Effects of Visual Aging upon Driving Performance

Abstract

Advancing adult age is associated with functional declines in both the sensory and perceptual stages of visual information processing (see Schieber, 1992). This paper reviews the recent research literature (i.e., 1988-1994) which has attempted to assess the impact of age-related visual declines upon driving mobility, safety and performance.

VISION LOSS AND DRIVING MOBILITY

In a 10-year longitudinal assessment of mobility patterns, Jette and Branch (1992) found that elderly adults were heavily dependent upon automobiles to meet their essential transportation needs. A more recent analysis by Hu, Young and Lu (1994) suggests that the dependence of the elderly upon the automobile may be increasing. Data from the 1983 and 1990 administrations of the Nationwide Personal Travel Survey were compared. A general increase in driving frequency and mileage was found; those ages 65 and older reported a 14% increase in mileage during the 7-year span examined. This increase in driving frequency occurred despite the fact that the average age of the 65-and-older group actually increased during that same time period — primarily due to the explosive growth of the 80-and-older population.

Despite the increase in the amount of driving by the 65-and-older group, a significant number of elderly drivers report giving up their driver’s licenses and/or the cessation of all driving activity. Campbell, Bush, and Hale (1993) studied driving cessation patterns in a large sample of ambulatory, community-resident elderly in Florida (ages 70-96). This longitudinal study employed annual screenings in which clinical test data and self-reports of disease, symptoms, and medical complications were collected. During the eighth year of the study the participants were also asked questions about their driving behavior. The sample consisted of 1,656 persons who had been driving at the beginning of the study. Approximately 17% (N=276) of these individuals reported that they had quit driving. Campbell, et al. found that medical problems related to visual loss were the single most powerful predictors of driving cessation (e.g., macular degeneration, retinal detachment, retinal hemorrhage, etc). The probability of driving cessation increased exponentially with advancing age, and women — at all age levels —
were twice as likely to give up driving as their male counterparts. It is interesting to note, however, that diagnosis of cataract and glaucoma were not statistically related to driving cessation. (These negative finding may reflect the successful treatment of these disorders among this relatively affluent sample.) Campbell, et al.’s findings are consistent with the self-report data of Kosnik, Sekuler, and Kline (1990) who found that older persons who had quit driving were more likely to report serious problems with everyday vision. Laux (1991) also reported that frail elderly with poor vision were more likely to quit driving at a 15-month follow-up.

Persson (1993) interviewed 56 residents of retirement communities who had quit driving. They ranged in age from 66 to 96 (mean age of 81). The majority were women (63%), widowed (68%), and Caucasian (98%). Although all the participants had stopped driving within the last 5 years, only 37% of them no longer held a valid driver’s license. Like the studies cited above, visual problems were reported as critical factors behind the decision to stop driving. Trouble seeing cars and pedestrians (20%) was second only to “advice from doctor” (27%) as a major reason for quitting. The four most commonly diagnosed diseases among the sample of former drivers were, in order of prevalence, arthritis, cataracts, macular degeneration and glaucoma. It should be noted, however, that 61% of the former drivers rated their eyesight as “excellent” or “good.”

VISION AND DRIVING SAFETY

Several recent studies have reconfirmed the previously established link between visual field loss and automobile accidents among elderly as well as young drivers (see Keltner and Johnson (1992) for a brief review). Szlyk, Brigell and Seiple (1993) studied the driving simulator performance of 6 elderly patients with hemianopic visual field deficits resulting from strokes (mean age: 71, range: 53 to 80). Data was also collected from 7 healthy older subjects (mean age 70) and 31 younger controls (mean age 39). Participants operated an Atari driving simulator for 15 minutes on a practice course and then for 5 minutes along an experimental route upon which data was collected. Performance indices measured included number of lane boundary crossings, lane position, steering wheel position, vehicle angle to the road, average slowing and slopping distance to traffic signals, mean speed, gas pedal pressure, brake pedal pressure, and simulator accidents. Older field loss patients differed from both control groups on a number of driving simulator performance measures. They demonstrated significantly greater numbers of lane boundary crossings, slower average stopping rates, slower average speed, greater variability in accelerator and brake pedal pressures, and far more simulator accidents. Eye movement monitoring suggested that patients with field loss tended to compensate by making greater use of head and eye movements. In fact, those with the most active head/eye movements were the patients with the fewest simulator accidents. These findings suggest that active training of eye movement scanning patterns might serve to remediate driving deficits resulting from visual field loss. Although such a conclusion is highly speculative given the small number of persons observed, it should be noted that similar conclusions have also been reported by Lövsund, Hedin, and Törnros (1991) and in another study of patients with severe visual loss (retinitis pigmentosa) reported by Szlyk, Alexander, Severing, and Fishman (1992). However, Owsley, et al. (1993) measured far peripheral field sensitivity (using a Humphrey automated static perimeter) in a sample of 53 older drivers ranging in age from 57 to 83 (mean age: 70). Although the loss of far peripheral sensitivity was significantly related to age (r = 0.36), field loss was not found to be
significantly related to the number of accidents accrued during the prior 5 years. The pattern of results reported above clearly suggests that visual field deficits yield measurable increases in crash risk, but not until the sensory losses become quite severe.

