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Taxonomy of Older Driver Behaviors and Crash Risk

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16. Abstract

This project's objectives were to identify risky behaviors, driving habits, and exposure patterns that have been shown to increase the likelihood of crash involvement among older drivers; and to classify these crash-contributing factors according to a set of underlying functional deficits specific to, or more prevalent among, the older driver population. Such deficits may result from normal aging, age-related medical conditions, or medication use. A further goal was to identify and critically examine behavioral countermeasures with the potential to mitigate functional loss and/or diminish the occurrence of risky behaviors—and thus ameliorate crashes among older drivers.

The first task was an analysis of older driver injuries and fatalities using national databases (FARS, GES), to identify driving patterns, driving tasks, and contributing factors associated with crashes by older drivers; more details are available in a separate document, Report No. DOT HS 811 093, "Identifying Behaviors and Situations Associated With Increased Crash Risk for Older Drivers." Additional project tasks included a review of the literature describing age-related functional changes, and evaluations of existing behavioral countermeasures to reduce older drivers' crash risk; an expert panel meeting to supplement the information from the database analyses and literature review; and unstructured interviews with older drivers who have had crashes within the previous three years, and an age-matched group who have not had crashes within that period, to determine whether these groups differ in factors such as exposure or use of countermeasures.

The outcomes of these project activities were used to develop and refine a taxonomy table that captures critical relationships between topics and subtopics highlighted in the literature review and crash database analyses. This table identifies critical performance errors that underlie crash types where older drivers are most strongly overrepresented; the functional deficits that are implicated in causing such performance errors; and the countermeasure strategies that presently appear to hold the greatest promise to ameliorate or to accommodate those (age-related) deficits.

The taxonomy table is a resource that provides at-a-glance, state-of-the-knowledge information to assist researchers, health care practitioners, and others concerned about older driver safety to identify particular risk factors, and what can be done to reduce the risk. A hard copy version and an expanded, electronic version of this resource were developed.

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APPENDIX D: LITERATURE REVIEW

Effects of Functional Aging, Medical Conditions, and Medications on Driving Performance and Behavioral Countermeasures to Reduce Crash Risk

A Task Report for
Taxonomy of Older Driver Behaviors and Crash Risk
Contract DTNH22-05-D-05043, Task Order 008

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NHTSA does not endorse the prescription or use of any particular type or brand of medication mentioned in this report.

DIMINISHED SENSORY/PERCEPTUAL CAPABILITIES

To respond appropriately to all manner of stimuli in the roadway environment, a driver must first detect and recognize physical features of the roadway, traffic control devices, other vehicles, pedestrians, and a wide variety of other objects and potential hazards of a static and dynamic nature. On rare occasions, critical information concerning the presence or position of traffic may be conveyed through an auditory signal. In the vast majority of cases, however, the visual system is preeminent at this (input) stage of processing.

The classification of older individuals as visually impaired, from a human factors perspective, depends very much on the context of expected performance. For example, many individuals who are seriously affected by presbyopia (farsightedness), to the point of not being able to read without strong corrective lenses, may be relatively unaffected in viewing objects at a distance while driving. In another example, glare from ocular media scatter may pose serious problems at night, in rain, or in bright sunlight, but presents little difficulty on mildly overcast days. Nevertheless, a very high proportion of drivers 60 and older will show a serious limitation in visual performance under at least *some* typical driving conditions.

AN OVERVIEW OF CHANGES IN VISION WITH AGING

The visual sensory input system is a complex biological composite of optical and neural components, including the cornea, aqueous humor, iris, lens, vitreous body, and retina. All of these elements change with age in ways that interact with each other and cause deterioration of visual performance. However, the largest single factor contributing to declining visual performance in the non-pathologic eye is increased light absorption and scattering in the crystalline lens. A distant second as a contributing factor is deterioration in the structures of the retina and neural pathway.

The lens of the eye is a mechanically dynamic structure transparent to the visible spectrum, whose function is to focus an image clearly onto the neural retina where the process of seeing is initiated. Two well documented changes in the lens occur as a function of normal aging. First, the lens grows constantly thicker and less able to contract in the act of accommodation for focusing on near objects. Second, the lens becomes more yellow with age, indicating increased light absorption in a lens pigment that differentially absorbs short wavelength (blue) light. Neither the reduced ability to accommodate to near objects, nor the loss of color discrimination in the blue-yellow range carries consequences for driving that rival the formation of opacities in the lens, in the form of cataracts.

A cataract results when protein particles in the lens increase in size to the point of producing significant light scatter; it may develop relatively quickly, over 1 to 5 years. It is estimated that approximately 40% of people between 55 and 64 have identifiable lens opacities, and 5% have fully developed cataracts (Truscott, 2000). Approximately 50% of Americans 65 to 74 may have cataracts, as do approximately 90% of those75 and older (Kline, Kline, & Linton, 1992).

The major effect of the cataract is to back-reflect light and scatter it within the eye. This impairs acuity, contrast sensitivity, and color discrimination, especially under conditions of dim illumination or strong glare (Kline & Li, 2005). Clouded distance vision may occur, making it difficult to read highway signs on very bright days or at dusk. Kline and Li (2005) cite research that shows that the performance, safety, mobility, comfort, and driving habits of older drivers are affected adversely by cataract-induced visual loss. Owsley, Stalvey, Wells, and Sloane (1999) found that compared to older drivers without cataract (n=105, mean age 67), older drivers with cataract (n=279, mean age 71) were approximately 2 times more likely to report reductions in days driven and number of destinations per week, driving slower than the general traffic flow, and preferring someone else to drive. Those with cataract were 5 times more likely to have received advice about limiting their driving. Those with cataract were 4 times more likely to report difficulty with challenging driving situations, and those reporting driving difficulty were 2 times more likely to reduce their driving exposure. Drivers with cataract were 2.5 times more likely to have a history of at-fault crashes in the prior 5-year period (adjusted for miles driven per week and days driven per week). These associations remained even after adjusting for the confounding effects of age, impaired general health, mental status deficit, and depression.

Owsley, Stalvey, Wells, Sloane, and McGwin (2001) found that severe contrast sensitivity impairment due to cataract elevates at-fault crash risk among older drivers, even when present in only one eye. However, surgical replacement of the cataractous lens provides striking improvements in sight, which enhance older drivers' performance and safety. According to Kline and Li (2005), the relative benefits of treating cataracts unilaterly versus bilaterally have yet to be determined. Javitt (2002) expresses concern that unilateral cataract treatment usually results in good vision in one eye and poor vision in the other. The resultant impairment of depth perception that increases the likelihood of falls and fractures could also increase the risk for driving.

The retina is the multi-layered, innermost membrane of the eye that contains the initial neural substrate of vision, and is by far the most complex element of the visual system. Between 1 and 5% of people over 60 develop the pathological condition of senile macular degeneration (SMD), which is the leading cause of blindness in this age group (more people have glaucoma and cataracts, but fewer end up blind). Although people with age-related macular degeneration typically do not lose all of their sight, they may be incapable of reading road signs or be unable to see cars because of loss of central vision (Klein, 1991). Other important retinal pathologies include diabetic retinopathy and retinal artery and vein occlusions, all of which increase in frequency in old age. In diabetic retinopathy, contrast sensitivity may be affected, with losses across all spatial frequencies as retinopathy progresses (Klein, 1991). This process ultimately leads to vascular disorganization, hemorrhage and blindness.

Finally, a pathologic condition with relevance to driving found with increasing frequency among older people is high interocular pressure (IOP), leading to glaucoma. Glaucoma eventually results in destruction of optic nerve fibers and is the second leading cause of blindness in older patients. There is a gradual constriction in the peripheral visual field, which can result in a total loss of vision; however, the condition is painless and patients are often unaware that they are suffering any deficits in visual field. Drivers suffering from open-angle glaucoma and peripheral visual field loss may have difficulty seeing cars or pedestrians approaching from the side, and may show reduced contrast sensitivity (Klein, 1991).

Assessment techniques common to visual psychophysics provide a variety of tools that can be used to define the status of an intact visual system. Information provided by these functional assessments can then be evaluated in light of what is known of the relevant visual factors present in the driving situation. It is not always easy to make the connection between test performance and driving performance; the relative importance of performance factors such as image sharpness, glare, contrast, and color can vary enormously depending upon such factors in the driving environment as the presence of rain, wet surfaces, frost, night, twilight or daylight conditions.

These problems notwithstanding, functional tests in the following categories provide the best available information on performance of the aging visual system as it may relate to driving: (1) static visual acuity; (2) dynamic visual acuity; (3) contrast sensitivity; (4) visual fields; (5) depth and motion perception; and (6) dark adaptation and glare recovery functions. A seventh category—(7) color vision—is deemed of lesser importance to the driving task, but receives comment below. Accordingly, the following material will address each of the seven categories of visual performance named above, presenting evidence of age differences in functional capability and citing studies of the effects of such differences on driving performance.

STATIC VISUAL ACUITY

Since driving is a highly visual task, an expectation that the higher prevalence of visual problems and eye disease in older people will lead to driving difficulty is understandable. This assumption also provides a rationale for assessing visual acuity in (some) States for license renewal. However, while the ability to resolve stationary, sharply defined figures viewed in high contrast with their background is relatively easy to measure, and people with poor acuity are more likely to report difficulty or to restrict driving, static visual acuity statistically is not a strong predictor of crash involvement (Rubin, Ng, Bandeen-Roche, Keyl, Freeman, & West, 2007).

Letter acuity declines during adulthood and older adults' loss in acuity is accentuated under conditions of low contrast, low luminance, and where there is crowding of visual contours (Adams, Wong, Wong, & Gould, 1988; Sloane, Owsley, Nash, & Helms, 1987). Normal physiological causes for the decline in acuity include pupillary miosis and changes in the ocular media, which result in greater sensitivity to glare and a reduction in contrast sensitivity. Many of these changes can be remediated through increased illumination and optical correction. Several diseases also contribute to declining acuity, including cataracts, macular degeneration, and glaucoma.

With respect to driving, static visual acuity has consistently been found to have weak relationships to traffic crashes and convictions. For example, in a now-classic large sample study investigating the relationship between visual function and crash rate, Burg (1967) reported that the three static visual tests evaluated in their protocol had the second strongest relationship with crashes, with dynamic acuity having the strongest relationship. These three correlations, ranging from -0.053 to -0.129, were small but significant given the large sample size (n>17,000). In other smaller sample studies, Henderson and Burg (1974) found a significant relationship between static acuity and crash rates for younger drivers only (25 to 49).

In another study, Rogers and Janke (1992) compared the driving records of heavy-vehicle drivers whose vision was unimpaired, with the driving records of heavy-vehicle drivers who were found to have a deficit in static acuity. The visually-impaired group was further subdivided into those who were moderately impaired and those who were severely impaired. As a group, the visually-impaired drivers were found to have a higher incidence of crashes and convictions than the unimpaired drivers. However, the incidence of crashes for moderately-impaired and unimpaired drivers did not differ significantly, regardless of age. In fact, the older drivers in this sample had lower conviction and crash rates, despite their overall poorer visual acuity as a group. This points to the difficulty with drawing age-related conclusions based on age group averages.

Diller, Cook, Leonard, Reading, Dean, and Vernon (1999) found that 11,363 licensed drivers in the medical program in Utah with a history of eye conditions that may affect visual acuity had significantly higher rates of citations, crashes, and at-fault crashes than a comparison group of drivers who were not part of the medical program matched on age, gender, and county of residence. The relative risks for citations, crashes, and at-fault crashes were 1.35, 1.35, and 1.52 for unrestricted drivers, and 1.31, 1.42, and 1.56 for restricted drivers during the study period. The rates for citations, crashes, and at-fault crashes were significantly higher than those of the comparison drivers ($p<.05$).

Ruben et al. (2007) found no association between static acuity and future crashes in a population-based, prospective study, using 1,801 current drivers 65 to 85. Owsley, McGwin, and Ball (1998) found no significant relationship between impaired acuity (defined as resolution worse than 20/40) and injurious crash risk in an exploratory case-control study, using 193 drivers 55 to 87. Nor was a significant relationship found in their prospective cohort study with 3 years of follow-up crash data using 294 drivers 55 to 87 (Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 1998). Similarly, Keeffe, Jin, Weih, McCarty, and Taylor (2002) found no relationship between impaired vision (defined as visual acuity worse than 20/40) and self-reported crashes in a retrospective, population-based, case-control study using 2,594 drivers 44 to 101 years old.

By comparison, Ivers, Mitchell, and Cumming (1999) found that visual acuity in the right eye worse than 20/60 was significantly associated with self-reported crashes in the prior 12-month period. Their sample consisted of 2,326 drivers 49 to 80 and older. Sims, Owsley, Allman, Ball, and Smoot (1998) found that acuity was significantly correlated with State-recorded at-fault crashes at the univariate level in the prior 6 years, for a sample of 174 drivers 55 to 90. However, acuity failed to remain significant in the logistic regression model.

Two more studies conducted in the early 1990's have evaluated the relationship between static acuity and crash frequency in older drivers (Owsley, Ball, Sloane, Roenker, & Bruni, 1991; Ball, Owsley, Sloane, Roenker, & Bruni, 1993). In these studies, the subject population was stratified with respect to age group and crash frequency. Correlations between visual acuity and crash frequency varied in the two studies (r =0 and r=0.20, respectively). This variation was most likely a result of sampling differences, since the second study expanded on the first with a much larger sample size and less restriction of range within each of the independent variables.

With respect to the second study (Ball et al., 1993), one useful way of characterizing any particular predictor variable is in terms of its ability to identify drivers who have a history of crashes from those who do not. To determine whether a particular measure, such as static acuity, can adequately make this discrimination, the criteria for good and bad performance can be varied and drivers can be sorted into four categories: (1) those with "good" acuity and clean driving records; (2) those with "good" acuity and crashes on record; (3) those with "poor" acuity and clean driving records; and (4) those with "poor" acuity and crashes on record. Hits and false alarms can then be determined, where a hit represents the correct categorization of a crash-involved driver as at risk, and a false alarm represents the incorrect categorization or a crash-free driver as at risk. Using this procedure, no cutoff criterion in acuity was found that would place people in the high-risk category without including a significant number of crash-free drivers in this category as well. Thus, a particular acuity cutoff, as imposed in driver licensing, must be regarded as a somewhat arbitrary decision with regard to crash risk.

In fact, many have observed that this measure fails to represent the visual requirements of driving, and should not be expected to be strongly tied to crash involvement. Ball and Rebok (1994) argue that relationships between measures of visual sensitivity and driving performance have been weak, not because vision is unrelated to driving performance, but because the measurements of visual function that are used to diagnose ophthalmological disease require very little concentration or attentional demand, and because of the possibility that crashes result from the inability to attend to the visual information rather than a sensory deficit.

Other studies have linked visual acuity to other types of driving performance measures. In Marottoli, Richardson, Stowe, Miller, Brass, Cooney, and Tinetti's (1998) study of 125 community-living older people who were active drivers (77+), corrected near visual acuity worse than 20/40 was one of the factors independently associated with (self-reported) adverse driving events (crash, moving violation, being stopped by police during previous 5.75 years) in multivariate analyses adjusting for driving frequency (Risk Ratio = 11.9; 95% Confidence Interval 1.3 - 109.1).

In a study of 82 drivers (age 60 to 91) referred to California Department of Motor Vehicles (DMV), correlations between static acuity score (20/20, 20/80, and 20/200) and weighted errors on a driving test were not significant. However, correlations between static acuity response time at each level of acuity and weighted error scores on the driving test were as follows: 20/40 time: r=.34 ($p<.004$); 20/80 time: r=.42 ($p<.000$); 20/200 time: r=.20 ($p<.090$) (Janke & Eberhard, 1998; Janke & Hersch, 1997; Staplin, Gish, Decina, Lococo, & McKnight, 1998). In McKnight and McKnight's (1999) study of 407 drivers62 and older, static visual acuity (measured with Automated Psychophysical Test [APT]) was correlated (relatively low but significantly) with incidents of unsafe driving; correlations between incidents of unsafe driving and time to respond to the acuity stimuli (r=.28) were higher than acuity errors (r=.18). The study sample consisted of 253 drivers referred to the California DMV for re-examination based upon reports of deficient driving incidents received from police, families, and other observers, and 154 drivers not previously referred to the DMV (incident-free).

In a follow-up study of community-dwelling subjects 60 and older (Gallo, Rebok, & Lesikar, 1999), self-reported vision impairment was associated with driving status (those with vision impairment were more likely to be former drivers than current drivers) and with having adapted driving habits (those with vision impairment were more likely to avoid driving at night, in the rain, or in rush hour). However, self-reported visual impairment was not associated with reported adverse events while driving (citations or crashes in the prior 2-year period), which, as the study authors note, may reflect that older adults with vision impairment have limited their driving so that they are less likely to be involved in a crash. Visual impairment was determined based on the response to a self-report question on the survey. The question and responses were: *Which statement best describes your vision (wearing glasses or contact lenses)—no trouble seeing, a little trouble, or a lot of trouble*? Freund and Szinovacz (2002) also found that drivers with self-reported vision impairment were more likely to restrict driving to short distances or cease driving, than drivers with good vision. Self-assessment of vision was based on a question on how individuals judged their eyesight (with correction, if any). Answer categories ranged from 1 (excellent) to 5 (poor).

McGwin, Chapman, and Owsley (2000) found that visual acuity impairment of .21 logMAR or greater (slightly worse than 20/30) in the better eye in a sample of 384 drivers 55 to 85 was independently associated with self-reported difficulty driving in the following high-risk situations: in the rain, on the interstate, at night, on high-traffic roads, during rush hour, alone, and making left turns. In a study of 2,594 drivers age 44 to 101, Keeffe et al. (2002) reported that drivers 65 or older with impaired vision were significantly more likely than similarly impaired younger drivers to restrict their driving at nighttime, during peak hour, and in city areas. Although a greater percentage of older vision-impaired drivers than younger vision-impaired drivers restricted driving in bad weather or restricted their distance traveled, these differences were not significant. People with impaired vision were more likely to give impaired vision as the reason for stopping driving than giving another reason. The proportion of drivers who ceased driving and gave vision impairment as the reason increased as vision impairment worsened. Of those who stopped driving, 4.6% of those with acuity 20/40 or better cited vision as the reason. This increased to 33% for those with acuity less than 20/40 and 43% of those with acuity less than 20/60. The most frequent cause of vision impairment for the sample of 46 drivers with less than 20/40 acuity was refractive error (80%), followed by cataract (7%) and retinal disorders, including age-related macular degeneration (4%). The authors note that the refractive error of the majority of those with impaired vision was poorer than 20/40 but better than 20/60 (i.e., one line of acuity) and therefore likely correctable with an eye examination and an appropriate spectacle prescription. Similarly, those with cataracts could have their vision corrected with surgery, restoring acuity to better than 20/40 in most cases.

DYNAMIC VISUAL ACUITY

Dynamic visual acuity (DVA), like static acuity, also declines with age, with some suggestion that the age-related declines in DVA are larger than for static visual acuity (Burg, 1966). Dynamic acuity reflects the ability to resolve the details of a moving target; this measure of acuity is arguably more relevant to the actual demands of driving. Some activities that appear to rely on dynamic acuity are reading street signs while in motion, locating road boundaries when negotiating a turn, and making lateral lane changes. In these situations, greater speeds are associated with poorer DVA.

The earlier studies on driving and older people that have assessed both static and dynamic acuity have indeed found that DVA is more strongly associated with crash risk than static acuity. However, the statistically significant correlations between dynamic visual acuity and crash rate have also been consistently weak. For example, the correlation between DVA and crash rate for the older drivers, as reported by Hills and Burg (1977), was too low (r=0.054) to be of any practical significance for identifying at-risk drivers.

Burg (1964) made several points concerning dynamic visual acuity as it relates to the driving task. First, DVA becomes worse as target speed increases. Declines are noted when the lateral rate of the target approaches 20 degrees per second. Above 30 degrees per second, smooth eye pursuit becomes impossible and saccadic movements must be used to keep the target in central vision. Second, DVA improves with longer viewing time, brighter illumination, and practice. Third, DVA is best for foveal targets since all visual acuity deteriorates as targets are presented more eccentric to central vision (Shinar, McDowell, & Rockwell, 1977). Finally, DVA varies widely from one person to the next, and is frequently uncorrelated with static acuity.

Studies that have correlated the on-road driving performance of older subjects and dynamic acuity are described below.

Wood (2002) studied the effects of visual impairment and age on driving performance for 139 licensed drivers in 5 groups: 30 young drivers (mean age = 27 years) with normal ocular health and acuity at least 20/25; 25 middle-age drivers (mean age = 52 years) with normal ocular health and acuity at least 20/25; 37 older drivers (mean age = 69 years) with normal ocular health and acuity at least 20/25; 26 older drivers (mean age = 71 years) with mild ocular disease; and 21 older drivers (mean age = 71 years) with moderate to severe ocular disease. Those with ocular disease had at least 20/40 acuity. Mild ocular disease was defined as slight clouding of the crystalline lens (early cataracts), or very early glaucoma, or age-related macular degeneration in one or both eyes. Moderate to severe ocular disease was defined as nuclear sclerosis in both eyes, advanced glaucomatous cupping in one or both eyes, or significant age-related macular degeneration in one or both eyes. Measures of visual performance included static acuity, dynamic acuity, contrast sensitivity, disability glare, static and kinetic visual fields, and central motion sensitivity (dot motion in any of 4 directions). Driving performance was measured on a closed road course free of other vehicles and representative of rural roads. Tasks included road sign recognition, hazard recognition and avoidance, gap-width perception (perceptual judgment of whether a lateral gap defined by 2 cones was wide enough to drive through), a divided attention task (braking in response to LED illumination on the windshield), maneuvering in and out of 9 traffic cones, and parking maneuvering using the reverse gear. A composite driving score was derived from the scores on each task, using equal weighting.

Significant differences in dynamic and static acuity performance were found between the youngest driver group and each older driver group. Static acuity did not enter a stepwise linear regression model in which vision measures predicted overall driving performance. However, dynamic visual acuity was included as the last component in a model that predicted 50% of the variance in overall driving score, following measures of visual attention and contrast sensitivity.

In a study of 82 drivers (age 60 to 91) referred to California DMV, correlations between dynamic acuity score (20/20, 20/80, and 20/200) and weighted errors on a driving test were not significant. However, correlations between dynamic acuity response time at each level of acuity and weighted error scores on a driving exam were as follows: 20/40 time: r =.31 ($p<.010$); 20/80 time: r =.33 ($p<.005$); 20/200 time: r =.33 ($p<.004$). (See Janke & Eberhard; Staplin et al., 1998). In a study of 407 drivers 62 and older, correlations between dynamic visual acuity and incidents of unsafe driving were relatively low but significant; the correlation between incidents of unsafe driving and time to respond to the acuity stimuli was r=.19, as was the correlation between unsafe driving incidents and acuity errors (McKnight & McKnight, 1999).

Next, the loss of static and dynamic acuity can be used to predict the distance at which text of varying size can be read on highway signs, under a given set of viewing conditions (Kline & Fuchs, 1993). Uc, Rizzo, Anderson, Shi, and Dawson (2005) found that near and far visual acuity were significantly correlated with the percentage of road signs and commercial landmark signs identified by their sample of 170 older drivers in an on-road research study. However, acuity did not remain a significant predictor in the regression model.

Malfetti and Winter (1987) observed older drivers who stopped suddenly at unexpected times and in unexpected places, frequently either within the intersection or 40 ft (12 m) before the intersection, to read street signs. This was categorized as an unsafe behavior; it is confusing and disruptive to following traffic when the lead vehicle brakes for no apparent reason.

A field investigation of the effect of driver's age on nighttime legibility of highway signs indicated that older subjects perform substantially worse than younger subjects on a nighttime legibility task using a wide range of sign materials (Sivak, Olson, & Pastalan, 1981). When subjects in two age groups (under 25 and over 61) were matched on high luminance visual acuity, the demonstrated legibility distances for the older subjects were only 65 to 75% of those for the younger subjects. These researchers concluded that age-related performance decrements on nighttime legibility tasks are primarily the result of sensory (visual acuity) deficits, rather than shortcomings in higher information-processing (e.g., reading or comprehension) skills (Sivak & Olson, 1982).

CONTRAST SENSITIVITY

A primary function of the visual system is to process contrast information, which underlies our ability to see patterns in the environment. Contrast sensitivity tests measure the response to the full range of spatial frequencies, including not only sharply-defined, black-on-white targets—as in an acuity test—but also those that are grayer, and with less-distinct edges.

There has not been universal agreement concerning how aging affects spatial contrast sensitivity (Owsley & Burton, 1991). In general, older adults tend to have decreased contrast sensitivity, especially for higher spatial frequencies, and this loss is more pronounced at lower light levels (Sloane, Owsley & Alvarez, 1988; Sloane, Owsley, & Jackson, 1988) that can result in a heightened sensitivity to glare. There is also evidence that contrast sensitivity is the earliest visual function affected by glaucoma and that it correlates well with the progression of the disease (Szlyk, Taglia, Paliga, Edward, & Wilensky, 2002).

Using 900 subjects 55 to 80+ years old from the longitudinal epidemiological studies by the Buck Center for Aging in Novato, California, Brabyn, Haegerström-Portnoy, Schneck, and Lott (2000) found that by age 75, the median (50^{th} percentile) person requires at least twice the contrast in a scene to see as well as a younger person, and over age 90 the median person needs 6 times as much contrast. These results are based on use of the Pelli-Robson chart (Pelli, Robson, & Wilkins, 1988), and assume that lighting conditions are good.

McGwin, Chapman, and Owsley (2000) found that decreased (> 1.25 log units) contrast sensitivity in the better eye was independently associated with self-reported difficulty driving on high-traffic roads and making left turns in a sample of 384 drivers age 55 to 85. Results were adjusted for demographic characteristics (age and gender), driving exposure (weekly mileage), and cognitive status, as well as visual performance (acuity, contrast sensitivity, disability glare, and useful field of view).

