A Review of Visual Functions and Their Impact on Driving Behavior

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It has often been reported that vision is an important component of operating a motor vehicle. However, which properties of vision are most important for safe and effective driving? In this presentation I will provide a summary of what is currently known about the significance of specific visual performance factors on driving tasks.

Visual Acuity – Visual acuity is the most common visual function that is tested for driver’s license applicants. Fine detail, such as traffic signs, road hazards highway markings and related information requires a best-corrected visual acuity of 20/40 or better (which is the requirement for many states). However, each state in the USA has variations (both eyes, the better eye, use of optical devices such as a bioptic telescope, etc). Many investigations have demonstrated that poor visual acuity is a risk factor for safe driving.

Contrast Sensitivity – Several studies have indicated that contrast sensitivity is an important visual feature for safe driving, particularly for detection and identification of low contrast objects under impoverished visual conditions (rain, snow, fog, nighttime, etc.). Contrast sensitivity has become a topic of greater interest in driving studies recently, and there are now several rapid test procedures that are available for population based testing.

Glare disability – Investigating the influence of glare on driving is a complicated task. There is glare disability and glare recovery. Some aspects of glare are related to road conditions and weather and some are due to lighting conditions and other oncoming vehicles. (Question: are the new high intensity headlights a good thing [for drivers] or a bad thing [a hazard for oncoming vehicles because of glare]?). Glare can certainly disrupt safe driving abilities, and changes in a driver’s lens with increasing age produce greater problems with glare with older drivers. However, there is currently no consensus among experts as to what test procedure
is appropriate for assessing this property in drivers, and no standardized test is currently available for performing this test.

**Visual Fields** – Early investigations found no relationship between visual field extent and driving performance (evaluated by accident and conviction records). However, these studies were performed with visual field test procedures that had not been validated and were known to have poor performance characteristics (low sensitivity and specificity and high false positive and false negative rates). A large population-based study of licensed drivers applying for renewal (using a clinically validated visual field screening procedure) found that a small percentage of these drivers had visual field abnormalities, that the prevalence was greater in older populations, and that there was no difference in accident and conviction records in drivers with normal visual function and those with visual field loss in only one eye. However, the accident and conviction rate was more than double this amount for drivers with visual field loss in both eyes. More recent studies have confirmed that visual field reductions are a risk factor for safe driving. Initial investigations reported that the visual field of the better eye was the primary determinant and that moderate to advanced loss was associated with driving problems. However, the latest investigations have found that even mild visual field losses are associated with driving problems, even if it is only in one eye.

**Stereoacuity** - Although stereopsis has been examined as a potential visual function that may affect driving, there is no compelling evidence that it plays an important role. There are many individuals without stereopsis (amblyopia or “lazy eye” is present in more than 2% of the population, and these drivers are not worse than those with normal visual function). Stereopsis is a rather slow visual response that has its primary benefits for near work (less than 4 feet), so it would not be effective for high-speed activities requiring quick responses to distant objects. It should also be kept in mind that stereoacuity is not equivalent to depth perception – it is only one of many visual cues for determining depth.

**Color Vision** – The literature indicates that color vision is important for being able to properly detect and recognize traffic signals, and the ability to recognize illuminated taillights from a distance at night. Approximately 8% of the male population has some form of congenital color vision deficiency, and only a small percentage of women have this condition (less than 0.1%). However, many eye diseases produce color vision problems. Devices that are reported to “correct” color vision loss have not been shown to be effective. However, driving
performance and related studies have demonstrated that it is only those individuals with moderate to severe color vision loss that have an impairment in their driving abilities (less than 2% of the population). The automotive industry has altered their color designations for tail lights (less red and more orange) to improve their design for individuals with red (protanope) color vision problems.

**Vernier Acuity** – Vernier acuity, or the ability to align the position of adjacent objects, is one of the most sensitive and precise visual functions. It is useful for tasks for measurement (using a ruler or other measuring device) or for obtaining accurate readings from a dial or other indicator. However, it does not appear to be important for driving, and there are no known studies that have demonstrated that this is an important component of the driving task.