Decina and Staplin (1993) assessed binocular visual acuity, contrast sensitivity, and the extent of horizontal visual field in 12,400 Pennsylvania license-renewal applicants. The visual acuity screener was capable of measuring values ranging from 20/20 to 20/200. Suprathreshold horizontal visual fields were assessed using mini-lamps placed at 45, 55, 75, and 85 degrees (temporal and nasal). Contrast sensitivity was measured using sinusoidal test patches presented at 6, 12, and 18 cycles/degree. Pass/fail cutoffs were based upon Pennsylvania state law for acuity and fields and age-related norms for contrast sensitivity. Neither visual fields nor acuity alone were related to driving crash rate regardless of driver age. However, a composite score based upon the pass-or-fail outcome for these two measures plus contrast sensitivity was found to be significantly related to increased crash rate (per mile driven) for drivers 66 years of age or older. Once more, no increase in crash rate was observed among older drivers who passed all three visual screens. It is interesting to note that a composite metric of visual function based upon the same triumvirate of measures (i.e., acuity, horizontal field, and contrast sensitivity) has also been shown to be related to subjectively rated driving proficiency scores among 40, mostly elderly, low-vision patients (Buyck, Missotten, Maes, and van de Voorde (1988).

Perhaps the most ambitious and programmatic line of research relating vision to driving safety (i.e., accidents) among older adults has been initiated by Ball and her colleagues. Owsley and Ball (1993), lamenting the equivocal findings of past research attempting to relate driving accidents to visual function, wrote:

> Despite the intuitive appeal of a link between vision and driving ability, [past] studies have found only weak correlations between visual deficits (e.g., visual acuity, visual field loss) and vehicle crashes (Henderson and Burg, 1974; Shinar, 1977). These correlations were often statistically significant due to very large sample sizes but accounted for less than 5% of the crash variance in these studies. Thus, the (existing) data are insignificant in reaching the practical goal of successfully identifying which older drivers are seriously at risk for crash involvement (p. 389) (italics added for emphasis).

Ball and her colleagues have developed a measure of visual function which they term the “useful field of view” (UFOV) and have reported that UFOV scores account for significantly more crash variance among older drivers than previous studies of visual function. Their UFOV test assesses the extent of the area over which a visual target embedded in noise (i.e., distracting background) can be accurately localized during a brief stimulus exposure. The first major evidence linking UFOV to automobile crashes was reported by Owsley, Ball, Sloane, Roenker, and Bruni (1991). They administered an extensive battery of visual and cognitive tests to a sample of 53 subjects ranging in age from 57 to 83 years (mean age: 70). These subjects were recruited from a university ophthalmology clinic. Self-reports as well as official reports of accident records for the previous 5 year period were collected. Owsley, et al. found that self-reported accident histories tended to severely “under report” the frequency of at-fault accidents as compared to official state driving records (p. 407). Simple correlational analyses revealed that UFOV was the
only measure that was significantly related to crash frequency \((r = 0.36)\) — accounting for 13% of the at-fault crash variance. Neither the correlations for acuity nor peripheral field measures were significant. An interesting finding was that performance upon a brief mental status exam designed to assess the magnitude of age-related dementia (i.e., the Matis Organic Mental Status Syndrome Examination, or MOMSSE) was also highly related to crash frequency \((r = 0.34,\) or 11.6% of the at-fault crash variance). Taken together, the UFOV and the MOMSSE jointly accounted for 20% of the crash variance — far exceeding the predictive power demonstrated by previous studies of the relationship between vision and driving accidents. Although the UFOV and MOMSSE were highly correlated with one another \((r = 0.32)\), LISREL “causal modeling” of accident frequency suggested that each had a relatively independent influence upon driving safety. However, such conclusions are highly speculative and require confirmation via follow-up modelling upon an independent dataset (see Ball, et al., 1993). Owsley, et al. rank ordered their subjects on the basis of their UFOV scores and found that those in the “worse” half of the distribution were 4.2 times more likely to have experienced an at-fault crash during the last 5 years than those in the “better” half of the distribution. Finally, the relationship between UFOV and driving safety was reanalyzed for the type of crash for which the elderly appear most vulnerable — intersection accidents. As expected, the majority of the crashes reported (67%) occurred at intersections. The correlations between the UFOV and intersection accident frequency was 0.46. UFOV, by itself, accounted for 21% of the crash variance. Those in the “worse” half of the UFOV distribution accounted for all but one of the intersection accidents reported; they, therefore, were 15.6 times more likely to have experienced an intersection accident than those with UFOV scores in the “better” half of the distribution — a truly remarkable relationship.

