Night Driving and Advancing Age

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The purpose of this report is to consider the body of research pertinent to the study of vision, old age, and driving at night. Although it seems both intuitive and obvious that vision difficulties, whose prevalence increases drastically in the later years and especially under conditions of low illumination, should be strongly related to driving performance, research to date has failed to establish high correlations between visual function and driving in older drivers [1, 2, 3]. There are a number of possible reasons for this: First, older drivers may adjust their driving practices to compensate for their decreasing visual capabilities. In support of this possibility, the National Highway Traffic Safety Administration [4] concluded in a recent study that older drivers are likely to do most of their driving in the daytime. Second, since crashes and convictions are relatively infrequent events, it is difficult to establish statistical relationships without extremely large sample sizes. A third, related, problem is that visual function measures that can be applied uniformly over a large sample tend to be relatively crude measures of overall visual capability such as visual acuity, that may not accurately characterize those visual functions that are important in driving. Finally, a view currently being espoused by some investigators, is that attentional rather than sensory factors may be more important determinants of driving performance in older people.

Despite the current lack of good statistical models relating vision and driving performance, and regardless of which factors are found empirically to be *most* important in driving performance, a close look at the relationship between visual factors and driving still seems worthwhile, for two reasons. First, there are many optical and physiological changes to the visual system that are well-established, typical concomitants to aging. Many of these, considered below, are known to affect performance of visual tasks under conditions of low illumination, and driving seems unlikely to be excepted. Our knowledge of how these changes affect performance of the central task required in our society's dominant mode of travel is of value in its own right. Since large sample studies have failed to shed light on this issue, smaller, in-depth studies are clearly needed to elucidate the nature of what must obviously exist at some level: a strong relationship between visual function and driving performance.

A second reason for studying night vision and driving is that older people's avoidance or elimination of night driving significantly restricts independence and social contact. To the extent that night vision problems can be ameliorated in older people, quality of life can be enhanced. Recent technological advances discussed below make this goal addressable.

In sections following, we examine more closely some of the visual changes that accompany age that can be expected to affect driving performance of the older driver, consider one possible framework under which to study this issue, and examine some promising technologies for amelioration of night driving difficulties.

Age Related Changes in Visual Structures and Visual Function

In this section, we outline the most important age-related changes to the eye and visual function that are likely to affect night driving performance by older persons.

- Increased lens density — Throughout the lifespan, for reasons that are still only partly understood, the lens gradually increases in thickness by adding new layers of cells. Because these cells are not completely transparent, this increase in thickness results in a cumulative increase in opacity of the lens as a whole, since each new layer of cells filters out more of the light that might pass through to the retina. The normal aging process, then, quite typically results in a dimming of the retinal image, and the diminution of visual function that goes along with seeing under lower levels of illumination.

- Lens yellowing — Presumably to protect the retina from the harmful effects of ultraviolet (U-V) radiation, cells of the young human lens contain a pigment that blocks out this range of wavelengths. This blockage does not end neatly, however, where the visible part of the spectrum begins, but gradually becomes less effective over a range of wavelengths that typically appear bluish and violet. By selectively absorbing these wavelengths of light rather than passing them on to the retina, the lens takes on a slightly yellowish appearance. The increased thickness of the lens, then, brings with it especially increased U-V and visible short wavelength blockage with advancing age.

  The visual impact of this blockage, of course, is to render short-wavelength lights (typically appearing bluish and violet) less visible. Also, surfaces that are high in short-wavelength reflectance will appear darker. Additionally, attenuation of the short-wavelength end of the spectrum can render surfaces of certain colors less discriminable from each other, e.g., bluish from greenish and yellowish from white. Interestingly, these types of color confusions resemble those shown by persons with certain age-related visual disorders (e.g., macular degeneration, diabetic retinopathy and glaucoma). In both cases, the color confusions result from a diminution of response of the class of cone photoreceptors most sensitive to short-wavelength light. Finally, the rod photoreceptor system that operates in low intensity vision has its peak sensitivity in the short-wavelength end of the spectrum and would as a result of lens yellowing suffer a greater sensitivity loss relative to those cone systems sensitive to longer wavelengths. Thus, absolute sensitivity to luminance suffers in the dark.

