Driving and Low Vision: Validity of Assessments for Predicting Performance of Drivers

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Abstract: The authors conducted a systematic review to examine whether vision-related assessments can predict the driving performance of individuals who have low vision. The results indicate that measures of visual field, contrast sensitivity, cognitive and attention-based tests, and driver screening tools have variable utility for predicting real-world driving performance.

Many individuals with low vision want to lead independent lives and carry out their day-to-day activities by continuing to drive their automobiles. The loss of driving privileges can result in an overall reduced quality of life by increasing isolation and limiting access to community resources. The issues surrounding visual impairment and driving are often controversial, partially because of the absence of a consensus and evidence on visual assessment and licensing regulations, and the use of low vision devices while driving (Peli & Peli, 2002). Driving is a complex and demanding activity, requiring the integration of many factors: the human; the vehicle; and environmental factors, such as road conditions and weather (Owsley & McGwin, 1999). Driver-related factors are comprised of visual performance measures, such as visual acuity, contrast sensitivity, and visual field, as well as age, experience, and risk assessment. The relationship between driving ability and various diagnostic eye conditions is somewhat specious, since it is more precisely the deficits in functional vision that are associated with these disorders that may be predictive. Knowing the classical, tested vision loss associated with each eye disease or condition helps to explain the observed impacts on driving performance and safety that have been reported for each presentation. With these issues in mind, the objective of this review was to synthesize the best evidence related to how well vision-related assessments predict the performance of drivers with low vision.

Driving performance assessments

The visual requirements for obtaining and keeping a driver's license are frequently

The research on which this article was based was supported, in part, by a grant from the E. A. Baker Foundation of the Canadian National Institute for the Blind (CNIB). The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of CNIB. The authors thank Shirra Cremer for her assistance with the research for this article.

irregular and variable. People are usually allowed to drive after they comply with a range of criteria that have been established by regulatory authorities within each driving jurisdiction. A common feature of these criteria is the inclusion of standards that require certain minimum levels of tested visual function. In general terms, regulators accept the notion that certain visual attributes are highly correlated with the safety and ability of drivers. Visual acuity and visual field are readily accessible clinical performance metrics that have been used to differentiate various levels of *visual function*, ranging from "normal" vision to "blindness." *Functional vision* describes how the person performs in vision-related activities. In addition to assessments of visual skills, one should not overlook the importance of nonvisual factors like decision-making ability, reaction time, driving experience, and other medical conditions when predicting safe driving. Coeckelbergh, Brouwer, Cornelissen, and Kooijman (2004) suggested that compensatory viewing strategies should not be overlooked as a possible method of predicting driving ability, especially with respect to individuals with central or peripheral field impairments.

In Canada, driving privileges are determined after a thorough assessment of visual abilities is conducted. The Canadian Medical Association's guidelines for determining fitness to operate a motor vehicle recommend the following assessments: visual acuity, contrast sensitivity, visual field, color vision, depth perception, dark adaptation, glare recovery, or the presence of diplopia or double vision (Canadian Medical Association, 2006). Cognitive and visual perception, attention, and speed-of-processing tests have also been used to determine or predict the driving performance of individuals with visual impairments and those who have had strokes (Ball, Beard, & Roenker, 1988; Korner-Bitensky et al., 2000). In addition to real-world driving tests, some studies have incorporated driving simulators or closed-road driving assessments, which allow researchers meticulously to standardize and precisely to control the driving environment (Parkes, 2005).

Methods

We sought to answer the following question with this research synthesis: For adults who have low vision, what is the evidence that vision-related driving assessments can predict actual, on-road driving performance? We also posed supplementary questions about the relationship between vision-related factors and driving performance, as presented in the Driving performance and visual impairment and Self-regulation sections.

Procedure

We conducted literature searches to locate research related to *low vision* and *visual impairment* conditions, as well as *assessment* and *driving*, based on methods and criteria outlined in the report on which this review was based (Strong, Jutai, Hooper, Russell-Minda, & Evans, 2007). The population of interest was individuals with low vision. The interventions of interest included any form of low vision driving assessment. All types of study designs, methods, and outcomes were considered for the review. The following sources were searched: PubMed, CINAHL, Cochrane Reviews, EMBASE, MEDLINE, PsycInfo, and specific published bibliographies. Hand searches of relevant journals and references were conducted. All potential sources for "gray literature" (unpublished or government-related technical documents) were searched. Books, proceedings, and presentations were excluded. The search was limited to sources published from 1980 to 2006, in English, and on adults aged 19 or older. Systematic reviews and meta-analyses were also sought to compare the transparency and rigor of the assessment methods that are used in this research synthesis. One systematic review of the influence of visual impairments on involvement in automobile crashes was reviewed to compare methods and content (Charlton et al., 2004). One meta-analysis of studies of useful field-of-view (UFOV) assessments (Clay et al., 2005) was located and is discussed in the Driving performance and visual impairment section. The initial literature search identified 2,405 abstracts. A standardized procedure was used for the inclusion and exclusion of abstracts in the review ($n = 754$). Two of the authors (Russell-Minda and Evans) reviewed both the titles of the citations and the abstracts to determine the articles' suitability for inclusion. A second reviewer (Strong or Jutai) confirmed the decision to exclude any of the abstracts.