As remarkable as Owsley, et al.’s (1991) findings were, it must be noted that their predictions were based upon the observation of a mere 25 accidents (Ball, et al. (1993), p. 3111). Ball, Owsley, Sloane, Roenker, and Bruni (1993) conducted a confirmatory study of the Owsley, et al. UFOV model based upon a highly stratified sample of drivers aged 55 and older. The sampling strategy consisted of 7 age groups (55-59, 60-64, 65-69, 70-74, 75-79, 80-84, and 85+) crossed with 3 levels of 5-year crash history (0, 1-3, and 4+ accidents). Subjects were recruited from licensed drivers in Jefferson County, Alabama in an attempt to fill the 21 resulting sample cells. The final sample consisted of 294 adults ranging in age from 56 to 90 (mean age: 71). The distribution of subjects by crash history category was: 33% with no accident involvement, 49% with 1-3 accidents and 18% with 4 or more accidents. (A total of 364 at-fault accidents occurred.) Simple analyses revealed statistically significant correlations between accident frequency and several visual measures, including far peripheral fields \((r = 0.26)\), contrast sensitivity as measured with the Pelli-Robson chart \((r = -0.24)\), binocular acuity \((r = 0.225)\), and UFOV \((r = 0.52)\). These measures accounted for 6.8, 5.8, 5.1, and 27% of the crash variance, respectively. Again, the UFOV was far more closely associated with accident risk than any of the other visual measures. In fact, the relationship was even stronger than the one demonstrated in the small-scale Owsley, et al (1991) study described above. The mental status exam (MOMSSE) was also significantly related to at-fault crash frequency \((r = 0.34)\). Confirmatory LISREL analysis upheld the original model proposed by Owsley, et al. (1991) — adding strength to the conclusion that mental status (MOMSSE) and UFOV were related to crash frequency through relatively independent mechanisms. Ball, et al. argued that the UFOV test demonstrated statistical properties which make it a good candidate for mass screening of at-risk
older driver license renewal applicants. Namely, assuming a 40% reduction in the UFOV as a pass-or-fail cutoff score, the test yielded a sensitivity of 89% and a specificity of 81%. That is, given that a subject was crash-involved, the probability of failing the UFOV test was 0.89; whereas, given that a subject was not crash-involved, the probability of passing the UFOV test was 0.81. A frequency table supporting these calculations appears below.

<table>
<thead>
<tr>
<th>UFOV Score</th>
<th>Crash-Involved</th>
<th>No Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failed (UFOV &gt; 40)</td>
<td>142</td>
<td>25</td>
</tr>
<tr>
<td>Passed (UFOV ≤ 40)</td>
<td>18</td>
<td>109</td>
</tr>
</tbody>
</table>

It is unlikely, however, that the sensitivity and specificity levels observed in this study will hold up under real-world mass screening conditions. Ball, et al. greatly oversampled the at-risk older population. For example, the probability of randomly drawing a person with an accident from this sample was 67%. Significantly greater than one would expect if sampling from the general population of elderly license applicants (The probability of randomly drawing a person with 4 or more accidents was an astounding 18%. Such drivers are exceedingly rare in the actual older driver population). Whenever a subject “failed” the UFOV test in the Ball, et al. study, the a priori probability that he/she was also accident-involved was 67%. This a priori probability, by mathematical necessity, greatly inflates the value of any sensitivity estimate. However, an elderly driver sampled from the general population — as in the case of a mass screening application — will have a much lower a priori probability of being crash-involved. The next study to be reviewed provides a rough estimate of the predictive power of the UFOV battery under “less optimized” conditions.