As noted by Rubin et al. (2007), reduced contrast sensitivity is associated with poor driving performance, self-reported driving difficulty, self restriction, and prior crash involvement. Poor contrast sensitivity predicts future crashes, but the association is not significant after adjusting for miles driven and other predictors of crash involvement. In their large, population-based prospective study of visual impairment and crash risk, impairments in contrast sensitivity were not associated with crashes.

Owsley, Stalvey, Wells, Sloane, and McGwin (2001) conducted a cross-sectional analysis of 274 older drivers 55 to 85 with cataract and 103 older drivers free of cataract (age 55 to 79). They found that severe contrast sensitivity impairment due to cataract elevates at-fault crash risk among older drivers, even when present in only one eye. The association is twice as strong for impairment in both eyes. Three types of visual function were assessed: acuity, contrast sensitivity, and disability glare. Crash data for the 5 years prior to enrollment were obtained from State police records, and only at-fault crashes were included in the analyses.

Significant differences in all visual measures were found for crash-involved and non-crash involved drivers, in both the better eye and worse eye. For both the better and worse eye models, contrast sensitivity was independently associated with crash involvement, whereas visual acuity and disability glare were not. Drivers with a history of crash involvement were 8 times more likely to have a serious contrast sensitivity deficit in the worse eye (Pelli-Robson score of 1.25 or less) than those who were crash free (OR=7.86, 95% CI=1.55-39.79). The association was weaker for the better eye, but still statistically significant (OR=3.78, CI=1.15-12.48). Crash-involved drivers were 6 times more likely to have severe contrast sensitivity impairment in both eyes (OR=5.78, CI=1.87-17.86) than crash-free drivers. A severe contrast sensitivity deficit in only one eye was still significantly associated with crash involvement (OR=2.70, CI=1.16-6.51). Odds ratios were adjusted for age, sex, race, cognitive status, general health, and driving exposure. In this sample, crash-involved drivers were approximately 2.5 times more likely to have a cataract than were crash-free drivers. However, analyses including the three visual functions plus cataract group indicated that contrast sensitivity was the mediator of this effect; the association between cataract group and crash involvement became nonsignificant while contrast sensitivity remained statistically significant.

Earlier studies that have included contrast sensitivity as a predictor of driving crashes have shown that, while it is a slightly better predictor than acuity, the strength of the relationship is still relatively weak (Ball & Owsley, 1991; Owsley et al., 1991; Ball et al., 1993). Sims et al. (1998) found that although contrast sensitivity was significantly correlated with prior State-recorded at-fault crashes at the univariate level, it failed to remain significant in a logistic regression model.

In a study of 12,400 drivers age 16 to 75+ in Pennsylvania, who came to Photo ID centers for license renewal, Decina and Staplin (1993) failed to find a significant relationship between contrast sensitivity and crash rates in a 3.67-year retrospective study. Neither visual acuity nor horizontal field measures in isolation were significantly related to crash involvement. However, they did find that a composite measure including contrast sensitivity, binocular visual acuity, and horizontal field measurement was related to crash involvement for drivers 66 and older. Failure on the combined criteria that incorporates the current PennDOT standard (binocular acuity of 20/40 and horizontal visual field of 140 degrees) and a broadly defined contrast sensitivity criterion (scores below normal for 1 or more of the 3 spatial frequencies tested using Vistech contrast sensitivity gratings via an Optec 1000 vision tester) produced the strongest relationship linking poor vision and high crash involvement, especially for 66-75 and 76+ driver age groups (Decina & Staplin, 1993).

In Brown, Greaney, Mitchel, and Lee's (1993) study of 1,475 ITT Hartford Insurance Co. policyholders (age 50-80+) divided into two groups based on the presence or absence of recent at-fault crashes, the Pelli-Robson Letter Sensitivity Chart (a 48-letter test of contrast sensitivity at one spatial frequency) consistently yielded the highest correlation to crashes in the sample during 1989-1991 ($r = -0.11$, $p < 0.05$). The researchers noted that since contrast sensitivity was negatively correlated with age itself ($r = -0.40$), the relationship between performance on the Pelli-Robson chart and crash involvement was probably understated.

Contrasting results were found by Owsley, McGwin, and Ball (1998) in an exploratory retrospective case-control study of injurious crashes and eye disease. Impaired contrast sensitivity (defined in the study as a log contrast score of 1.5 or worse, measured on the Pelli-Robson chart) was not associated with injurious crashes in the prior 5-year period for the sample of 193 subjects age 55 to 87. Nor was a significant relationship found in their prospective cohort study with 3 years of follow-up crash data using 294 drivers age 55 to 87 (Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 1998). Similarly, Hennessy (1995) found that contrast sensitivity scores were not associated with prior 3-year crash involvement in the sample of 1,272 drivers 26 to 70 and older, when considered in isolation. However, for the group of drivers 70 and older who reported avoiding driving in heavy traffic, contrast sensitivity performance explained 5.3% of the variance in crash involvement. For drivers 26 to 39, contrast sensitivity performance explained 7.8% of the variance in crash involvement for the group that avoided driving heavy traffic, 6.9% for the group that avoided driving in the rain or fog, and 5.9% for the group that avoided making left turns.

Additional studies that have correlated older drivers' on-road performance with static contrast sensitivity are described in the following pages.

In a study to determine which functional abilities were most strongly related to the on-road driving performance of older drivers in Australia, contrast sensitivity was the only vision measure that independently predicted driving performance (Baldock, Mathias, McLean, & Berndt, 2007). In this study, 82 subjects recruited from the general community and 8 subjects recruited from a driving assessment rehabilitation client pool completed a 40- to 60-minute on-road test in traffic, with increasingly complex traffic patterns. A scoring system was developed that assigned higher weights to driver instructor interventions than to other hazardous errors and habitual errors. A weighting of 10 was given to instructor interventions (applying brakes, taking hold of the steering wheel, explicit verbal guidance). A weighting of 5 was given to "hazardous" errors such as exceeding the speed limit, inappropriate high speed, unsafe gap selection, unsafe positioning, disobeying stop signs or traffic lights. "Habitial" errors such as failure to check mirror or blind spots, failure to signal, inappropriate lane selection, and poor parking, were given a score of 1. The total weighted scores ranged from 18 to 443, with a mean of 117.6 (sd=78.3); the large range of scores and the large standard deviation indicate that the driving abilities of the sample varied widely. Subjects' acuity, contrast sensitivity, and visual fields were measured, in addition to visuospatial memory, visual attention, mental, and physical abilities.

The error score on the road test was significantly correlated with contrast sensitivity (r = -.33, p<.01), but not with any of the other visual (sensory) measures. Binocular contrast sensitivity of the sample ranged from 0.00 to 2.25. Age was also significantly correlated to driving performance, in addition to speed of information processing, visuospatial memory, and 9 measures of visual attention. In a regression analysis that included age along with the significantly correlated measures, contrast sensitivity remained significant (entering the model second), along with visual spatial memory and two measures of visual attention reaction time. These four measures explained 35% of the variance in driving ability. Age did not remain an independent predictor in the regression model. Therefore, drivers with better visual attention, better contrast sensitivity, and better visuospatial memory performed better on the on-road driving test (Baldock et al., 2007).

In Wood's (2002) study of visual impairment, age, and driving performance described earlier, Pelli-Robson letter contrast sensitivity emerged as a significant predictor of driving performance. Both driver age and the level of ocular disease significantly reduced contrast sensitivity. The youngest driver age group had significantly better contrast sensitivity scores than the older group with normal vision, and both older groups with ocular disease. The older normal vision group had significantly better contrast sensitivity than both older groups with ocular disease. Many of the drivers in the ocular disease groups had cataracts, which can significantly reduce letter contrast sensitivity. Contrast sensitivity emerged as the second highest correlation between visual function and overall driving score (r =.57), behind central dot motion (r =-.60).

In particular, the ability to recognize and avoid the road hazards was strongly affected by visual status, but not by age of the participants. The road hazards were 3.2- by 7.2-ft (1- by 2.2-m) sheets of 31-in (80-cm) thick grey foam rubber, placed on the roadway at 9 locations. They represented objects that were large relative to the resolution limits of the eye, but were of low contrast. The Wood (2002) study results indicate that older drivers with early ocular disease are likely to have significant problems with seeing and avoiding such hazards, which could include potholes, highway debris, speed bumps, pedestrians, and other vehicles, and when driving in poor visibility conditions such as rain or fog.

Szlyk et al. (2002) found that lower (worse) contrast sensitivity in the better eye in a sample of 25 glaucoma patients (mean age 57.4 years) was correlated with slower speeds, more lane boundary crossings, and longer braking response times in a driving simulator study. Patients had significantly worse contrast sensitivity than controls (mean in the better eye 1.58 versus 1.75), but their acuity performance was not significantly different. Acuity did not correlate with any simulator performance measures. Patients had a significantly smaller visual field than controls (mean 129 versus 140 degrees total peripheral extent with III-4-E target), but had considerable visual field remaining. Visual field loss did not correlate with simulator measures of performance.

In a study of 82 drivers (age 60 to 91) referred to the California Department of Motor Vehicles, static contrast sensitivity response time for the high contrast 20/80 target was significantly correlated (r = .39, p< .001) with weighted error score on the driving test (see Janke & Eberhard, 1998; Janke & Hersch, 1997; Staplin et al., 1998). In Janke and Eberhard's (1998) study of 102 "referred" subjects 60 to 91 years old (34 of whom were identified as probably being cognitively impaired to some degree) and 33 paid volunteers 56 to 85 years old, the correlation between Pelli-Robson errors and weighted error score on a road test was significant (r =.41, p<.0001) for combined referrals and volunteers. For the referral group only, the correlation between Pelli-Robson errors and weighted error score on the road test was also significant (r = .21, p<.044). In McKnight and McKnight's (1999) study of 407 drivers 62 and older, correlations between low contrast acuity (measured with APT) and incidents of unsafe driving were low but significant; correlations between on-the-road performance and time to respond to the low contrast acuity stimuli (r=.21) were higher than contrast sensitivity errors (r =.17).

Uc et al. (2005) found that contrast sensitivity was significantly correlated with detection of road signs and commercial landmark signs in an on-road study using 170 older drivers (r_s = 0.44, p<.0001). Subjects with better contrast sensitivity were able to identify a higher percentage of the signs than subjects with poorer contrast sensitivity. Contrast sensitivity remained significant in the regression model.

In a study conducted to determine whether age-related differences in the ability to read highway signs could be measured by contrast sensitivity performance, Evans and Ginsburg (1985) used their own test chart (i.e., Vistech VCTS 6500) to obtain binocular contrast sensitivity measurements of 13 younger observers (age 19 to 30) and seven older observers (age 55 to 79) at spatial frequencies of 0.75, 1.5, 3.0, 6.0, 12.0, and 24 cycles per degree (cpd), while also measuring Snellen visual acuity. Observers then performed a highway sign discrimination task requiring each observer to view a movie film projection of an approaching road sign designating either a cross (+) or T intersection. The dependent variable was the discrimination distance for correct responses. Results showed that the difference in road sign discrimination distance was statistically significant; older drivers had to be significantly closer to the highway sign to determine whether it denoted a cross or T intersection, with a 25% average discrimination distance between the younger and older groups. The older group showed significantly lower contrast sensitivity than the younger group at 3.0, 6.0, and 12.0 cpd; significant correlations between highway sign discrimination distance and contrast sensitivity were shown at 1.5 and 12 cpd. There was no significant difference between Snellen acuities of each age group, and no significant correlation between Snellen acuity and discrimination distance.

Aside from difficulties in the use of signing, problems for older drivers at intersections most likely to result from (age-related) deficits in spatial vision relate to the timely detection and recognition of pavement markings and delineation of curblines, medians, turning islands, and other intersection features. In a pertinent laboratory study, two groups of subjects (age 19 to 49 and 65 to 80) viewing a series of ascending and descending brightness delineation targets were asked to report when they could just detect a roadway heading (either left or right) from simulated distances of 100 and 200 ft (30.5 and 61 m) (Staplin, Lococo, & Sim, 1990). Results showed that the older driver group required a contrast of 20% higher than the younger driver group to achieve the discrimination task in this study.

The comparative abilities of younger and older drivers to recognize downstream pavement markings has also been modeled extensively using the DETECT and PCDETECT programs developed by the Ford Motor Company (Bhise, McMahan, & Farber, 1976). Analyses conducted for the Federal Highway Administration (Staplin et al., 1990) and for Transport Canada (ADI, 1991) using these computer models yield results consistent with related empirical studies: The age-related decline in spatial vision predicts delineation recognition ability for the best-performing quartile of the normative older (75+) driver population, which is roughly equivalent to the poorest-performing quartile of the youngest (18 to 35) driver group.

Dynamic contrast sensitivity has also been studied with respect to driving performance. In a study of 82 drivers (age 60 to 91) who were referred to the California Department of Motor Vehicles, the correlation between dynamic contrast sensitivity response time for the high contrast 20/80 target and weighted errors on the road test was significant (r =.25, p<.049). The stimuli in this study consisted of square wave gratings with vertical bars, with a rate of movement across the screen of 12 degrees per second (see Janke & Eberhard, 1998; Janke & Hersch, 1997; Staplin et al., 1998).

VISUAL FIELDS

First, it is crucial to distinguish reduced visual field size or sensitivity as a *sensory* function from the related component of visual attention commonly termed "useful field of view," for which reliable age differences have also been demonstrated. This distinction will be elaborated upon in a separate chapter addressing cognitive performance effects.

Visual sensitivity throughout the field of view is an ability adversely affected by the aging process that has been linked to driving performance and safety. It has long been established that the borders, or isopters, of the visual field are constricted with age; studies using automated, static-type perimetry have found that older adults exhibit a generalized loss in sensitivity throughout the central 30 degrees of the field, with a slightly greater sensitivity reduction in more peripheral areas (Jaffe, Alvarado, & Juster, 1986; Johnson, Adams, & Lewis, 1989).

Most of the earlier studies examining visual field sensitivity and crashes have failed to find a relationship between them (e.g., Henderson & Burg, 1974; Shinar et al., 1977; Waller, Gilbert, & Li, 1980). One exception is a large sample study (n=10,000) by Johnson and Keltner (1983) who found that the small subset of drivers with severe binocular visual field loss (mostly older drivers) had crash and conviction rates twice as high as those with normal visual fields. Similarly, Ball et al. (1993) reported that those with severe sensitivity loss in both eyes among a sample of 294 older drivers had twice the number of crashes as did those with normal visual field sensitivity. Additional insight is provided by a study in Sweden using a driving simulator, which documented large individual differences among subjects with visual field defects; detection capability was impaired, specifically, for test stimuli in the affected parts of the visual field (Lovsund, Hedin, & Tornros, 1991). An important conclusion is that the effect of a visual field loss on driving is strongly related to its location: defects in the central field are likely to be more important than peripheral defects, as are losses in the horizontal meridian.

In the most recent large population-based prospective study of visual fields and crash risk, Ruben et al. (2007) found a significant increase in crash risk, 1.31 times, for drivers exhibiting a binocular visual field loss of 20 points or more. The hazard ratio was adjusted for age, race, sex, cognitive status, education, comorbidities, living alone, and depression. Field losses in the lower peripheral region were the most important for predicting future crash involvement. Central and upper peripheral fields were not associated with crash risk. In this study of 1,801 current drivers age 65 to 85, visual fields were tested separately in each eye using the 81-point, single-intensity screening test strategy on the Humphrey Field Analyzer. State motor vehicle crash records were obtained for the 4-year follow-up period.

In an exploratory, retrospective case-control study of 193 drivers age 55 to 87, Owsley, McGwin, and Ball (1998) found that older drivers involved in injurious crashes were more likely to have impairment in visual field sensitivity. At the univariate level, the odds ratio was 2.6 (95% CI = 1.1-6.3) for a defect depth greater than 10 db in central visual field sensitivity. A similar effect was shown for impaired peripheral visual field sensitivity (OR=2.4, CI=1.3 to 4.5). However, visual field sensitivity failed to remain statistically significant in the multivariate logistic regression model. Nor was a significant relationship found in their prospective cohort study with 3 years of follow-up crash data using 294 drivers age 55 to 87 (Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 1998).

Interestingly, in the multivariate model run by Owsley, McGwin, and Ball (1998), glaucoma remained statistically significant, with cases 3.6 times more likely to report glaucoma than controls (CI=1.0-12.6). Glaucoma is often a manifestation of visual field sensitivity loss. McGwin, Owsley, and Ball (1998) also found that glaucoma was a potentially important predictor of State-recorded crashes in the prior 5-year period (Odds Ratio = 3.0, CI=0.8 to 11) in a sample of 278 drivers age 56 to 90. And in two earlier studies, the odds ratio associated with crashing for people with glaucoma was 1.5, and reached borderline significance (Foley, Wallace, & Eberhard, 1995; McCloskey, Koepsell, Wolf, & Buchner, 1994). In a panel data analysis by Hu, Trumble, Foley, Eberhard, and Wallace (1998) an association between glaucoma and highway crashes was found for older male drivers (OR=1.7).

Adler, Bauer, Rotunda, and Kuskowski (2005) interviewed a group of older male drivers with glaucoma (n=52, mean age = 73 years) and a control group of older drivers without glaucoma (n=147, mean age = 71 years) to learn about their driving habits and expectations about driving cessation. Ninety-eight percent of the cases had open-angle glaucoma, and for 67% of the cases, the disease affected both eyes. In the year prior to the study, significantly more drivers with glaucoma changed their driving habits at night (67% of cases versus 43% of controls), on freeways (46% of cases versus 24% of controls), and in unfamiliar areas (50% of cases versus 30% of controls) than controls. No group differences were found in changes to driving in rush hour, in bad weather, and driving alone.

At intersections, where safety problems for older drivers are well documented, an impact of reduced visual field size will be poorer peripheral detection of vehicles and pedestrians during merging and turning maneuvers. When the visual field is restricted, increased eye movement may be invoked as a compensatory strategy. When traffic signals are mounted to the right side of an intersection, drivers' eye movement distances from the signal to a crosswalk on the left must increase as the driver approaches the intersection in preparation for a left turn. Given older drivers' documented loss of range and flexibility of neck rotation, age-related decline in visual field size therefore may delay the detection of pedestrians, and increase the likelihood of maneuver errors at intersections.

Zhang, Baldwin, Munoz, Munro, Turano, Hassan, Lyketsos, Bandeen-Roche, and West (2007) found that older drivers (67 to 80+) with a binocular visual field loss of 10 points or more (Humphrey Field Analyzer II, Full Field 81-Point Test) had significantly slower brake reaction speeds, both in terms of initial reaction time and total reaction time than drivers without this deficit, independent of attention, age, and gender. The 1,039 subjects were licensees 67 and older in the vicinity of Salisbury, Maryland. The brake reaction test measured simple reaction time to move the foot from the accelerator to the brake when a green "traffic light" stimulus changed to red. Initial reaction time was measured from the time the signal turned red until the time there was a motor response (foot moving off the accelerator pedal).

Tarawneh, McCoy, Bishu, and Ballard (1993) included visual field measurements provided by a Keystone telebinocular testing device in a 2-year study of 105 drivers age 65 to 88 at the University of Nebraska, where a variety of mental, physical, and functional status indicators were used to account for variance in subjects' on-road driving performance, emphasizing intersection turning maneuvers. Driving performance was evaluated using the on-road Driving Performance Measurement (DPM) protocol developed at Michigan State University (Vanosdall & Rudisill, 1979). In this study, a driver education expert trained in the use of the DPM technique evaluated subjects' speed control, directional control, and visual search, as they drove in their own cars. The DPM route was a 12-mi (19-km) circuit designed to evaluate the subjects in the situations that are most often involved in the crashes of older drivers (e.g., left turns at intersections). Correlational analysis of the study's results revealed a significant relationship between right visual field size and driving performance (r = .22).

A simulator study of peripheral visual field loss and driving impairment that also examined the actual driving records of the study participants, and used multiple regression analyses to predict both simulator crashes and real-world crashes was carried out by Szlyk, Severing, and Fishman (1991). It was found that visual function factors (including acuity as well as visual field measures), could account for 26% and 6% of the variance in real-world and simulator crashes, respectively. When these factors were combined with simulator response indices, including deviation in lateral lane position, out-of-lane events, brake pedal pressure, and reaction distance, 71% of the variance in real-world crashes and 80% of the variance in simulator crashes could be accounted for in the study sample. Also, greater visual field loss was associated in the simulator data with greater distance traveled ("reaction distance") before responding to a peripheral stimulus (e.g., a stop sign).

While age was one variable according to which experimental and control groups were matched in this research, with both groups including participants ranging in age from their late 20s to late 60s, there was no attempt in this research to account for study outcomes in terms of age per se. Still, this study by Szlyk et al. is noteworthy in that subjects with peripheral field loss attempted to compensate through increased lateral eye movement; but this strategy is less likely to be applied effectively as a person advances in age beyond the range included in this study. A subsequent simulator study by Szlyk, Brigell, and Seiple (1993) that did incorporate age as an independent variable indicated that lateral and vertical head movements, but not eye movements, increased for patients with hemianopic visual field loss relative to an older, normally sighted group.

Wood et al. (1992; 1993; 1995) evaluated the impact of simulated visual field restriction on closed course driving performance in a series of papers. These studies suggest that simulated visual field impairment compromised some (e.g., identification of road signs, avoid obstacles, reaction time) but not all (e.g., speed estimation, stopping distance) aspects of driving performance. Lovsund and Hedin (1989), using a driving simulator, also reported that visual field defects impaired the detection of stimuli. It must be emphasized, however, that the impact of sudden, simulated visual field restriction is likely to be different from that of naturally occurring restriction from eye disease, in that drivers may develop compensatory mechanisms over time. Further, closed course or simulator driving is likely to be less complex and demanding than actual driving and may not allow for the observation of critical driving problems (e.g., crashes). Owsley (2004) reports that in several studies where real-world driving performance was assessed, drivers with visual field impairment were not at increased risk

DEPTH AND MOTION PERCEPTION

A driver's ability to use stereo (binocular) depth cues to perceive relative distances logically plays an important role in gap judgment and intersection safety. This ability appears to decrease with age (Bell, Wolf, & Bernholtz, 1972; Henderson & Burg, 1973, 1974; Shinar & Eberhard, 1976). A study by Staplin, Lococo, and Sim (1990) found that the angle of stereopsis (seconds of arc) required for a group of drivers age 75 and older to discriminate depth using a commercial vision tester was roughly twice as large as that needed for an 18- to 55-year-old group to achieve the same level of performance.

Ruben et al. (2007) found no association between stereoacuity and future crashes in a population-based study using 1,801 drivers age 65 to 85. In an exploratory, retrospective case-control study of 193 drivers age 55 to 87, Owsley, McGwin, and Ball (1998) found that older drivers involved in injurious crashes were more likely to have impairment in stereoacuity (500 arc seconds or worse). At the univariate level, the odds ratio was 2.2 (95% CI = 1.1-3.3). However, this predictor variable failed to remain statistically significant in the multivariate logistic regression model. Ivers et al. (1999) found that difference in acuity between the eyes was associated with self-reported crashes in the prior 12-month period, and suggest this may represent poor depth perception. In a study using a vision tester to measure depth perception, Tarawneh et al. (1993) demonstrated a significant correlation ($r = 0.35$) between this variable and intersection negotiation performance, using the DPM on-road evaluation protocol (Vanosdall & Rudisill, 1979).

McKnight, Shinar, and Hilburn (1985) studied the importance of retinal disparity— the difference between the images of the eyes—by comparing visual and driving performance of 40 monocular and 40 binocular tractor-trailer drivers. Monocular and binocular drivers differed on only one measure related to driving performance, that being the distance at which they were able to read road signs. Thus, retinal disparity may have only minor importance with respect to driving. In agreement with this, Owsley et al. (1991) found that the correlation between stereoacuity measured in the lab and vehicle crashes was insignificant ($r = .12$).

While accurate perception of distances and gaps is logically important for safe performance, researchers have placed a relatively greater emphasis on motion perception where dynamic stimuli—usually other vehicles—are the primary targets of interest. Motion perception is related to dynamic visual acuity (DVA); but unlike DVA, the perception of angular motion appears to be primarily limited by age-related deficits in neural mechanisms, rather than oculomotor ones (Shinar & Schieber, 1991). Shinar et al. (1977) have asserted that the ability to judge the distance between one's vehicle and other vehicles moving at approximately the same rate of speed is one of the most critical driving abilities.

Several investigators have addressed motion perception abilities pertinent to driving, including time-to-collision and gap-acceptance judgments. In time-to-collision (TTC) estimates drivers estimate how long it takes, moving at a constant speed, to reach specified points in their paths. They are hypothesized to be based either on an "optic-flow" process, in which the driver's analysis of the relative expansion rate of an image (such as an oncoming vehicle) over time provides the estimate of TTC directly (Gibson, 1966; Lee, 1974, 1976), or on a cognitive process in which TTC is estimated using speed and distance information. In the first case, the driver relies on two-dimensional information—that is, angular separation cues (the image gets larger)—to estimate TTC; in the second, the driver calculates TTC on the basis of three-dimensional information. Several studies (Schiff & Detwiler, 1979; Cavallo, Laya, & Laurent, 1986) have supported the optic-flow model and the idea that two-dimensional, angular separation cues, separate from background information suffice to allow drivers to estimate TTC.

De Raedt and Ponjaert-Kristoffersen (2000) found that older drivers' performance on a laboratory movement perception test was strongly and significantly correlated with overall road test performance (r=.73, p<.007). It explained 53% of the variance in global road test scores. Subjects were 84 individuals age 65 to 96 who were referred to a fitness-to-drive assessment center. Individual correlations between motion perception performance and specific observations during the road test that were significant were: anticipation (r=.65); perception and reaction to traffic signals (r=.59); understanding, perception, and quality of traffic participation (r=.68); and distance from car in front/adjusting distance appropriately (r=.70).

