Effects of visual deficits on ability to drive in traumatically brain-injured population

This article reviews the importance and overall role that vision plays in the driving task. Visual system deficits identified in the literature that are most commonly associated with traumatic brain injury are discussed in relation to their possible effect on driving performance. Emphasis is placed on the driver evaluator's responsibility for accurate vision evaluation and interpretation of test results. Behaviors that can be taught to assist patients to compensate for deficits along with clinical observations and experience in their use are discussed.

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IT IS ESTIMATED that approximately 90% of the information processed while driving is taken in through the visual system.[1] Auditory, kinesthetic, and vestibular senses account for the remaining percentage. To state that the visual system is the most important sensory system for driving is not debatable. Profoundly deaf individuals are not restricted from operating a motor vehicle anywhere in the United States and are generally considered safe drivers. In fact, the usual recommendation for compensatory techniques to the hearing-impaired population is to "increase their visual vigilance."[2(p315)] By contrast, every state has established baseline visual requirements for the issuing of a valid driver's license. While *it has long been recognized that these are not* the only visual skills necessary for successful maneuvering of a motor vehicle,[3,4] each state includes in its licensing standards minimum requirements for visual acuity and visual fields. Examinations of color detection and depth perception (stereopsis) are routinely performed in many states, but a driver's license is not denied to individuals lacking these skills.

NOT FIELDS

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The driver evaluator has a twofold task when confronted with the responsibility of evaluating the ability of a traumatically brain-injured (TBI) patient to return to driving. The first task is to determine if the patient meets legal visual requirements. The second and more difficult task is to determine what additional visual problems exist and what effect, if any, they may have on driving performance. Fig 1 represents schematically the driving task in its simplest form as a series of events beginning with visual input and ending with the execution of a motor response.[4] While the chain can and often does break down at any of its links and is influenced by such things as previous driving experience, the process must begin with adequate visual input.[4,5]

The information processing link is dependent on the adequate acquisition of visual information; only then can accurate processing take place. Moreover, the speed at which the visual information must be acquired is regulated by the posted speed limit and often by less-than-desirable weather conditions. How quickly and accurately the visual input is processed will have bearing on the decision made by the driver and the subsequent motor response.

The incidence of visual system disturbance is more prevalent than one would suspect in this population. Elisevich et al[6] report in a retrospective study that visual disturbances range from moderately reduced visual acuity to a full 63% with bilateral or monocular blindness. The optic nerve was cited as the most frequent site of injury, often accompanied by injuries to other parts of the visual system. Elisevich et al also conclude that it may not be the initial trauma itself that results in damage to the visual system, but rather brain swelling as a consequence of increased intracranial pressure.[6] The resultant visual disturbances can be quite varied. There also does not appear to be a correlation between estimates of severity of injury established during the acute phase and incidence of visual problems. Individuals who appear to have made a good physical recovery may have undetected visual disturbances, particularly visual field deficits.[6–8]

The driver evaluator is usually more concerned with outcome (actual performance) than with establishing site of injury. The driver evaluator must determine if a visual problem with which a patient presents will interfere with ability to drive.

This article addresses visual deficits commonly associated with damage to the primary visual system. It does not include the "seeing but not recognizing phenomenon" described by Trobe and Bauer.[9] Rather, it deals with those visual deficits usually detected through routine clinical testing and supported in the literature as the most common.[6–8]

VISUAL ACUITY

Visual acuity (VA) is defined as a measurement of the eye's ability to distinguish object details and shapes.[10] For driving, acuity for distance (far point) rather than for reading (near point) is the main concern.

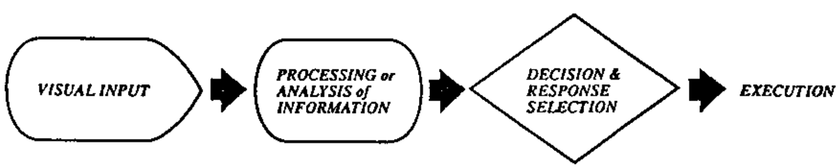

Fig 1. Schematic representation of the driving task. Adapted from Panek PE, Barrett GV, Sterns HL, et al: A review of age changes in perceptual information processing ability with regard to driving. *Exp Aging Res* 1977;3:387–449. Copyright Beech Hill Enterprises, Inc, 1977.

