loss of dendritic spines, and a decrease in extracellular space.[58,65] The electrophysiologic properties of the visual system also exhibit aging-related changes. Older adults exhibit a reduced amplitude of the full-field electroretinogram and of the pattern electroretinogram,[11,45] and an increased latency of the first primary component of the visual evoked potential.[15,57] In summary, there are several ways in which the neuroanatomy and physiology of the visual system change in later life, although it is still unknown to what extent these alterations in the neural substrate are directly responsible for the visual functional problems of older adults.

Changes in Visual Function

Many aspects of visual function undergo changes during the course of adulthood even in adults who are free from eye disease. A brief overview is offered here, focusing on those aspects of visual function that

seem particularly pertinent to driving. For more in-depth discussion the reader is referred to other sources for a more detailed treatment of this diverse topic.[42,51,62,63] The standard way of evaluating visual function in a clinical examination is by measuring visual acuity. There have been many studies on how acuity changes during adulthood. All agree that there is a decline between early and late adulthood, although the rate of decline and the decade of onset are not widely agreed upon.[43] Viewing conditions that have low contrast or luminance exacerbate older adults' acuity deficits.[2] Contrast sensitivity also is impaired in older adults.[19,41] Tests of contrast sensitivity measure how much contrast a person requires to detect patterns of various sizes, where size is expressed in terms of the spatial frequency of a bar grating. At daytime light levels, older adults typically exhibit a loss in contrast sensitivity for targets having intermediate and higher spatial frequencies (i.e., medium- and small-size patterns).[19,41] They require about three times more contrast to see these targets than do young adults. This visual deficit is primarily caused by the optical problems that frequently occur in aged eyes, as previously discussed, rather than to deterioration of the visual nervous system.[14]

At lower light levels, such as at twilight or at night, older adults' contrast sensitivity deficits are even greater in magnitude.[55,56] Research has not yet clearly defined the locus of this loss, although neural deterioration in the visual pathways is believed to play some role. Both acuity and contrast sensitivity loss in older adults is likely to affect the visibility of objects and obstacles during driving. Given that these deficits are accentuated at lower light levels, it is not surprising that many older adults minimize or entirely avoid nighttime driving.

The temporal characteristics of visual processing also are impaired in older adults. A number of deficits have been reported. Tests of critical flicker fusion measure the temporal frequency at which a light appears to be fused (nonflashing). This fusion rate is lower in older adults compared with young adults, suggesting that the temporal resolution of the visual system is decreased in old age.[16,38] Contrast sensitivity for flickering targets is impaired in elderly individuals, also suggesting a change in the time constant of the neural response.[61] In general, there is a slowing in the speed of visual processing in older adults,[29] which implies that processing rapidly occurring visual events, as when driving, poses special difficulties for elderly individuals.

Visual sensitivity throughout the visual field, including peripheral vision, is affected adversely by the aging process. Studies using kinetic perimetry have indicated that the borders or *isopters* of the visual field are constricted in older adults.[21,64,67] Studies using automated perimetry have found that older adults exhibit a generalized loss in sensitivity throughout the central 30 degrees of the field, with some studies suggesting a slightly greater sensitivity reduction in more peripheral areas.[13,25,30] These impairments cannot be accounted for by changes in the optics of the older eye, implying a neural basis for the loss.[32] Another way of assessing the visual field is to measure the *useful* or *functional* visual field.[7,48] These terms are used typically to refer to the spatial extent of the visual field required for a specific visual task, such as localizing or identifying suprathreshold targets or events. The limits or borders of the useful field of view are dependent on several stimulus and task features, such as presence of both primary and secondary tasks, the presence of distracting visual events, and the salience of the visual event to be detected.[9] Older adults tend to have a shrinkage of the useful field of view compared with young adults.[5,49,50] For example, older adults are more likely to make errors in a peripheral localization/identification task while simultaneously performing a task in central vision. This performance problem is believed to relate to older adults' attentional deficits (e.g., difficulty dividing attention and ignoring irrelevant information), as well as to a generalized slowing in their rate of visual information processing. In summary, then, older adults may exhibit problems with tasks involving peripheral vision (e.g., driving) because of a loss of visual sensitivity throughout the visual field, a shrinkage in their useful field of view, or both.

Visual adaptation is a term used to refer to the process by which a person visually adjusts to different levels of environmental illumination. Probably the best known example is when an individual walks into a dark movie theater after being out in the bright outdoors, or vice versa. Older adults require a longer time than young adults to adjust to abrupt changes in lightness or darkness,[37,59,60] which is presumably related to changes in retinal function during aging. Elderly drivers often report difficulties dealing with the sudden onset of bright lights, such as the headlights from an oncoming car. Their visual adaptation deficits may underlie these reported problems. Another factor that could contribute to these visibility problems is their heightened sensitivity to disability glare.[66] As previously discussed, the older eye has increased intraocular light scatter, which reduces the contrast of the retinal image, thus creating visibility problems.