Relative to younger subjects, a possibly exponential decline for older subjects in the ability to detect angular movement has been reported. Using a simulated change in the separation of taillights, indicating the overtaking of a vehicle, a threshold elevation greater than 100% was shown for drivers age 70 to 75 versus those 20 to 29 for brief (0.3 second) exposures at night. In this study, older subjects required 3.1 min of arc for detection of motion, compared to younger subjects who required only 1.43 min of arc (Hills, 1975). Older people may in fact require twice the rate of movement to perceive that an object's motion-in-depth is approaching, given a brief (2.0 seconds) duration of exposure. In related experiments, older people required significantly longer to perceive that a vehicle was moving closer at constant speed: at 19 mph (31 km/h), decision times increased 0.5 second between ages 20 and 75 (Hills, 1975). The age effect was not significant when the vehicle was moving away from the subject.

Next, research has indicated that relative to younger subjects, older subjects underestimate approaching vehicle speeds (Hills & Johnson 1980). Specifically, Scialfa, Guzy, Liebowitz, Garvey, and Tyrrell (1991) showed that older adults tend to overestimate approaching vehicle velocities at lower speeds and underestimate at higher speeds, relative to younger adults. Furthermore, analysis of judgments of the "last possible safe moment" to cross in front of an oncoming vehicle has shown that older people (especially men) allowed the shortest time margins at 60 mph (96 km/h) approach speeds—older people accepted a gap to cross at an average constant *distance* of slightly less than 500 ft (152 m), whereas younger men allowed a constant *time* gap and, thus, increased distance at higher speeds.

In a driving simulator study, Yan, Radwan, and Guo (2007) evaluated the effects of age, gender, and major road speed on drivers' left turn gap acceptance judgments at stop-controlled intersections. The study sample included 28 younger subjects (20 to 30), 21 middle-aged subjects (31 to 55), and 14 older subjects (56 to 83). Subjects "drove" along the minor road and stopped at a stop sign at a major road, with approaching vehicle speeds of either 25 mph (40.2 km/h) or 55 mph (or 88.5 km/h). Vehicle gap sizes ranged from 1 to 16 s. The driver's task was to wait at the stop sign on the minor road for an appropriate gap to turn into on the major road.

In general, older drivers accepted larger gaps than young and middle-aged drivers, and females accepted larger gaps than males. Oncoming vehicle speed played an important role in gap size accepted by drivers, with drivers accepting smaller gaps for the higher major road approach speed than for the lower approach speed scenario. This implies that drivers show more sensitivity to oncoming vehicle distance than to oncoming vehicle approach speed.

An interaction effect between age and speed in the Yan et al. study showed that for the lower approach speed scenario, the older drivers accepted lager gaps than the young and middle-aged drivers; however, for the higher-speed approach, the minimum gaps accepted by the older drivers were not significantly larger than the younger drivers. This finding that older drivers did not select larger gaps than younger drivers at higher speed roads indicates that they rely principally on perceived distance to make gap acceptance judgments.

Finally, during the process of turning, older drivers turned the steering wheel slower and used smaller acceleration rates to achieve the major road traffic speed than young and middle-age drivers. The larger the gaps that drivers accepted, the slower their accelerations to turn onto the road, reflecting older drivers' conserving driving attitude. Speed reduction rates of following vehicles (to accommodate the turning vehicle) were higher for all driver ages when turning into higher-speed traffic than into lower- speed traffic. However, older drivers contributed to more speed reduction rates on the major road than young and middle-aged drivers, with older females causing the highest speed reduction rates of following vehicles. This puts them at a higher crash risk, because at the same time they are causing a shorter separation from the following vehicle, they are steering slower and accelerating slower than the younger drivers, and causing more effects on major road traffic. This suggests that at stop-controlled intersections, older drivers—in particular, older female drivers—are more likely to collide with speeding vehicles approaching on the major road.

Andersen and Enriquez (2006) found age-related differences in detecting collisions with moving objects, for conditions simulating a static observer as well as a moving observer. In this laboratory study, 11 younger subjects (mean age = 21 years) and 11 older subjects (mean age = 71 years) were presented with 3D scenes consisting of a roadway with a richly textured scene (but no buildings, vehicles, hills or trees). In the scene was a single object (a red dot that expanded in size as it got closer to the observer) that was either on a collision path with the observer, or on a non-collision path that would pass to the right or left of the observer. The observer's task was to indicate whether or not a collision would occur. In two experiments the observer was stationary and in 2 experiments the observer moved at a constant simulated velocity of 45 mph. Within each block of stationary versus moving observer trials, the display duration was either 1 s or 2.5 s. The simulated speed of the object was 30, 45, and 60 mph. TTC was varied by manipulating the initial distance of the object from the observer, simulating TTC of 2s, 3.5s or 5s.

Older observers had less sensitivity than younger drivers in detecting a collision, as TTC increases. Sensitivity in detecting a collision decreased with an increase in speed, with a greater decline for older observers than for younger observers. Increases in display duration (from 1 to 2.5 s) resulted in a slight improvement in sensitivity for older drivers, and a much larger increase in sensitivity for older observers, when the observer was stationary. In fact, younger observers showed no difference in sensitivity regardless of the presence or absence of observer motion.

For older observers, detection sensitivity was the same if they were moving versus stationary for the 30 mph condition, dropped slightly for the 45 mph condition, and dropped considerably for the 60 mph condition. This indicates that older observers had increased difficulty in detecting a collision when moving at higher speeds. Also, they had decreased sensitivity in detecting a collision at higher speeds despite increases in display duration from 1s to 2.5 s. Andersen and Enriquez (2006) note that the age-related decrements found in this study may underestimate the potential crash risk for older drivers in real-world settings with more complex and distracting scenes, and suggest that perceptual training on collision detection tasks may be a valuable intervention for minimizing risk and improving driving skill.

Failure to yield the right-of-way has been found to be a primary cause of older drivers' casualty accidents (Gebers, Romanowicz, & McKenzie, 1993). Hakamies-Blomqvist (1993) found the predominant type of accident for older drivers to be one in which one vehicle was crossing the path of another. One factor in crashes involving right-of-way violations when vehicles' paths are crossing may be a decline among older drivers in the ability to detect angular movement, as reported by Staplin and Lyles (1991). In an analysis of at-fault, police-reported crashes for 73 drivers age 35 to 54, 78 drivers 70 to 79, and 76 drivers 80 and older, Braitman, Kirley, Ferguson, and Chaudhary (2007) found that the most frequently occurring driver actions were failure to yield the right of way (40%). Failure-to-yield crashes increased with age, and accounted for more than half of the crashes involving drivers 80 and older. For drivers 70 to 79, failure-to-yield crashes generally occurred when drivers saw the other vehicles but misjudged whether there was enough time to proceed.

One promising finding in the literature is that practice, with or without feedback, was able to improve ability to detect movement of peripheral targets at eccentricities greater than 20 degrees (Johnson & Leibowitz, 1974). In this study, the effect of practice on movement thresholds was determined at nine stimulus locations in the horizontal meridian, from 0 to 80 degrees of eccentricity in 10-degree intervals, for the dominant (right) eye at an observation distance of 30 in (77 cm). Subjects' heads were positioned in a head and chin rest, and subjects were instructed to fixate on a stimulus centered directly ahead; trials during which eye movements occurred were disregarded. Four sessions were completed, with each session consisting of threshold determinations at each of the nine eccentricities presented in successive order from the fovea to 80 degrees. Subjects reported whether the stimulus moved to the left, to the right, or was stationary. Practice had no effect on movement thresholds in the fovea, but improved the detection of movement beyond 20 degrees of eccentricity. The major effect of practice occurred by the third session, beyond which, little improvement occurred. Notably, the effects of practice were still detected 3 months later. Because study subjects were four college students experienced in visual psychophysics, caution in generalizing study findings to older adult drivers may be warranted.

Johnson and Leibowitz (1974) note that the theoretical basis for improved peripheral discrimination with practice is not clear; it may be the result of learning to use a previously unpracticed sensory area or the result of learning to shift attention from central to peripheral parts of the visual field. Successive experiments with the same subjects to determine the effects of refraction and feedback on motion detection in the periphery found that the correction of refractive error produced the most profound effects (a dioptric influence), but practice and feedback improved movement detection for the uncorrected periphery (a neurological influence).

Thresholds obtained upon retesting at 3 months were similar to those obtained after the initial practice sessions, suggesting that practice effects may be longer lasting than feedback effects.

GLARE SENSITIVITY

At the same time aging reduces contrast sensitivity, the detrimental effect of glare—i.e., stray light within the eye that "veils" a visual target an observer is fixated upon—on a 70-year-old versus a 20-year-old driver increases by a factor of about two. Assuming that the effects of age and glare on contrast sensitivity are independent, older drivers are *very* much at a disadvantage in (night) driving situations in which glare is prevalent (Farber & Matle, 1989).

Glare is mostly debilitating to central vision, since this region is most sensitive to light and is instrumental for seeing detail (Henderson & Burg, 1974). At intersections, additional light from roadside sources and even traffic signals can create glare problems for older drivers. At relatively low pavement luminance levels, glare—or, more specifically, veiling luminance—can be treated as a contrast sensitivity reduction factor, and its effect can be compared with the direct effect of age on contrast sensitivity noted earlier.

Some researchers have found age-related declines for contrast sensitivity and static acuity in the presence of glare. However, age differences vary somewhat across studies, making it difficult to draw conclusions concerning aging and glare effects. Contrast sensitivity in the presence of glare remains relatively unaffected until the mid-to-late 40's; glare recovery follows a similar pattern (Burg, 1967). Shinar et al. (1977) measured acuity in the presence of both veiling and spot glare. These data suggested that significant differences do not appear as a function of age until around age 65.

The lack of consistency among studies may be due, in large part, to the extreme individual differences found in glare sensitivity. While pathologies such as cataracts and glaucoma may have only a small impact on acuity (depending on their location), they still may increase light scattering in the eye, resulting in increased glare effects (Shinar et al., 1977). In a sample of 35 older drivers with cataracts in one or both eyes, and acuity at least 20/40, Mäntyjärvi and Tuppurainen (1999) found that lines lost on the acuity chart ranged from 0 to 6 in the presence of high glare, and from 0 to 4 with medium glare. High brightness was 400 ft-lamberts, resembling lighting on a sunny day outdoors. Medium brightness was 100 ft-lamberts, resembling lighting on a cloudy day outdoors. None of the control subjects (11 older drivers without cataracts) lost any lines of acuity in either eye, under glare conditions.

Brabyn, Haegerström-Portnoy, Schneck, and Lott (2000) studied the visual performance of 900 subjects 55 and older from the longitudinal epidemiological studies by the Buck Center for Aging in Novato, California, found that people in the 90-plus age group take approximately 8 times as long to adapt to sudden changes in light levels as do those below age 65. Changes in light levels comparable to or greater than those used in their study may easily occur when driving into a tunnel or after being dazzled by oncoming headlights. The median recovery time of longer than 90 seconds for people in the oldest age group is a dangerously long time to have severely impaired vision for tasks such as driving.

Despite evidence that glare sensitivity and glare recovery are important age-related visual changes, and that many older drivers complain of glare when driving at night, evidence is sparse that glare is associated with actual driving performance. The most recent study on glare sensitivity and prospective crash involvement (up to 4 years) in a population-based study of 1,801 drivers age 65 to 84 showed that older drivers with 3 or more letters lost in the presence of glare on the Pelli-Robson chart were 2.32 times more likely to crash (Rubin et al. 2007). This association was significant after adjusting for age, race, sex, cognitive performance, education, comorbities, living alone, and depression. However, no relationship was found between disability glare and crashes in an earlier prospective cohort study with 3 years of follow-up crash data using 294 drivers age 55 to 87 (Owsley, Ball, McGwin, Sloane, Roenker, White, & Overley, 1998).

Burg's (1967) study and the reanalysis by Hills and Burg (1977) demonstrated a significant relationship between glare recovery rate and crash rate; however, the relationship was relatively weak. Headlight glare was attributed as a possible "environmental" factor in approximately 2.3% of night crashes in another study (Indiana University, 1975; cited in Mortimer, 1988). Glare was mentioned as a factor in 3 of 30 crashes where drivers ran off of the road, in a study by Boyce, Hochmuth, Meneguzzer, and Mortimer (1987; cited in Mortimer, 1988). Further, glare was named as a factor in 30 of 231 crashes in which adverse environment was involved (Sabey & Stoughton, 1975; cited in Mortimer, 1988). The time needed to recover from glare was also included in Burg's (1971) study, and was found to correlate weakly with crash rates. Other studies, however, have failed to find a direct relationship between glare sensitivity measures and driving performance (Shinar et al., 1977; Wolbarsht, 1977; Burg, 1967; Owsley et al., 1991).

Still other evidence suggests that glare tolerance in relation to driving performance declines with age. Henderson and Burg (1974) found that 50-year-old drivers who had the lowest 10% of visual acuity in the presence of veiling and spot glare had crash rates higher than that of the population mean. Pulling, Wolf, Sturgis, Vaillancourt, and Dolliver (1980) studied the acceptable level of oncoming headlight illuminance using a simulated driving task. Prior to age 70, performance slowly decreased and individual differences were large, but after age 70 the ability to tolerate glare decreased rapidly.

Puell, Palomo, Sánchez-Ramos, and Villena (2004) found that mesopic contrast sensitivity and glare sensitivity appear to be stable until age 50, from which point they start to decline at a rate of 0.1 log contrast sensitivity loss per decade. Also, mesopic contrast sensitivity was improved as photopic visual acuity increased, in the absence as well as in the presence of glare. Puell et al. (2004) tested the mesopic contrast sensitivity of 297 licensed drivers in Spain stratified into 6 age groups, under conditions of glare and no glare. The six age groups and number of participants was as follows: 21-30 (58); 31-40 (56); 41-50 (53); 51-60 (49); and 70 and older (33). Mesopic contrast sensitivity was measured by presenting a Landolt ring against a background luminance of 0.032 cd/m^2 without glare and 0.10 cd/m^2 with glare, corresponding to driving conditions at twilight or at night. The contrast of the Landolt ring can be decreased in steps of 0.10 log contrast sensitivity units. The most critical setting was the 1:5 contrast level, which is the critical level for driving a car at night, according to recommendations of the German Ophthalmic Society. Glare was set at 0.35 lux on the pupil, at a visual angle of 3 degrees. Disability glare was defined as the difference in contrast sensitivity in the absence and presence of a glare source and was expressed as log contrast units lost with glare.

Puell et al. (2004) found that the median contrast sensitivity without glare decreased 0.3 log units between the oldest and youngest age groups. With glare, the reduction was greater than 0.3 log units. The no-glare contrast sensitivity median decreased gradually from the 51-60 year group onwards, with the first 3 age groups being homogenous. Under glare conditions, the decrease started earlier, in the 41-50 group, and median values reached zero for subjects older than age 70, of whom 75% could not discriminate any contrast. Across the whole sample, 21% could not fulfill the contrast limit of 1:5 under no-glare conditions, while 41% could not fulfill the limit in the presence of glare. Focusing only on the two older age groups, 31% of those 61-70, and 64% of those 70 and older could not fulfill the contrast limit of 1:5 under no-glare conditions, while under glare conditions, 76% of the 61-70 group and 94% of the 70+ group failed to do so.

Puell et al. (2004) asked subjects whether they were habitual drivers (i.e., drove at least 6 days per week) and whether they avoided driving at night. Significantly fewer subjects age 61 to 70 and 70 and older drove habitually compared to those in the younger age groups, and significantly more drivers in the two oldest age groups avoided nighttime driving than the younger drivers. Poorer contrast sensitivity was associated with avoiding night driving without glare and with glare, but habitual driving and contrast sensitivity were only associated for glare conditions. The driving habits effect on contrast sensitivity was only statistically significant in the oldest age group.

Owens, Wood, and Owens (2007) reported on questionnaire responses obtained from the Wood and Owens (2005) study sample. Young and middle-age drivers reported night driving percentages that were 4 to 5 times higher than those for older drivers. The younger and middle-aged drivers also reported feeling more comfortable when driving at night, both in clear and in rainy weather. Older drivers rated glare from headlights to be more troublesome than younger and middle-aged drivers.

McGwin, Chapman, and Owsley (2000) found that impairment in acuity due to disability glare was associated with difficulty driving on high-traffic roads, during rush hour, alone, and making left-hand turns, when adjusting for age, gender, weekly mileage, and cognitive impairment, in a sample of 384 drivers age 55 to 85. However, after adjusting for visual characteristics (acuity, contrast sensitivity, and useful field of view), no areas of driving difficulty were associated with impaired acuity under disability glare.

COLOR VISION

A number of studies have documented a differential increase in blue-yellow errors as a function of age for subjects with no observable ocular pathology (Verriest, 1963, Verriest, van Laetham, & Uvijls, 1982; Knoblauch et al., 1986). In these studies, the mean error for naive subjects over 70 years of age is greater than 100, compared to a mean error score of 37 for the 20- to 30-age decade on the Farnsworth-Munsell 100-hue test. While the precise locus of this effect is unclear, studies of changes in color matching and wavelength discrimination performance suggest a minimal role for retinal factors in the age-related loss of blue-yellow discriminability (Ruddock, 1965; Moreland, 1978).

Driver performance studies that have examined the effects of age and color vision have keyed on motorists' responses to sign and signal elements. As one example, a laboratory study has shown that increasing driver age (in conjunction with greater numbers of signs and higher background complexity in a roadway scene) leads to increased error rates in the recognition and identification of traffic signs for the particular color combinations of white-on-green and white-on-black (Woltman, Stanton, & Stearns, 1984). Another study conducted to determine the impact of dimming traffic signals at intersections at night found that older people have reduced levels of sensitivity to intensity and contrast, but not to color (Freedman, Davit, Staplin & Breton, 1985).

Tests of color vision have been included in assessment batteries administered by Tarawneh et al. (1993), Brown et al. (1993), and Temple (1989), among others. Correlations of deficiencies in color vision with on-road driving performance were not significant and, where significant correlations with simulator performance could be demonstrated, findings have not suggested any practical consequence for performance of critical driving tasks at intersections. Color vision was not significantly correlated with older drivers' prior at-fault crashes in studies by Owsley et al. (1991) and Ball et al. (1993).

Thus, while age-related deficits in color sensitivity may account for a statistically significant portion of the variance in the conspicuity of selected traffic sign elements, there is no compelling reason to believe that older people will experience *operationally* significant differences in the overall ability to drive safely—at least for individuals who were not anomalous during their younger and middle-aged years—specifically as the result of deficits in color vision.

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DIMINISHED COGNITIVE CAPABILITIES

There is a broad distinction in the vast literature on cognitive functions and their assessment that must be taken into account in this review of how performance differences relate to safe driving for older versus younger people. Two major categories of cognition have been defined, one that pertains to *accumulated knowledge* (e.g., vocabulary, general knowledge, intelligence), and one that pertains to the *efficiency of acquiring, transforming, retaining, and applying new information*. The present focus is on measures of processing efficiency, which often show older adults to be at a disadvantage in relation to younger adults (Salthouse, 1990).

An overall slowing of mental processes has been postulated beginning as early as the fifth decade and accelerating for most individuals as they continue to age into their seventies and beyond (Cerella, 1985), and a decline has been demonstrated in a number of specific cognitive activities with high construct validity for predicting driving difficulties, particularly at intersections. The cognitive functions included in this processing stage perform attentional, decisional, and response selection functions most important to the safe performance of driving tasks at the "tactical" and "operational" levels (cf. Michon, 1979), under everyday operating conditions. At the same time, it must be noted that the degree of age-related decline in information processing ability also varies a great deal from one individual to another, among increasingly older cohorts; and, it is strongly affected by task variables.

Specifically, our interest is in age-related decrements in particular cognitive functions among the normatively aging population, which can be logically or empirically related to at-risk driving behavior. These include (1) working memory; (2) speed of processing; (3) pre-attentional and attentional processes—encompassing visual attention, selective attention, and divided attention; (4) executive functioning— higher-order cognitive processes like initiation, planning, hypothesis generation, cognitive flexibility, decision making, regulation, and judgment; and (5) visuospatial abilities, such as pattern perception and visualization of missing information. Except for a brief mention in relation to the latter functional ability, the consequences of dementia for driving are deferred to a separate chapter of this review.

WORKING MEMORY

Memory functions are constantly coming into play as drivers must remember the route they wish to follow, the information acquired from traffic control devices as an action is initiated, and the rules for expected behavior in specific situations, at a minimum. Memory is also important as a factor in other cognitive tasks, particularly "working memory," which allows the integration of continuous sensory information over time, the manipulation of information in memory for problem solving and decision making, and the division of attention between multiple, relevant sources of information such as an intersection control display and oncoming traffic. By comparison, the operational significance of demonstrated age differences in the commonly-distinguished categories of sensory (iconic), short-term (primary), and long-term (secondary) storage is less apparent. Pending successful registration of incoming sensory information, only gross deficits in the memory processes noted above are likely to disrupt vehicle control in familiar situations where drivers can rely on accumulated knowledge to perform overlearned responses. Accordingly, the vast literature on these memory processes is not reviewed herein.

Deficits in working memory have been related to crash and violation experience, and poor driving performance. In Staplin, Lococo, Gish, and Decina's (2003) study of 1,876 drivers age 55 and older who had just renewed their licenses, subjects who scored poorly on the cued-delayed recall test (2 out of 3 verbal stimuli recalled incorrectly after an intervening task) were 2.92 times more likely to be in an at-fault crash and 1.72 times more likely to be cited for a moving violation than older drivers who performed well on the test. Crash and violation history included 1 year of retrospective data and 20 months of prospective data. In an updated analysis from this sample that added 12 more months of prospective driving history, the odds ratio for crashing increased to 3.34 for drivers who performed poorly on the delayed recall measure (Staplin, Gish, & Wagner, 2003).

In a panel data analysis of 507 female drivers and 375 male drivers who participated in the Iowa 65+ Rural Health Study from 1981-1993, having impaired cognitive ability (low score on word recall test) was associated with a 40% increase in the likelihood of older males being involved in a crash (Hu, Trumble, Foley, Eberhard, & Wallace, 1998). Foley, Wallace, and Eberhard (1995) interviewed 1,791 drivers 65 and older, and found that drivers who could remember fewer than 3 of the 20 words given in a free-recall memory test had an increased crash risk (Relative Risk = 1.4, Confidence Interval: 1.1 to 1.9, $p< 0.05$).

Lee, Lee, Cameron, and Li-Tsang (2005) found that poor performance on a working memory task by older drivers (60 to 88) during simulated driving was significantly associated with self-reported crashes in the prior 1-year period. The working memory task in the interactive PC-based simulator (STISIM, System Technology Incorporated, Hawthorne, CA) required drivers to recall 5 street names and 5 maneuvers (turn left or right) after 10 minutes of simulated driving. Prior to beginning a drive, subjects were given 5 minutes to memorize the route to a fictitious park marked on a road map. In a logistic regression, the working memory measure, plus a measure of decision and judgment, a measure of speed compliance, and age correctly classified 87.7% of the 129 participants on the occurrence/nonoccurrence of self-reported crashes. The model had 82.3% specificity and 91.4% sensitivity. Each added point on the working memory scale was associated with a 45% decrease in risk, on the decision and judgment scale with a 61% decrease in risk, and on the speed compliance scale with a 17% decrease in risk. Each increase of 1 year in age could elevate crash risk by 13%. The decision and judgment measure assessed rapid decision and judgment under time pressure, and required drivers to avoid crashing into pedestrians 30 yards ahead running across the road hastily, a car parked on the roadside moving into the driver's lane without signaling, and a car in front of the driver suddenly slowing down.

In a study of 37 drivers 65 and older in a case group (those with license suspensions or crash involved) and 37 matched controls (no suspensions or crashes), cases had significantly lower immediate memory task performance ($p<.010$) compared to matched controls (Johansson, Bronge, Lundberg, Persson, Seideman, & Viitanen, 1996; Johansson, 1997). Immediate memory was tested by a 5-item delayed recall test, where the subject was required to name and recall 5 objects viewed on a desk after a 10-minute period. Comparison of the 23 case subjects with crashes and the 29 control subjects with no crashes in the past 5 years showed that the crashed drivers had poorer 5-item recall ($p<.003$).

In McKnight and McKnight's (1999) study of 407 drivers age 62 and older (split into incident-involved and non-incident-involved samples), measures of short-term and delayed short-term memory showed significant and fairly strong correlations between accuracy and unsafe driving (r^2=.28 and r^2=0.32, respectively for short-term and delayed short-term memory) and response time and unsafe driving (r^2=0.31 and r^2=0.28). This research used a battery of 22 visual, attentional, perceptual, cognitive, and psychomotor abilities, delivered using the Automated Psychophysical Test (APT). The other measures relevant to this discussion that correlated significantly with membership in the incident-involved sample included perceptual speed (r^2 = .28 for time and 0.22 for errors), selective attention (r^2=0.29 for time and 0.33 for errors), and divided attention (r^2=0.15 for time and 0.33 for errors).

Hunt, Morris, Edwards, and Wilson (1993) administered the Logical Memory subscale of the Wechsler Memory Scale, which assesses immediate or delayed recall of verbal ideas presented in two paragraphs, read aloud by the experimenter. Each subject then drove for 1 hour on a pre-designed route using urban streets and highways that included common driving situations (stop signs, traffic signals, left turns at intersections, entering and exiting an interstate highway, changing lanes, merging, diagonal and parallel parking). Subjects drove in low-volume conditions. A gestalt “pass/fail” rating was given by each observer in the vehicle. In a sample of 13 healthy older controls (mean age = 73.5) 12 subjects with very mild dementia (mean age = 72.5) and 13 subjects with mild dementia (mean age = 73.4), the correlation between the pass/fail outcome on the road test and performance on the Logical Memory test was significant at the $p<.0009$ level.