Although the American Association of Motor Vehicle Administrators[11] has recommended 20/40 as a national standard, VA requirements vary from state to state, with 20/70 to 20/80 being acceptable in some states with or without restrictions. The restrictions usually take the form of speed limitations or daytime-only driving.

There has been a long standing debate on the effectiveness of static visual acuity testing as a requirement for driver licensing. Studies relating static VA levels to accident records have provided conflicting results. It has, however, long been recognized that among the vision variables studied, dynamic VA shows the strongest and most consistent relationship with driving records.[12,13] Dynamic acuity introduces the element of movement into the test. To date, a low-cost test easily administered in a testing facility by persons with a nonmedical background has not been developed. In all probability, both tests of acuity are relevant.

Highway traffic signs usually feature 5-in to 6-in letters designed for viewing by a person with 20/40 acuity traveling at the then posted speed limit of 60 mph. This was determined to be the size necessary to allow adequate time to read the sign, process the information, and take whatever corrective action (such as exiting a highway) is necessary. For a driver with 20/20 vision, this allows 4 seconds at 60 mph (slightly more at 55 mph). With 20/40 acuity, the same driver has just 2 seconds to perform the same task.[12,14] Therefore, a person with better acuity will see a situation sooner and have more time to respond. However, VA is a complex function and is interdependent with contrast levels between objects and their background, level of illumination available, and exposure time.[1,4,14,15] A condition internal or external to the eye that alters any one of these elements in turn affects VA. It is estimated that this same driver at night has in the realm of 20/100 acuity due to the reduced amount of light available and the decrease in contrast.

Patients who present with reduced levels of acuity may drive in a short-sighted manner. They fail to see far enough ahead to plan their actions appropriately, frequently waiting until the last minute to take a corrective action. Good acuity allows for early recognition of small obstacles such as children, motorcycles, animals, and even potholes.[12] Wylie[1] claims that good VA is essential for a driver to read the faces of other drivers (make eye contact), to see if the wheels of a vehicle are turned in a particular direction, or to see where the other driver is looking.

The most common compensation technique for decreased acuity is to slow down to increase the time available to read signs. This may or may not prove practical, depending on the traffic situation at the time. TBI patients also need training to predict from which direction trouble is likely to come. This predictive skill develops as a driver gains more experience.[16] It is not surprising then that statistics indicate 16- to 20-year-olds are involved in five times as many accidents as those aged 45 to 50 years.

Loss of vision in one eye produces a decrease in the visual field to the affected side and a loss of depth perception. Kite and King[17] found that drivers with a one-sided visual field deficit were associated with a sevenfold increase in traffic accidents. This has serious implications for the driver evaluator and instructor. This functional deficit alone will not automatically prevent someone from driving again. Currently, most states permit one-eyed individuals to operate a motor vehicle with only one restriction: that an outside mirror be placed on the affected side. Many states do place an additional limit on driving of such individuals to daytime driving only, and some have speed limit restrictions. However, these are largely nonenforceable laws, since external vehicle identification is not part of that restriction.

Frequent rapid head turns is the most commonly recommended compensatory technique.[1,18] However, it is important to remember that the blind area in any visual field constriction is always present. When looking to the affected side (such as when merging into traffic), drivers must turn their heads sufficiently to view traffic approaching from the rear with the intact field. The monocular driver is also unable to compensate for the normally occurring blind spot in the good eye.[17]

In the case of left peripheral field loss, when gaze is directed forward, the sideview mirror will fall within the deficit area. Turning the head to the affected side in combination with moving the eyes in that direction is essential. Relocation of the sideview mirror well forward to the front fender is recommended, since it places the mirror where it may be viewed with only eye movement.

Stereoscopic vision is defined as the "visual blending of two similar but not identical images into one, with resulting visual perception of solidity and depth."[10(p198)] Loss of vision in one eye results in a loss of true stereoscopic vision. Opinions vary as to the need for driving restrictions for the monocular driver and the importance of this visual function to the driving task.

Depth perception is the ability to determine relative distance of one object to another. It plays a significant role in judging space gaps such as following and stopping distances and positions of cars on the road in relation to one's own vehicle.[1,2] Depth perception therefore assists in passing maneuvers, in judging the approaching speed of a vehicle, and in determining if the vehicle ahead is slowing down. The monocular driver would appear to be at a tremendous disadvantage in these situations, which may account for the fact that the majority of accidents for this population occur at intersections.