- Pupillary miosis — This term refers to the fact that for a given illuminance level, the average diameter of the pupil decreases with age. As a result, less light reaches the retina at a given illuminance level at all luminance levels. It is well documented that at reduced illuminance levels, young observers begin to display similar color confusions on standard tests as those shown by individuals with a defect in the cone photoreceptors most sensitive to short-wavelength light. Older observers make these kinds of color confusions at higher illuminance levels than younger persons (e.g., [5]). Thus, reduced illuminance level as a result of pupillary miosis is likely to have a similar effect on color discrimination as lens yellowing (see Lens yellowing, above). Furthermore, as pointed out by Weale [6], there is an interaction between these two age related changes in the eye. Light loss and increased lens density with its concomitant color discrimination losses due to the *combination* of miosis and lens yellowing are much greater than they would be due to either of these factors alone. This interaction is caused by the fact that a smaller pupil size restricts passage of light through the thickest and most absorptive part of the lens.

- Neural losses — In addition to the losses in sensitivity that result from optical filtering by structures of the eye, there are documented overall losses of retinal sensitivity to light that are correlated with age [7] and are not accounted for by optical factors. The net effect of these optical and neural losses in sensory information is that older observers must operate as if they were under a lower illuminance level. To the extent that performance on a given task is luminance dependent, older persons will require a higher luminance level to reach the same level of performance as a younger person. The increased incidence of subclinical macular changes, which might in more advanced cases be diagnosed as maculopathy, may contribute to such observations.

- Acuity and contrast sensitivity losses — Some types of pathological changes in the eye with age, like cataract, lead to degradation of the retinal image resulting in losses of acuity and contrast sensitivity. Older observers with relatively clear optic media can show such losses also as a result of the effective reduction of luminance at the retina by some of the factors discussed above, since these measures are luminance dependent. It would be expected that older persons, as a result, might also experience greater degradation of acuity and contrast sensitivity than younger persons as luminance is reduced. Sturr, Kline and Taub [8], for example, found that the percentage of observers over age 65 passing a 20/40 acuity criterion, the minimum best corrected acuity required for driving in approximately

80% of the states, decreased from 94% to less than 20% as the luminance level was reduced from photopic to mesopic levels. This contrasts with their younger sample for whom the percentage reaching this criterion was greater than 75% for the same luminance reduction. Even when such factors are controlled, however, older persons show a loss of contrast sensitivity at high spatial frequencies that is likely due to neural changes [9, 10]. Such sensory losses will show effects on tasks requiring discrimination of fine spatial detail.

Older persons may show luminance dependent changes in contrast sensitivity at lower spatial frequencies that cannot be explained by light losses in the eye [10]. Some of these losses may depend on the temporal characteristics of the stimulus (whether it is in motion or modulating on and off at a certain rate). These types of sensitivity loss could be more relevant to driving as the sensory input in driving is constantly changing and the visual scene is in motion.

- Glare — Many older observers experience increasing problems with glare. This may result from increased levels of fluorescence in the lens and eye, by increasing particle scatter from the eye media, or by loss of the photoreceptors that mediate vision of high intensity lights (cones). Glare of the scatter type is usually referred to as veiling or disability glare. Its effect is to reduce the effective contrast of retinal images through light scatter, thus, lowering contrast sensitivity.