In a laboratory study evaluating the left-turn performance of older female drivers at intersections, a measure of working memory explained the largest variance in subjects’ decision time in choosing a gap to turn through oncoming traffic (Guerrier, Manivannan, & Nair, 1999). The working memory task involved mentally solving 5 sets of additions, where each set included 3, 2-digit numbers. The greater the working memory capacity, the longer the driver waited. The authors explain this (unexpected) finding by the possibility that those with better working memory capacity recognized a traffic pattern (e.g., larger gaps found later in the scenario) that resulted in the strategy to wait longer. Working memory also had an indirect effect (through its direct effect on decision time) on the size of the gap accepted, with better working memory performance associated with larger gaps. Subjects included 26 women age 61 to 84 years old.

SPEED OF PROCESSING

The construct of *working memory* signifies that the primary store is a place where information is operated upon. In other words, primary memory cannot simply be construed as a repository for information; it is also the unit that performs higher level cognitive functions. Clearly, an important factor influencing the performance of these functions is the speed with which information is processed. There is now a general consensus among investigators that older adults tend to process information more slowly than younger adults, and that this slowing not only transcends the slower reaction times often observed in older adults but may, in part, explain them (Waugh, Thomas, & Fozard, 1978; Salthouse & Somberg, 1982; Byrd, 1984).

Part of this general cognitive slowing seems to be attributed to an increase in the time it takes older adults to retrieve information from primary memory (Waugh et al., 1978; Hunt, 1978). Insofar as information in primary memory has a limited "lifespan," one would expect older adults to perform poorly on short-term memory tasks that require substantial attentional resources or on tasks that require the reorganization of to-be-remembered information. Thus, while there is no compelling evidence to suggest that older adults differ from younger adults in either the capacity of, or the rate with which information is lost from primary memory, older drivers will still be at greater risk in situations such as intersections that require rapid mental operations for appropriate vehicle control, especially when they are simultaneously required to perform such operations and retain other (e.g., navigational) information for future use.

Salthouse and Babcock (1991) reported that age-related variance in working memory function was largely accounted for by measures of comparison speed, suggesting that the fundamental mediator of age-related decline is speed, not working memory capacity. In a later study, Salthouse (1993) found that measures of perceptual speed accounted for 83% of the age-related variance in paired associate memory, and Salthouse (1994) reported that measures of perceptual speed accounted for 70 to 80% of the variance on measures of spatial rotation, matrix reasoning, and associative memory. The breadth of these findings attests to the generality of the speed mechanism in accounting for age-related decline in cognitive function. Lindenberger, Mayr, and Kliegl (1993) also found that even for a very older sample of adults, age-related variance on a range of cognitive tasks that included reasoning, memory, verbal fluency and verbal knowledge was mediated through speed. Finally, Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, and Gaines (1994) measured both speed and working memory and their relationship to three types of memory, using structural equation modeling techniques. They found that age-related variance was mediated through speed, and that working memory exerted a direct effect on other types of memory *only* when the task was highly-resource demanding.

In a sample of 1,235 drivers 26 to 70 and older renewing their licenses, Hennessy (1995) found that speed of processing deficits (measured using the Visual Attention Analyzer, Useful Field of View subtest 1) accelerated after age 70. In terms of crash prediction, when all age were combined, speed of processing was not significantly associated with crashes in the prior 3-year period. However, for drivers 70 and older, poor performance on the speed of processing subtest accounted for 2.8% of the variance in crash involvement ($p<.05$), without adjusting for demographic, exposure, or performance on other functional measures administered to the sample. After adjusting for age, gender, and driving exposure in the group of drivers 70 and older, performance on the speed of processing subtest accounted for 4.1% of the variance in crash involvement. Across all age groups, and looking only at drivers who failed the Department of Motor Vehicle Snellen acuity test, performance on the speed of processing test accounted for 8.4% of the variance in crash involvement, after adjusting for gender, age, and exposure. Poor performance on this measure was significantly associated with self restriction or avoidance of driving at night, in the rain or fog, at sunrise or sunset, alone, in heavy traffic, and making left turns. However, less than 5% of the variance in self restriction for any of these situations was explained by speed of processing performance or driver age.

For drivers 70 and older, Hennessy paradoxically observed that older drivers who have an impairment in visual attention *and* who (report that they) often or always avoid left turns, are *more likely* to be crash-involved compared to drivers *without* these functional limitations. This is interpreted by Hennessy as a reflection of what he terms the “inadequate compensation hypothesis,” whereby not only will older individuals be at increased risk, but behavioral compensation will be the least protective, when they experience worsening impairments of multiple (visual) abilities.

A measure of visual search ability (Trail-Making Part A) has been used frequently in driving performance research. Stutts, Stewart and Martell (1996, 1998) studied the association between Trails A performance and police-reported crashes in the 3-year period prior to assessment testing in a sample of 3,238 drivers 65 and older, who applied for renewal of North Carolina driver's license. The correlational coefficient with number of crashes, 0.065, was significant at the $p<0.001$ level. Subjects who scored in best quartile had 47% fewer crashes (.037 crash involvements per year) than drivers who scored in the worst quartile (.054 crash involvements per year). Lesikar, Gallo, Rebok, and Keyl (2002) found that older drivers who scored poorly on the Trails A Test (in the lowest tercile, or greater than 58.65 seconds) were 3.15 times more likely to be crash-involved in the following two-year period than drivers who scored in the highest terciles. Crashes were self-reported in this study.

Goode, Ball, Sloane, Roenker, Roth, Myers, and Owsley (1998) found that the Trails A time distinguished between 124 older drivers who had experienced one or more State recorded at-fault crashes in the prior 5-year period from 115 older drivers who were crash free, with a sensitivity of 57.3% and a specificity of 62.6%. In a study of 146 drivers 65 and older (mean age = 72.0), Keyl, Rebok, and Gallo (1997) found that those who performed poorly on the Trails A test (106 seconds or longer to complete) had an odds ratio of crashing (self-reported) in the prior 2 years. Keyl et al. (1997) also found that poor performance on the Brief Test of Attention—a measure of auditory selective attention—was associated with an odds of crashing of 4.90 in the prior 2-year period. Poor performance was defined as 11 or fewer correct responses out of 20 or non-completion of the test.

Lundberg, Hakamies-Blomqvist, Almkvist, and Johansson (1998) found that older, crash-involved drivers with suspended licenses (n=23) took significantly longer to complete the Trails A test than older, non-crash-involved drivers whose licenses had been suspended for violations (n=14) and older control drivers with clean driving records (n=31). The main crash types in this sample were violations of priority rules (e.g., running red lights, not yielding right-of-way rules, and not heeding stop signs). Assessments were conducted approximately 10 months following the crash.

Szlyk, Myers, Zhang, Wetzel, and Shapirio (2002) found performance on a speed of processing measure (the Digit Symbol Subtest of the Wechsler Adult Intelligence Scale-Revised) by a sample of 22 subjects 67 to 85 was significantly correlated with the number of lane boundary crossings in a driving simulator.

Hunt, Morris, Edwards, and Wilson (1993) found that the correlation between the pass/fail outcome on a road test and performance on Trails A was significant at the $p<.02$ level, in their sample of 13 healthy older controls (mean age = 73.5; CDR[1] score =0), 12 subjects with very mild dementia (mean age = 72.5; CDR score = 0.5), and 13 subjects with mild dementia (mean age = 73.4; CDR score = 1.0). The road test was conducted on a pre-designed route using urban streets and highways that included common driving situations (stop signs, traffic signals, left turns at intersections, entering and exiting an interstate highway, changing lanes, merging, diagonal and parallel parking). Subjects drove in low volume conditions, for approximately 1 hour. Five subjects—all in the CDR 1 stage—failed the in-car on-road test. The ability to follow the driving instructor's directions, the demonstration of appropriate decision-making

[1] Clinical Dementia Rating Scale

(‘judgment’) in traffic, and interpretation of traffic signs were highly correlated with overall driving performance. Other behaviors demonstrated by subjects who failed the in-car exam included coasting to a near stop in the midst of traffic, drifting into other lanes of traffic, stopping abruptly without cause, simultaneously pressing the brake and accelerator while driving, delay in changing lanes when an obstacle appeared, and failure to understand why other drivers signaled them in frustration or exaggeration. Zhang, Baldwin, Munoz, et al. (2007) found that older drivers (67 to 80 and older) with poorer scores on the Trails A test had slower perception-reaction times (PRT) as well as slower brake-movement times, in response to a computerized test where the task was to move the foot from the accelerator to the brake pedal when a traffic light turned from green to red. These researchers also found that poor scores on the Brief Test of Attention (a measure of auditory selective attention) were related to slower PRT and movement times.

Wikman and Summala (2005) found that older drivers had more total eyes-off-the-road time, made longer off-road glances (>2s), and had greater lateral vehicle displacement in the lane than young and middle-aged drivers, when required to perform an in-vehicle time-sharing task, and that these age effects were mediated by performance on the Trails A test. Subjects included 30 drivers in each of three age groups (20 to 24, 26to 44, and 57 to 73) who drove an instrumented vehicle on a 217 mi (350 km) trip consisting of divided 4-lane highways with speed limits of 75 mph (120 km/h) and undivided 2-lane highways with speed limits of 50 mph (80 km/h). Subjects performed 50 trials of an in-vehicle task while driving, where they pushed 8 buttons in numeric sequence, the position of which were randomized after each trial on half of the trials (simulating a multifunction touch-screen display) or verbally read out the 8 numbers from left to right and top to bottom (a vocal, as opposed to a manual keying response).

For the older drivers (but not for the other two age groups), the motor response almost doubled the time to complete the task and the number of glances needed, in comparison to the vocal response. Older drivers also showed 50 to 60% larger lateral displacement in lane position during the keying task, compared to the younger participants. Older participants did not substantially compensate their slowness by lowering their speed (e.g., there was no main effect of age on speed; they did slow down a few km/h while performing the keying task, in comparison to only reading the numbers on the display). The authors concluded that time-sharing ability in driving is dependent on cognitive performance level, which declines with age, and can be predicted with the Trail-Making test. In addition, because of their difficulties in controlling time sharing in highway driving, they should compensate for their decline in cognitive performance at the strategic level by avoiding self-imposed time sharing while driving.

PRE-ATTENTIONAL AND ATTENTIONAL PROCESSES

The following material addresses two complementary functions that are essential to safe driving performance, and that have been associated with significant age differences. The first, *selective attention*, involves the earliest stage of visual attention used to quickly capture and direct attention to the most salient events in a driving scene. Because of the vast quantity of information that is continuously available in the driving environment, the ability to selectively attend to information that is of primary relevance for maintaining driving function is key. The second, *divided attention*, pertains to the ability to monitor and respond effectively to multiple sources of information at the same time; for example, a driver entering a freeway must track the curvature of the ramp and steer appropriately, keep a safe distance behind the car ahead, and check for gaps in traffic on the highway, while at the same time accelerating just enough to permit a smooth entry into the traffic stream.

The most promising work addressing issues of selective attention and traffic safety arose, interestingly, from the general failure of earlier studies to find a reliable relationship between visual field sensitivity and motor vehicle crash experience (cf. Burg, 1968; Henderson & Burg, 1974; Waller, Gilbert, & Li, 1980). At the same time, investigators of age-related diminished capabilities, following reports of disproportionately high crash and violation rates for older drivers indicating specific problems with turning and merging maneuvers and failure-to-yield, especially at intersections noted that all these activities involve the processing of information from the peripheral visual field (Moore, Sedgley, & Sabey, 1982; Kline, 1986; Staplin & Lyles, 1991).

Driving, however, unlike conventional visual field sensitivity tests, involves complex scenes with moving and/or distracting stimuli, plus the necessity of constantly dividing one's attention between central and peripheral vision. Thus, a preferred paradigm for conducting research in this area has emerged—the "functional" or "useful" field of view (UFOV). Measures of this field involve the detection, localization and identification of targets against complex visual backgrounds (Verriest, Barca, Dubois-Poulsen, Houtmans, et al., 1983; Verriest, Barca, Calbria, Crick, et al., 1985). UFOV is also influenced by the presence of distractors or multiple stimuli in the field of view (Drury & Clement, 1978; Sekuler & Ball, 1986; Scialfa, Kline, Lyman, & Kosnik, 1987; Ball, Beard, Roenker, Miller, & Griggs, 1988), as well as the time available to process the display (Bergen & Julesz, 1983; Ball, Roenker, & Bruni, 1990).

Most importantly, tests assessing the useful field of view appear to be better predictors of driving problems than are standard visual field tests. In a meta-analysis of the relationship between useful field of view and driving performance in older adults Clay, Wadley, Edwards, Roth, Roenker, and Ball (2005) found that the relationship was robust across multiple indices of driving performance (State-recorded crashes, on-road driving, and driving simulator performance), and several research laboratories. Poorer performance on the useful field of view test is associated with negative driving outcomes.

One study examining State crash records for 53 (older) drivers who had been tested for visual/cognitive capabilities found that a composite predictor variable that included mental status and the size of the useful field of view (a measure of visual attention) accounted for 20% of the variance in crash frequency during the prior 5-year period, and 29% of the variance in intersection crashes specifically; this model was much stronger than predictions based only upon visual sensory function that excluded measures of information processing at higher levels (Owsley, Ball, Sloane, Roenker, & Bruni, 1991). In this study, drivers with restrictions in useful field of view had *15 times* more intersection crashes than those with normal visual attention, and the correlation between crash frequency and useful field of view exceeded $r = 0.55$ (Ball, Owsley, Sloane, Roenker, & Bruni, 1994). In an analysis of 278 drivers from this sample, McGwin, Owsley, and Ball (1998) found that the odds ratio for crashes for drivers with a 40% or more reduction in useful field of view was 13.7 compared to drivers with less than 40% reduction when the dependent measure was State-recorded crashes, and was 3.4 for self-reported crashes. Both odds ratios were statistically significant.

Owsley, McGwin, and Ball (1998) found that restricted Useful Field of View was a significant independent predictor of injurious crash risk in an exploratory retrospective case-control study, using 193 drivers age 55 to 87. In this study 115 subjects had experienced no crashes in the prior 5-year period, and 78 had experienced at least one vehicle crash in the prior 5-year period in which any person in any of the involved vehicles was injured, according to the crash report. Odds ratios for reductions in the useful field of view of 23 to 40%, 41-60%, and more than 60% were 4.2, 13.6, and 17.2, respectively, compared to reductions of less than 23%.

Goode et al. (1998) found that the useful field of view measure reliably distinguished between older drivers who had experienced one or more State recorded at-fault crashes in the prior 5-year period from older drivers who were crash free. Their sample was 239 drivers age 60 and older (mean 70.4), drawn from the Ball et al. (1994) study, 115 of who were crash free and 124 who were crash involved. The overall classification rate (for the standard 40% reduction score) was 85.4%, with a sensitivity of 86.3% and a specificity of 84.3%. Useful field of view had the highest level of sensitivity and specificity of all traditional neurocognitive indicators evaluated (mental status [MOMSSE], attention [Trails A and B], and visual memory [Rey-Osterrieth Complex Figures Test and the Visual Reproduction Subtest of the Wechsler Memory scale]), although each measure was significantly associated with crash status, and each measure was significantly correlated with useful field of view.

It must be reiterated that useful field of view research incorporates measures of selective attention, divided attention, and speed of visual information processing to arrive at an overall measure of performance. Since these measures depend upon information coming through a driver's visual sensory channel, people with serious visual loss are also likely to evidence serious impairment in useful field of view. The converse is not true, however; many adults who evidence impairments in useful field of view have normal visual fields; this measure is therefore a more comprehensive measure of information processing ability than visual sensory status alone.

The relationship between useful field of view and older driver performance was explored further in a simulator study conducted by Walker, Sedney, and Mast (1992). The age-related narrowing of the useful field of view was examined in this research using dynamic vehicle targets presented in realistic contexts on large-screen video systems, as opposed to the smaller CRT test monitor used by the applied vision researchers most active in developing this paradigm. A central tracking task of varying difficulty simulated the control tasks of driving, while vehicle images were introduced on the left and right periphery, and on a screen to the rear of the subject. Results indicated significant slowing of older (65 to 70) drivers' responses to peripheral targets as the effort required to perform the forward tracking task was increased, while no effect of central task loading was obtained for young (20 to 25) and middle-aged (40 to 45) drivers. Age differences in simple reaction time (RT) as an explanation of these results was subsequently ruled out, supporting the interpretation of significant narrowing of the useful field of view with age in a test protocol more closely representing the visual cues present during actual driving. The study authors, noting the strong predictive relationships between useful field of view and intersection crash involvement found in the literature (see Ball & Owsley, 1991), suggest that reduced useful field of view may contribute to the "looked, but didn't see" crash category. It is interesting to note that older drivers experience roughly the same proportion of lane-changing crashes as drivers in other age groups, but individuals over the age of 70 are twice as likely to be cited as at fault in this crash type (Monforton, Dumala, Yanik, & Richter, 1988).

De Raedt and Ponjaert-Kristoffersen (2000) found that the useful field of view test correlated significantly with global road test performance (*r*= -.66, p<.007), in a sample of 84 older people referred to a fitness-to-drive assessment center. It explained 44% of the variance in road test scores. Useful field of view performance was significantly correlated with the following items on the road test: tactical anticipatory behavior in changing situations (*r*= -.66); visual behavior and communication—e.g., eye/hand movements, and contact with other road users (r=-.60); and understanding, perception, and quality of traffic participation—e.g., insight, sense of context, and practical implementation (*r*=-.61). Useful field of view was one of four neuropsychological tests that remained significant in a forward stepwise regression model predicting total road test score, together that accounted for 64% of the variance. The other three tests measured constructs of motion perception, selective attention, and cognitive flexibility. The selective attention task used in this research involved a self-paced sustained selective attention task with visual scanning on a dynamic background (a moving road behind the stimuli), where the objective was to count 8, 9, or 10 dots appearing in the central field of view (the simple task condition of Brouwer's Tracking Dot-Counting task). Median reaction time of the correct responses was calculated. Selective attention with visual search correlated significantly with global road test score (*r*=0.44, p<.007). It accounted for 19% of the variance in the global road test scores. It correlated significantly with visual behavior and communication (*r*=-.43) and perception and reaction to traffic signals (*r*=-.37).

Myers, Ball, Kalina, Roth, and Goode (2000) included the useful field of view test in a clinical driving assessment battery to predict the on-road driving performance of 43 individuals (age 61-91) referred to an adapted driving program for evaluation of their ability to drive safely. The road test included a 10- to 15-minute warm up in a parking lot, followed by a 13-mile long drive on secondary roads, a suburban highway, a shopping center parking lot, and in downtown traffic. A driving instructor sat in the passenger seat to direct the participant along the course, and a driving evaluator sat in the back seat to rate the driver' performance. Both the instructor and evaluator were Certified Driver Rehabilitation Specialists. Study findings indicated that useful field of view performance, visual tracking, visual acuity, simple reaction time, split attention, and visual perceptual functioning were all significantly related to outcome on the driving test when examined individually. Useful field of view had the strongest relationship with driving test results, with an odds ratio of 13.43. Using a multiple linear regression model, useful field of view performance alone correctly classified on-road driving performance of 86% of the participants. Including all measures in the regression equation did not improve prediction of road test performance; only 6 participants (14%) were misclassified using useful field of view alone, whereas 9 participants (21%) were misclassified using all performance measures. In addition, the logistic regression model found that the risk of failing the road test increased linearly, with greater reductions in useful field of view indicating a higher risk of failing the road test. For useful field of view scores of 70% and greater, the probability of failing the road test was over 80%.

Wood (2002) employed a measure of the useful field of view in her study of young, middle-aged, and older drivers with normal visual function, and older drivers with mild and moderate visual impairment, as a predictor of on-road driving performance. The computer-generated task presented targets for 90 ms centrally and then peripherally. Participants were required to detect the central targets and at the same time, determine the location of the peripheral targets that were presented against either an empty field or a distractor array. The number of targets missed in the periphery was recorded. The on-road test score was a composite of the scores obtained on the following driving tasks: road sign recognition, hazard recognition and avoidance, gap-width perception, a divided attention task (braking in response to LED illumination on the windshield), maneuvering in and out of 9 traffic cones, and parking maneuvering using the reverse gear. The younger drivers made significantly fewer useful field of view peripheral detection errors (mean = 6.3) than the middle-aged (mean = 10.2) and older drivers (mean = 12.9) with normal eyesight, and both the older driver groups with vision impairment (mean= 13.7 for mild impairment and 13.8 for moderate impairment). Useful field of view also entered a linear regression model second to a measure of central motion sensitivity, followed by contrast sensitivity, and dynamic visual acuity that, together, accounted for 50% of the variance in overall driving score.

In a study to evaluate the associations between visual function and self-reported difficulty with driving tasks, McGwin, Chapman, and Owsley (2000) found that impairment in the Useful Field of View (e.g., a reduction of 40% or greater) was independently associated only with self-reported difficulty driving in the rain, in a sample of 384 drivers 55 to 85. Results were adjusted for demographic characteristics, miles driven per week, cognitive status, and visual characteristics.

Drivers' difficulties in the negotiation of intersections also may reflect the *divided* attention demands they face in such situations. Given the concurrent demands for lane selection, and vehicle control for path maintenance, plus vigilance for potential conflicts with other vehicles and pedestrians, it is important to highlight recent efforts to measure age differences in this critical cognitive activity.

Baldock et al. (2007) developed a measure similar to the useful field of view for their study, to measure visual attention in the presence of moving stimuli, as encountered in the road environment. The Computerized Visual Attention Test (CVAT) required participants to detect and react to targets in both central and peripheral vision, and was designed to measure selective and divided attention. Two reaction time measures from this test were highly correlated with on-road driving performance on a standardized test conducted by an occupational therapist from a driver assessment rehabilitation service and a driving instructor, and made significant, independent contributions to the prediction of driving ability: (1) a measure assessing selective and divided attention for stimuli in the peripheral visual field (r=.46, $p<.001$); and (2) a measure assessing simple visual attention for stimuli in the peripheral visual field (r=.35, $p<.001$).

Baldock et al. (2007) state that the study findings highlight the importance of being able to quickly detect stimuli in the visual periphery when driving, and suggest that visual attention is the most important ability for safe driving of older drivers, ahead of age and a large number of other functional abilities. Psychological measures (depression and state-trait anxiety), a physical measure (neck mobility), mental status (Mini-Mental Status Exam and Modified Mini Mental), total visual field, and visual acuity were not significantly correlated with on-road driving performance in this sample. Although a measure of processing speed (Symbol-Digit Modalities test) was significantly correlated with driving performance (r= -.32, $p<.01$), it was not independently associated and did not remain in the regression model. The only other functional measures that remained significant, independent predictors of driving performance (along with the two measures of visual attention from the CVAT) were binocular contrast sensitivity, and visuospatial memory; together these four measures explained 34% of the variance in driving ability, demonstrating the difficulty of developing measures for identifying at-risk drivers in the general community, as well as the complex nature of the driving task.

In a sample of 857 older drivers, Rubin, Ng, Bandeen-Roche, Keyl, Freeman, and West (2007) found that a reduction in the Useful Field of View of 40% or greater was associated with a 2.12 increase in crash risk in the following 2-year period (using State-recorded crashes, but not determining fault) compared with drivers with no loss, after adjustment for demographic and health-status variables (95% CI=1.32-3.39, p<.01). After adjustment for miles driven, the hazard ratio increased to 2.21 (95% CI=1.32-3.39, p<.01). Analyzing the three subtests of the useful field of view protocol separately, the strongest association was with divided attention (with a hazard ratio of 1.47, p=.0001). The hazard ratio for processing speed was 1.27 (p=.04) and for selection attention was 1.45 (p=.22). There was a significant ceiling effect for processing speed, with 77% of the participants exhibiting no loss, and a significant floor effect for selective attention, with 58% of the participants exhibiting maximum loss.

In a study of 1,876 drivers 55 and older who had just renewed their licenses, Staplin et al. (2003) found that older subjects who scored poorly on the useful field of view subtest that measures divided attention (i.e., those who took 300 msec or longer to complete the test) were 3.11 times more likely to be in an (at-fault) crash in the 20 months following assessment than older drivers who performed well on the test. Looking at 20 months of prospective driving history data plus 1 year of retrospective driving history data, drivers performing poorly on the useful field of view test of divided attention were 2.48 times more likely to be crash involved and 1.67 times more likely to be cited for a moving violation. In the updated crash analysis conducted by Staplin, Gish, and Wagner (2003) that added 12 more months of prospective crash data, the odds ratio for at-fault crashes was 2.23.

Edwards, Leonard, Lunsman, Dodson, Bradley, Myers, and Hubble (2008) found that older drivers with a history of (self-reported) at-fault crashes in the prior 2-year period performed significantly worse on the useful field of view divided attention subtest than older drivers without a history of crashes. The sample included a convenience sample of 119 drivers age 65 and older. The association was found after adjusting for miles driven. The mean time to complete the test for the 23 crash-involved drivers was 198.4 ms, compared to 108.7 ms for the 96 crash-free drivers. Interestingly, no correlation was found between performance on the divided attention task and self-perception of driving ability.