**Dark Adaptation, Night Vision** – Dr. Fred Owens will present a summary of the role of vision for night driving and some of the complications that it creates. There are more accidents that occur at night, visibility is less at night than in the daytime, many drivers do not adjust their speed of driving for night conditions, and there is tremendous individual variability in night vision among drivers. Moreover, it is a challenge to design a test that could be rapidly administered to prospective drivers to test for night vision. Some eye diseases specifically reduce the ability to see at night, or result in greatly prolonged times to adapt from a light environment to darkness.

**Flicker and Motion (Temporal visual processing)** – Although visual changes produced by flicker and motion are important factors related to driving (self-motion and motion of other objects), there is little that is currently known about these factors related to driving safety. Exceptions to this include the study of biological motion, time to collision, judging the relative speed of other vehicles, and spatial orientation related to motion influences. More work is needed in this area.

**Dynamic Visual Acuity** – Because drivers are mostly moving when operating a motor vehicle and many outside objects are also in motion, the ability to identify fine detail under these conditions (dynamic visual acuity) is important. However, this is also a topic that has not received as much attention as other visual functions, partly because it is again a complicated issue with many variations, making it difficult to achieve a standardized, quantifiable approach.
Other Visual Functions – There are additional issues that are important for driving (visual search, “pop-out” phenomena, eye-hand coordination, multitasking, visual-auditory compatibility, etc.) that require additional exploration, as well as issues related to the use of one eye (monocular) or two (binocular), visual capabilities of individuals with differing levels of function between the two eyes, etc.

Summary

Although there are many other factors related to the task of driving (e.g., decision making, cognition, attention, multitasking, etc.) there are many aspects of vision that are important for safe and effective driving abilities. Visual acuity, contrast sensitivity, glare, visual fields, color vision, night vision, motion perception and dynamic visual acuity are all important for being able to successfully perform the driving task.

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Vision and Driving: The United States

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Abstract: Minimal visual standards for obtaining driving licensure in the United States principally use 2 measures: visual acuity and visual field. Although research studies have established a correlation between performance on these measures and safe driving, the correlations are weak and mostly retrospective. These measures remain in place in screening centers largely because they (especially visual acuity) are practical. A newer test of visual attention, called the useful field of view, may be more predictive of safe driving than the traditional measures, but it has not been widely applied in licensing bureaus.

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Driving is a complex multifaceted activity in which visual performance is a critical feature. Research projects utilizing more detailed and thorough approaches have produced new insights into the role of vision during the driving task and the use of technological advances to improve the driving experience for individuals with visual impairments. We review the research directed toward vision and driving with an emphasis on visual acuity, contrast sensitivity, color vision, and visual fields. Although attention, visual search, decision making, and other cognitive functions are also clearly involved with driving performance, these components are reviewed elsewhere (1,2).

While it is a fundamental responsibility of licensing bodies to identify drivers with impairments that place them at an unacceptable risk for crashes, the decisions they make about licensing must be legally and morally defensible and must not unfairly restrict the mobility of disabled or aging drivers. It is important, therefore, that the licensing criteria for visual fitness be based on scientific evidence establishing their effectiveness and predictive value for unsafe driving performance, particularly for older drivers (1). Surprisingly, there is no rigorous evidence to support the hypothesis that vision screening leads to a reduction in motor vehicle crashes involving older drivers or that a specific cutoff value for vision performance improves safety (2). This seeming conundrum is probably resolved by acknowledging that driving safety depends less on what the driver sees than on how quickly, adequately, and accurately he responds to what is seen (2).

Many review articles have evaluated the relationships among driving performance, vision, decision-making behavior, risk-benefit analysis, and related factors (3–9); but few have incorporated these issues within the context of visual performance, driving demands, and visual and cognitive impairment questions that arise during the course of an eye examination. Following a brief review of visual factors affecting driving, we discuss the issues directly pertinent to eye care providers.