Aging may influence discomfort glare as well. Discomfort glare is defined as resulting from "light that reduces visual comfort, but does not interfere with resolution" [11]. It has been found that the efficiency of monochromatic lights for producing discomfort glare under night driving conditions is approximated by the sensitivity function mediated by the rod photoreceptors [12]. Additionally, older persons tended to consider a light of a given intensity as more discomforting than younger observers. As indication of the influence of lens density on visual function, the glare efficiency curve for older observers appeared shifted slightly to longer wavelengths relative to the young observers' curve, as would be expected from the greater attenuation of short-wavelength lights by older lenses (Flannagan, personal communication). The effect of this greater attenuation is that older observers would need a greater intensity short-wavelength light than a younger observer to produce the same effective discomfort glare. Thus, while older persons may become relatively more resistant than younger persons to the effects of short-wavelength lights on discomfort glare, their absolute sensitivity to such types of glare seems to increase.

Increased sensitivity to discomfort glare at night, while not necessarily disturbing visual functions used in driving, may interfere with attentional processes. A driver who feels not able to cope with the myriad of sensory impressions that need to be processed while driving because of increased distraction due to discomfort glare may lose confidence in his/her driving abilities and be more reluctant to drive at night.

- Enophthalmos — Since there is less fat deposited in the orbits, eyes of older persons sink more deeply into the head. As a result, the nose and the bony structures of the orbit protrude more deeply into the peripheral visual field, constricting the total area of the visual field. Sensory losses of this sort are likely to influence tasks that require extensive use of the peripheral visual field, e.g., spatial orientation and mobility.

- Adaptation — Sturr et al. [13] found that older observers showed a systematic slowing of early light adaptation in peripheral visual field as a function of age. Young observers typically show a transient decrease in sensitivity at onset of a light that lasts about 0.1 second. The peak of this loss of sensitivity occurs as much as 50 milliseconds later in older observers and the total duration of the loss is greater, as well. Sturr et al. [14] have also shown that older observers display a slower recovery (by a about a factor of 2) of sensitivity to offset of a flash of light (early dark adaptation). These results were not obtained under night driving conditions but, nevertheless, suggest that older drivers may not adapt as well to rapid and large changes in illumination as occur from oncoming headlights. They also may indicate a decrease in the speed at which some information is processed in the visual system of older persons that would lead ultimately to slower response times under some conditions.

- Attentional effects — Older observers show a reduced ability to direct attention to a focal stimulus in the presence of distractor stimuli presented to the peripheral field of view, and recent work by Ball and her colleagues suggests that such attentional factors may be more important determinants of driving performance than previously supposed [15] Indeed, Ball et al. go so far as to propose that such factors are more important even than are sensory visual factors.

The preceding descriptions indicate a large range of factors likely to compromise the vision of an older person driving at night. In the next section, we consider one scheme that has been suggested for systematizing the changes in visual function in relation to night driving and whether it provides a useful context within which to analyze the performance of older persons driving at night.

A Framework Within Which to Consider Night Driving Performance

Liebowitz and Owens [16] have proposed an heuristic scheme for analyzing visual function under night driving conditions. Because it is the only such scheme that has as yet been proposed, we discuss it here. Liebowitz and Owens consider visual functions in driving to be composed of at least two subsystems or modes of function: those that utilize "focal" vision and those that utilize "ambient" vision. Focal vision involves tasks in the central visual field, such as form perception, identification and recognition. Ambient vision utilizes information from the peripheral retina and subserves various tasks concerned with spatial orientation and mobility of the individual through space. The two types of vision have been considered to be addressing two different questions about visual information. Focal vision tries to answer "what" questions about visual information and ambient vision tries to answer "where" questions [17]. (The motivation for this distinction comes from a large literature based on physiological, anatomical and behavioral indices that has argued that these distinctions are relevant to all aspects of visual function, not just driving.) The two types of visual function also differ with respect to their sensitivity to luminance variation. Focal vision is seriously degraded by luminance reduction, while ambient vision is degraded considerably less so.