We evaluated studies using the Downs and Black (1998) 27-question checklist for assessing the methodological quality of both randomized controlled trials and nonrandomized controlled trials. The checklist is sensitive to important qualities of research designs, with items distributed among key components as follows: (1) reporting (9 items), which assessed whether information provided in the study was sufficient to allow a reader to make an unbiased assessment of the findings; (2) external validity (3 items), which addressed the extent to which the findings could be generalized to the population from which the subjects were derived; (3) bias (7 items), which addressed biases in the measurement of the intervention and outcome; (4) confounding (6 items), which addressed bias in the selection of the subjects; and (5) power (1 item), which attempted to assess whether the negative findings of a study could be due to chance. The highest possible score is 28 for randomized controlled trials and 25 for nonrandomized controlled trials.

Studies were assigned the following levels: randomized controlled trial (1), cohort (2), case control (3), case series (4), and expert opinion (5) (Canadian Task Force on the Periodic Health Examination, 1979). Downs and Black score ranges were given corresponding levels of quality: excellent (26–28), good (20–25), fair (15–19), and poor (less than or equal to 14). Only randomized controlled trials could be assigned a quality level of "excellent." These quality levels were then mapped to strength-of-evidence levels and used to formulate the results. The following strength-of-evidence levels were adapted from methods that were used by the authors of the Evidence-Based Review of Stroke Rehabilitation project (Foley, Teasell, Bhogal, & Speechley 2003): Level 1a (very strong), the findings were supported by the results of two or more studies of at least "excellent" quality; Level 1b (strong), the findings were supported by at least one study of "excellent" quality; Level 2a (moderate), the findings were supported by two or more studies of at least "good" quality;

Level 2b (limited), the findings were supported by at least one study of "good" quality; Level 2c (weak), the findings were supported by at least one study of "fair" or "poor" quality; Level 3 (consensus), in the absence of evidence, agreement by a group of experts on the appropriate treatment course, regarded as the lowest form of evidence; and Level 4 (conflicting), disagreement between the findings of at least two randomized controlled trials. Where there were more than four randomized controlled trials and the results of only one were conflicting, the conclusion was based on the results of the majority of the studies unless the study with conflicting results was of a higher quality.

Results

Of the 88 studies that were selected and evaluated in the report on which this review was based (Strong et al., 2007), 13 were randomized controlled trials and 75 were nonrandomized controlled trials (cohort, case control, and case series). The twenty-six studies that supported the strongest conclusions related to the assessment of low vision and driving are listed in Table 1 and discussed in the Results section. (In addition, the online version of Table 1 presents a higher level of detail than the one included in this print edition. Visit <www.afb.org/jvib> to log in to *JVIB* Online.) In the interest of the length limitation guidelines for this article, studies were selected according to the strongest levels of evidence from which the authors could base their conclusions. Complete evidence tables were developed for data-extraction purposes (available on request from the corresponding author).

Driving performance and visual impairment

One of the supplementary questions we explored was, For adults who have low vision (including those who have had strokes), what is the evidence that vision-related driving assessments can accurately predict on-road driving performance? A considerable body of research has examined the correlations between standard visual deficits, driver's performance, and safety. Attempting to determine which vision tests can accurately predict driving performance is a continually challenging issue for licensing authorities. Moderately strong (Level 2a) evidence from two good-quality studies suggests that the UFOV test is an effective predictor of on-road driving performance for survivors of strokes and may be a useful assessment tool for determining readiness to drive in survivors of traumatic brain injury (Fisk, Novack, Mennemeier, & Roenker, 2002; Fisk, Owsley, & Mennemeier, 2002). A cumulative meta-analysis of eight studies (Clay et al., 2005) found that the UFOV assessment may be a valid and reliable tool in determining driving performance and safety in older adults (the study's inclusion criteria were based on adults aged 55 and older, with no particular criteria set for the level of visual impairment).