The Hartford Insurance Company, in association with the American Association of Retired Persons (AARP), conducted a large-scale field study of factors related to accidents among older drivers (Brown, Greaney, Mitchel and Lee, 1993). The Hartford study sampled 1,475 AARP-Hartford automobile insurance policy holders in 3 states (Connecticut, Florida, Illinois). The age distribution of the sample was such that 26% were ages 50-64, 54% were ages 65-74, and 20% were ages 75 or older. An attempt was made to over-sample those policy holders who had experienced accidents during the past 3 years so as to yield an “increase in the statistical power of the study.” Drivers with at-fault accidents — determined on the basis of insurance company records as well as official state reports — represented 42% of the sample. Thus, accident-involved drivers were over-represented relative to the insurance population. However, the number of extreme cases (i.e., multiple accidents) was far fewer than those observed in the Ball, et al. (1993) study described above. A wide variety of assessment procedures were administered to each participant, including a number of visual tests. The visual tests included acuity, stereopsis, color blindness, contrast sensitivity (Pelli-Robson chart), UFOV (Ball’s Visual Attention Analyzer), the UNLV driver vision test battery (see Temple, 1989), and a questionnaire surveying self-reported visual problems related to driving. Simple correlational analyses were performed relating these measures of visual function to at-fault accident frequency incurred during the previous 3 years (1989-1991). The results of these correlational analyses are summarized in the table below:

Hartford Study Correlational Analyses of At-fault Accident Frequency
The principal investigators in the Hartford study hypothesized that the UFOV test would be the most powerful predictor of at-fault accidents among older drivers. This was clearly not the case. Although the observed correlation of 0.05 was statistically significant (due to the large sample size), it accounted for less than 1% of the crash variance. By Owlsley and Ball’s own criterion, it failed as a viable test for identifying at-risk elderly drivers (1993, p. 389). The visual test with the strongest link to crash history was contrast sensitivity. This finding contributes to a growing body of evidence which suggests that low contrast vision is deficient in many older adults and predictive of performance problems with many everyday activities (also see below). The Hartford study reported a linear increase in the likelihood of accident-involvement as Pelli-Robson contrast sensitivity decreased. For example, those with a contrast sensitivity of 89 (log CS = 1.95) had a 0.47 probability of being accident-involved. This probability increased to 0.65 for those with a contrast sensitivity of 22 (log CS = 1.35). However, even contrast sensitivity accounted for only slightly more than 1% of the total crash variance.

Even with the “latest and greatest” tools, our ability to predict crash involvement and identify at-risk drivers on the basis of safety criteria remains weak. However, given careful thought, this really should not be seen as a surprise. Accidents are caused by many factors as well as the interactions among those factors. These combinations of causative influences rarely repeat themselves; and, in fact, it has often been claimed that “no two accidents are alike.” As such, the size of statistical main effects relating accident variance in a large population to any factor will be small (see Shinar and Schieber (1991) for a commentary on accident-based driving research). It has become clear that advances in driving research, especially in the domain of older drivers, will accrue only to the extent that we free ourselves from the “tyranny of the accident criterion” and focus upon performance-based driving criteria. This shift from a focus upon driving safety (i.e., accidents) to driving competence (i.e., performance) is already underway as evidenced by the studies reviewed in the following section of this report. However, an important barrier remains before this shift in the prevailing research paradigm can become fully actualized — namely, the issue of research support and funding. The principal source of support for driving-related research has been from agencies of the U.S. Department of Transportation (FHWA and NHTSA) and DOT-funded programs at the state level. The mission of these agencies has been the improvement of safety. Hence, the criterion for the assessment of safety has been — and remains — the frequency or rate of accidents. The research community must develop initiatives to demonstrate the logic and value of the performance-based paradigm. Recent interest in the mobility of older drivers and the explosive growth of IVHS human factors have reinforced the need for performance-based research. This trend must be actively cultivated.
VISION AND GENERAL DRIVING PERFORMANCE

Acuity
Several recent studies have examined the relationship between acuity and road test performance in samples of “representative” community-resident older adults. All of these studies have failed to demonstrate measurable declines in road-test performance in the presence of age-related reductions in acuity among licensed drivers. The largest of these studies was reported by Schreuder (1988). Data was collected from 903 middle-aged and older members of the Royal Dutch Touring Club — an active group of driving enthusiasts from the Amsterdam area. All drivers completed a highly formalized 1-hour road test as well as a battery of optometric tests including visual acuity (left eye, right eye, and binocular). Seven items on the road test were related to perceptual aspects of driving (e.g., perception of traffic and roads, detection of traffic signs and signals, proper “look ahead,” etc). A composite score based on these 7 road test items was related to visual status via correlational analyses. No relationship between acuity and road test performance was demonstrated.

Schlag (1993) examined 80 older (ages 60-82) and 30 middle-aged drivers (ages 40-50). All drivers were given a comprehensive road test and completed a battery of laboratory assessments including: photopic acuity, night acuity (using the Rodenstock Nyktometer) and a tachistoscopic test of the recognition of common roadway hazards. The driving test consisted of a 35-km standard route encompassing many types of traffic situations (in Cologne, Germany). The instrumented test vehicle was capable of measuring time, distance, velocity, brake operation, accelerator pedal position, and steering wheel angle. Although significant age-related performance deficits were observed for all of the laboratory tasks, on-the-road assessment of driving performance was not statistically linked to age-related declines in acuity.