According to Liebowitz and Owens [16], the primary tasks of a driver are steering a vehicle and staying on the road, which demand continuous attention. They posit that as a task of dynamic spatial orientation, these require ambient vision and are mediated largely by peripheral vision. Recognition and detection of objects on the road while also critical for safe driving require focal vision, are mediated by central vision and are only involved in the driving task intermittently. Since ambient visual tasks are not seriously degraded by reductions of luminance, drivers can steer well at night and are less aware of their degraded focal visual functions that are called into use less frequently. Liebowitz and Owens suggest that drivers, thus, tend to be overconfident and do not adjust their driving behavior to accommodate to the increase in limitations to their performance. Additionally, they suggest that drivers who are aware of focal visual limitations outside of the driving situation may be more reluctant to drive at night. Examples that they give of conditions that would produce such disabilities are cataract and small (miotic) pupils from glaucoma therapy.

If age-related sensory losses, such as those described above, interfere with focal vision to sufficient degree that the individual is aware of such interference, this scheme predicts that older drivers would be reluctant to drive at night, as other evidence suggests the case to be. The scheme implies, however, a dichotomy between confidence in driving, dependent on awareness of focal visual function, and ability to drive safely, based on integrity of visual function. If such a dichotomy makes sense, the logical approach would be to attempt to ameliorate the loss of visual function with the hope that it would firstly improve the ability of older persons to drive safely at night and secondly boost their confidence in driving at night. Loss of visual function, as we will discuss below, in older observers is not just with respect to focal visual function, however, and it would not suffice to introduce measures that only improved focal visual function and neglected ambient function.

How do changes in visual function with age differentially affect focal vs. ambient vision as defined by Liebowitz and Owens? Certainly, declines in acuity, contrast sensitivity and color discrimination that are independent of luminance reductions at the retina are diminutions of focal visual function. Recall that according to these authors focal visual functions suffer greater degradation than ambient functions by luminance reduction. The effect of several age related factors described above (lens yellowing, pupillary miosis, etc.) is to reduce the amount of light reaching the older retina and as such leads to greater degradation of focal visual function in older observers at night than is found in younger observers (e.g., [8]). Other of the factors described above directly influence the peripheral visual field (e.g., enophthalmos) and would be expected to interfere with ambient visual functions. Glare, adaptational and attentional effects are less easily categorized as they may involve the interaction of both types of visual function. On the one hand, disability glare reduces peak contrast sensitivity and acuity which are required for focal visual functions like recognition and identification. On the other hand, discomfort glare because of its nature as a distractor is likely to affect attentional processes and, thus, may influence ambient processes.

While the focal/ambient distinction may capture the salient aspects of visual function loss in night driving by younger observers, the preceding analysis should make clear that the problems for the older driver are more complex, and such a distinction, while interesting as a point of discussion, only partially clarifies the difficulties that an older driver would be expected to experience driving at night. The scheme suggests a relation between driver self-confidence and awareness of integrity of visual function, but falls short of providing a framework to relate visual function and driving performance. The framework does accentuate the diversity of visual functions involved in performance of a complex behavior like driving and in so doing, perhaps, provides an important clue as to why simple measures of visual function like visual acuity fail miserably to predict driving performance.

Alternative Approach

We can propose another, perhaps more practical, framework for evaluating the relationship between visual function and driving performance at night. Since driving seems to depend in a complex fashion on diverse aspects of visual function, it might be useful to determine a profile of visual function for a sample of older observers and to correlate this profile with driving ability. Such a profile would entail assessing performance of older observers on a range of visual tasks that are important in driving and likely to be affected during night driving by the changes in the eye that accompany aging. We also need dependent variables that are practical to use with small samples, such as performance on a driving simulator. Several such simulators are currently under development in research laboratories around the country.

The age-related changes in structure and function enumerated above suggest several categories that would be important to include in such a profile. First, loss of acuity, contrast sensitivity and color discrimination with age all seem to depend, at least in part, on reductions in available light. We need to know to what extent such losses of function can be compensated by increasing illuminance levels. To obtain this information would entail developing an estimate of how much retinal illuminance is reduced in the older eye relative to younger eyes (e.g., using measures of pupil size, lens opacity and other concomitants of light loss with age) and explicit measures of the losses in visual function due to this factor. Such data will provide quantitative information on the minimum lighting levels necessary for optimum performance of visual function of older observers. At the current time, this information is only available for average observers, obtained on isolated visual functions.