Limited (Level 2b) evidence from one good-quality study suggests that a modest loss of visual acuity alone does not create an increased risk of driving accidents (OR = 0.97, CI 95%: 0.68–1.38) (Gresset & Meyer, 1994). The risk of accidents among drivers with both a minimal loss of visual acuity and the lack of binocularity was moderately higher than among other

Table 1
Selected studies that supported the strongest conclusions related to the assessment of low vision and driving.

Study	Level[a]	Downs and Black score[b]
Nouri & Lincoln (1993)	1	24
Owsley et al. (2002)	2 (prospective)	24
Ivers et al. (2000)	2	22
McGwin et al. (2005)	3	24
Gresset & Meyer (1994)	3	20
Owlsey et al. (2001)	4 (cross-sectional)	25
Owsley et al. (1999)	4 (comparative)	25
Fisk, Owsley, & Mennemeier (2002)	4 (comparative, cross sectional)	24
Brenner et al. (1993)	4 (prospective, comparative)	23
Korner-Bitensky et al. (2000)	4 (retrospective)	23
McGwin et al. (2004)	4 (comparative)	23
Monestam & Wachtmeister (1997)	4 (prospective)	23
Scilley et al. (2002)	4 (comparative; cross sectional)	23
Elliott et al. (2000)	4 (comparative)	21
Szlyk et al. (2004)	4	21
Szlyk et al. (2002)	4 (comparative)	21
Szlyk et al. (1993)	4 (comparative)	21
Fisk, Novack, Mennemeier, & Roenker (2002)	4 (comparative)	20
Klavora et al. (2000)	4 (comparative)	20
Pager et al. (2004)	4	20
Szlyk et al. (1995)	4 (comparative)	20
Szlyk et al. (1992)	4 (comparative)	20
Szlyk et al. (1991)	4	20
Wood & Carberry (2006)	4 (interventional, comparative)	18
Fishman et al. (1981)	4 (comparative)	17
Szlyk et al. (2005)	4 (comparative)	17

[a] Levels: (1) = randomized controlled trial; (2) = cohort, experimental design with at least one control group, "outcomes" study, or observational (prospective or retrospective); (3) = case control; (4) = case series (comparative—with controls).
[b] Downs and Black score: Score ranges were given corresponding levels of quality: excellent (26–28), good (20–25), fair (15–19), and poor (less than or equal to 14).

drivers (OR = 1.23, CI 95%: 0.88–1.72). The results of a study conducted with drivers aged 60 and older (with and without visual impairments) on a closed-circuit driving course found measures of high-contrast visual acuity to be a poor predictor of driving performance (Wood, 1999). These drivers were tested on the detection and recognition of road signs. Limited (Level 2b) evidence from two good-quality studies indicated that the results of tests of visual acuity and contrast sensitivity are poorly correlated with driving-simulator performance by persons with diabetic retinopathy (Szlyk et al., 2004) and that peripheral field devices that are used in many driver-screening centers (Keystone View Tester and Titmus Vision Tester) are poorly correlated with the results of standard Goldmann perimetry tests (Szlyk, Fishman, Master, & Alexander, 1991). The Goldmann perimeter has been considered to be the clinical "gold standard" for measuring visual fields. There is limited (Level 2b) evidence from one good-quality study that contrast-sensitivity testing provides the best predictive model for real-world driving in persons with glaucomatous vision loss (Szlyk, Taglia, Paliga, Edward, & Wilensky, 2002).

Limited (Level 2b) evidence, based on one good-quality randomized controlled trial, suggests that on-road testing and a stroke driver's screening assessment (SDSA) tool are the best methods to use when evaluating the driving abilities of persons who have had strokes and correctly predicting their driving outcomes (Nouri & Lincoln, 1993). In this randomized controlled trial, the SDSA correctly predicted the on-road performance of 81% of the persons in the experimental group (n = 27). Performance was correctly predicted in 56% of the control group (n = 25), which was conducted via advice from the subjects' general practitioners without the use of the SDSA. Limited (Level 2b) evidence from one good-quality study suggests that the Motor-Free Visual Perception Test is an inadequate screening tool for predicting on-road driving abilities (Korner-Bitensky et al., 2000). In addition, limited (Level 2b) evidence, based on one good-quality study, suggests that survivors of stroke who pass the Cognitive Behavioral Driver's Inventory (CBDI) and specific tasks in the Dynavision Performance Assessment Battery (DPAB) will successfully complete the on-road driving assessment (Klavora, Heslegrave, & Young, 2000). The CBDI and DPAB were administered beforehand (off-road) to predict the passing or failure of the on-road driving assessment. The accuracy rate for the CBDI in predicting success or failure of the road test was 66%. The accuracy rate of the "endurance Dynavision task" component of the DPAB was 75%. Road-test outcomes were predicted using linear stepwise regressions models and odds ratios for the four variables of the DPAB test battery; the CBDI variable; and the age, gender, and lesion lateralization variables.