Another recent study also failed to demonstrate a relationship between age-related acuity changes and road-test performance. Carr, Jackson, Madden and Cohen (1992) used the Miller Road Test to assess the driving skills of 20 very young (ages 18-19), 20 young (ages 25-33) and 20 older (ages 69-84) adult volunteers. The average visual acuity for each of these age-groups was 20/15, 20/15 and 20/36, respectively. The acuity loss for the oldest group was statistically significant. Despite the sizable decrement in acuity, however, no age-related decline in road-test performance was noted. In fact, the oldest group performed better than either of the younger groups in several test categories.

None of the studies discussed in this section employed large numbers of subjects with remarkable levels of acuity loss. Once more, none of the road-tests employed represented situations that “challenged” the drivers to perform at or near the “edge of the envelope.” As such, the failure to observe a statistical relationship between acuity and driving performance was to be expected. Studies that examine older individuals with pronounced acuity losses due to macular degeneration and related disorders are needed. Initial research in this area might be best served through simulation protocols that could push all drivers to their limits in order to detect even small behavioral deficits. Great success has recently been demonstrated using this strategy...
in studies of visual field disorders and their relationship to driving-related performance (see below).

**Contrast Sensitivity**

Measures of contrast sensitivity have recently been demonstrated to be significant predictors of age-related driving problems. As already noted above, contrast sensitivity (assessed via low-contrast letter charts) provides for greater differentiation between young versus older observers than high-contrast acuity (Owsley, et al., 1990; Schieber, 1988); and, accounts for a significant proportion of the accident variance among older drivers (Brown, et al., 1993). Recently, contrast sensitivity has been shown to be associated with age-related changes in the number and magnitude of self-reported visual problems, models of roadway visibility at night, legibility distance of highway signs, and closed-course driving performance of older persons with cataract.

Schieber, Kline, Kline, and Fozard (1992) used a survey instrument to examine the extent to which normal adult aging affects self-reported visual problems related to driving. A large number (N=397) of male and female adults from the Baltimore Longitudinal Study on Aging were examined. They ranged in age from 22 to 92 years with over half of the participants being aged 65 or older. Contrast sensitivity data was also collected from approximately half of the sample. Factor analysis of the survey responses revealed that visual problems related to driving increased in their frequency and magnitude with advancing adult age. These emerging age-related visual difficulties occurred in five major problem areas: unexpected vehicles appearing in the peripheral field of vision, instrument panels that were too dim, uncertain judgment about vehicular speed, difficulty seeing through windshields, and the inability to read street signs. Canonical correlation analysis revealed that age-related reductions in contrast sensitivity — at both intermediate and high spatial frequencies — were significantly associated with age-related increases in self-reported visual problems. These findings served to partially validate the previously reported vision survey results of Kline, et al., 1992 and contribute to the growing database linking contrast sensitivity measures to age-related driving problems.

Wood and Troutbeck (1994) examined the effects of age and cataracts upon driving performance on a closed-circuit driving course. Ten young (mean age 22.6), 18 old (mean age 67.7) and 18 old-with-cataract (mean age 68.6) drivers served as subjects. All subjects received a comprehensive visual assessment consisting of a disability glare test (Berkeley Glare Test), contrast sensitivity (Pelli-Robson low-contrast letter chart) and a modified “useful field of view” test. Participants drove five laps around the track during which the following behaviors were assessed: peripheral stimulus awareness, car maneuvering, reversing, reaction time detection of an instrument panel alarm, speed estimation and maintenance, lateral position keeping and overall time to complete the course. Results indicated that the young performed significantly better than the normal-old who performed better than the old-with-cataracts on most of the driving-related tasks. Among the three visual measures, the contrast sensitivity data were, by far, the most successful for discriminating between subjects on the basis of age, cataract and driving performance.

Kline, Ghali, Kline, and Brown (1990) studied age differences in the relative legibility distances of text versus symbol highway signs. They found that acuity was not significantly related to individual differences in observed legibility distance. This finding was not surprising
since they utilized a rigorous screening criterion which resulted in virtually all observers having visual acuities of 20/20 or better (i.e., a restricted range which eliminated the opportunity to observe covariation). Despite near equivalence on the visual acuity measure, sizable individual differences in contrast sensitivity at intermediate and high spatial frequencies remained. Upon conducting a simple regression analysis, Kline, et al. found that contrast sensitivity accounted for nearly half of the variance in the legibility distance data. These findings replicate and extend previous work reported by Evans and Ginsburg (1984).