It is normally assumed that one-eyed drivers can rely on environmental cues such as shadows, contrast, and movement to compensate for a lack of depth perception,[1,12] all of which are absent at night or with poor illumination. During daytime driving, it is possible to train individuals to calculate following and stopping distances to reduce their risk in these circumstances.

Peripheral vision has been identified as one of the most important ways information about the environment is received while driving. The American Medical Association's Committee on Medical Aspects of Automobile Safety[18] has recommended that 140° measured along the horizontal plane be accepted as the national standard. The basis for this recommendation is well supported in the literature. Studies have shown that drivers with fields of less than 140° are associated with an increase in intersection accidents, usually from the affected side.[15,19,20] There is virtually no evidence to support lowering this recommendation.[21] Nevertheless, the peripheral field requirements do vary from state to state.

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One of the primary functions of peripheral vision is to operate as a sensing system. A driver looking straight ahead is simultaneously aware of events taking place to the left and right through peripheral vision. It is not, however, possible to identify an object through peripheral vision. Ability to detect details decreases considerably from the fovea to the periphery.[1,22,23] However, peripheral vision is sensitive to both movement and light.[17] In order to actually identify an object that has captured the driver's attention, it is necessary to fixate the object with the fovea, which is usually accomplished through a saccadic movement and frequently accompanied by head movement in the same direction.[24,25] Without the ability to receive a stimulus from the periphery, this fixation reflex would result in random and inefficient eye movements.[24]

In addition to functioning as a sensing system, peripheral vision also plays an important role in monitoring other vehicles, the speed of one's own vehicle, and lane positioning.[12] The driver is able, while maintaining fixation on the traffic ahead, to monitor the road edge and lane markings through peripheral vision.[24]

Peripheral fields then provide the driver with general overall information about the driving environment and relative position of objects within the environment. It is important to understand that while visual field (VF) deficits are usually presented schematically as symmetrical, sharp-edged delineations, they can be extremely variable in shape and form. Elisevich et al[6] provide an overall review of this variability.

It is imperative that the driver evaluator have an understanding of the representation of the visual fields anatomically in order to properly interpret peripheral field testing results and to understand what the patient sees.[7] To provide a better understanding of how deficits in peripheral vision may affect ability to drive, several types of deficits will be discussed briefly along with potential associated problems that may occur. It must be remembered, however, that depending on the site and extent of injury, more than one visual deficit may exist.

The term *homonymous* means "the same side." Hemianopsia indicates that half of the visual field has been affected. A left homonymous hemianopsia indicates that the left half of each eye has been affected, resulting in the patient being blind to one half of the entire visual field—a common consequence of TBI. Most often there has been macula sparing so the patient may still have intact visual acuity.[8] This deficit translates into an inability to receive peripheral stimuli from the affected side and, depending on the extent of the loss, usually legally precludes return to driving. As with all suspected visual field deficits, it is appropriate and strongly recommended that the patient be referred to an eye care specialist for accurate charting of the actual amount of deficit to evaluate any improvement and to detect any small islands of vision still intact within the deficit area. These may allow the driver to remain in the legal-to-drive category, which does not automatically guarantee safe driving, but allows the evaluator to evaluate driving performance on the road.

The discussion of possible ways to compensate for VF deficits while driving has centered on compensatory head movements and placement of mirrors on the outside of the vehicle.[26] A compensatory technique, however, does not change the legal visual field requirement imposed by the state. Patients who present with left or right upper quadrant field deficits and those with bitemporal deficits may also be legally prevented from driving.

All drivers have had the experience of having their attention caught by something on the sidewalk. They direct their fovea (and attention) toward the object or event, then suddenly become aware that the vehicles in front of them have stopped moving. They respond immediately by redirecting their attention forward, hopefully in time to apply the brake. This awareness may be the result of stimulation (brake lights of cars in front) of peripheral fields, which are directed forward at the time. Compensatory head movements (rotating of head from side to side) frequently places the patient with peripheral vision deficits in the undesirable position of having the blind area oriented forward. Since it is estimated that the average driver can only perform three fixations a second, and since at 55 mph 77 ft/s of highway is traveled,[14,15] the time spent fixating remotely placed mirrors or rotating the head results in considerable time and distance not being monitored either with the fovea or through the intact portion of the peripheral field.