Owsley, Ball, McGwin, Sloane, Roenker, White, and Overley (1998) found that older drivers (55 to 87) with a 40% or greater impairment in their useful field of view were 2.2 times more likely to be crash involved in the 3-year period following useful field of view testing than drivers with less than a 40% reduction. This association was after adjusting for age, sex, race, chronic medical conditions, mental status, and days driven per week. Further analyses determined that that divided attention component of the useful field of view test was associated with a 2.3-fold increased crash risk; neither the selective attention nor the speed of processing component was significantly associated with crash experience. Visual processing variables that failed to be significantly associated with crashes in this study were visual acuity, contrast sensitivity, depth perception, central and peripheral visual field sensitivity, and disability glare. However, older drivers who reported driving fewer than 7 days per week had a 45% decreased crash risk compared with those who reported driving daily. The sample included 294 community-dwelling licensed drivers. The majority of crashes (70%) involved failure to yield the right of way, failure to heed a stop signal, or misjudgment of stopping distance.

Hoffman, Atchley, McDowd, and Dubinsky (2005) also found that the divided attention subtask, but not the selective attention or the processing speed subtasks of the useful field of view test, was a unique significant predictor of simulator driving impairment in a study of 155 older adults, tested in the STISIM. Together, the three useful field of view subtests accounted for 34% of the variance in driving impairment. Subjects in the Hoffman et al. (2005) study were not selected based on prior crash history or greater visual impairment, and results may be more generalizable to the overall population of older adults. A receiver-operator characteristic curve for predicting simulator driver impairment found the best sensitivity rate of 85% at the cost of 48% false positives.

In Hennessy's (1995) study of 1,235 drivers 26 to 70 and older renewing their licenses, performance on the divided attention subtest of the Visual Attention Analyzer Useful Field of View test was not significantly associated with crashes in the prior 3-year period, when considering all age groups. However, for drivers 70 and older, poor performance on the divided attention subtest accounted for 2.3% of the variance in crash involvement ($p<.05$), without adjusting for demographic, exposure, or performance on other functional measures administered to the sample. After adjusting for age, gender, and driving exposure in the group of drivers 70 and older, performance on the divided attention subtest accounted for 4.3% of the variance in crash involvement. Poor performance on this measure was significantly associated with self restriction or avoidance of driving in the rain or fog, and at sunrise or sunset (accounting for 5% or more of the difference in divided attention ability or age) as well as when driving alone, in heavy traffic, and making left turns (with less than 5% of the variance in self restriction for any of these situations explained by divided attention performance or driver age). However, divided attention predictive values (percent of variance in crash involvement accounted for) were not moderated by any form of self restriction.

Wood (2002) employed a divided attention task as part of an on-road, closed-course driving evaluation, which required drivers to press the brake pedal as quickly as possible when any of the 5 LEDs mounted on the windshield at the driver's eye level were illuminated. Each LED was illuminated 3 times during the 3 mi (5 km) test circuit. Performance on the divided attention task was affected by age: the older participants saw significantly fewer targets (mean age= 7.3) than did the younger (mean age = 11.5) and middle-aged participants (mean age=10.2).

Driving simulation studies with two continuous performance tasks—a compensatory lane-tracking task and a (self-paced) visual choice reaction time task—have been performed at the Traffic Research Centre in The Netherlands. Researchers in this laboratory took the important step of controlling for impairments already present at the single-task level. That is, single task difficulty was adjusted to stable and equivalent levels for younger and older subjects before initiating experiments on allocation-of-resources effects under divided-attention conditions. One notable experiment was conducted by Ponds, Brouwer, and van Wolffelaar (1988). For their tracking task, in which subjects used the steering wheel to compensate for "sidewinds" that pushed the vehicle away from a straight-ahead heading, a time-on-target (TOT) score was the dependent measure, defined as the time the subject's car was wholly within its lane boundaries. For the visual reaction time task, subjects had to count the number of dots in a randomly generated array superimposed within a predefined rectangular area in their forward field of view;

either 9 dots out of 40 possible locations were filled in (50% of cases) or 8 or 10 dots (25% of cases each) on a trial, with counting accuracy as the dependent variable on this self-paced task. A new dot array was presented as soon as the subject had performed a “9” versus “not 9” choice to the previous array, separated by a 500 milliseconds visual masking stimulus. Subjects' resource allocation between the two tasks was governed by verbal instructions within separate blocks of test trials, according to five different strategies: concentrate solely on tracking, emphasize tracking, give equal attention to tracking and dot counting, emphasize dot counting, and concentrate solely on dot counting.

The Ponds et al. (1988) study constructed performance-operating-characteristic (POC) curves based on the results obtained under each resource allocation strategy, where performance in one task is plotted as a function of performance on the other task, for each block of test trials. Differences between POCs thus represent differences in divided attention ability. This analysis revealed a clear decline in dual task performance for older (mean age = 68.6) versus younger (mean age = 27.5) and middle-aged (mean age = 46.7) subjects, manifested principally through larger performance decrements on the tracking task. This outcome is explained in part as reflecting the self-paced nature of the visual choice task. Assuming that both of these adaptive, continuous tasks compete for the same attentional resources (cf. Wickens, 1984), these results are important in establishing an empirical basis for the reports of exaggerated difficulties for older drivers in divided attention conditions, and particularly at intersections.

A follow-on study by Brouwer, Waterink, van Wolffelaar, and Rothengatter (1991) sought the locus of the divided attentional impairment reported above. Since the response mode for the visual discrimination task was a button-push, and since it has been documented that aging particularly affects the integration of motor skills (Korteling, 1991), Brouwer et al. (1991) replicated the earlier work using an additional, vocal response mode for this task. The tracking task remained as described above. Using correct dot counts and time on target measures, as noted earlier, these researchers again plotted POC curves. Divided attention deficits for older subjects due principally to tracking task impairments were again indicated, and differences between young and old subjects were larger when they responded manually (button-push) on the dot-counting task than when they responded vocally (though vocal responding led to more errors). This finding supported the hypothesis that response integration may play a significant role in age-related divided attention deficits associated with performance of (simulated) driving tasks.

Brouwer, Ickenroth, Ponds, and van Wolffelaar (1990) varied this research methodology such that the dot array in the self-paced visual choice task was presented peripherally as well as in the driver's central field of view. This study was prompted by the observation that their initial effort left out one key component of divided attention demands under actual driving conditions: active visual search for information at unpredictable locations. According to other investigators (Plude & Hoyer, 1985), and as documented earlier in this review, the efficiency of visual search processes is especially age-sensitive. Brouwer et al. (1990) found that varying the resource allocation strategy (via instructions) did not influence older drivers on the dot-counting task for centrally-presented patterns, but had a significant effect for peripheral stimuli. The shifting allocation strategies presumably affected the extent of active visual search (i.e., involving eye movements). This finding suggests that if drivers must increase their attention to—for example—an unfamiliar roadway feature downstream to make appropriate maneuver decisions during an intersection approach, an impairment in the discrimination of peripheral targets is likely.

Another perspective on this problem is provided by attempts to measure the mental workload imposed upon vehicle operators under varying traffic conditions. As attentional demands for varying driving tasks shift according to situation, increase in task loading may produce few or no measurable increases in error rates as the operator allocates more resources to the task in question. At some point, when all available resources are allocated, a sharp increase in errors results from further task loading. At low levels of load, an individual's resources not committed to a task represent “spare capacity.” In describing age differences in attentional ability related to safe performance at intersections, it would clearly be useful to establish the level of demand that can be met before the “break point” in error rate occurs. By requiring the operator to perform a subsidiary task that uses unallocated attentional resources, estimates of both spare capacity and primary task load can be derived. A field study of subsidiary task measures in driver loading is noteworthy in this regard (Zeitlin, 1993).

The Zeitlin (1993) study built upon earlier work (Zeitlin & Finkelman, 1975) indicating delayed digit recall and random digit generation, using oral responses, to be appropriate subsidiary tasks for driver workload measurement, according to these criteria: (1) minimal interaction with the primary task; (2) greater performance degradation as a function of decreased capacity than the primary task; and (3) monotonic or predictable changes in performance as a function of spare capacity. Data reported by Zeitlin (1993) were collected over a 4-year period for van pool drivers commuting from upstate New York to New York City while traversing a mix of rural secondary roads, limited access highways and expressways, urban arterials, and city streets. During a 2-minute test period on both inbound and outbound commutes, subjects performed each subsidiary task under conditions of varying primary task difficulty. The primary driving task difficulty was gauged in terms of speed and traffic density, the frequency of brake applications by the driver, and subjective ratings of driving difficulty. A workload index calculated by dividing the number of brake actuations by the square root of speed—a composite measure of steady state and transient driving conditions—was correlated highly (r =.83) with errors on the digit recall task. In addition, the digit recall task correlated highly (r =.62) with rated driving difficulty. This convergence supported the author's assertion that the digit recall subsidiary task can provide a good measure of spare capacity and can be used to infer primary task workload.

While the study reported by Zeitlin (1993) did not examine age differences, specifically, it deserves mention in this review because of the indicated sensitivity of the working memory measure (delayed digit recall) to concurrent attentional demand *under actual driving conditions*. The construct of working memory (cf. Salthouse, 1990), which incorporates the allocation and control of attentional capacities (Baddeley, 1986), is a dominant theoretical framework guiding research on age differences in cognition. Baddeley (1986) has characterized working memory as “a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks.” An age-related limitation in the information processing capability of working memory is the central tenet of much of the work that demonstrates a decline by older subjects on cognitive tasks, including the selective attention and divided attention processes cited above as crucial to safe intersection negotiation.

Pietras, Shi, Lee, and Rizzo (2006) found that older drivers with selective attention deficits had shorter TTC values (5.60 s versus 6.86 s), took longer to cross the roadway (5.42 s versus 4.84 s), and had shorter safety cushions (the difference between TTC and time to cross the roadway) than older drivers with no impairment in their selective attention capabilities. Selective attention was assessed for 20 community-dwelling older drivers with the useful field of view subtest 3 and 4 of the Visual Attention Analyzer, Model 3000. Their traffic entry judgments were made from an instrumented vehicle parked in an entry driveway perpendicular to a busy two-way, 4-lane highway. Oncoming traffic entered the view of the participant approximately 1,000 feet away, and drivers were asked to press a button to mark the last possible moment that he or she would cross the road in front of a specific oncoming vehicle, for 10 trials. Despite their differences in selective attention abilities, the 10 drivers with impaired selective attention and the 10 drivers without deficits in this ability were significantly different only in their Trails B test completion time. There were no differences in their visuoconstructive abilities, working memory, fine motor control, gross motor control, contrast sensitivity, acuity, 3D structure from motion, or driving exposure. A simulation model was run to determine crash risk for an approaching vehicle speed of 45 mph, under 2 assumptions—the approaching vehicle maintains a constant speed (does not brake), and the approaching vehicle reacts with a 0.3-g deceleration. In the situation where the approaching vehicle does not brake, drivers with impairments in selective attention are 6.8 times as likely to crash compared to drivers without selective attention impairments. In the situation where the approaching vehicle brakes (i.e., compensates for short time-to-contact values), drivers with impaired selective attention deficits are 17.9 times more likely to crash than non-impaired drivers.

In Richardson and Marottoli's (2003) study of 35 community-dwelling drivers 72 and older, significant correlations were found between performance on an on-road driving test and measures of visual attention (measured with the number cancellation task, r=.43), executive function (measured with the Trail-Making Test Part B, r= -.38), and visual memory (measured with the Visual Reproduction subtest of the WMS-R, r=.40). Drivers with poor visual attention scored poorly on 25 of the 36 specific driving behaviors scored during the road test including: scanning the environment (scanning from side to side); interaction with traffic and/or pedestrians (yielding the right of way, responding to other vehicles or pedestrians, using directional signals, making turns in an intersection), vehicle positioning and control (centers car in lane, positions car for turns, proper lane selection, appropriate steering recovery, exiting, merging, and lane changing), monitoring speed and judging distances appropriately (gas-to-brake response time, following at a safe distance), decision making, and attitudes and emotions. Visual memory was associated with 16 maneuvers and executive function with 17 maneuvers, all overlapping with visual attention, with the exception of when and at what speed to enter highways. Visual attention accounted for 18% of the variance on the road test. The driving behaviors with the highest relationship to visual attention involved interactions with other vehicles and pedestrians (r=.53, p<.01). These maneuvers include scanning the visual field for potentially dangerous obstacles, maintaining one's speed and distance with respect to other vehicles, yielding the right of way, and negotiating turns or merges safely. They are very likely to occur at intersections, where older drivers are overrepresented in crashes compared to younger drivers.

Older driver failure to detect pedestrians and other vehicles in driving scenes was shown by Caird, Edwards, Creaser, and Horrey (2005), using a change blindness method in a laboratory setting to assess turn decision accuracy at intersections. Change blindness—the inability to detect changes made to an object or scene during a saccade, flicker, or blink— was used in this study to assess visual attention. Subjects included 62 drivers distributed across 4 age groups: 18-25, 26-64, 65-73,and 75+. Drivers 65 and older had especially low accuracy scores compared to younger drivers, for intersections where pedestrians appeared in a scene at or in a crosswalk. Failure to detect the pedestrians may have led older drivers to decide the intersection was clear and a turn maneuver was safe to complete. Older drivers also missed detecting relevant vehicles that were relatively large and conspicuous.

In a driving simulator study using the PC-based STISIM, Bolstad (2001) found that poor performance on the divided attention and selective attention subtasks of the useful field of view test (but not the processing speed subtest) was significantly correlated with the amount of information correctly reported during a memory probe when the simulation was stopped at random intervals (as a measure of situational awareness, or the ability to attend to important information while driving). The correlations for divided attention and selective attention were -.32 and -.40, respectively, and were significant at $p < .05$. These associations were significant only under high complexity simulator scenarios (3 times the number of stimuli than in the moderately complex scenarios, in terms of oncoming vehicles, vehicles in participant's lane, buildings, gas stations, intersections with cars, traffic signals, speed limit changes, sharp curves, subtle curves, school zones, and construction zones). Subjects included 16 drivers in each of 3 age groups: 16 to -25, 40 to 50, and 65 to 80. Older adults reported significantly less information than younger- and middle-aged adults, whose performance on the memory probe task did not differ. Probe questions queried the following information: current speed; relative speed of leading driver; travel time to nearest pedestrian; current color of closest traffic signal; ability to cross nearest intersection legally, if one present at the time the simulation was stopped; whether current travel speed is at, below, or above speed limit; geometry of road 30 seconds ahead of current position; and location of other cars in the simulation with respect to current position.

Fildes, Charlton, Muir, and Koppel (2007) found differences between older (65 to 75) and younger (25 to 35) drivers' visual search strategies and responses to hazards presented by other vehicles in driving scenarios presented in a high-level driving simulator with full vehicle controls, that may be a result of deficits in selective and divided attention. Older drivers demonstrated a delayed fixation on hazards, a broader visual scanning pattern, and spent less time looking at the hazard relative to younger drivers. Examples of hazards were a vehicle entering an intersection without yielding, into the driver's path; a motorcycle overtaking the driver on a curve and then braking in front of the driver; a pedestrian suddenly stepping into the path of the driver. Older drivers were more likely to divide their total time looking across areas of the driving environment both inside the car (e.g., at their speedometer) and outside the vehicle (from peripheral left to peripheral right) than younger drivers. Older drivers overemphasized looking at their speedometer compared to younger drivers; during one scenario, they spent 13% of their time looking at the speedometer compared to only 3% for younger drivers. Although there was a speed limit sign in the scenario, the time spent looking at the speedometer meant that they also spent half of the equivalent time looking at the critical target (the hazard) than younger drivers. Drivers with poorer cognitive abilities tended to be slower in directing their gaze toward critical hazards and drove at slower speeds. Despite delayed fixation on hazards, older drivers were able to take appropriate action to avoid the hazards, even braking much earlier than younger drivers. Wider visual search, slower speed, and early braking may be compensatory techniques for age-related changes in functional abilities (e.g., visual fields, slowed information processing).

Similarly, DeRamas (2005) found that old-old drivers (75 to 79) scanned risky areas in the periphery more often than middle-aged (40-50) and middle-old (70-74) drivers, but just as often as young-old drivers (60 to 69). This study used 16 subjects in each of the four age groups, and a driving simulator with 16 scenarios, each with an area of the roadway that should be sampled to avoid a risk. Vehicle position and velocity were recorded. An eye movement analysis found that the old-old drivers scanned areas of the roadway without potential threats equally as often as they scanned areas with potential threats. The middle-aged drivers scanned the areas of the roadway with potential threats more often than the areas where no threat existed. The old-old drivers scanned non-risky areas more often than the middle-aged drivers. It may be that old-old drivers were compensating for a loss in their useful field of view, but not doing so strategically—they did not select, divide, or sustain attention well enough to selectively scan the environment, accurately predict risks, and plan for appropriate driving maneuvers.

Shinar (2008) cautions that care must be taken when interpreting eye movement data, because visual fixations are not synonymous with attention. Although people tend to move their eyes to the targets of their attention, the converse is not always true. The location of a fixation does not always reveal the target of attention. An example is the "looked-but-did-not-see" phenomenon that precedes many crashes. Eyes always fixate somewhere in space, but concentration may actually be on nonvisual stimuli such as auditory inputs and deep thoughts. When this occurs, there are fewer eye movements and the driver's gaze on the road ahead is a misleading indication that his or her attention is also focused there.

In a study using animations simulating the view from the perspective of a driver in a moving automobile (but no subsidiary task representing the attentional demands of driving), Mapstone, Rösler, Hays, Gitelman, and Weintraub (2001) found that older cognitively intact subjects and subjects with mild probable Alzheimer's disease (AD) made fewer fixations overall (an eye position remaining within a 6-pixel horizontal by 4-pixel vertical area on the display for at least 100 ms), made fewer fixations in the central region of interest (road surface directly ahead), and moved their eyes more often to the periphery than younger control subjects. The two older groups did not differ from each other. The sample was comprised of 13 patients with mild probable AD (mean age 75.7 years), 13 age- and education-matched cognitively intact older controls (mean age = 73.9), and 11 young controls (mean age = 27.4 years). The simulations approximated a speed of 30 mph for 20-second scenes that differed with respect to the density of stationary distractors on the street side, as well as moving vehicles approaching from the periphery at 2 intersections. Subjects were instructed to view the simulations as if they were safely driving to emphasize reliance on a more global attentional strategy. The authors state that the infrequency of eye movements made by young normal controls outside the central region of interest, even in the presence of peripheral distractors, may indicate an ability to attend to the periphery without shifting their gaze. Also, it may be that the age-related changes in visual attention may represent increased caution in older subjects, who may need to compensate for generally reduced reaction time by more extensive scanning with the eyes. Driving records were not compared in this study, so the fixation patterns could not be related to driving safety.

Conflicting evidence that older and younger drivers do not differ in their eye fixation scanpaths and hazard perception performance was reported by Underwood, Phelps, Wright, van Loon, and Galpin (2005). This may be explained by the study protocol employed by these researchers, which did not require a subsidiary task to simulate the attentional demands of driving. Subjects simply watched films and pressed a response button when they saw a hazard in the driving scene.

In Braitman et al's (2007) study of driver errors that contribute to older driver's intersection crashes, search and detection errors were more prevalent among drivers 80 and older (71% of the crashes) than among drivers 70 to 79 (36% of their crashes) and drivers 35 to 54 (45% of their crashes). Inadequate search errors (did not see the other vehicle or traffic control) increased significantly with age, accounting for 27% of search and detection errors among drivers 35 to 54 and 65% among drivers 80 and older. Among drivers 80 and older, search errors (looking but not seeing) predominated in failure to yield crashes. Failure to see other vehicles may be due to age-related declines in visual ability, but more likely are the result of decreased ability to process multiple sources of information simultaneously.

In a study of the effects of an auditory-verbal distraction task on the driving performance of 82 older subjects with deficits in selective attention capabilities (but no diagnosable neurological disease) and 78 neurologically normal older controls, Rizzo, Stierman, Skaar, Dawson, Anderson, and Vecera (2005) found that on-road driving performance did not differ significantly between the two groups between the distractor and baseline conditions. The distraction task in this study was the Paced Serial Addition Task (PASAT), where subjects were required to add serial pairs of randomized digits, so that each digit is added to the digit immediately preceding it. Driving while engaged in a conversation requires similar attentional demands. Both neurologically normal and selective-attention-impaired subjects reduced their vehicle speed and made more steering wheel reversals greater than 6 degrees under the distraction task condition than under the baseline (no distraction) condition. Controls showed more safety errors under the PASAT condition; the impaired group also made more safety errors under the PASAT, but this was not significant. Drivers with selective attention loss (measured using Subtests 3 and 4 of the Visual Attention Analyzer) had lower PASAT scores than neurologically normal controls, both in the laboratory and on the road.

The study authors explain that some drivers with reduced attention capacity may have a relatively intact supervisory system (executive control) that allows them to allocate attention where it is needed the most—to controlling the vehicle safely—at the expense of poorer performance on a demanding, but safety-irrelevant task such as the PASAT. There also may have been no group differences in performance because the highway driving was uneventful. The test route consisted of a rural 4-lane interstate freeway with a speed limit of 65 mph on which subjects were asked to drive at a speed they felt comfortable, and a rural 2-lane road on which drivers were permitted a maximum speed of 45 mph. The assessment incorporated several left turns, right turns, as well as stopping at a stop sign and maintaining vehicle control. It did not include demanding conditions such as high traffic, complicated maneuvers, or intersections that required rapid interactions with multiple objects and rapid decisions.

It has been shown that those with poor cognitive functioning may voluntarily self-restrict or cease driving. For example, Freund and Szinovacz (2002) found that in a sample of 5,460 community-dwelling drivers 70 and older, those with poorer cognitive functioning (assessed using tests of working memory, immediate and delayed memory, and mental status) were more likely to restrict or cease driving than those with no cognitive impairment. Among men, only 8% with no cognitive impairment ceased driving, compared with 19% of those with mild impairments and 43% of those with severe cognitive impairments. However, about 20% of severely cognitively impaired men drove long distances, compared to 60% of men with no cognitive impairment. Among severely cognitively impaired women, 76% do not drive, and only 7% drive long distances, compared with 22 and 36% of women with no cognitive impairment, respectively.

Finally, a reflexive attention mechanism called the “Inhibition of Return” (IOR) was evaluated as a predictor of safe driving abilities by Bédard, Leonard, McAuliffe, Weaver, Gibbons, and Dubois (2006). IOR prevents perseverance of attention. Having efficient IOR promotes sampling of the whole environment, while poor IOR results in a continual return to previously attended stimuli (either prior locations or prior objects). Bédard et al. (2006) measured IOR in a laboratory using a detailed computer paradigm for 41 subjects 55 to 84. Subjects then completed an on-road driving evaluation conducted by a licensed driving instructor, which focused on compliance, vehicle handling, route planning, observation, crash prevention practices, and application of rules of the road, similar to that conducted for licensing by the Ontario Ministry of Transportation. Older age was associated with poorer overall driving score. Higher IOR was associated with better overall driving score. A regression model for overall driving score found that age alone had an adjusted r^2 of .16 (p=.006). Adding IOR to the model improved the model significantly to an adjusted r^2 of .23. IOR also improved the model predicting one particular error component of the driving evaluation: scanning the environment. Age and IOR together had an adjusted r^2 of .28 for predicting scanning errors on the road test. Bédard et al. (2006) suggest that IOR is an important basic search mechanism that is crucial to complex activities such as driving, particularly for effective scanning of the environment. In the research study, effective reflexive visual attention was an independent contribution to safe driving, beyond the contribution of age.

EXECUTIVE FUNCTIONING

Executive function has been defined as general cognitive processes that support strategic organization and control other processes important to complex, goal-oriented tasks. Long-term and working memory often depend on executive functions because strategic processes are required for task performance (Buckner, 2004). Daigneault, Joly, and Frigon (2002) describe executive function as a variety of loosely related higher-order cognitive processes like initiation, planning, hypothesis generation, cognitive flexibility, decision making, regulation, judgment, feedback utilization, and self perception that are necessary for effective and contextually appropriate behavior.

Royall, Lauterbach, Cummings, Reeve, Rummans, Kaufer, LaFrance, and Coffey (2002) state that there is no single overarching executive construct, and that most studies find multiple dimensions of executive control. Studies confirm a “rule discovery” factor labeled by tests such as the Wisconsin Card Sorting task categories; a “working memory” factor labeled by such tests as the California Verbal Learning test, the Wechsler Intelligence Scale for Children-Revised (WISC-R), Digit Span (verbal), and the Tower of London (nonverbal); an “attentional” control labeled by tests such as the Continuous Performance task or Digit Cancellation; and a “response inhibition” factor labeled by the WISC-R Digit Span backwards, Trails B, or the Stroop. Neurologically, rule discovery and working memory are most closely related to dorsolateral cortical function. Attentional control and response inhibition depend more on ventromedial regions of the frontal lobes. MacPherson, Phillips, and Della Sala (2002) found age-related performance differences on tasks of working memory and executive function (dependent on dorsolateral prefrontal function), but not on tasks of emotion and social decision making (dependent on ventromedial prefrontal function). This suggests that dorsolateral prefrontal functions may be more sensitive to healthy adult aging than ventromedial prefrontal functions.

Reduced executive control can be detected in healthy adults as young as 45 to 65 years of age, relative to education and gender-matched 20-35 year olds (Daigneault, Braun, & Whitaker, 1992), and in longitudinal studies, executive control function deteriorates at an exponential rate (Palmer, Royall, Chiodo, et al., 2001). Corey-Bloom, Wiederholt, Edelstein, Salmon, Cahn, and Barrett-Connor (1996) found that the neuropsychological profiles of older (65-74) and very old (85+) could be distinguished almost exclusively by examining performance on executive tasks. Royall et al. (2002) cite the work of Grigsby, Kaye, Baxter, et al. (1998) that found that the prevalence of impairment in executive control function in a large community sample of 1,145 older adults residing in western Colorado (mean age = 72.9) was 25.5%. Half of these subjects had normal scores on the Mini-Mental State Examination (MMSE). Zelazo, Craik, and Booth (2003) cite research showing that there are systematic, age-related improvements in executive functioning during childhood and into adolescence, which show declines with age, suggesting that executive function follows an inverted U-shaped curve when considered across the life span. Although older adults are capable of high levels of conscious reflection and are capable at formulating and using high-order rules, doing so is resource demanding and effortful.