Other aging-associated changes in visual function also could theoretically impact driving skills. For example, depth perception as mediated by stereo depth cues reportedly starts to decline after the fourth decade,[10,31] but existing studies are fraught with methodologic problems, so results must be viewed with caution (see reference 42 for a review). Older adults' sensitivity to monocular depth information (e.g., motion parallax) has been largely neglected in the research literature. Depth perception seems crucial for successively navigating a vehicle around obstacles, so this may prove to be a fruitful avenue for future research. The control of eye movements is also an area that is especially relevant to driving, because the driver must constantly scan the environment for guidance information and potential obstacles. When tracking a moving object, older adults exhibit slower pursuit velocities compared with young adults and increased latencies in initiating a smooth pursuit movement.[52] Older adults also show increased latencies in initiating saccadic eye movements.[1]

Before turning to a discussion of vision and driving, it is important to underscore several points. First, there are wide individual differences in the visual functional abilities of older adults. Although on average one can expect older adults to have the types of visual deficits previously discussed, most studies also suggest that there is considerable variability within a single age group. In other words, simply because a person is old does not automatically mean this individual has a vision impairment. A

second point worth emphasizing is that almost all studies on visual function and aging have been based on cross-sectional comparisons. Thus, these studies properly tell us about group trends, rather than the kinds of changes that occur within a single individual during the course of a lifetime. Third, as will be discussed in this article, although a specific visual deficit may be prevalent among older adults, this does not necessarily mean that this factor is successful at identifying which older adults have driving difficulties and crash problems.

RELATIONSHIP BETWEEN VISION AND DRIVING PERFORMANCE

Several studies sponsored by state and federal agencies have examined the relationship between vision and crashes in large samples (e.g., $N > 1000$) of older adults.[26,27,54] All these studies found statistically significant relationships between various aspects of vision (e.g., acuity, disability glare, peripheral vision) and the number of crashes incurred during a specified time period; however, these correlations were very weak, accounting for less than 5% of the crash variance and thus are insignificant from the practical standpoint of identifying crash-involved drivers with high sensitivity and specificity.

Why have previous studies failed to document a firm link between vision and driving performance in older adults? One possible problem is in using vehicle crashes as a measure of driving performance. A crash is a rather uncommon occurrence when one considers the many miles driven each year, and thus the researcher has the statistical burden of predicting an improbable event. In addition, subject samples from many earlier studies had a preponderance of drivers with zero crashes on record, making it difficult to evaluate a model designed to predict crash frequency. Another problem stems from the use of self-reported crash frequency as the dependent measure, rather than obtaining crash data from records kept by the Department of Motor Vehicles (i.e., in some studies subjects were simply asked how many crashes they had over some specified period of time). This self-report measure of crash-frequency, although easy to collect, has questionable validity when compared against state records. For example, a recent study found that those older drivers with the highest number of crashes listed on the state record were largely men who tended to underreport crash involvement on a questionnaire.[6] Yet another possible reason for poor links between vision and driving is that poor vision may cause drivers to modify their driving behavior, such as avoiding challenging roadway conditions (e.g., night driving, rush-hour traffic). These self-imposed restrictions by older adults with vision impairment would work against finding a strong correlation between poor vision and crash involvement.

A crucial reason why earlier studies may have failed to identify visual risk factors is because of the tests chosen to evaluate visual function in these studies. Visual sensory tests as used in the earlier studies (e.g., acuity, contrast sensitivity, and visual field sensitivity), although quite appropriate for the clinical assessment of vision loss, do not reflect the visual complexity of the driving tasks. Because the visual demands of driving are quite intricate, these tests would not be expected to reveal a strong relationship between vision and driving. Controlling a vehicle takes place in a visually cluttered environment, involves the simultaneous use of central and peripheral vision, and the execution of both primary and secondary visual tasks. The driver is usually uncertain as to when and where an important visual event will occur. Visual sensory tests do not typically incorporate these stimulus and task features but instead seek to minimize perceptual and cognitive influences. Thus, in designing a visual test to predict driving problems, it would be advantageous to incorporate stimulus and task features that more accurately reflect the visual demands of driving.

Recent research from the authors' laboratory has illustrated that this may be a more fruitful approach, i.e., to actually identify potent visual risk factors for crash involvement.[8,40] The authors' research approach assessed visual sensory function and also used a comprehensive approach by assessing other aspects of the visual information-processing system, including the health status of the visual system, visual attentional skills, and cognitive skills, all within the same sample of older drivers. The inclusion of a visual attention test was deemed crucial because some older adults have serious impairments in visual attentional skills such as visual search, attention switching, dividing attention, and ignoring irrelevant stimuli.[9,44] On face value, all these skills seem relevant in driving. Previous work also has suggested that visual attentional skills may be crucial in safe driving. A study that analyzed accident reports filed by the police indicated that most crashes by older drivers are caused by alleged "driver inattention."[53] Owing to these considerations, it seemed worthwhile to evaluate the ability of visual attentional skills to predict crash problems in older drivers.