Lövsund and Heden[21] also report that results of attempts to train persons with VF deficits to use functional visual fields rather than static visual fields have been disappointing. They also did not find that one type of VF deficit was more responsive to training than others.

Nasal hemianopsias and lower quadrantanopsias appear to present the least amount of difficulty regarding return to driving. Patients with this type of VF loss are sometimes unaware of the existence of a deficit in their vision. Increasing the patient's awareness can be extremely effective in preventing a future accident.

The patient with a left lower quadrant deficit has slightly more difficulty returning to driving than one who presents with right lower quadrant deficits. Both have problems detecting vehicles passing on the affected side until the driver compartment of the other vehicle enters the intact portion of the visual field. The patient with a left lower quadrant deficit has the additional problem of not being able to check the sideview mirror without performing a saccade and head movement to bring it into view. Patients with sensory deficits on the left side may be unable to activate turn signals without first fixating on them. These persons seem to have greater difficulty adjusting to this type of field loss and frequently have lane positioning problems. Whether this is because the patient cannot view the lane dividing line to the affected side or the lack of sensation or a combination of the two is difficult to determine. A unilateral temporal hemianopsia constitutes the deficit easiest to compensate for with externally placed mirrors.

It is when working with patients with various types of VF deficits that the driver evaluator has the most difficulty distinguishing between a visual and a perceptual deficit. In both instances patients tend to drive toward the side of involvement and generally have difficulty with lane positioning.

Altitudinal hemianopsia (deficits above or below the horizontal meridian) is generally not a common clinical entity. In all probability superior altitudinal loss would result in sufficient deficits to render the patient inappropriate for return to driving. Inferior losses with macular sparing will present with difficulties similar to those discussed in quadrantanopsias.

Scotomas within a visual field are frequently not detectable by other than extensive visual field charting. If they occur in an area where there is visual overlap, they may not constitute a problem for driving. If not, the effect on driving must be evaluated on an individual basis once the extent of the loss is known.

In response to the need to provide uniform consistency in the administration of vision tests by motor vehicle personnel, testing facilities have begun using mechanico-optical vision screening systems to replace the standard Snellen wall chart. All systems that test peripheral fields require the patient to maintain fixation on a central fixation point.[23,27] Failure to do so will produce unreliable, inaccurate results. Care should be exercised in selecting a unit that ensures compliance with this requirement.

In addition to acuity testing, mechanico-optical screening systems also test color, depth perception, and visual fields. One of the primary advantages of such a unit is the availability of a constant level of illumination within the unit itself. In addition, the units are portable and self-contained and do not require excessive amounts of clinic space. Units of this type are now being used in many predriver assessment programs. Careful interpretation and understanding of screening results are essential to properly counsel patients.

The peripheral field perimeters used in some units present a stimulus to each half of each eye. That is, there is a stimulus for testing the temporal half of the left eye and the nasal half of the same eye. A patient who does not respond to either stimuli presented in this fashion probably is unsighted in one eye and does not have homonymous hemianopsia, which is indicated when the patient does not respond to the temporal stimulus on one eye and the nasal stimulus on the opposite eye.

When evaluating VA with a mechanico-optical vision screening system, each eye is tested individually and simultaneously. Frequently patients will respond to the VA test slide by reading half of the acuity chart. Occluding the good side and repeating the test may then elicit a response to the previously ignored images. Failure to elicit a response may indicate VA discrepancies between the eyes, and a higher level of magnification should be tried before assuming the patient has a neglect or lack of vision in that eye. Muscle imbalance may result in eye misalignment, causing the positioning of the tester to prevent a clear view of the information to one eye. The occurrence of this phenomenon has been noted only since the advent of the mechanico-optical tester. When using a standard wall chart, the information is presented to each eye individually but not simultaneously so that phorias, suppression, and so forth are not detected.

OCULAR MOTOR DEFICITS

Ocular mobility problems secondary to TBI do not occur as frequently as VF losses but are usually associated with more severe head injuries.[28,29] In individuals who have had surgery to correct ocular deviation, possible resultant eye mobility problems should be assessed.