Complex cognitive processing requires a considerable expenditure of attentional resources, whose availability depends on the integrity of the frontal lobes (Craik & Grady, 2002) and the dopamine system (Braver et al., 2001). These biological systems decline in efficiency in the course of normal aging, with the result that older adults may need extra time to access and reflect on higher-order representations in the “levels of consciousness” hierarchy (Zelazo, 2004). Furthermore, because many situations will be familiar to older adults, they may be more likely to access higher-order representations that are pre-formed, context bound, and relatively inflexible. The necessity to switch rapidly between sets of rules will be difficult for older adults, resulting in perseverative errors. According to Stuss, Shallice, Alexander, and Picton (1995), deficiencies in executive functions may make people less flexible in performing tasks requiring adjustment and may involve reduced ability for planning and problem solving. As stated by Daigneault et al. (2002), certain complex situations require the ability to adapt behavior to the environment and make a less automatic response when driving.

Keys and White (2000) conducted a study to determine if age is uniquely related to changes in executive abilities or if such changes simply reflect reductions in psychomotor speed. Their subjects included 46 younger adults (17 to 23) and 40 older adults (56 to 82). Two aspects of executive function were measured: set formation, and set shifting. They found that poorer executive performance was associated with increasing age, and although psychomotor speed attenuated the relationship, age accounted for a unique and significant proportion of variance in executive performance, after controlling for psychomotor speed.

Poor performance on tests of executive function has been related to increased crash risk (Stutts, Stewart, & Martell, 1998; Rizzo, Reinach, McGehee, & Dawson, 1997; Goode et al., 1998; Daigneault et al., 2002; Staplin, Lococo, Gish, & Decina, 2003) and poorer driving performance (Cushman, 1988, 1992; Tallman, Tuokko, & Beattie, 1993; De Raedt & Ponjaert-Kristoffersen, 2000; Szlyk, Myers, Zhang, Wetzel, & Shapiro, 2002; Edwards et al., 2008). Stutts, Stewart, and Martell (1998) evaluated the Trails B performance of 3,238 drivers 65 and older applying for license renewal. Drivers in the poorest decile of performance had a predicted average annual crash rate of 1.5 times that of drivers in the highest decile of performance. The correlational coefficient with the number of police-reported crashes in the prior 3-year period was .07 ($p<.001$). Annual crash involvements increased with increasing (poorer) scores. Goode et al. (1998) found that the Trails B time distinguished between 124 older drivers who had experienced one or more State recorded at-fault crashes in the prior 5-year period from 115 older drivers who were crash free, with a sensitivity of 50.8% and a specificity of 60%. Rizzo et al. (1997) found that performance on Trails B was a significant predictor of simulator crashes, with an odds ratio of 30.19.

In a study of 1,876 drivers 55 and older renewing their licenses in Maryland, Staplin et al. (2003) found that poor performance on the Trails B test was associated with at-fault crashes in the prospective 20-month period (Odds Ratio = 2.21), at-fault crashes in the 20-month prospective period plus the 1-year retrospective period (OR=3.50) and with moving violations in the prospective plus retrospective period (Odds Ratio = 1.72). In an updated analysis that included 32 months of prospective plus 1 year of retrospective driving history data, poor performance on Trails B was associated with a 1.8 times increase in the risk of an at-fault crash (Staplin, Gish, & Wagner, 2003).

Edwards et al. (2008) found that older drivers with a history of (self-reported) at-fault crashes in the prior 2-year period performed significantly worse on the Trails B test than crash-free older drivers. The association was found after adjusting for miles driven. The mean time to complete the test for the 23 crash-involved drivers was 153 s, compared to 103.5s for the 96 crash-free drivers. No correlation was found between performance on the divided attention task and self-perception of driving ability.

Tarawneh, McCoy, Bishu, and Ballard (1993) found a significant correlation between performance on the Trail-Making B test and performance on an on-road drive test, with a correlation coefficient of -0.42 ($p<.0001$). Their subjects included 105 licensed drivers 65 to 85. The driving performance of the subjects was evaluated using the on-street driving performance measurement (DPM) technique developed by Vanosdall and Rudisill (1979). The subjects were evaluated by a driver education expert trained in the use of the DPM technique, while they drove in their own cars. The DPM route was a 19-km circuit designed to evaluate the subjects in the situations that are most often involved in the crashes of older drivers. Therefore, their performance was evaluated at 7 intersections where they were required to make left turns at 5 intersections and right turns at the other 2 intersections. Four of the left turns were made from left-turn lanes onto four-lane divided arterial streets in suburban areas, and one was made from a left turn lane onto a two-lane one-way street in an outlying business district.

Szlyk et al. (2002) found that the Trails B performance of 22 subjects 67 to 85 significantly correlated with the following measures of driving simulator performance: lane boundary crossings, speed, and brake pedal pressure. Also their performance on the Digit Span test correlated significantly with brake pedal pressure and horizontal eye movement in the simulator. Individuals who scored well on these tests drove faster, applied more brake pressure, made fewer lane boundary crossings, and made more horizontal eye movements. The increased brake pressure may suggest that the subjects used their brakes more over the driving course when they encountered stop signs, stop lights, crashes, and other road hazards. Faster speed may indicate more confidence in driving abilities.

Daigneault et al. (2002) examined the association between performance on four tests of executive function and crashes in the prior 5-year period for 30 crash-free older males and 30 older males who had 3 or more crashes. Subjects were 65 and older, with a mean age of 70 years; crash-free and crash-involved drivers were matched on age, kilometers driven in the past year, and residential municipality. Executive function was measured using the Color Trail Test (a version of the Trails B test using colors to avoid evaluation bias for people suffering from reading disorders or aphasia), the Stroop Color Word test, the Tower of London, and the Wisconsin Card Sorting Test.

For the measures related to speed of test completion, the group with crashes took significantly longer than the crash-free group on the Stroop test, and the Tower of London Test (both planning time and execution time). There was no significant difference between the groups in speed of completing the Trails test. Regarding the number of errors committed on the tests, the crash-involved group had significantly poorer performance than the crash free group on Trails errors, Stroop errors, Tower of London errors, and Card Sorting perseveration errors. A logistic regression analysis showed that the number of errors on these 4 tests predicted group membership (crash-involved versus crash free) with a correct prediction rate of 80%. Prediction success rate was lower for older drivers with crashes (73%) than for older drivers without crashes (86%). When comparing group means to normative data for the Color Trails Test, the crash-involved group performed at the 30th percentile for speed and between the 2nd and 5th percentile for errors. The crash-free sample performed at the 50th percentile for both speed and errors. For Card Sorting task perseveration errors, the crash-involved drivers performed at the 13th percentile and the crash-free group performed at the 39th percentile. For Tower of London execution time, the crash-involved group performed at the 6th percentile and the crash-free group performed at the 45th percentile. Thus, drivers with crashes made more errors that reflect mental rigidity (perseveration errors, flexibility problems) and had poorer ability to plan and solve problems.

De Raedt and Ponjaert-Kristoffersen (2000) found that a test of cognitive flexibility correlated significantly with global road test performance (r= -.55, p<.007), in a sample of 84 older people referred to a fitness-to-drive assessment center. In this study, cognitive flexibility was defined as the ability to switch from one behavioral strategy to another. During this test, four-choice visual (manual response) and aural response (response by feet) were first presented separately and then combined with one another (alteration). Subjects were told that the most important task was the visual task. They monitored the visual task and had to switch to another modality when an aural stimulus was presented. The quality of the switching capacity is reflected in the median reaction time to the aural stimuli. The reaction time of the simple task condition was subtracted from the double-task condition to correct for reaction speed. Cognitive flexibility performance accounted for 30% of the variance in road test scores. It correlated significantly with mechanical operations (fluency and timeliness of steering and pedal control) during the drive test (r= -.45). Cognitive flexibility was one of four neuropsychological tests that remained significant in a forward stepwise regression model predicting total road test score, together that accounted for 64% of the variance. The other three tests measured constructs of motion perception, selective attention, and useful field of view.

More recently, Snellgrove (2005) found that performance on a maze task discriminated with high accuracy (77.8% sensitivity and 82.4% specificity), between participants who failed an on-road driving test and those who passed it. The maze task was developed as a timed paper-and-pencil test of attention, visuoconstructive skills, and executive functions of planning and foresight. It was based on the Porteus Maze Test, which was originally designed to assess the specific executive functions of planning and foresight. Performance was scored according to time (seconds) to complete the test, and total number of errors. Errors were determined by counting the number of times a participant entered a dead-end alley or failed to stay within the lines. The driving assessment consisted of a 45-minute, in-traffic test along a predetermined route in business and residential areas, using licensing authority road test criteria (South Australia). Participants included 115 community-dwelling older drivers (65 and older, mean age 76.9 years), recruited through a memory clinic with either mild cognitive impairment (MCI), as indicated by a Clinical Dementia Rating score of .05 and intact general cognitive function with memory complaint, or probable (early) dementia.

Approximately 50% of those with MCI failed the on-road driving test, while 75% of those with early dementia failed the on-road test. On-road driving faults were related to poor planning and observation skills, an inability to monitor and control the speed of the car, poor car positioning, confusion with pedals, and a lack of anticipatory or defensive driving. As Maze time increased, participants were less likely to pass the road test. Participants who failed the on-road test took longer than 60 seconds to complete the maze. Conversely, those who passed the on-road test took 60 seconds or less and made zero errors or only 1 error on the Maze Test. Classification using Maze time alone was 69.6% accurate. As Maze errors increased, participants were less likely to pass the road test. Maze errors alone had an overall accurate classification of 71.3%. Using both time and errors increased the accuracy of classification to 77.4%, correctly classifying 84% of the fails and 61.8% of the passes. For every 30-s increase in time to complete the Maze, the likelihood of passing the road test decreased by 64.5%. For each increase in Maze errors, the probability of passing the road test decreased by 75.5%. According to Snellgrove (2005), the association between the Maze Task and known measures of attention, visuoconstructional skills, and executive functions of planning and foresight may explain its predictive validity (particularly anticipatory and defensive driving).

Ott, Festa, Amick, Grace, Davis, and Heindel (2008) also examined the ability of maze tests in predicting road test performance of older drivers (40 to 90). They used a set of 5 computerized mazes, and included a healthy control group in their sample (45 subjects), along with a group with probable Alzheimer's disease (65 subjects), and a group with possible Alzheimer's disease (23 subjects). Other clinical tests included a test of global cognition (MMSE), visuospatial abilities (Rey-Osterreith Complex Figure), executive function (Trail-Making Part B), psychomotor speed and visual tracking (Trail-Making part A), motor (Finger Tapping test), and memory (Hopkins Verbal Learning Test).

Within 2 weeks of the clinical assessment, subjects completed an on-road drive test based on the Washington University Road test, with a driving instructor blind to the subject's diagnosis. Participants received a driving score based on safe completion of each of the required maneuvers, ranging from 0 (best score) to 108 (worst score), in addition to a global rating as safe, marginal, or unsafe. Only 121 subjects completed all mazes and the road test. Road test total score was significantly correlated with total time for the 5 mazes (r=.54, $p<.0005$). This maze score was significant for the AD subjects (r=.40, $p<.0005$) and the control subjects (r=.53, $p<.0005$). One maze required less than 2 minutes to complete, and was highly correlated with driving performance score (r=.57, $p<.0005$) for the entire sample. Road test total score was significantly correlated with total planning time for the 5 mazes for controls but not for AD subjects.

For the standard neuropsychological tests, the highest correlations with road test score were for Trails A, Trails B, and the Hopkins Verbal Learning Test for the entire sample; for Trails A and Hopkins Verbal Learning in the AD subjects, and Trails A and finger tapping among the normal subjects. Using a logistic regression model and all three subject groups' driving competency designation as safe versus marginal or unsafe, maze total time accounted for 15% of the variance with a correct classification rate of 68.6%. Adding age, verbal learning, and Trails A scores accounted for 31% of the variance with a correct classification rate of 81%. Looking only at the mildly cognitively impaired sample (CDR = .5) and the controls, maze total time accounted for 23% of the variance, with a correct classification rate of 76.5%. Adding age, verbal learning, and Trails A scores accounted for 35% of the variance, with a correct classification rate of 85%.

VISUOSPATIAL ABILITIES

Visuospatial abilities of greatest interest in relation to safe driving include pattern recognition and the visualization of missing information. There are mobility impacts as well: Walsh, Krauss, and Regnier (1981), in a study of the relationships between spatial ability, environmental knowledge, and environmental use by older individuals, reported that the use of services and facilities and the confidence with which trips are initiated from home are directly linked to spatial ability and spatial knowledge. Finally, there is clinical evidence for demented populations that a disruption in spatial skills is the most common reason cited by older drivers in self-acknowledgments of diminished functional capacity (Odenheimer, 1989).

Neuropsychological tests of visuospatial skills that have been used in driving research include the Block Design Test, which measures perceptual organizational ability, Clock Drawing Test, which assesses visuospatial and constructional abilities, the Visual Closure subscore of the Motor-Free Visual Perception Test (MVPT) that detects poor visual pattern perception and measures the ability to visualize missing information, and the Rey-Osterrieth Complex Figure test that measures visuoconstructional skills (copy portion) visuospatial memory (recall portion). Performance on the pentagon copying task from the Mini-Mental State Exam has also been correlated to driving ability.

De Raedt and Ponjaert-Kristoffersen (2001) included the clock drawing test as a measure to assess visuospatial function in their short cognitive/neuropsychological test battery for primary care practitioners for first-tier, fitness-to-drive assessment of older adults. The clock test relies on a number of cognitive, motor and perceptual functions for successful completion, including orientation, conceptualization of time, visual spatial organization, memory, executive function, auditory comprehension, visual memory, motor programming, numerical knowledge, semantic instruction, inhibition of distracting stimuli, concentration, and frustration tolerance (Wells, Taylor, & Crocker, 2008). Subjects were 84 drivers age 65 to 96 referred for a fitness to drive assessment by their physician or insurance company. Those with a diagnosed neurological pathology or suspected of dementia/cognitive decline by their family doctor were excluded. The test battery included acuity, Trail Making Part A (selective attention with visual scanning and search), the MMSE (global cognitive functioning), and the clock test. Age was also included in the regression model. An on-road, in traffic road test was administered by two driver instructors of the fitness-to-drive center, and a discriminant function analysis was used to determine the predictive value of the test battery to the judgment of the driver instructor: fit-to-drive without restrictions; fit-to-drive with restrictions; not fit to drive. The MMSE score was not selected by the model, as it did not add significant discriminary power. Using the combined test score as the independent variable and the judgment of the driving evaluator as the dependent variable (fit/not unconditionally fit) yielded a significant discriminant function with a specificity score of 85% (percent of subjects correctly classified as fit to drive) and a sensitivity of 80% (percent of subjects correctly classified as not unconditionally fit), and an overall hit ratio of 82.5%. Individually, the Trail-Making Part A test accounted for 33% of the variance, age for 36%, clock drawing 38%, and visual acuity 38%.

In Gallo et al's. (1999) study of 589 community-dwelling subjects 60 and older, those who had ceased driving in the 2 years before the interview were significantly more likely to have made an error on the pentagon copying test (from the MMSE) than were people still driving (Odds Ratio = 1.79, CI 1.42-2.25). This association persisted after multivariate adjustment (adjusted odds ratio = 2.39, 95% CI 1.41-4.04). In addition, older drivers who reported adaptation in their driving habits (avoiding nighttime, bad weather, or rush hour) were significantly more likely to make an error on the copy design task than drivers who reported no adaptation in habits (OR=1.45, CI 1.08-1.95). This association was not significant in the multivariate analysis, however. The copy design task did not discriminate between those who reported having been involved in an adverse driving event (crash or citation not involving parking tickets) in the prior 2-year period.

Marottoli, Cooney, Wagner, Doucette, and Tinetti (1994) found that people with borderline cognitive impairment (MMSE score of 23-25) were more likely to have adverse events (traffic crash, violation, or stopped by police) in the year following examination than those with higher or lower scores (relative risk 2.0, 95% CI, 1.1-3.7). The authors examined the components of the MMSE individually and by cognitive domain (orientation, memory, attention, language, and visuospatial ability), and found that the item most closely associated with adverse events was impaired design copying (24% of people who could not correctly copy the intersecting pentagons had events compared with 8% of those who could [relative risk 3.0, CI, 1.6-5.6]).

Szlyk et al. (2002) found performance on a test of visuospatial organization and visuomotor coordination (the Block Design Subtest of the WAIS-R) by a sample of 22 subjects 67 to 85 was significantly correlated with the number of lane boundary crossings and driving speed in a driving simulator. Better performance on the Block Design test was associated with faster speed and fewer lane boundaries. Lundberg et al. (1998) found that older, crash-involved drivers with suspended licenses performed significantly worse on the immediate recall portion of the Rey-Osterrieth Complex Figure test (assessing visuospatial memory) and on the Block Design test than older non-crash-involved drivers whose licenses had been suspended for violations and older control drivers with clean driving records. The main violation types leading to license suspension (for 24 of the 37 suspended drivers) were violations of priority rules (e.g., running red lights, not yielding right-of-way rules, and not heeding stop signs). The violation led to a crash for 16 of these drivers, but not for 8 others.

In the study by Baldock et al. (2007), the Wechsler Spatial Span test (a test of visuo-spatial memory) was significantly correlated with on-road driving performance, in a sample of 90 drivers 60 and older (r= -.30, p<.001). Ninety% of the sample was comprised of community-dwelling older adults, while 10% were recruited from a pool of drivers referred for assessment of their driving abilities. Spatial Span is a spatial analog of digit span, and was one of the four variables that predicted driving ability in the regression analysis (in addition to contrast sensitivity, a measure of selective and divided attention, and a measure of simple visual attention).

Goode et al. (1998) found that the performance on the Rey-Osterrieth Complex Figures test and the Visual Reproduction subtest of the Wechsler Memory Scale (WMS-VR) distinguished between 124 older drivers who had experienced one or more State recorded at-fault crashes in the prior 5-year period from 115 older drivers who were crash free. The Rey-Osterrieth test involves first copying a complex figure and then attempting to draw the figure from memory. The WMS-VR requires memorization of a visual stimulus and construction of the stimulus from memory. The WMS-VR had a sensitivity of 66.1% and a specificity of 52.2%. The Rey-Osterrieth copy accuracy score had a sensitivity of 50% and a specificity of 61.7%. Immediate recall accuracy had a sensitivity of 64.5% and a specificity of 47%.

In the study by Staplin et al. (2003), older subjects who scored poorly on the MVPT-visual closure subscore (5 or more incorrect out of 11) were 6.22 times more likely to be in a crash in the 20 months following assessment than older drivers who performed well on the test. Crash and violation history were obtained from the motor vehicle administration driver history database. Adding 1 year of retrospective crash history to the 20 months of prospective crash history resulted in an odds ratio for at-fault crashes of 4.96 and an odds ratio for moving violations of 4.53. In the updated analysis by Staplin, Gish, and Wagner (2003) that looked at 32 months of prospective plus 1 year of retrospective driving history data, the odds ratio for at-fault crashes was 3.60. Lesikar et al. (2002) found that older drivers who scored poorly on the motor-free visual perception test/visual closure subscore (in the lowest tercile, or less than 9 of 11 correct) were 2.83 times more likely to be involved in a crash (self-reported) during the 2-year follow-up period, than those who scored in the upper terciles. Also, drivers who scored poorly (in the lowest tercile) on the Standardized Road Map Test of Directional Sense (a spatial orientation test) were also at increased crash risk (RR=2.33 for more than 11 errors and 1.96 for longer than 106 s to complete), compared to those who scored in the upper terciles.

In Tarawneh, McCoy, Bishu, and Ballard's (1993) study of 105 drivers age 65-88, among the visual perception factors, Visual Closure response-time score (from the MVPT) correlated significantly with an on-road driving performance measure (r= -0.38). As response time increased, performance on the driving test decreased.

Finally, visuospatial deficits are commonly observed in early dementia. Deficits are represented by a disturbance in formative activities such as assembling, building, and drawing, so that an individual is unable to put together parts to make a whole (Benton, 1990). Intact visuoconstructive skills are necessary for accurate vehicle positioning on the road/in the lane, and proper vehicle maneuvering. Visuospatial skills also come into play when judging distances and predicting the development of traffic situations (Johansson & Lundberg, 1997). In a meta-analysis of 12 studies, Reger et al. (2004) found that when including a control group along with subjects with dementia, studies of neuropsychological functioning and on-road driving performance show a significant relationship for performance on tests of mental status, attention and concentration, visuospatial skills, memory, executive function, and language, with correlations ranging from .36 to .48. As cognitive functioning declines, driving abilities tended to decline. However, when control subjects were excluded, relationships between driving performance and tests of neuropsychological functioning were significant only for the domains of attention and concentration, and visuospatial skills, all with lower correlations (.25 and .29, respectively). Correlations were also determined for neuropsychological tests and non-road tests (9 studies) and caregiver's reports of driving ability (8 studies). When correlations with control participants were removed from the analyses, tests of visuospatial skills generally related best to driving abilities across the different types of driving tests, with a correlation of .31 for nondriving tests (e.g., simulator and driving knowledge tests) and .19 for caregiver reports of driving ability. Only visuospatial ability and mental status tests correlated with caregiver reports of driving ability. Reger et al. (2004) state that tests of visuospatial skills may be most helpful in identifying at-risk drivers, within samples of dementia.

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DIMINISHED PHYSICAL/PSYCHOMOTOR RESPONSE CAPABILITIES

AN OVERVIEW OF CHANGES IN PHYSICAL ABILITIES WITH AGING AND INCREASED CRASH RISK

The physical capabilities (motor functions) needed for driving include: strength; range of motion of extremities; trunk and neck mobility; and proprioception. With the exception of proprioception—the ability of the kinesthetic receptors to determine where one's limbs are at any given moment, allowing for the coordination of movement—it has been well established that physical capabilities decline as a function of age and also as a function of general health. Aging (as well as disease and disuse) brings about changes in the components and structure of the articular cartilage—cartilage near the joints—underlying bones, ligaments and muscles. These changes impair the capability of the musculoskeletal system to perform the driving task. While there is evidence that older individuals have diminished psychomotor abilities necessary for driving, the extent to which *specific* declines impair performance or safety is debatable (Marottoli & Drickamer, 1993; Janke, 1994).

National estimates of the prevalence of age-associated functional impairments for mobility are available from studies such as the *National Health Interview Survey* (Pleis & Lethbridge-Çejku, 2007), which reported on the percentage of people by age group who have difficulty in physical functioning in least 1 of 9 physical activities without the assistance of another person, and without using special equipment. The survey was completed by 220,267 people. The 9 activities in the survey were: walking a quarter of a mile; climbing 10 steps without resting; standing for 2 hours; sitting for 2 hours; stooping, bending, or kneeling; reaching overhead; grasping a handle or small object; lifting or carrying 10 pounds; and pushing or pulling large objects. The percentage of people 75 and older reporting such difficulty or inability in at least one of these activities was 48%. This compares to 30% for those 65 to 74, 17% of those 45 to 64, and 6% of those 18 to 44.

In the *National Health Survey*, age was positively associated with an arthritis diagnosis and the presence of chronic joint symptoms (excluding the back and neck, which were queried separately). Fifty-one% of adults 75 and older had an arthritis diagnosis, compared with 48% of those age 65 to 74, 29% of those 45 to 64, and 7% of those 18 to 44. Forty-four% of adults 75 and older had chronic joint symptoms, compared with 43% of adults age 65 to 74, 34% of those 45 to 64, and 15% of those 18 to 44. Adults 18 to 44 were less likely to have experienced pain in the lower back during the 3 months prior to the survey than older adults (i.e., pain lasting a whole day or more; not fleeting or minor aches and pains). The percent age by age group were: age 18 to 44 (24%), 45 to 64 (31%), 65 to 74 (31%), and 75 and older (32%). Neck pain was less frequent among those 18 to 44 than among the older groups (12% for 18 to 44, 19% for 45 to 64, 16% for 65 to 74, and 14% for those 75 and older); it was also less frequent than back pain for all age groups.

Thus, there is ample evidence that aging is associated with decreasing physical function, pain, and discomfort. The extent to which research has been able to link these age-related changes with increased crash risk is examined below.

Sims, McGwin, Pulley, and Roseman (2001) conducted a population-based case-control study of drivers in Mobile, Alabama who were 65 and older and involved in a police-reported at-fault crash (n=244 cases) or were not crash involved (n=475 age- and gender-matched controls) in 1996. Self-reported physical impairments were obtained by telephone in 1997. Following adjustment for potentially confounding factors (age, race, gender, miles driven annually, previous vehicle crash, and number of diagnoses and medications), cases were significantly more likely to report difficulty walking one-quarter mile (Odds Ratio = 2.0, 95% Confidence Interval =1.2-3.6), and have difficulty moving outdoors (OR=2.7, 95% CI=1.1-7.0). Crash-involved older drivers were marginally more likely to have fallen in the prior year (OR = 1.5, 95% CI = 0.9-2.6) and to have difficulty carrying a heavy object 100 yards (OR=1.4, 95% CI=0.9-2.1). The Sims et al. (2001) findings support a hypothesis that older drivers who have sustained a motor vehicle crash are more likely to experience limitations in physical function. One study limitation is the retrospective design, which makes it impossible to determine whether functional impairments preceded vehicle crashes.