Another supplementary question we sought to examine was, Are specific eye diseases associated with poor driving performance? The impacts of visual impairment on driving may be adequately predicted or explained by considering the nature and levels of tested impairments that are associated with each condition. Frequently, poor driving is linked to impairment deficits and not to the condition that causes these deficits. Moderately strong (Level 2a) evidence has shown that driving performance is better correlated with specific impairment deficits than with specific sight-limiting conditions (Ivers, Mitchell, & Cumming, 2000).

With respect to glaucoma, limited (Level 2b) evidence, based on one good-quality study, suggests that contrast-sensitivity testing provides the best predictive model for real-world driving in persons with glaucomatous vision loss (Szlyk et al., 2002). Limited (Level 2b) evidence from one good case-control study (McGwin et al., 2005) supports the conclusion that older adults with moderate to severe central field loss in the central 24-degree radius field (in the worse-functioning eye) are at an increased risk of being in a motor vehicle collision than are those with glaucoma and no field loss. The subjects' visual field defects were scored using the Advanced Glaucoma Intervention Study tool (Advanced Glaucoma Intervention Study 2, 1994). Weak

(Level 2c) evidence, based on one fair-quality study, shows that persons with glaucoma who have a peripheral field loss (visual field reduced to less than 100 degrees of horizontal extent) have a greater risk of accidents, based on the results of assessments of simulated driving performance (Szlyk, Mahler, Seiple, Edward, & Wilensky, 2005).

For individuals with central field loss, macular degeneration has not typically been associated with an increased risk of crashes (McCloskey, Koepsell, Wolf, & Buchner, 1994; Szlyk, Fishman, Severing, Alexander, & Viana, 1993). However, Szlyk et al. (1995) reported that their group of individuals with macular degeneration performed poorly on certain driving-simulator measurements, such as braking response times, lane crossings, and driving speed, compared to an age-matched control group.

Visual impairment as a result of cataracts can have a significant impact on driving safety and performance, especially at night. There is moderately strong (Level 2a) evidence from two good-quality studies that drivers with cataracts have a greater history of crashes than do older drivers who do not have cataracts (Owsley, Stalvey, Wells, & Sloane, 1999; Owsley, Stalvey, Wells, Sloane, & McGwin, 2001). On the basis of the results of one good-quality study (Owsley et al., 2002), there is limited (Level 2b) evidence that persons who have had cataract surgery have lower crash rates than do persons with cataracts who opt not to undergo surgery. Moderately strong (Level 2a) evidence, based on five good-quality studies, suggests that cataract surgery resolves the visual performance deficits that are associated with older drivers (Brenner, Curbow, Javitt, Lagrow, & Sommer, 1993; Elliott, Patla, Furniss, & Adkin, 2000; Monestam & Wachtmeister, 1997; Pager, McCluskey, & Retsas, 2004; Wood & Carberry, 2006). These studies measured subjective visual function and quality of life before and after surgery, with the exception of Wood and Carberry (2006), which assessed objective measures of visual function and driving performance before and after surgery. The results of Wood and Carberry's (2006) study coincided with the subjective level of improvements that was found in the other studies.

Drivers with retinitis pigmentosa had poorer driving performance than did sighted individuals, as revealed by self-reported accidents and driving-simulator performance (Szlyk, Alexander, Severing, & Fishman, 1992). Limited (Level 2b) evidence from this good-quality study showed that binocular field area and field extent are valid predictors of diminished driving performances in persons with retinitis pigmentosa. There is limited (Level 2b) evidence, based on one good-quality study (Szlyk et al., 1993) and one fair-quality study (Fishman, Anderson, Stinson, & Haque, 1981), that younger persons with central or peripheral vision loss exhibit more lane-boundary crossings and longer braking responses relative to age-matched individuals with no vision loss, but drivers with RP have reported significantly more accidents than have those with central vision loss. Fishman et al. (1981) described the use of a common clinical approach in which two monocular fields are summed to obtain estimates of the binocular field. However, the reported calculations indicated that the two whole-field dimensions were summed, rather than using the temporal field extent for the right eye and the temporal field extent for the left eye. In spite of this limitation, the authors presumably were able to differentiate between a central field deficit and a field constriction. A preferred method for calculating binocular visual fields was described by Arditi (1988), in which a "map" of the volume of visual fields may be constructed to determine the functional visual field, as was used in a later study by Szlyk et al. (1993).