The most common visual complaint presented by this population is double vision (DV), which frequently occurs only when gazing in a particular direction or with head rotation. It is important to note when DV occurs, since it will determine the extent of possible interference with driving.

Patching of one eye is a frequently employed method of compensation. The acuity level of each eye must be determined before patching the eye to ensure that sufficient vision is present in the remaining eye to drive safely. As with the monocular driver, this produces a VF loss to the occluded side, a depth perception deficit, and complete blindness in the normally occurring blind spot.

In longstanding DV problems, the patient may have learned to suppress one image and is no longer bothered by DV.[29] However, under conditions of fatigue or low illumination, the eyes have difficulty with fusion, and sudden onset of DV may occur.[15] It is appropriate to recommend daytime-only driving for these individuals. Turning the head rather than moving the eyes can compensate for DV on a particular gaze. This requires training, particularly for the inexperienced driver.

Since many TBI patients are young, lack of driving experience is a significant factor in the return to driving. Mourant and Gremson[1] have shown that novice drivers tend to respond to peripheral stimuli with eye movements followed by head movement. As drivers gain more experience, they perform predictive head movements; that is, they anticipate where trouble will come from and begin to turn the head in that direction before saccadic fixation takes place. This type of movement must be trained.

As with most visual disturbances, eye mobility problems vary in degree. In severe cases, there may be a sufficient difference between retinal images to prevent fusion.

Another possible deficit encountered in the TBI patient is anisocoria, which causes a difference in the amount of light falling on the retina and may result in stereoscopic errors for targets moving horizontally across the visual field.[15] Errors in entering traffic, particularly at intersections, may result.

Ptosis, which can result from oculomotor nerve involvement, can effectively occlude vision. It is usually seen in combination with displacement of the eye and dilated pupil. The patient may experience related problems such as retinal image disparity and stereoscopic errors for movement.

When screening for eye mobility, the driver evaluator should note if the patient is able to maintain fixation on a moving target. Saccades should be smooth with accurate movement of the eye from one point to another. Abnormal saccades greatly affect quick and accurate fixation on a target in the periphery and ability to return to the central fixation point—the traffic ahead. Since this skill is used constantly while driving to assess information both internal and external to the vehicle, deficits result in an inability to respond quickly to rapidly changing traffic situations. These problems are most likely to appear as the traffic patterns become more complex and the driver's visual workload increases.[22]

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Visual acuity, peripheral fields, and eye movements are all necessary to the driving task. Their roles in driving are interrelated and in the normally sighted individual function as a well-organized system. Injuries that affect any one of these functions in turn affect the others and the operation of the system as a whole. Low illumination exacerbates the effects of deficits.[30,31] With training in compensation techniques, it is often possible to return the patient to independent driving. However, patients should always be aware that any compensable visual deficit deteriorates when the driver is tired, ill, or under stress.

Statistics indicate that the majority of TBIs occur in young people involved in motor vehicle accidents.[6] This population also possesses the best premorbid visual skills but the least experience and the highest accident rate.[5] Visual deficits in this group in particular can have a devastating effect on driving ability. Interestingly, but not surprisingly, this population is the most anxious to return to driving following a TBI. Unfortunately, the driver evaluator has no way of knowing the level of the patient's driving skill prior to the onset of the current disability. The evaluator can only rely on what is observed at the time of the evaluation and make recommendations based on clinical knowledge and state licensing laws combined with an understanding of the role vision plays in driving and the driving task itself.

Numerous articles have been written and studies conducted that explore the relationship between visual perception skills and driving ability in the brain-injured population.[32–34] The relationship between visual disturbances and driving ability has not been as extensively explored. There is, however, an abundance of articles that generally address the issue of how vision is used in driving and what elements in the environment affect visual input.[1,3,13,17,29] Articles on the occurrence of visual deficits secondary to a TBI are now available.[6,7,26] While awaiting further research, the driver evaluator must attempt to synthesize available information to guide the TBI patient in the return to safe, independent operation of a motor vehicle.

This society is extremely mobile and is dependent on personally licensed vehicles to provide freedom of movement. Driving is an essential activity of daily living. For brain-injured individuals, the sooner they are able to regain this vital mode of independent travel, the sooner they can return to the economic and social mainstream of life.

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