In another retrospective case-control study, Sims, Owsley, Allman, Ball, and Smoot (1998) found that scores on the Performance Oriented Mobility Assessment (POMA) had marginally significant associations with crashing in the previous 6-year period, for their sample of 174 drivers 55 to 90 (p=.077). There was an indication of worse balance and gait among those who crashed. The POMA evaluates several qualitative features of balance (e.g., rising from and sitting down on a chair; balance with eyes closed, neck turning, reaching up, bending over, and sternal nudge) and gait (e.g., initiation of gait; step height, symmetry, and continuity; path deviation; and turning while walking). Sims et al. (1998) also concluded that functional problems and medications may be more highly associated with crash-prone drivers, than are medical conditions.

In a prospective study of 174 drivers 55 to 78, Sims, McGwin, Allman, Ball, and Owsley (2000) found that the following self-reported activity limitations were significantly associated with crash involvement in the subsequent 5-year period: difficulty with yardwork or light housework (RR = 2.1, 95% CI=1.1, 4.0, p=.02) and opening a jar (RR=3.1, CI= 1.4,6.7, p=.004). Arm reach ability approached significance (RR=2.32, CI=0.95, 5.67, p=.07). Arthritis was not significantly associated with future vehicle crashes. Also, prior crashes predicted future crashes. Older adults who had experienced a vehicle crash in the 5 years preceding the collection of medical and physical performance data were twice as likely to be crash involved in the subsequent 5-year period.

Lyman, McGwin, and Sims (2001) found that drivers who had reduced their exposure to three or fewer days per week were more likely to have the following physical functional impairments than subjects who did not reduce their exposure: difficulty using stairs, walking at least a quarter of a mile, and carrying a heavy object.

In a prospective, population-based case-control study of medical conditions and medications, Cui (2001) found that cases (drivers 65.5 and older who reported to an emergency room as a result of injuries sustained in a motor vehicle crash) were 1.25 times more likely to have a medical diagnosis of joint/spine disorders in the 2-year period prior to the crash, than their non-crash-involved controls (95% Confidence Interval 1.06-1.48, p=.01). Tuokko, Rhodes, and Dean (2007) found that health-related symptoms experienced in the body areas involving the spine and lower body (e.g., limited strength or movement, lack of feeling or sensation, stiffness, involuntary movement, or chronic pain) are relevant to difficulties with driving. They also determined that health-related symptoms, rather than health conditions, were more clearly associated with driving difficulties, and mediate the relations between health conditions and driving difficulties. Their research involved a telephone survey of 318 drivers 60 and older, who provided self reports of health conditions, health-related symptoms, physical fitness levels, and specific types of driving difficulties.

One conclusion from the finding that respondents who were not physically active reported more difficulties with driving tasks involving the spine (e.g., shoulder checking, fastening a seat belt, bending to get in a vehicle door), is that physical activity involving spinal flexibility may be useful for enhancing specific aspects of driving performance, such as turning to check for traffic. Seventy-four percent of the respondents in the Tuokko et al. study indicated interest in participating in a fitness program geared to improving in-car strength and flexibility.

Diller, Cook, Leonard, Reading, Dean, and Vernon (1999) found that licensed drivers in their medical program in Utah who had functional motor impairment, but no license restrictions had a significantly higher citation and at-fault crash rate than a comparison group of drivers who were not part of the medical program matched on age, gender, and county of residence. The relative risks for citations and at-fault crashes were 1.42 and 1.18, respectively. Impaired functional motor ability in this program includes difficulties with muscular strength, coordination, range of motion, spinal movement and stability, amputations or the absence of body parts, and/or other abnormalities affecting motor control.

Difficulty with head turning and fatigue were reported as impairments that make driving difficult by approximately 17% of the participants in a focus group study by Gutman and Milstein (1988). Thirty-seven percent of the 162 participants believed that older drivers were involved in crashes as a result of their slowed reactions. This response was more frequent for drivers 76 and older (52%), compared to drivers 66 to 75 (30%), and drivers 56 to 65 (37%). It should be noted that subjects contributed multiple responses to this question. More drivers 76 and older attributed older driver crash involvement to physical impairments (11%) and driving beyond one's capabilities (11%) than drivers 56 to 65 and 66 to 75. Excluding vision/visibility problems associated with nighttime operations, difficulty with head turning placed first among *all* concerns mentioned by older drivers in a focus group conducted by Staplin, Harkey, Lococo, and Tarawneh (1997) to examine problems in the use of intersections.

Finally, physical problems have been associated with voluntary driving cessation by older community-living individuals. Marottoli, Ostfeld, Merrill, Perlman, Foley, and Coony (1993) found particularly that Parkinson's disease, stroke, arthritis, hip fractures, inability to perform one or more basic activities of daily living (ADL) or Rosow-Breslau items (climbing stairs, walking one-half mile, heavy house work), and lack of participation in physical activities (active sports, physical exercises, gardening and walking) were significantly associated with driving cessation. Similarly, Stewart, Moore, Marks, May, and Hale (1993) found that stroke, hospitalization in the past year, and Parkinson’s disease significantly predicted the likelihood of driving cessation.

The following discussion more specifically examines the roles of movement time (versus decision time); strength; range of motion of extremities; and trunk and neck mobility in explaining differences in measures of driving performance and safety.

RESPONSE TIME RELATED TO MOVEMENT

Contemporary views on the effects of age on body movements as they relate to driving behavior clearly distinguish between the complementary processes of *response initiation* and *movement time* (see Stelmach & Nahom, 1992). Response initiation reflects response preparation, response selection, and response programming, and is sensitive to changes in task complexity and requirements for speed versus accuracy of response. Measures of movement execution, by comparison, address individual and group differences in movement trajectories and kinematics, kinetics (muscular force), coordination, joint flexibility, and sensory-motor integration. Prior studies have been consistently characterized by cross-sectional research designs, indicating that there is age-associated slowing in motor performance across all component processes. Questions remain, however, as to the aspect(s) of psychomotor capability that account for the greatest variance in the overall accuracy or latency measures of driver response.

It has been hypothesized by Salthouse (1985) that nearly all cognitive motor processes are slowed by approximately the same proportional amount with increasing age. The stages of response selection and response programming may be particularly sensitive to age-related decline, however. Response selection represents the output stage of sensory/perceptual and cognitive processing of information from the roadway environment, up to and including decision-making. Given the dynamic nature of the driving task, individuals are continuously engaged in the discrimination of “most relevant” stimuli, and subsequent initiation of a best—or at least an adequate—vehicle control response.

Investigations of response selection compare reaction times (RTs) as the number of response alternatives, or level of uncertainty, increases. In simple RT tasks, only slight age differences are commonly obtained (Gottsdanker, 1982). This type of study is generally characterized as one in which a substantially suprathreshold and unambiguous signal and a well-learned response are both known in advance of a test trial. In contrast, using a choice RT paradigm, many researchers have determined that older adults are significantly slower than younger adults when response uncertainty is increased, indicating a disproportionately heightened degree of risk for older drivers when faced with two or more choices of action (Simon & Pouraghabagher, 1978).

Tarawneh (1991) examined findings published by proponents of both “parallel” and “sequential” (serial) models of driver information processing, seeking to determine the best estimator for older individuals of a perception-reaction time (PRT) encompassing six different component processing operations for determining traffic signal change intervals: (1) latency time (onset of stimulus to beginning of eye movement toward signal); (2) eye/head movement time to fixate on the signal; (3) fixation time to get enough information to identify the stimulus; (4) recognition time (interpret signal display in terms of possible courses of action); (5) decision time to select the best response in the situation; and (6) limb movement time to accomplish the appropriate steering and brake/accelerator movements.

Tarawneh's (1991) review produced several conclusions. First, the situation of a signal change at an intersection is among the most extreme, in terms of both the information-processing demand and subjective feelings of stress that will be experienced by many older drivers. Second, the most reasonable interpretation of research to date indicates that the best "mental model" to describe and predict how drivers respond in this context includes a mix of concurrent and serial-and-contingent information-processing operations. In this approach, the most valid PRT estimator will fall between the bounds of values derived from the competing models thus far, also taking age-related response slowing for recognition, decision making, and limb movement into account. Tarawneh indicated the need to increase design values—relative to those derived from studies of young drivers—by 5 to 45% for the stimulus recognition phase, 20 to 100% for response decision, and 20 to 90% for limb movement, to accommodate 95% of the older driver population. In one application, this author recommended an increase in the design standard for signal change time from 1.0 to 1.5 seconds.

A contrasting set of results was obtained in an FHWA-sponsored study of traffic operations control for older drivers (Knoblauch, Nitzburg, Reinfurt, Council, Zegeer, & Popkin, 1995). This study compared the decision/response times and deceleration characteristics of older drivers (age 60 to 71+) with those of younger drivers (under 60) at the onset of the amber signal phase.

Results of the Knoblauch et al. (1995) study showed no significant differences in 85th percentile decision/response times between younger and older drivers when subjects were close to the signal. When subjects were further from the signal at amber onset, older drivers had significantly longer decision/response times than the younger drivers. The authors suggested that the significant differences between older and younger drivers occurred when the subjects were relatively far from the signal, and that some older subjects will take longer to react and respond when additional time is available for them to do so—and that this is not necessarily an inappropriate behavior. In terms of deceleration rates, there were no significant differences, either in the mean or 15th percentile values, between the older and younger subjects. Together, these findings led the authors to conclude that no changes in amber signal phase timing are required to accommodate older drivers.

A study by Stelmach, Goggin, and Garcia-Colera (1987) examined response preparation where the independent variables were pretrial information level (complete, partial, or none) concerning which arm to move, the direction of movement, and the extent of movement. They demonstrated a significant and disproportionate slowing of response for older (60 to 65) versus both young (18 to 25) and middle-aged (ages 40-47) adults as uncertainty level increased. Based on related work, Goggin, Stelmach, and Amrhein (1989) concluded that preparatory intervals and length of precue viewing times appear to be crucial determinants of age-related differences in movement preparation and planning. When older adults are permitted to have longer stimulus exposures and longer interstimulus intervals, they exhibit less slowing of movement (Eisdorfer, 1975; Goggin et al., 1989).

The "programming" of driver responses is a closely related issue. Stelmach, Goggin, and Amrhein (1988) predicted that older adults would have greater difficulty in situations in which anticipated driving actions must be altered. Subjects received pretrial information about the type of movement which was to occur following a cue. Accurate pretrial information (80% probability) defined a "planning" condition, and inaccurate information (20% probability) defined a "restructuring" condition in this experiment. As expected, older subjects were slower to initiate a response than younger subjects, particularly when performing under the restructuring condition. These researchers conclude that older drivers will have greater difficulty in situations in which anticipated driving actions must be rapidly altered. In related work, Staplin and Fisk (1991) asserted that maneuver decisions and hence, response selection during intersection left turn approaches could be facilitated by “priming” the driver with redundant upstream signing to generate an expectancy for traffic operations ahead.

A related measurement of physical response capability was undertaken by Staplin, Lococo, and Sim (1990) in an experiment examining cumulative latencies for brake, accelerator, and steering wheel responses in a driving simulator. Three conditions were tested: (1) a baseline condition, where only a single control response was required; (2) a two-movement response sequence; (3) and a three-movement response sequence. The various permutations of response types within each sequence were tested (e.g., accelerate-brake-steer), with right- and left-steering responses equally distributed across trials. Slides with simple icons (red ball, green ball, and right- and left-pointing blue arrows) cued the subjects to make specific control movement sequences on a given trial. The slides were presented for a 400-millisecond (ms) duration with a 50 ms interstimulus interval, at a common fixation point. Results showed an advantage for younger subjects in performing a single control response that was very small, while the relative decrement for older subjects in speed of response widened progressively as the required control movement sequences included two and three reactions. These data were interpreted as an indication that older drivers will be at relatively greater risk than younger or middle-aged drivers when they must override a just-initiated vehicle control movement with one or more successive movements.

The movement execution factors contributing to response slowing in older adults, apart from response selection, programming, and preparedness, are relatively more straightforward. A review by Welford (1984) indicates that movement time—the interval between the initiation of movement and its completion—is significantly slower among the older population than among the young. Such age-related motor impairments have been linked to decreases in muscle mass and elasticity, decreases in bone mass, and a reduction of central and peripheral nerve fibers (Welford, 1982). Muscular atrophy and related neural losses during aging are known to disproportionately affect the ability to control movement rapidly and accurately (Larsson, Grimby, & Karlson, 1979). Also, Goggin and Stelmach (1990) reported findings that show that muscular force control may be impaired in older adults, with the result that movement corrections during movement execution are slower and much less efficient.

McKnight and McKnight (1999) found that both simple and choice reaction times were significantly associated with incident involvement in a study of 407 drivers 62 and older. The study sample consisted of 253 drivers referred to the California DMV for re-examination based upon reports of deficient driving incidents received from police, families, and other observers, and 154 drivers not previously referred to the DMV (incident-free). The correlation between simple reaction time and unsafe simulated driving for brake light appearance was .30 ($p < .01$). The correlation between complex reaction time (responding to a pattern of brake lights) and unsafe driving was also .30 ($p < .01$).

Zhang et al. (2007) found that older drivers 67 to 80+ who reported 3 or more complaints of pain in the feet, hips, legs, or current treatment for arthritis had significantly slower brake reaction speeds, both in terms of initial reaction speed and physical response speed than drivers with no complaints of pain in these areas. The 1,039 subjects were recruited from the population of licensees 67 and older in the ZIP Codes that encompass greater Salisbury, Maryland. The brake reaction test measured simple reaction time to move the foot from the accelerator to the brake when a green "traffic light" stimulus changed to red. Initial reaction time was measured from the time the signal turned red until the time there was a motor response (foot moving off the accelerator pedal). Physical reaction time was the time between the foot starting to move from the accelerator until the time the brake pedal was fully depressed. The finding that physical condition was associated with initial reaction time was unexpected, but the authors suggested that participants with pain in the lower extremities may find it more difficult to initiate movement, and the delay may contribute to slower initial reaction time.

STRENGTH

Decreases in muscle strength are due primarily to decreases in total muscle mass, decreases in the number and size of muscle fibers, and a reduction in biochemical activity within the body. While literature in the medical field has reported on the effects of aging and disease on strength, very little research has seriously addressed the relationship of strength (and tests of strength and levels of physical function) and older driver performance. In the 1960s, the United States Public Health Services provided guidelines regarding musculoskeletal ability and driving. The guidelines indicated that to operate a private vehicle, a driver should have at least normal strength in the right lower extremity and both upper extremities, i.e., the muscle should hold the joint against a combination of gravity and moderate resistance (Stock, Light, & Douglass, 1970). Gurgold and Harden (1978) assessed the driving potential of people with disabilities, and reported that a 3.15 kg (7 lb) tangential force is needed for steering, and 60 lbs of force for braking. Today's vehicles typically have power steering and anti-lock braking systems, suggesting that earlier recommendations may be too conservative.

An indirect association between grip strength and driving was found by Retchin, Cox, Fox, and Irwin (1988) who examined grip strength in both the dominant and nondominant hands of over 100 frequent and infrequent male drivers 65 and older. They found that the strength of the nondominant hand was significantly and positively associated with driving frequency, or continuation of driving by older individuals; that is, the weaker the nondominant hand, the less likely the older individuals were driving.

McCarthy and Mann (2006) assessed the ability to perform 20 strength tests (10 on each side) with or without resistance by the examiner. Strength tests included: shoulder flexion, abduction, and adduction; wrist flexion and extension; hand strength; hip flexion and extension; and ankle dorsiflexion and plantar flexion. Each joint tested received a score of 0 (no muscle contraction detected) to 5/5 (normal strength). They found that the strength measures had no association with an on-road driving evaluation administered by a driving rehabilitation specialist. Only 1 of 50 subjects failed the strength test. McCarthy and Mann (2006) conclude that strength may not be an important issue, given the decreased physical requirements of operating a modern motor vehicle.

FLEXIBILITY AND RANGE OF MOTION OF EXTREMITIES

Age alone is not the sole determinant for declines in flexibility and range of motion; it is principally degenerative disease and disuse that leads to a loss of flexibility (Adrian, 1981). Still, joint flexibility declines 20 to 30% in older adults on average reflecting a combination of histological and morphological changes in joints, including cartilage, ligaments, and tendons (Adrian, 1981; Serfass, 1980). The greater calcification of cartilage and surrounding tissue, the shortening of muscles, increased tension and anxiety, and the prevalence of arthritic and other orthopedic conditions all contribute to reduced flexibility (Piscopo, 1981).

Roberts and Roberts (1993) evaluated the effects of arthritis on the older driver. They reported that arthritis can result in several anatomical changes, including: cervical rotation; weak or painful wrist; painful proximal and distal interphalangeal joint (lower and upper finger area) or first carpalmetacarpal; pain or decreased range in knees or hips; ankle rigidity; pain in metatarsophalangeal joints; and single inflamed digits, either acute or subacute, in the hand or foot. Arthritic conditions can affect entering and exiting the vehicle, as well as positioning and comfort in the vehicle. The following control tasks are affected by arthritis: turning the wheel, gripping the wheel, and difficulty stepping on brake. These difficulties may impair backing up, parking, and turning maneuvers.

Cornwell (1988) reviewed several techniques used at a mobility center to assess arthritic drivers. The report assessed the type and level of difficulty arthritic drivers experienced, and provided recommendations for vehicle modifications. Arthritic drivers were lower in stature than the "able-bodied" population, leading to the recommendation for a seat raise for 30% of the arthritic group, and a forward seat tilt for 25% of the group. Side supports were recommended for 13% of the arthritic group, to reduce fatigue and increase comfort and stability. Many arthritic drivers were recommended to have nearside and offside mirrors together with panoramic rear view mirrors, to compensate for painful or restricted neck and trunk rotation. A steering wheel with a reduced diameter was recommended for 29% of the arthritic group, to accommodate restricted shoulder movement. Finally, almost 40% required servo-assistance to aid in braking.

In a panel data analysis of remaining eligible drivers in 1993 (507 female drivers and 375 male drivers) who participated in the Iowa 65+ Rural Health Study from 1981-1993, older females who had difficulty extending their arms above their shoulders had an increased probability of being involved in a crash (Hu, Trumble, Foley, Eberhard, & Wallace, 1998). Specifically, an older female with difficulty extending her arms above shoulder height was more than twice as likely to be crash involved than another female with no difficulty, given that both drive 6,000 mi/yr. Also, Sims, Owsley, Allman, Ball, and Smoot (1998) found that crash-involvement was significantly associated with difficulty "reaching out" ($p=.042$) in a case-control study of 174 drivers age 55 to 90 (mean age=71.1), where cases had at least 1 State-recorded at-fault crash in the 6 years preceding the assessment ($n=99$) and controls had no State-recorded at-fault crashes in the prior 6 years ($n=75$).

Turning to a focus on the lower extremities, Marottoli, Cooney, Wagner, Doucette, and Tinetti (1994) found that the timed performance test most strongly associated with adverse events (traffic crash, violation, stopped by police) in the year following testing was the rapid-pace walk (> 7 seconds versus ≤ 7 seconds [relative risk=2.0, 95% confidence interval=1.0-3.8]) in a sample of 283 community-dwelling individuals age 72 to 92 (mean age=77.8). Nine percent of the faster walkers had adverse driving events, compared to 17% of the slow walkers. This difference was significant at the p<.05 level. In the activity domain, walking less than 1 block per day was associated with adverse events (relative risk [RR]=1.9, 95% confidence interval [CI]=1.1-3.5). Twenty-one percent of the subjects who walked less than 1 block per day had adverse driving events, compared to 11% of the subjects who walked 1 block or more each day. This difference was significant at the p< .05 level.

More recently, the Maryland Pilot Older Driver Study collected and analyzed data describing the functional status of 1,876 License Renewal applicants, tested in Motor Vehicle Administration (MVA) field offices between November 1998 and October 2001 (Staplin, Lococo, Gish, & Decina, 2003). This sample was deemed sufficiently representative of its age cohort to permit generalization to the broad population of older drivers, with respect to crash and violation experience; it served as the test bed for project data analyses examining the relationship between functional ability and a number of traffic safety outcome measures. Four screening procedures addressed physical abilities—the *Rapid Pace Walk* and *Foot Tap* tests measured lower limb strength and mobility as needed to sustain steady control over brake and accelerator operation, and to quickly shift from one pedal to the other as circumstances may require; *Head/Neck Rotation* measured whether or not an individual could look directly over his/her shoulder as needed to safely change lanes or merge, with the lower torso fixed in place with a seatbelt as when driving; and the *Arm Reach* test measured upper limb strength and flexibility as needed for effective steering control.

The strongest relationships were consistently demonstrated between functional status and <u>at-fault</u> crashes (as opposed to all crashes and at-fault plus unknown-fault crashes). Crash history included 1 year of retrospective crash data plus an average prospective observation interval of 20 months. Among the physical measures, the *Rapid Pace Walk* and *Head/Neck Rotation* had the greatest potential value as predictors of driving impairment, with odds ratios of 2.64 and 2.56, respectively. The peak odds ratio for the *Rapid Pace Walk* was obtained with a pass-fail cutpoint of 9 seconds. No statistically reliable relationships with the conviction measures were demonstrated for any of the physical measures. Staplin, Gish, and Wagner (2003) reanalyzed the data, including 1 year of additional prospective crash history (1 year of retrospective crash history plus 32 months of prospective crash history). The odds ratio for the *Rapid Pace Walk* increased for at-fault crashes to 3.23, and remained statistically significant. The odds ratio for the *Head/Neck Rotation* measure decreased to 2.01, and only approached significance (p<.08). The authors concluded that measured declines in key functional abilities, in many cases, hold diminishing value for discriminating high-risk drivers as the length of the observation period extends beyond 2 years; however, the *Rapid Pace Walk* ran counter to this trend.

McCarthy and Mann (2006) examined the effectiveness of the Assessment of Driving-Related Skills (ADReS) in identifying drivers who are at-risk for unsafe driving, and found that range of motion was the variable most significantly associated with safe driving. The measure of effectiveness was performance on a road test (pass versus fail) administered by an experienced driving rehabilitation specialist. The ADReS contains these tests of motor ability: rapid pace walk, range of motion testing, and the manual muscle test. The rapid-pace walk—already linked to adverse driving outcomes, as noted above—is an indicator of gross proprioception, lower extremity strength, and endurance. The score is the time to walk a distance of 10 feet, turn around, and walk back 10 feet. The manual test of range of motion includes neck rotation, finger curl, ankle plantar and dorsiflexion, and a combined measure of shoulder and elbow flexion. The score is based on clinical judgments of "within normal limits" or "not within normal limits" in a combined measure obtained by asking a participant to imagine holding a steering wheel and making wide turns to the left and right. The Manual Test of Motor Strength assesses the ability to perform 20 tests (10 on each side) with or without resistance by the examiner. Strength tests include: shoulder flexion, abduction, and adduction; wrist flexion and extension; hand strength; hip flexion and extension; and ankle dorsiflexion and plantar flexion. Each joint tested received a score of 0 (no muscle contraction detected) to 5/5 (normal strength). The test sample consisted of 50 drivers age 65 to 90, 4 who had been referred for a driving evaluation and 46 volunteers.

Significant relationships were found with driving performance (pass/fail) only for the measures of range of motion (p=.001) and rapid pace walk (p= .023) among the motor function measures. McCarthy and Mann (2006) state that range of motion deficits in particular body parts that may interfere with the basic requirement of maneuvering a car (e.g., turning head to check traffic, turning the steering wheel, using the accelerator and brakes) are good candidates for interventions, with the most logical being a referral to a driver rehabilitation specialist who has the medical background to determine whether the client would benefit better by compensation (e.g., adaptive equipment) or remediation (e.g., exercise to increase range of motion). Study limitations included the small sample size, and the small number who failed the road test (n=8).

HEAD AND NECK MOBILITY

With advancing age there is decreased head and neck mobility. In a survey of the problems of older people by Yee (1985), 21% of the older drivers reported difficulty in turning their heads and looking to the rear when driving. In addition, 17% stated that painful or stiff joints have interfered, to some extent, with their ability to drive.

A restricted range of motion can reduce an older driver's ability to effectively scan to the rear and sides of his/her vehicle to observe blind spots, and may hinder the timely recognition of conflicts during turning and merging maneuvers at intersections (Ostrow, Shaffron, & McPherson, 1992). Schroeder, Allen, and Ball (1973) found that restricting the head resulted in more driving errors and fewer long eye movements. Restricting the head also may alter where a driver "look" in the visual environment; and the frequency with which individuals shift their fixations is negatively correlated with errors—more eye movements are related to fewer driving errors.

Hauer (1988) reported that intersection angles of 75 degrees or less cause problems for older drivers, since this situation requires extensive head movement. Hunter-Zaworski (1990) studied the effect of restricted head and neck movement on driving performance, by measuring decision time at simulated T-intersections. A fixed-based driving simulator that incorporated video recordings of intersections (180 degree field of view) was used in the study. Subjects were between the of 30 and 50, or between the of 60 and 80; half in each group had a restricted range of neck movement, where neck impairment was defined as a combined static range of movement of the head, and visual field of less than 285 degrees. Results showed that decision time increases with age and level of neck impairment, indicating that younger drivers were able to compensate for their neck impairments, but older drivers both with and without neck impairments were unable to make these compensations in their driving performance.

In a study of 125 community-living older people who were active drivers (77+), limited neck range of motion (RR = 6.1, CI = 1.7-22.0) was one of the factors independently associated with self-reported adverse driving events (crashes, moving violations, or being stopped by the police) after adjusting for driving frequency (Marottoli, Richardson, Stowe, Miller, Brass, Cooney, & Tinetti, 1998). Range of motion of the neck was measured by having the subject stand against a wall, and turn his or her head to identify a number placed behind either shoulder.