Bhise, Matle, and Farber (1989) have incorporated age-specific contrast sensitivity data (of Blackwell and Blackwell) into their DETECT model of nighttime visibility (under automobile headlights). Simulations generated with the revised model revealed that the 50th percentile 80-year-old could detect a pedestrian on the side of the road at a distance of 140 ft — a distance that is less than half of that expected for the 50th percentile 20-year-old (313 ft). Adding the age-specific contrast sensitivity data to the model had a much more deleterious effect upon visibility distance than incorporating an age-related glare parameter.

Contrast sensitivity has emerged as one of the most — if not the most — powerful links between visual status and driving-related performance. The work of Bhise, et al. (1989) demonstrates the potential value of this quantitative index of visual function for generating models of driver performance. Such models would be invaluable for a variety of automotive and highway engineering endeavors. Work is needed to develop such models but must also be expanded to validate them against real observations from the field.

Peripheral Vision

Previous research has repeatedly demonstrated that greatly reduced fields of peripheral vision are associated with increases in both simulator and real-world driving accidents (e.g., Hedin and Lövsund, 1986; Keltner and Johnson, 1992; Szlyk, et al., 1992; 1993). Lövsund, Hedin and Törnros (1991) found that driving competence (in a specially constructed simulator) was difficult to predict on the basis of clinical assessment of visual field loss. This was because of wide individual variations in the nature and magnitude of the compensatory behaviors exhibited by patients with nearly identical types of field loss. However, eye-movement monitoring revealed that the “successful” drivers clearly tended to overscan the area in which they had experienced severe losses of visual sensitivity. What remains a mystery is why some individuals develop such compensatory behaviors while others do not. Clearly, the possibility of training eye movement strategies which may help overcome these deficits remains an intriguing issue that is worthy of future research. The results of such work might also be readily generalizable to older adults demonstrated to have greatly restricted “useful fields of view.”

Retchin, Cox, Fox, and Irwin (1988) found that horizontal field loss (together with diminished dynamic visual acuity and grip strength) was associated with significant decreases in driving frequency — and, hence, mobility — in a sample of 143 male patients recently admitted to a Veterans Administration hospital (mean age: 70). (It is historically interesting to note that this is the only driving-related research using the dynamic visual acuity measure that will be mentioned in this report. Apparently, DVA is no longer being actively investigated as a predictor of driving performance and/or accident involvement.)
Wood and Troutbeck (1992) examined the effects of restricted fields of view upon driving performance on a closed-circuit track. Although no elderly subjects were examined, the effects of age-related visual field losses were simulated in a group of nine drivers ranging from 24 to 35 years of age. Four visual field conditions were studied: baseline (full fields), monocular vision, and two levels of peripheral field restriction (20 degrees versus 40 degrees — total binocular field). Field restrictions were implemented through the use of a modified pair of swimming goggles. Compared to baseline performance, constriction of the binocular field did not significantly affect driving speed estimation (i.e., maintaining a constant speed without access to the vehicle’s speedometer), emergency stopping distance in response to an object thrown directly in front of the vehicle, or the time taken to reverse into a parking space or maneuver through a narrow, winding lane delineated by two lines of traffic cones. However, binocular field restriction did significantly reduce performance in a number of other driving areas: (1) The time taken to complete the course increased, and there was a markedly reduced ability to (2) detect and correctly identify road signs, (3) avoid obstacles and (4) maneuver through restricted spaces; and, (5) the accuracy of lane keeping and reversing were also impaired. The monocular condition did not significantly affect performance for any of the driving tasks assessed. McKnight, Shinar and Hilburn (1991) also reported similar negative findings in an assessment of commercial heavy-truck drivers with monocular vision. Given a wide variety of performance assessments, monocular truck drivers were found to be deficient in only one category: highway sign reading distance.

**Driving Speed and Distance Perception**

Staplin and Lyles (1992) argue that age-related motion perception deficits combine to eliminate important cues needed for driving and may directly impact the safety of older drivers. Consistent with this claim, several studies have demonstrated systematic age differences in the ability to judge the speed of automobiles (e.g., Hills, 1980; Scialfa, Guzy, Leibowitz, Garvey, and Tyrrell, 1987). Older females, in particular, appear to exhibit pronounced errors in estimating the “time-to-arrival” of approaching vehicles (Schiff, Oldak, and Shah, 1992).