HISTORICAL PERSPECTIVE

The foundations of research on vision and driving can be traced back to the Transactions of the Section on Ophthalmology of the American Medical Association’s Seventy Sixth Annual Session in Atlantic City, New Jersey, on May 25–29, 1925 (10). The Committee on Visual Standards for Drivers of Motor Vehicles recommended that driver license applicants demonstrate a visual acuity of at least 20/50 in one eye and at least 20/100 in the fellow eye, with or without glasses. Applicants with visual acuity worse than 20/100 in the poorer eye could be qualified to drive a motor vehicle by a special board under certain circumstances. Diplopia would disqualify an applicant from obtaining a license to operate a motor vehicle.

The next formal report concerning vision standards for driving appeared on October 16, 1937 in the Organization Section of the Journal of the American Medical Association (Vision Standards for Licensure to Operate a Motor Vehicle) (11), which indicated that the 1925 recommendations for a board of physical licensure in each county had proved to be impracticable and had therefore not been embodied into law or practice. The report also indicated that standards of good vision necessary for efficient operation of a motor
vehicle could not be arbitrarily fixed because the problem of safety also depended on factors such as the driver’s natural aptitude, experience, and general mental and physical fitness. The lack of good vision might be compensated for by a high degree of efficiency in aptitude, experience, and mental and physical fitness. The report modified the vision standard for driving licensure to 20/40 or better in one eye (with or without glasses) and 20/100 or better in the fellow eye (with or without glasses). It recommended a horizontal extent of the visual field of at least 45° to both sides of the point of fixation; a binocular single vision; and the ability to distinguish red, green, and yellow. A limited driving license could be obtained with a visual acuity of at least 20/65 in the better eye, a field of vision extending at least 125° horizontally in one eye, and the absence of diplopia. Personal qualities that could compensate for minor defects of vision would have to be highly rated in those to whom a limited license was to be issued.

The 1937 report was followed by investigations performed by Burg (12–15) in landmark studies published in the 1960s. These studies evaluated a large population of California drivers on an extensive battery of vision, reaction time, and decision-making tests. This work served as a basis for establishing vision requirements for a driving license, although many questions arose concerning the individuals selected for inclusion in the study, the methodology used in some of the test procedures, and the analysis procedures used in evaluation of the data. Burg’s work (12–15) was a retrospective study of the association of vision and cognitive properties with driving accidents and convictions; no validation or prospective evaluations were performed. Subsequent studies of vision and driving have explored the influence of visual impairment on driving, the use of devices to accommodate disabilities, and cognitive and decision-making aspects of driving (1,2,7,16–93). Using driving simulators, population-based studies, closed road tracks, and retrospective reviews of driving accidents and convictions, they have provided more sophisticated information on visual performance and driving behavior, as described in a later section of this article. The factors most often considered are visual acuity, contrast sensitivity, visual fields, and color vision.

Despite much research on these topics, there remain significant differences in vision requirements for driving licensure throughout the world. In fact, each of the 50 states in the United States has its own requirements.

**VISUAL FUNCTIONS AND OTHER FACTORS RELATED TO DRIVING**

Most studies indicate that visual acuity, contrast sensitivity, visual fields, and color vision have the strongest relationship to driving performance (12–43). We will provide a summary of results from these investigations, and direct the interested reader to the more comprehensive reviews (6–11). In the past, most research was directed at establishing the relationship between vision and driving among individuals with normal vision. Only recently, there have been efforts toward evaluating the driving abilities of individuals with vision impairments (1,44–55).

**Visual Acuity**

Visual acuity is the most universal vision requirement for obtaining a driving license. Tests of visual acuity can be administered rapidly with a standardized test procedure by personnel with minimal visual testing skills. It is acknowledged as critical for interpreting traffic signs and detecting road hazards. In the United States, most jurisdictions require an unaided or best-corrected visual acuity of 20/40 in the better eye (7). Most of the signage and other roadside information have been designed to be read by individuals with 20/40 or better visual acuity who are operating a motor vehicle at or below the speed limit.