Second, we need to characterize more fully the nature of glare sensitivity in older person. Specifically, it will be necessary to develop measures that distinguish different types of glare (e.g., disability, discomfort and neural glare) and the extent to which each type interferes with visual tasks associated with driving.

Third, we need measures of the integrity and extent of the visual field. Such measures would include changes in size of the visual field due to explicit field restrictions, and to the sensitivity losses across the visual field that accompany aging.

Fourth, we must measure attentional performance under conditions of low illumination and under conditions producing discomfort glare (e. g. from headlights). This can be accomplished by using tasks similar to those developed by Sekuler and Ball [18].

Given measures of ocular functioning on such dimensions, we can use multiple regression and other statistical techniques to determine which are the most important variables that account for performance in the simulated night driving task. Armed with such information we will then be in a better position to make recommendations regarding appropriate environmental modifications that can lead to safer and more confident night driving by older people, and regarding requirements for promising new aids for night driving.

Technology and Night Driving

A number of simple recommendations can be made that would enhance older observers' visual function at night and might help them drive more safely and with more confidence.

Some of these will, of course, entail modifying standards used to analyze the average observer, who is usually assumed to be young. For example, in the technical literature, one distinguishes between photopic vision at high intensities, scotopic vision at low intensities, and mesopic vision at intermediate intensities. These three types of normal vision are mediated by different photoreceptor types. Based on average data, the intensity transitions between these types of vision have been specified and are useful for characterizing the light level requirements for young observers with normal vision. But these transitional intensity levels are likely to be incorrect when dealing with the vision of older persons and would require redefinition to account for older individuals' lower sensitivity. So, whereas the light levels employed in night driving are usually considered to be in the mesopic (intermediate light levels) range, for older observers, the same levels might be effectively scotopic (low light levels). A shift to scotopic vision is likely to have profound functional consequences since scotopic vision suffers from lower spatial and temporal resolution than photopic vision.

Since many age-related changes lower retinal illuminance, it ought to be helpful if road illuminance levels were increased at night. One should choose, however, light sources and luminaires that minimize glare since older observers seem to experience more difficulty with glare. Flannagan's work (1989), mentioned above, suggests that lights that minimize rod excitation relative to cone excitation would minimize their contribution to discomfort glare. How such lights would influence driving tasks is not known. If the spectral efficiency of driving tasks matched that of the rod system of vision, there may be no advantage to redesigning the spectral content of the illumination. On the other hand, if, for example, visibility while driving depended on cone excitation, then minimizing rod excitation and maximizing cone excitation would be expected to be optimal. Such constraints might also be of value in choosing the intensity and spectral composition of headlights, a major source of glare from oncoming traffic.

Changes in the field of view with age might be ameliorated by modifying the design of cars. Potentially optimal placement of mirrors or use of curved mirrors (to give a wider field of view) could compensate for some loss of size of visual field experienced by older observers. The inclusion of measures of the extent of the visual field in a profile of visual function would provide the quantitative information for modeling and making recommendations for such improvements in motor vehicle design.

Attentional and temporal losses of visual function and adaptation might be of less concern for vehicles traveling at lower speeds, and one can accordingly recommend lower speed limits to address such deficiencies of the older driver. The practicality of such a recommendation aside, it could be recommended to older drivers that they choose routes with lower speed limits. To the extent that attentional deficits are due to other factors, such as increased sensitivity to discomfort glare, recommendations should be directed to correcting these factors, instead.

One might also consider whether the factors discussed above would lend themselves to design of a device that older drivers might use to enhance the visual information available to them while driving at night. Certainly no device is available (at least not in the non-military sector and at an affordable price) which would combine the appropriate field of view and appropriate image enhancing properties that also would be able to render color coded traffic signals discriminable and road signs legible. Nevertheless, the type of profile of visual function that we recommend for assessing older persons vision in relation to driving performance might provide the minimum specifications that such a device must meet.

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