Scialfa, Guzy, Leibowitz, Garvey, and Tyrrell (1991) examined age differences in the magnitude estimations of vehicle velocity for actual automobiles travelling around a test track at speeds varying from 15-50 mph (24-80 kph). Young (mean age: 22.2) observers tended to underestimate the speed of slowly moving vehicles (15 mph) and overestimate the speed of the most rapidly moving vehicle (50 mph). Older (mean age: 65.3) observers demonstrated a similar, but less severe, slow-underestimation/fast-overestimation bias. The resulting psychophysical functions suggested that older observers were less sensitive to relative changes in speed; but, at the same time, they demonstrated more accurate absolute judgements of speed at the two ends of the velocity range examined. Although the ability to make relative speed judgments in driving is clearly important, the role of absolute speed judgments remains less well understood. Staplin, Lococo, and Sim (1993) have recently completed a series of complementary simulation and field studies, which suggest that the perceptual basis of “time-to-collision” and “traffic gap acceptance judgments” changes significantly with advancing adult age.
Divided Visual Attention

In a recent series of reviews, Parasuraman and Nester (1991; 1993) have concluded that divided attention deficits play a major role in mediating age-related driving difficulties — especially among cognitively impaired drivers (e.g., those with dementia). Their analyses revealed that attention “switching” appeared to be the critical element linking clinical assessment to driving history. Emerging age-related problems in attention switching from one aspect of the driving environment to another is consistent with the difficulties older adults demonstrate in the “deallocation” and/or “reallocation” of attention in complex visual search tasks (Madden, 1992).

Ranney and Simmons (1992) recently investigated the effects of uncertainty upon age differences on a driving-related divided attention task. Middle-aged (ages 30-45) and older (ages 65-75) subjects drove a closed-circuit course with a simulated Y-intersection. Upon approaching the intersection, information was provided as to which fork-in-the-road to take. This information could come from either a changeable message sign (CMS) or from an arrow indicator located in an overhead traffic signal. The driver’s task was to report the prescribed direction by engaging the car’s turn signal (left or right) as quickly as possible. During some trials, the driver was informed as to which source would be providing the task-critical information (CMS or overhead traffic light). On other trials, no advance information was provided and the drivers had to divide their attention across both spatial locations. Although decision-time was slowed as a result of positional uncertainty for both age groups, the older drivers demonstrated significantly more slowing (16%) than their younger counterparts (11%). These results mirror the findings observed in the laboratory — viz., older adults demonstrate slower visual search times in complex environments. Positional uncertainty appears to exacerbate this emerging age-related deficit.

Ponds, Brouwer and van Wolffelar (1988) examined age differences in the ability to divide visual attention in a simulated driving task. The primary task measure was lane-keeping accuracy in a compensatory steering (“sidewinds”) driving simulation. The secondary task consisted of a rapid “dot counting” protocol in which either 7, 8, or 9 dots were presented in a 1 by 2 degree imaginary matrix, which was superimposed upon the simulator display. On half of the trials 8 dots were presented. Subjects responded — as quickly as possible — via a 2-position switch as to whether the pattern consisted of “8 dots” or “not 8 dots.” An interesting aspect of the Ponds, et al. study was that the difficulty level of each task, when performed in isolation, was matched to each individual’s unique capacity. That is, the difficulty of the steering task was manipulated to maintain 90% “time on target” accuracy for each individual. Whereas self-pacing was used to equate the information-processing load imposed by the dot-counting task. When drivers of different ages were tested in the dual-task condition, it was found that the introduction of the dot-counting task significantly reduced simulated driving performance in the old (mean age: 68.6) but not the young (mean age: 27.5) or middle-aged (mean age: 46.7) participants. Hence, older drivers appeared unable to absorb all the “costs” of divided attention. The authors speculated that this age-related simulated driving performance deficit emerged as the result of diminished “supervisory task control.” However, they offered an alternative explanation which has received some additional support in subsequent investigations – namely, that the elderly had excessive difficulty coordinating the two different motor programs required to execute the dual-task responses (steering versus button-pressing) into one smoothly operating motor plan. It would appear that an age-related problem due to a motor-level coordination
deficit would be much easier to compensate via engineering-based solutions than one resulting from an attention-level deficit.

Brouwer and his colleagues have performed a series of follow-up studies to the Ponds, et al. (1988) experiment, which have focused upon age-related problems in divided attention during simulated driving. Brouwer, Ickenroth, Ponds and van Wolffelaar (1990) repeated the Ponds, et al. study with a minor, but theoretically interesting, modification to the nature of the response in the secondary (dot-counting) task. Subjects made their response via a push button as in the original study or via a verbal response, which was processed by a voice-activated reaction time apparatus. Again, older subjects (mean age: 66.2) demonstrated declines in steering performance in the dual-task condition, and the young subjects (mean age: 30.2) did not. However, the size of the age-related reduction in steering accuracy under divided attention conditions was cut in half when a vocal response was required on the secondary task (as opposed to a manual response). Similar findings have been reported by van Wolffelaar, Brouwer, and Rothengatter (1991). This pattern of results suggests that both attentional (i.e., supervisory task control) and motor (i.e., dual-response coordination) deficits mediated the age-related performance problems in the Ponds, et al. (1988) study and that age-related deficits in driving performance may be offset somewhat by reducing the programming load of the motor channel. These findings appear to have great significance for the design of emerging IVHS interfaces, which must meet the needs of drivers without overloading the attentional capacity of the elderly. Experimental work in other domains also offers support for the potential gains in attentional efficiency among the elderly through the use of the voice channel in response selection and execution (see Salthouse, 1985).