A number of studies have evaluated the consequences of driving with reduced visual acuity produced by cataract or other ocular and neurologic diseases or by artificially degrading vision by means of lenses or translucent devices in persons with normal visual acuity (46,49,50,53–55). These studies have mostly been performed retrospectively by reviewing visual acuity status and traffic accidents and convictions in the general population, the elderly, the young, and those with physical or mental impairments. Prospective studies have measured driving performance on a closed road track or in a driving simulator (1,46–55). Reductions in visual acuity produce impairments in certain aspects of driving related to specific driving tasks, such as recognition of road signs, road hazards, highway markings, and objects entering the roadway (29).

**Contrast Sensitivity**

Evans and Ginsburg (17) and Ginsburg (18) have reported that contrast sensitivity is an important factor in being able to distinguish the legibility of highway signs and other properties of functional vision that are associated with driving, such as recognition of road signs, hazards, traffic signals, and indicator markers. In bad weather and in night driving, highway signs, road hazards, animals, and pedestrians have low contrast. For this reason, many studies have incorporated the detection and discrimination of low-contrast objects as part of their driving research (44).

**Night Vision**

At night, highways and intersections are not as well delineated. The span of usable vision is smaller due to nonuniform lighting of the highway and the short distance for which the headlights of a vehicle can illuminate the roadway. Paradoxically, drivers tend to maintain nighttime driving speeds at nearly the same level as daytime driving speeds (56–60). Accidents are more than twice as frequent at night (56–60). Regrettably, there has been very little useful research on night time driving.
Visual Fields and Attention

Early investigations did not find a meaningful relationship between peripheral vision and accident and conviction reports (13). Among the many factors responsible for this lack of a relationship are the low prevalence of visual field loss in the general population; self-restriction of driving by individuals with ocular or neurologic disorders; the use of peripheral vision test equipment with high false-positive and false-negative rates; and the lack of reproducibility, confirmation, and validation of test findings (19).

But with a visual field instrument of known performance characteristics, a study (19) finally found that drivers with significant visual field loss in both eyes had more than twice as many accidents and convictions as drivers with normal visual fields or loss in only one eye. Subsequently, many studies reported a relationship between visual field loss and driving performance (20–31). When the binocular visual field was reduced to 50°–60° in diameter, impairments in driving performance were noted (19,20,22). However, more recent investigations have found that even relatively minor amounts of visual field loss are related to deficits in driving performance (22,23).

The devices that perform clinical visual field testing rely on the subject’s ability to detect a single stimulus superimposed on a uniform background. Because driving is much more complex, investigators (32–37) have developed a test known as the useful field of view (UFOV), which combines peripheral target detection with measurements of reaction time, the ability to perform multiple tasks (including simultaneous central and peripheral target recognition), and the ability to localize targets and distinguish one from another (see Anticipated Future Developments). The intent of the UFOV test is to provide a more powerful surrogate of the visual and cognitive tasks encountered during driving. Studies (32–37) have verified that this test is useful in identifying task performance difficulties associated with driving impairments.

Color Vision

The role of color vision in safe driving is complex because deficient color vision can be congenital or acquired, stable or progressive, partial or complete, and affect primarily red (protan), green (deutan), blue (tritan), or all color sensitive visual mechanisms. Moreover, color is not the only visual attribute used to distinguish a critical visual target. Individuals with red (protan) deficiencies have greater difficulty seeing red traffic signals and automobile tail lights at night, thereby producing a higher risk of traffic accidents (39–41). Individuals with protan (red) and deutan (green) deficits have greater difficulty recognizing traffic signal colors and the conspicuity of signs and signals (39,41–43). Many sunglass manufacturers do not adhere to the recommended specifications for tint colorations and produce spectacles that create significant difficulties for color-deficient observers (38).

Although color vision performance is not a component of the standard for obtaining a standard driving license in the United States, it is a component for obtaining a commercial vehicle driving license. To obtain a US commercial driving license, the driver must be able to distinguish traffic control signals and devices showing red, green, and amber colors. Some European countries use it as a component for obtaining a standard driving license.

Other Factors

Even if visual modalities are intact, their integration with auditory, memory, and other sensory information can be an especially difficult task for youthful, elderly, or neurologically impaired individuals. This lack of integration may lead to an increase in vehicular accidents (61–64). For example, studies have shown that cellular telephone use during driving disrupts sensory tasks and driving performance (61–64).