The test of visual attention the authors used was a measure of the size of the useful field of view, the spatial area within which an individual can be rapidly alerted to visual stimuli.[9] Older adults with substantial shrinkage in the useful field of view were six times more likely to have incurred one or more crashes during the previous 5-year period. Our study found that the useful field of view test indeed had high sensitivity and specificity in predicting which older drivers had a history of crash problems.[8] For illustrative purposes, Figure 1 is an example of the useful field of view for an older driver with a normal useful field of view (*A*) and for older drivers with various reductions in the useful field of view (*B, C, D*). Note that for drivers in 1*B–D* the spatial area over which they can rapidly attend to visual information is drastically reduced.

To evaluate the utility of a useful field of view task as a diagnostic test for identifying crash problems, specificity and sensitivity were computed, and the results are listed in Table 1. Subjects were divided into two groups based on the percentages of their useful field of view reduction (≤ 40% vs. > 40%). Subjects in each of these groups were then divided into two categories based on their crash history (zero crashes vs. ≤ one crashes during the previous 5-year period). Sensitivity was 89% (given a subject was crash-involved, the probability of having a field of vision reduction

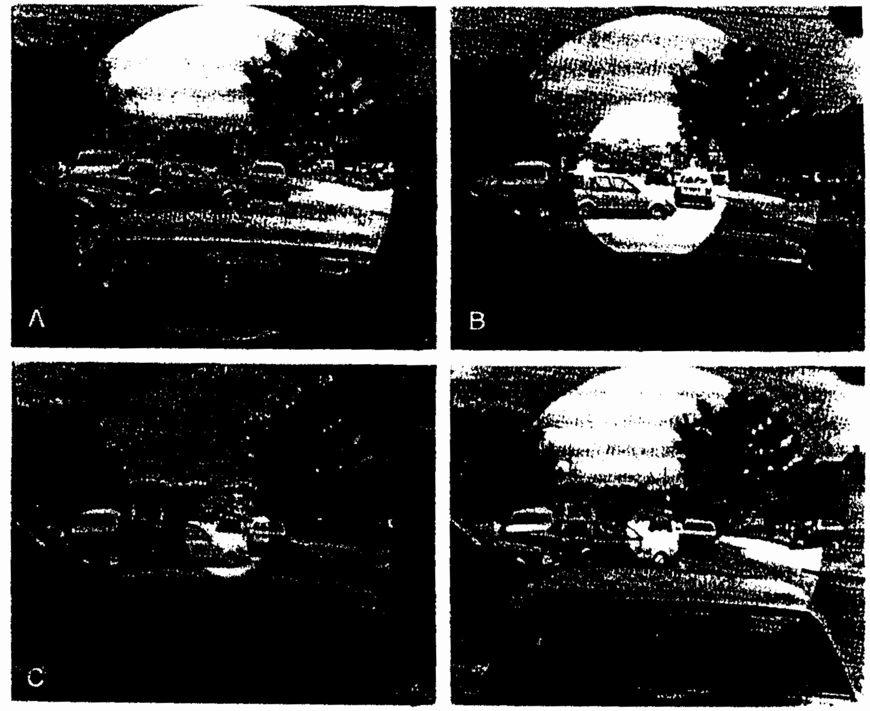

Figure 1. An illustration of how restrictions in the useful field of view (UFOV) may increase the probability of crashes. *A* displays the average size of the "attentional window" for individuals with no restriction of UFOV. *B* displays this window for individuals who have experienced a significant decline in the speed of visual information processing. *C* displays this window for individuals who have experienced both a slowing and an extreme sensitivity to distraction. Finally, the most extreme case of UFOV restriction is illustrated in *D* for those individuals who have experienced slowing, sensitivity to distraction, and the inability to divide attention between central and peripheral tasks. *Note that the areas depicted in this figure do not represent the size of the visual field, but are scaled to represent relative reductions in the size of the UFOV for different groups of individuals.*

Table 1. NUMBER OF SUBJECTS IN HIGH- VS LOW-RISK UFOV CATEGORIES STRATIFIED BY CRASH HISTORY

	Crash Category	
UFOV Category	**≥1 Crashes**	**0 Crashes**
UFOV Reduction > 40%	142	25
UFOV Reduction ≤ 40%	18	109

UFOV = Useful field of view

The sensitivity and specificity of this test were 89% and 81%, respectively. (*Adapted from* Ball K, Owsley C, Sloane ME, et al: (tentatively titled) Visual attention problems as a predictor of vehicle crashes in older drivers. Invest Ophthalmol Vis Sci, in press; with permission.)

greater than 40% was 0.89). Specificity was 81% (given that a subject was not crash-involved, the probability of having a useful reduction less than or equal to 40% was 0.81).