Korteling (1994) has also performed a series of simulator-based studies exploring age differences in the dynamics of divided visual attention during driving. Young (mean age: 27) and older (mean age: 70) subjects performed a steering and car-following task in an advanced driving simulator. Since both of these component subtasks of driving are such “well learned skills” one would expect that they might not yield sufficiently sensitive indices for the assessment of age-related attentional declines. To increase the potential sensitivity of these measures a stimulus-response incompatibility was introduced. That is, during some driving sessions pressing the gas pedal increased acceleration (normal condition) but, in other sessions, its function was reversed — pressing down on the gas pedal caused deceleration (inverted condition). No age-group differences in performance were observed for the “normal” condition, but a fascinating pattern of age differences emerged for the “inverted” condition. The age-related deficit in performance was found only for the steering task — not for the car following task, which required the difficult compensation due to the reversal of a previously overlearned skill. The older drivers clearly tended to focus their attentional resources upon the compensatory activities required to meet the challenges imposed by the “impaired” operational subtask, but at the expense of another important subtask — visually guided steering. This result is somewhat surprising since contemporary attentional theory would suggest that well learned skills (such as steering a car) have become “automatized” and, hence, should be immune to performance deficits during competition for attentional resources. These findings are most intriguing and provide the foundation for the development of an operational/tactical-level theory of driving behavior in the elderly. Korteling’s group at the TNO Human Factors Research Institute (Soesterberg, The Netherlands) appears to be actively pursuing such an agenda.
Useful Field of View
The area of the visual field over which visual attention may operate at any given time (i.e., single fixation) has been shown to operationally decrease with advancing age. These findings have recently been generalized from the laboratory to the driving environment. Brouwer and Ponds (in press) have modified their divided attention simulator (described above) to include a tertiary peripheral search task. While operating the basic driving simulator, the subjects must monitor two areas located approximately 30 degrees to the left and right of the display midline. Arrows pointing to either the left or right are occasionally presented at these positions. The subject’s task is to detect and identify these arrows by pushing a “left” or “right” button (manual condition) or by verbally reporting their direction (voice condition). Older drivers failed to detect significantly more of the peripheral targets (7.2%) than their young counterparts (2%) during dual-task simulator driving. This finding is consistent with the assertion that the functional field of view in older adults becomes narrowed by the attentional demands of driving. Once again, however, the size of the age-related peripheral detection deficit was reduced when a voice rather than manual response was required. This suggests that motor program integration activities have substantial attentional costs among older drivers. [Note: Brouwer and Ponds also ran 3 Alzheimer’s patients on this task. While they could successfully steer the simulated vehicle — their peripheral detection scores were poor — namely, 50, 90, and 100% detection failures, respectively.]

Walker, Sedney and Mast (1992) had young (ages 20-25), middle-aged (ages 40-45) and older (ages 65-70) adults operate a part-task driving simulator in which the difficulty of the central tracking (i.e., steering) task was manipulated. The part-task simulator was augmented by full side and rear views of simulated driving scenes. In addition to maintaining performance upon the central tracking task, the subjects were also required to monitor their peripheral vision for the appearance of overtaking vehicles, which could appear on either the right or left side. Age-related declines for the point at which the overtaking vehicles could be detected were consistent with the hypothesized “narrowing of the useful field of view.” These age-related effects, however, appeared to be limited to the most difficult levels of the central task. No reductions in the useful field of view or effects of central task load were observed for the other two age groups. Once again, it appears that the attentional requirements associated with driving result in a “resource shortfall” for the older operator.

INTERVENTIONS AND FUTURE RESEARCH
Much work has begun to identify and develop approaches to “compensate” for the deleterious effects of visual aging upon driving mobility, safety and performance. Recent research sponsored by the Federal Highway Administration has contributed greatly toward increasing our understanding of how highway design might be improved to better meet the emerging needs of older drivers. There also exists a growing database within the automotive engineering community which addresses how vehicle design can be improved to better suit the changing sensory, perceptual and cognitive characteristics of the older population (see Schieber, 1994). These developments represent a good beginning toward the development of programmatic efforts which, hopefully, will evolve into future vehicle and highway systems which are truly “elder friendly”.

REFERENCES