The effect of instruction, rehabilitation, and the use of assistive devices on driving performance has been controversial (11,24,25,30,48–50,54,55,58,61–64,70,71,77,83,92). For example, the use of bioptic telescopes by drivers who are visually impaired has been advocated by some vision specialists but considered hazardous by others (65–67). Among those who favor them, the assumption is that these devices will be used according to the instructions provided by the manufacturer and the eye care specialist prescribing them. Although there is evidence that drivers use them mostly to spot signs (65–67), they will experience inattention blindness as they switch their fixation from the carrier lens to the bioptic. A talking global position system might be a safer option for older drivers with visual impairments. Adaptive cruise control, lane alert warnings, and self-parking cars may also be a boon to drivers with visual impairments, but studies are yet to be forthcoming on these issues.

Aging

Driving accidents and convictions are higher in youths and in the elderly (2,68–77), but there are large individual differences. No consistent factors, such as cognitive decision making, attention, driving experience, or training programs, have been identified.

Stereopsis

Investigations of stereopsis and driving performance (78–80) have failed to disclose any important impact of reduced function.

TRADITIONAL VISION TESTING

Visual Acuity

Visual acuity has traditionally been evaluated by reading a series of progressively smaller letters or symbols on a chart. For the most part, this procedure has been shown to be effective in providing a quick, accurate, and easily
administered test that is relevant to the driving task. The methodology for visual acuity assessment has been standardized, and it is unlikely that meaningful improvements to the procedure will be achieved through more extensive research. This procedure therefore appears to be adequate for vision screening for a driving license.

Contrast Sensitivity
Contrast sensitivity is measured in many different ways with no consensus as to which method is most appropriate for driving. At the present time, contrast sensitivity is regarded as an important visual factor for driving, but the use of a specific screening procedure has not yet been achieved. Moreover, a determination of the amount and quality of information that it can provide beyond visual acuity needs further investigation.

Visual Fields
Visual field testing is time consuming. Rapid screening techniques such as the Humphrey matrix have been able to generate a screening procedure that takes 20–30 seconds per eye in those without defects and 60 seconds per eye in those with defects. However, this procedure only evaluates the central 30° radius of the visual field, thereby limiting its utility for evaluation of the full visual field. There are a number of other rapid screening techniques, but they have not been subjected to a rigorous investigation in this setting.

CURRENT ISSUES IN VISION AND DRIVING
As of 2004, all drivers licensed in Florida who are 80 years and older are required to meet a minimum visual acuity requirement to renew their driver licenses. They are required to pass a letter acuity test of 20/40 or better at the time of renewal or provide a certificate from a licensed allopathic physician, osteopathic physician, or optometrist demonstrating that they have passed a vision test within the past year. When comparing prelaw and postlaw periods, the all-cause fatality rate, adjusted for age, race, and sex, among all aged drivers increased by 6% but decreased by 17% among drivers aged 80 years and older (88). Prior research done by Shipp and others (89–93) had suggested that states with mandated visual acuity tests have lower motor vehicle collision fatality rates among older individuals. Grabowski et al (88) found that in-person license renewal was related to a significantly lower fatality rate among the most elderly drivers. More stringent state licensure policies related to vision or road tests and more frequent license renewal cycles were not independently associated with additional benefits. After controlling for middle-aged daytime driver deaths, the only policy related to significantly lower driving fatality rates was the requirement for in-person license renewal. License renewal included a visual acuity test or a referral to a medical practitioner for further medical screening in some states.

PHYSICIAN REPORTING OF VISUALLY IMPAIRED DRIVERS
Physicians working in jurisdictions where reporting a patient who is at high risk for a motor vehicle accident is not mandatory still have a moral and ethical obligation to report in order to preserve patient and public safety (83,84). The Duty to Warn is a legal rationale intended to provide a means of protecting the patient from an unreasonable risk of harm. Failure to warn patients of conditions that create a risk of injury will be upheld as a cause of action against eye care providers when it can be shown that the failure to warn is the proximate cause of an injury. Patients may argue that they had insufficient warning of their impairment, and because of their impairment, their operation of a motor vehicle or other machinery resulted in an injury. Thus, patients whose vision no longer legally qualifies them to operate a motor vehicle should be warned not to drive and a notation to this effect should be entered into the patient’s record (86,87).