It is important to note that our study did agree with earlier studies in that acuity, light sensitivity in peripheral vision, cognitive status, and eye health status were significantly correlated with crash frequency; however, these relationships were sufficiently weak that these factors were poor at identifying older drivers at risk for crash involvement, i.e., these variables had poor sensitivity and specificity. This study implies that current visual screening techniques, such as tests of acuity and peripheral vision as used at driver licensing sites, are not adequate in identifying which older drivers are likely to be involved in crashes. Screening tests of acuity and peripheral vision as given at the department of motor vehicles may have other benefits (e.g., identifying those in need of referral for eye care, screening out applicants with severe vision loss), but our study indicates that they do not screen out many older drivers who pose a safety risk to themselves and other drivers.

This study also found that even though visual problems are more prevalent in the older adult population, chronologic age itself did not successfully discriminate between crash-free and crash-involved drivers. Thus, this study clearly indicates that any policy to restrict driving privileges based solely on age is not scientifically well-founded. Decisions on the suitability of licensure in the older adult population are more appropriately based on an objective performance measure, given the diversity of functional capabilities in the elderly population. A visual test such as the useful field of view is an example of a measure that shows promise. The complexities of implementing such a test on a widespread basis are beyond our scope here, but clinicians and researchers alike must eventually consider how risk factors, once identified, can be used to enhance the safety of elderly drivers.

Future work must address a number of outstanding issues. Most studies on vision and driving to date have had retrospective designs, and thus do not directly address the question of whether visual functional variables predict future crashes, which after all is the crucial question. Medical variables, besides eye health status, also must be incorporated into studies of vision and driving. Variables such as medication usage, cardiovascular disease, musculoskeletal and motor disorders, and alcohol use have been associated with driving problems[39] and may interact with visual risk factors. In addition, previous studies on vision and driving in the elderly population have been largely preoccupied with the number of crashes as an outcome measure. It could be argued that researchers would be more successful in predicting driving performance if they used a dependent measure that reflected actual driving behavior, rather than a consequence of poor driving, such as crashes. For this reason, performance in a road test or in a driving simulator may prove useful in identifying visual risk factors. Although this may be true, it is important to keep in mind that one important goal of research on the elderly driver is to minimize crash involvement, which would have enormous social and financial implications to our society, as well as personal significance to

victims and their families. Thus, if these performance measures (as in a road test or simulator) were to be used for determining who is at risk for crash involvement, they would eventually have to be validated against actual crash frequency.

Possible Interventions

Given that research is just beginning to identify visual risk factors for driving problems in elderly individuals, the development of visual interventions is only in its infancy. An obvious way to minimize unsafe driving in older adults is to ensure that older drivers have their best possible vision and that all eye diseases and conditions have been evaluated by an eye care specialist. Older drivers should be encouraged to undergo an eye health examination on a yearly basis, or more often if they have a condition which requires frequent monitoring. Many eye conditions and diseases are treatable (e.g., cataract, glaucoma), especially when diagnosed early, and thus in many cases permanent vision loss can be prevented. It is also important for the eye care specialist to educate the patient about possible limitations in his/her visual capabilities due to vision impairment or deficits in higher order visual capabilities. The authors' study has indicated that some older adults who are at risk for crashes because they have serious vision impairment, modify their driving behavior by avoiding exposure to difficult driving situations (e.g., driving alone or at night, turning left across traffic).[8] This self-regulation of driving behavior was associated with a lower crash frequency. Therefore, it is possible that if older adults were better informed about their vision problems, some might voluntarily impose restrictions on their driving behavior, thus lowering their crash risk. Another potential intervention stems from the finding that shrinkage in the size of the useful field of view for some older adults can be at least partially reversed through a training program.[5] This training required only a modest investment of time, and the field expansion which resulted was still maintained 1 year after completion of the program. The question which remains is, given that the useful field of view shrinkage is associated with increased crash frequency, would expansions in useful field of view size through a laboratory training program lead to improved driving and decreased crashes? This hypothesis deserves detailed evaluation.

SUMMARY

It is likely that some older adults will have to be restricted from driving because of serious and irreversible deterioration in skills crucial to driving, due to vision impairment, visual attention deficits, and decreased cognitive status; however many older adults with driving difficulties can improve their driving skills or reduce their crash risk through education or training programs. Research to evaluate interventions such as those previously mentioned has high priority, given society's need to maintain the mobility and personal independence of older adults without sacrificing safety concerns.

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