Self-regulation

The final supplementary question we considered was, What are the effects of visual deficits on the self-regulation of driving habits? Individuals with situational visual deficits are able to recognize their vulnerabilities and respond by avoiding problem situations, such as driving in bad weather and heavy traffic. Some aspects of functional vision are correlated with the performance of drivers in adverse seeing conditions, such as driving at night. These impacts on visual performance are revealed by clinical testing, but are also recognized by these individuals, who often curtail night driving as a result. There is moderately strong (Level 2a) evidence, based on three good-quality studies, that drivers with impaired vision appropriately self-regulate their driving activities by avoiding potentially difficult driving conditions, such as driving in fog, in heavy rain, at night, during rush hour, on the highway, or in heavy traffic (McGwin et al., 2004; Owsley et al., 1999; Szlyk, Seiple, & Viana, 1995). Limited (Level 2b) evidence, from one good-quality study, suggests that deficits in contrast sensitivity that are associated with cataracts are associated with a greater risk of crashes by elderly people. These heightened risks appear to be appreciated by these individuals, who constrain their driving activities accordingly (Owsley et al., 2001). Limited (Level 2b) evidence, based on one good-quality study, suggests that sensitivity to glare is positively correlated with diminished driving ability at night, but that drivers with these problems self-regulate their driving activities to avoid driving conditions to which they are disproportionately sensitive (Scilley et al., 2002).

Discussion

The objective of this research was to assess the evidence related to the prediction of actual, real-world driving performance based on vision-related driving assessments. Moderately strong evidence indicates that tests of visual field and contrast sensitivity, UFOV, cognitive and attention-based assessments, and a screening assessment tool for drivers who have experience stroke have variable utility for predicting real-world driving performance. UFOV tests, which measure visual attention skills and visual processing speed, tend to be more successful in identifying high-risk older drivers. The results of the meta-analysis by Clay et al. (2005) strengthen the case for using the UFOV assessment as a method for reliably measuring driving performance. That meta-analysis examined studies that used criteria for driving performance from state-documented crash records, on-road driving, and driving-simulator performances.

Moderately strong evidence also suggests that assessments that are based on visual acuity alone may not be adequate in determining an individual's driving performance. In addition, specific levels of visual impairment should be considered in clinical and driving assessments, rather than just a diagnosis of the eye condition. A diagnosis of glaucoma, for example, should be followed with detailed tests of the individual's peripheral visual field, which is an important indicator of the person's level of mobility. Cataract surgery has been shown to reduce visual disability and to improve driving performance. There is limited evidence, however, that contrast-sensitivity testing may be a reliable predictor of a person's fitness to drive after cataract surgery. Drivers who have undergone cataract surgery, as well as individuals with other types of vision loss, generally tend to self-regulate their driving behaviors, choosing to avoid potentially challenging situations that are due to environmental conditions. There is strong evidence that this self-regulatory behavior predicts their level of comfort and hence their driving performance.

Owsley and McGwin (1999) suggested that current practices of visual acuity screening at driver's licensing sites should not be viewed as an effective means of identifying those with visual impairments who may have an elevated risk of crashes. Studies that have examined crashes as an outcome measure have obtained this information from self-reports and state records, which may not be accurate (Owsley et al., 1998; Owsley, McGwin, & Ball, 1998), and good alternatives for evaluating long-term driving performance do not exist. In addition, the validity of results from tests of simulated driving performances has been challenged by some researchers because these tests cannot always successfully predict on-road driving performance, because of variations in age and cognitive capabilities. There is a considerable debate over what degree of fidelity is required for the results obtained using a research driving simulator to be consistent with those obtained in real-world driving environments. To have meaningful discussions and comparisons across driving studies, the data should be adjusted to accommodate confounding factors, such as exposure to driving, age, gender, and comorbidities, which have typically been identified after the analysis of the performance data. Age is a major confounding factor in visual function and the results of driving performance; it is also a factor when making adjustments for exposure to driving. A major challenge in conducting a systematic synthesis of research on driving with low vision is to find adequate ways of comparing the studies' results. Comparisons of results are hindered when researchers fail to categorize the specific measures of visual function that are used to differentiate between drivers who are deemed to be visually impaired and those who are deemed to have no visual impairment. It is our hope that the results presented here will provide an objective evaluation of the evidence, which may ultimately influence how policies and practices are developed and implemented.

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