In 1999, the American Medical Association (AMA) House of Delegates approved a recommendation that calls on doctors to breach patient confidentiality for the good of both the patient and the society. The AMA stated that it is desirable and ethical for physicians to notify the Department of Motor Vehicles or an equivalent agency if an impaired patient fails to restrict driving appropriately (87).

Mandatory reporting concerns include the question of relative benefit, and different states have varying legal opinions about mandatory reporting. If mandatory reporting detours someone from confiding or getting necessary care, because he or she fears losing driving privileges, then reporting statutes could backfire, creating more hazardous drivers. There has been a long-standing controversy as to whether driving is a privilege or a right. Driving is subject to reasonable regulations in the interest of public safety and welfare. The suspension or revocation of an operator’s license is not intended as a punishment to the driver but is designed solely for the protection of the public. The AMA Physician’s Plan for Older Drivers’ Safety (2003) (3) states that every physician (we would include optometrists) should assess risk factors for older patients who drive (4). For those individuals at risk of unsafe driving, the practitioner should recommend a formal assessment of vision, cognition, and motor skills and also refer for a road test when appropriate.

ANTICIPATED FUTURE DEVELOPMENTS
The UFOV is a specialized visual field test that has been developed for evaluation of driving and peripheral vision (32–37). It differs from other tests of peripheral visual function by incorporating measures of reaction time, stimulus localization, simultaneous central and peripheral visual tasks (multitasking), target identification, and complex decision making. The UFOV provides a means of
evaluating the driver’s ability to perform multiple tasks accurately and quickly to simulate the driving task. Studies performed with this procedure indicate that it correlates with driving performance (32–37). This procedure is now being used by a greater number of health care professionals who are concerned with driving and other mobility tasks; but careful research has been limited to only a few laboratories, and there is a strong need for additional work. Currently, the UFOV test is considered too costly and time consuming to be used for screening on a widespread population basis.

The rapid increase in vision and driving research has generated a number of questions as to the impact on safe driving of multisensory integration of information and assimilation of sensory, cognitive, decision making, and attentional properties. Also, important are validation of laboratory studies when applied to population implementation and public policy, rehabilitation and training regimens to compensate for disabilities, evidence-based guidelines, and legal liabilities. No single group is capable of addressing all relevant issues, and a consolidation of this information through meta-analysis or overviews can sometimes be difficult. The Cochrane Report (69) provides a comprehensive objective assessment of current findings and directed efforts primarily toward identifying the importance of vision screening for prediction of traffic accidents and fatalities. The authors concluded that 1) no studies to date met their inclusion criteria (randomized controlled trial before and after studies comparing vision screening to nonscreening of drivers aged 55 and older), 2) there is insufficient evidence to assess the effect of vision screening on elderly drivers, and 3) valid and reliable vision screening tools need to be developed to properly evaluate this topic in a more thorough fashion.

CONCLUSIONS

Our knowledge concerning the relationship between visual performance and driving has increased in recent years. Highly competent laboratories and research teams have conducted a number of research studies and evaluations. However, policy decisions, accuracy and efficiency of testing large populations, interpretation of test results, legal ramifications, and risk assessment currently determine the requirements for a driving license. A procedure that is highly effective in a research project has not yet been found applicable for general use in screening drivers.

The United Kingdom and other countries have adopted a uniform vision standard for driving licensure. The United States has not, with the result that there are 50 standards of visual performance needed to obtain a driving license. There are also meaningful variations in the licensing requirements among different countries in Europe, Asia, and South America. We propose that the United States adopt a national vision standard for driving personal vehicles similar to that of the United Kingdom. Such a standard would place the responsibility on drivers rather than eye care providers to know if they are visually qualified to drive, and enforcement would be conducted by departments of motor vehicles and law enforcement agencies. This approach would also remove concerns about mandatory reporting of impaired drivers by health care professionals. It would be an application of the principle used in qualifying for a commercial driving license.

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