Isler, Parsonson, and Hansson (1997) evaluated the potential effects of restricted head movements on the visual field of the sample of drivers arriving at the decision point of a T-intersection. At the decision point, drivers need to judge the distance and speed of traffic approaching from the right (perpendicular to the forward line of sight), to find a safe gap to merge into following a left turn at the "T." This analysis was conducted for traffic conditions in New Zealand, where drivers keep to the left side of the road. In this situation, much head movement would be needed to bring intersecting traffic into central vision to allow speed and distance judgments, possibly augmented by some eye movements. In cases of restricted head movement, larger horizontal eye movements would be needed to compensate for the head movement loss.

The analyses of Isler et al. (1997) were based on measurements of the maximum head rotation of 20 drivers in each of four age groups: less than 30; 40 to 59; 60 to 69; and 70 and older, as well as their horizontal peripheral visual field. The oldest subjects exhibited an average decrement of approximately one-third of head range of movement compared with the youngest group of subjects. The mean maximum head movement (in one direction) was 86 degrees for the youngest drivers, 72 degrees for drivers 40 to 59, 67 degrees for drivers 60 to 69, and 59 degrees for drivers 70+. Three of the oldest drivers had less than 50 degrees of head movement and two of these drivers also had less than 20 degrees of horizontal peripheral vision.

The maximum achieved head movement angles of the older drivers in the Isler et al. sample would not be sufficient to bring oncoming traffic into central vision at distances exceeding 20 m without additional eye movements to the right. In contrast, many of the young drivers would be able to turn their head for more than 90 degrees, and would be able to focus on the traffic without additional eye movements at the largest distance used in the analysis (>100 m). With an additional 15 degrees of eye movement to the right (1 natural saccade), half of the older drivers (20 of the 40) still would not be able to focus centrally on traffic that is further away than 40 m, while only 15% of the younger and middle-aged drivers (6 of 40) would not be able to do so. Even after large eye movements of 30 degrees (2 saccades), eight of the older drivers (20%) would not be able to fixate on oncoming traffic 40 m away, while only 3 drivers in the two younger age groups (7.5%, with all in the middle-age group) were unable to do so. Finally, in addition to their restricted head movements, the oldest drivers also had restricted right horizontal peripheral vision of less than 30 degrees; such was the case for four of the oldest drivers, who would not be able to judge the speed and distance of an oncoming car at a distance of 50 m, even with 2 natural eye movements.

This analysis suggests that attention to, and perception of approaching vehicles would be delayed, with the delay more problematic and dangerous in rural environments, where vehicle approach speeds are higher. The authors state that the combination of restricted head movement combined with deficits in peripheral vision increases the difficulty of bringing an approaching vehicle into central vision, where acuity is the highest, and may help explain why older drivers have higher rates of intersection crashes that result in injury or death.

One encouraging note is that many of the movement execution problems associated with losses in flexibility pervasive among older road users may stem from an overall decline in physical fitness among this group, and is thus amenable to remediation. An exercise program conducted by Ostrow et al. (1992) was shown to be an effective intervention for older drivers for enhancing driving skills that accentuate demands on the range of motion, such as observing to the rear and parallel parking. The exercises consisted of chin flexion/extension, neck rotations, head side bending, chin tucks, rotating the shoulders backward, and trunk rotations. After participating in the program, older drivers showed improvements using a field-based assessment of automotive driving skill. Subjects in the experimental group who received the range-of-motion training looked more frequently to the sides and rear of their vehicle than drivers in a control group who did not participate in the exercise program.

Porter, Conci, Huebner, and Ogborn (2005) caution that failure to make head checks to the rear when backing up is a behavioral habit as well as a functional limitation, depending on the individual. In their study, neck and trunk rotation were measured in the laboratory for 20 subjects 70 to 80 (mean age for women = 77.3; mean age for men = 78.8), and then subjects performed a backing maneuver in their vehicles prior to driving a 330 m loop in a parking lot. The average measured cervical rotation of the subjects was not significantly different from the accepted normal value of 52 degrees for people age 80, or from the accepted normal value of 55 degrees for people age 70. Eight of the 20 subjects failed at least one of the neck or trunk rotation tasks measured in the laboratory. For the driving analysis, 17 of the 20 subjects did <u>not</u> turn and look behind when they backed their vehicle out of the parking space; instead they relied on their mirrors. The 3 subjects who did turn and look had flexibility values that were substantially higher (better) than the norms for 70- and 80-year-olds. For the group who did <u>not</u> look, 10 had flexibility scores higher than the norm for 70-year-olds, and 7 had flexibility scores below the norm for 70-year-olds (with 5 of these subjects having values worse than the norm for 80-year-olds). The finding that most of the drivers who did not turn their heads had the flexibility to do so, suggests that intervention programs should be individualized, providing instruction about the proper procedures for backing up for those with adequate flexibility, and stretching exercises for those with limited range of motion.

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MEDICAL CONDITIONS AND OLDER DRIVER SAFETY

AN OVERVIEW OF DISEASES AND MEDICAL CONDITIONS AND CRASH RISK

Individuals may experience impairments in their ability to drive safely not only as the result of normal aging, but also due to a host of medical conditions and diseases that are more prevalent in later years. While it is functional capacity that directly mediates driving performance—and functional losses that predict crash problems—the manner and extent to that critical abilities are compromised by underlying medical conditions, and the potential to accommodate or remediate these conditions and restore functional fitness-to-drive, is of keen interest to researchers and practitioners alike. This will be the focus of the present chapter.

A broad perspective on the traffic safety implications of medical conditions is provided by analyses emanating from the Crash Outcome Data Evaluation Systems (CODES) project. At least one State (Utah) participating in this project, in cooperation with NHTSA, has evaluated the crash risk of licensed drivers with self-reported medical conditions in comparison to drivers from the general population matched by age, gender, and county of residence, over 5-year periods. Viewed as a whole, drivers with medical conditions were at higher relative risk than the comparison drivers for violations, crashes, and at-fault crashes (Diller, Cook, Leonard, Reading, Dean, & Vernon, 1999). More in-depth analyses keyed to functional ability level within specific medical conditions, also demonstrated higher relative risk for crashes and at-fault crashes for these drivers versus their corresponding comparison groups for most conditions, even at the lowest levels of functional impairment (Vernon, Diller, Cook, Reading, & Dean, 2001).

A separate chapter examines, in detail, the relationship between age-related functional decline and driving safety and performance outcomes. In the present chapter, selected results of CODES analyses are cited in the discussion of particular diseases or medical conditions, without necessarily connoting functional status. It should also be emphasized that an exhaustive discussion of all conditions addressed in CODES was not intended for this document.

The potential scope of a review of material on this topic is enormous. Accordingly, boundaries for this project activity were established in recognition of other recent, exhaustive summaries addressing medical conditions and driving. Specifically, it is *not* a present goal to replicate the coverage provided in the NHTSA compendium *Medical Conditions and Driving: A Review of the Literature* (Dobbs, 2005); nor, to address all conditions covered in the Medical Fitness Guidelines released by NHTSA in 2010. Certain rare conditions that may result in loss of consciousness, such as epilepsy and syncope, are excluded; so, too, are the effects of alcohol on driving. Vascular and pulmonary conditions are included *only* given a demonstrated impairment in driving function. Finally, a number of the most prominent diseases that impair cognition including Alzheimer's and related dementias are deferred for review in a separate chapter.

One particular omission, of a disease that is becoming increasingly prevalent among older people, *diabetes mellitus*, deserves special attention. Some studies have suggested that diabetics experience an elevated crash risk, including the CODES analyses: over 10,000 drivers with diabetes mellitus and no other known medical condition, who had the least impairment in function (and therefore the least restriction of driving privilege), demonstrated higher rates of crashes and at-fault crashes than comparison drivers in Utah (Vernon et al., 2001). The effect size was modest, however – an odds ratio between 1.2-1.6 – and disappeared among drivers with higher levels of impairment (and greater restrictions on driving privilege). Thus, a diagnosis for diabetes, in and of itself, may have little value in explaining safety outcomes.

There is also reason to believe that it may be the medications used to treat diabetes, rather than the medical condition itself, that is of greatest concern. This assertion is based on evidence from research into the causes of "recurrent falls"; because vehicle crash involvement by older people has been significantly associated with a history of falling in the past two years (see Staplin, Lococo, Stewart, & Decina, 1999), they may share the same underlying causes.

Lee, Kwok, Leung, and Woo (2006) reviewed demographic data, falls history in the previous 12 months, medical diagnoses, and current medications for 4,000 community-dwelling men and women over 65. The purpose of the investigation was to determine whether medical illnesses or the medications used to treat them were the cause of falls in the older population. Because the study cohort contained a large proportion of diabetic patients not on drug treatment (25.7%), direct comparisons between diabetics with anti-diabetic medication and those without this medication could be made. The study indicated that anti-diabetic medications were related to recurrent falls, but being diabetic was not. While this evidence is by no means conclusive, it reinforces the notion that a diagnosis of diabetes, per se, may not be of primary importance as a contributing factor for motor vehicle crash involvement.

In summary, the focus in this chapter is on diseases and medical conditions that are prevalent among older adults; for which there is scientific evidence linking them to driving impairment; and that are likely to define priorities for detection by physicians—especially those who have requirements in their jurisdictions to report medically at-risk drivers—because of their effects on specific visual, perceptual-cognitive, and psychomotor functions. Selected diseases/conditions meeting these criteria are identified and discussed in the following pages, while also noting their common symptoms and available methods for screening and detection. These include cataracts, glaucoma, and macular degeneration in the area of visual function; stroke and sleep apnea in the cognitive domain; and arthritis in the psychomotor domain. This content is organized according to each principal domain of functional ability related to safe driving.

CONDITIONS THAT IMPAIR VISUAL FUNCTION

The most prevalent medical conditions affecting vision among older drivers are cataracts, glaucoma, and macular degeneration. Each of these conditions can be screened or detected by primary care physicians, using brief in-office methods. The common symptoms of each disease, and the aspects of visual function needed to drive safely that are affected, are discussed below.

A *cataract* is a clouding or opacity in the lens of the eye that can impair function with respect to visual acuity, contrast sensitivity, and disability glare. It is estimated that 20.5 million people in the United States older than 40 have a cataract in one eye, a number that will increase to 30.1 million by 2020 (*Eye Diseases Prevalence Research Group,* 2004). Besides advancing age, diabetes, smoking, alcohol use, ultraviolet light exposure, and certain medications are known to increase the risk of cataracts.

Cataracts account for the highest rate of self-reported visual impairment (Dana, Tielsch, Enger, Joyce, Santoli, & Taylor, 1990) and lead to more than 8 million physician office visits each year (Koch, 1985). The most common symptoms include blurry vision, double vision, faded colors, poor night vision, and halos around lights. Another symptom of the formation of cataracts is frequent changes in eyeglass prescriptions. In the physician's office, impaired vision due to cataracts may be detected through static acuity and contrast sensitivity tests, using eye charts; and impairments in visual function related to cataracts may be revealed through patients' questionnaire (VF-14) responses (Steinberg, Tielsch, Schein, & Javitt, 1997). In an eye clinic, cataracts are typically detected and graded through direct inspection in a slit lamp examination.

Cataracts have been associated with crash risk by Owsley, Stalvey, Wells, and Sloane (1999). Research by Higgins and Wood (2005) indicates that the most significant impairment for driving safety resulting from cataracts is the loss of contrast sensitivity. A reduction in crash risk following surgery to remove cataracts has also been demonstrated (Owsley, McGwin, Sloane, Wells, Stalvey, & Gauthreau, 2002), and Owsley, Stalvey, Wells, Sloane, and McGwin (2001) conclude that this effect is most likely attributable to improvement in contrast sensitivity. A study by Wood and Carberry (2006) found that improvement in contrast sensitivity after cataract surgery was the best predictor of improved driving performance during an on-road (closed course) test, including the ability to detect and avoid hazards.

One study found that over 20% of older adults returned to driving after cataract surgery (Monestam & Wochmeister, 1997) while another demonstrated an increase in the frequency of both daytime and nighttime driving (Bassett, Noertjojo, Nirmalan, Courtright, & Anderson, 2005). Conversely, those (older) adults who delay cataract surgery appear to be at greater risk of losing driving privileges (Leinonen & Laatikainen, 1999).

Another relatively common medical condition resulting in vision loss for older people is *glaucoma*. Characterized by elevated intraocular pressure, glaucoma destroys the optic nerve, which transmits images from the retina to the brain. At the turn of the century it was estimated that just under 2% of Americans over 40 and 3% over 55 have glaucoma in one eye (Weston, Albadi, & White, 2000). By 2020, the number of people with the disease is expected to rise to more than 3 million (Eye Diseases Prevalence Research Group, 2004).

However, while glaucoma is one of the leading causes of blindness, many are unaware of their condition because they do not experience any symptoms (Horton, 2001). With more advanced disease, patients may complain about the loss of peripheral vision (Grierson, 2000) and may require frequent changes in eyeglass prescriptions while experiencing blurred vision, difficulty adjusting to darkened rooms, rainbows around objects, or mild chronic headaches.

Two types of glaucoma are described as "acute narrow angle" and "chronic open angle." The former describes an emergency situation, posing a risk of sudden loss of vision; however, the latter is the much more common condition, and is the subject of this discussion. Open angle glaucoma is most prevalent among older people, African-Americans, and others with a family history of the disease (Carr, 2007). Additional risk factors include eye trauma and steroid treatment.

Screening for glaucoma can be performed in a family physician's office, using an ophthalmoscope to examine the optic disk. Also, there are portable, noninvasive procedures (tonometry) to measure intraocular pressure, but such measures are not sensitive as some patients with the disease have normal pressure. Ophthalmologists who diagnose the disease rely on techniques to map visual field loss in addition to changes or asymmetries in the optic disk. There are also questionnaires with items designed specifically to detect visual impairment associated with glaucoma, including the National Eye Institute Visual Function Eye Questionnaire (Mangione, Berry, Spritzer, Janz, & Klein, 1998) and the Glaucoma Symptom Scale (Lee et al., 1998).

Multiple studies have addressed the safety and mobility of older people with glaucoma. A 5-year retrospective study in Canada compared patients in a glaucoma clinic to controls. The glaucoma patients were at higher risk for motor vehicle crashes, including at-fault crashes (Haymes, LeBlance, Nicolela, Chiasson, & Chauhan, 2007). Other studies have also shown an increase in crash risk in patients with glaucoma (Hu, Trumble, Foley, & Eberhard, 1998; Owsley, McGwin, & Ball, 1998; Szlyk, Mahler, Seiple, Deepak, & Wilensky, 2005); but some have not (McGwin, Mays, Joiner, DeCarlo, McNeal & Owsley, 2004; McCloskey, Koepsell, Wolf, & Buchner, 1994). Two studies that found an elevated crash risk for glaucoma patients included individuals with moderate to severe disease, who had significant visual field loss (<100 degrees total horizontal field); or impairment in the central 24-degree radius field in the worse functioning eye (Szlyk et al., 2005; McGwin et al., 2004).

When glaucoma patients in an eye clinic were followed longitudinally, most retained functional vision across their life span, but almost half (47%) lost driving privileges due to their vision impairment (Szlyk, Taglia, Paliga, Edward, & Wilensky, 2002). Patients with glaucoma also have reported on questionnaires that they drive less at night, on freeways, and in unfamiliar areas than non-glaucoma patients (Adler, Bauer, Rottunda, & Kuskowski, 2005).

Another disease affecting visual function among large numbers of older people is *macular degeneration*. This condition affects the central region (macula) of the retina, where the highest density of photoreceptors—as required for good acuity, i.e., the ability to resolve fine detail—is found. Macular degeneration (MD) exists in a “wet” (exudative) and a “dry” form of the disease, and is graded by clinicians as mild, intermediate, or severe in its presentation. The wet form, though less common, has a poorer prognosis and accounts for the highest proportion of those suffering a loss of functional vision (Carr, 2007). Because of its increasing prevalence with advancing age, this disease is often labeled “age-related macular degeneration” (ARMD).

The Eye Diseases Prevalence Group (2004) estimates that 1.5% (1.75 million) of Americans over 40 have MD in one eye, and that over 15% of white women over 80 are affected by the disease. By 2020, the total number of people with MD is expected to approach 3 million. Aside from family history, the strongest risk factors are being Caucasian and female.

The dry form of MD results in the need for brighter light when reading, difficulty in adapting to dimly lit environments, blurred vision when trying to read print, a decrease in the intensity of colors, trouble recognizing faces, or a blind spot in the center of the visual field. The wet form of the disease can also cause a loss or blurriness in central vision, visual distortions (e.g., straight lines appear wavy), and in some cases hallucinations—despite intact cognition. A recent review by Fletcher and Schuchard (2006) documented measured declines in patients with ARMD in contrast sensitivity, visual fields, color contrast sensitivity, flicker detection, and dark adaptation.

Macular degeneration is detected and graded through a slit lamp examination. Screening for the disease may be accomplished in an office, using a procedure involving an Amsler grid (of evenly spaced vertical and horizontal lines, with a central fixation point). And, questionnaires such as the National Eye Institute's Vision Function Questionnaire 25 include items that screen for ARMD (DeCarlo, Faao, Wells, & Owsley, 2003).

Logically, ARMD will impair drivers in reading traffic signs, and in detecting hazards in the forward line of sight. Increased crash risk has been demonstrated for MD patients when driving at night (Szlyk, Fishman, Severing, Alexander, & Viana, 1993; Szlyk, Pizzimenti, Fishman, Kelsch, Wetzel, Kagan, & Ho, 1995), though both of these studies were qualified by small samples. However, in a larger study, Owsley et al. (1998) also found a significant association between MD and *at-fault* crash risk.

CONDITIONS THAT IMPAIR COGNITIVE FUNCTION

Setting aside the dementing diseases, the medical conditions that most commonly affect cognitive abilities needed to drive safely are *stroke* and *sleep apnea.* The prevalence, symptoms and diagnosis, and impact on function and on driving of these conditions are discussed below.

A stroke or cerebrovascular accident (CVA) occurs when the blood supply to the brain is reduced or interrupted. The CVA may be ischemic, producing an infarct (a small, localized area of dead tissue), or it may be hemorrhagic (bleeding). Each year, about half a million people in the United States experience a first stroke, and 200,000 experience a recurrent attack. Across all industrialized countries, stroke is the third leading cause of death, accounting for 10% of all deaths (Leske, Hejl, Hussein, Bengtsson, Hyman, & Komaroff, 2003). In the United States fatalities resulting from stroke are decreasing, but morbidity is on the rise; in fact, stroke is the leading cause of serious disability in the United States, with the annual cost of stroke-related disability estimated at $57.9 *billion* by the American Heart Association (2006).

While stroke symptoms can include vision and motor impairments, it is sensory loss (numbness or loss of sensation) and cognitive impairments that are most likely to cause problems with driving. These include memory loss, hemianopia (inattention/neglect to one hemisphere of vision) or visual field cuts, impairment of "executive" functions (e.g., decision-making) and aphasia (inability to understand or express speech); and muscle weakness or paralysis is also a possible consequence of stroke (Carr, 2007).

Fitness-to-drive studies with stroke patients have associated failure on a road test with measures of visual perception, attention, and information processing (Engrum, Lambert, & Scott, 1990). Lundzvist, Gerdle, and Ronnberg (2000) found that tests of working memory, attention, and "higher-order" cognitive functions were the best predictors of differences in driving skills among patients with CVA. Researchers in Europe have applied a battery known as the Stroke Driver Screening Assessment to classify performance (pass/fail) on a road test with 80% accuracy (Lundberg, Caneman, Samuelsson, Hakamies-Blomqvist, & Almkvist, 2003). This battery includes measures of selective attention (dot cancellation test); divided attention, visuospatial ability, and reasoning (compass test); and working memory, speed of processing, and executive function (road sign recognition test).

The evidence of crash involvement with stroke survivors remains inconclusive. Sims, McGwin, Allman, Ball, and Owsley (2000) report that a history of stroke/transient ischemic attack was the only medical condition significantly associated with crashing in a prospective cohort study of 174 older adults in Alabama. An increase in crash risk with stroke patients when compared to controls was found by Koepsell, Wolf, and McCloskey (1994), but not by Salzberg and Moffat (1998).

An additional perspective on these findings is provided by the fact that it appears a significant number (approximately 42%) of community dwelling stroke patients continue to drive (Legh-Smith, Wade, & Hewer, 1986), and as medical advances further increase longevity after stroke this number will certainly grow. Most notable is the finding by Fisk, Owsley, Vonne, & Pulley (1997) that 87% of stroke patients resumed the operation of a motor vehicle *without any type of formal screening or evaluation* for fitness to drive.

Sleep apnea, a periodic cessation of breathing during sleep—clinically, a cessation for intervals of 10 seconds or longer—is a common though often undiagnosed (and under-treated) condition with potentially serious consequences for driving safety. A prevalence rate similar to that of diabetes (4% of men, 2% of women) has been reported (Young, Palta, Dempsey, Skatrud, Weber, & Badr, 1993). Some patients experience a related condition, hypopnea, described as repeated episodes in which airflow is reduced during sleep. Five or more such episodes per hour are considered abnormal and may result in impaired cognitive function.

This condition may be manifested as "obstructive" sleep apnea, where there is resistance to airflow, versus "central" sleep apnea, in which a patient has a diminished drive to breathe. Obstructive sleep apnea is associated with the familiar symptoms of snoring, as the pharyngeal muscles relax and the upper airway collapses; this commonly occurs during periods of rapid eye movement (REM) sleep (Carr, 2007). Obese individuals, especially males, with a large neck girth are at highest risk. Other risk factors for sleep apnea include a history of hypothyroidism.

The daytime functional impairments of apnea-hypopnea include drowsiness/sleepiness, memory loss, impaired concentration and coordination, anxiety and depression. While symptoms also may include headache, sweating, dry mouth or drooling, and reflux, detection often follows reports of gasping, snoring, or breathing cessation during sleep by a bed partner (Olson, Moore, Morgenthaler, Gay, & Staats, 2003). Questionnaires have also been used in the diagnosis of sleep apnea, including the Berlin Questionnaire (Netzer, Stoohs, Netzer, Clark, & Strohl, 1999) and the Epworth sleepiness scale (Johns, 1991). Polysomnography, an overnight sleep study that allows clinicians to grade the presence and severity (mild, moderate, or severe) of the disease, remains the "gold standard" for diagnosis, however.

Studies have linked crash risk to the amount of sleep that was previously obtained (Garharino, Nohili, Beelke, De Carli, & Ferrillo, 2001); and anecdotal reports of drowsy driving as a crash contributing factor easily exceed 100,000 per year. Sleep apnea patients, specifically, have been associated with a 2- to a 7-fold increase in crash risk, depending on the study population (Teran-Santos, Jimenez-Gomez, & Cordero-Guevara, 1999). These drivers are also at significantly higher risk of serious injury in crashes (Medical News Today, 2007).

This is currently an active area of research. One investigator (Maycock, 1996) has correlated scores on the Epworth sleepiness scale with crash risk. Many additional studies have documented increased crash risk or impaired driver performance due to fatigue; and it has been shown that treatment for sleep disorders can reduce crash risk to baseline levels (George, 2001). For a comprehensive review of this literature see Charlton et al. (2004).

CONDITIONS THAT IMPAIR PSYCHOMOTOR FUNCTION

Impairments in psychomotor functioning that occur with increasing prevalence among older people may have a neurological origin (e.g., Parkinson's disease) or may be the result of musculoskeletal diseases that result in weakness, frailty, and/or restricted range of motion. According to the Parkinson's disease Foundation (2004), the muscle tightness resulting from this disease can slow reactions to hazards and changing traffic patterns. Again, however, it is the side effects of medications commonly used to treat Parkinson's that may be of greatest concern. As discussed in another chapter, these medications often produce sleepiness, dizziness, blurred vision and confusion, and one class (anticholinergics) can be especially dangerous, producing confusion and sedation along with memory impairment. Given this ambiguity, the present discussion will focus on the preponderance of evidence linking performance and safety outcomes to musculoskeletal disease, rather than neurological conditions.

The prevalence of *arthritis* among individuals in the United States is pronounced, with over 40 million (primarily older) people affected, 7 million of whom report limited activity as a result of the disease (Arthritis Foundation, 2007). The most common form is osteoarthritis, a degenerative joint disease characterized by the destruction of cartilage resulting in bone-on-bone friction, pain, deformities, and restrictions in mobility. The weight bearing joints (hips, knees, lower back) are most affected, but symptoms in the neck, hands, and feet are not uncommon. Obesity and advanced age, as well as family history, are the strongest risk factors for the disease (Carr, 2007).

Clinicians may diagnose arthritis through physical examination of patients who report symptoms including pain, swelling, loss of joint mobility and restricted range of motion; tools including dynamometers and goniometers, that provide a more precise measurement of the limitations in joint mobility, are more common in rehabilitation settings. A diagnosis of osteoarthritis is confirmed through x-ray imaging.

Driving difficulties reported by patients with musculoskeletal disease include problems with seat belt and key use, adjusting the mirrors and seats, transferring in and out of the car, steering—in particular, driving in reverse—and using the foot pedal (Hones, McCann, & Lassere, 1991). A diagnosis of arthritis and the use of NSAIDs were significantly associated with at-fault crash risk by McGwin, Sims, and Pulley (2000). Analyses of the Utah CODES data showed a higher crash rate for drivers with musculoskeletal disorders (Vernon, Diller, Cook, Reading, Suruda, & Dean, 2002). However, Koepsell et al. (1994) found that drivers with a diagnosis of osteoarthritis were at no higher risk than a control group. Also of note is a recent study by Henriskkson (2008) indicating that patients driving cars that have been adapted for their musculoskeletal restrictions are not at increased risk of a crash.

What appears to be the largest body of evidence in this area addresses the impact of weakness and restricted joint mobility on crash experience in the general population, i.e., not with a clinical population. While many in these research samples may in fact suffer from musculoskeletal disease, the medical diagnosis—and hence the prevalence of disease in the samples—is unknown; the only information pertains to the functional limitation itself. As discussed in more detail in another chapter, two areas of functional loss that significantly predict the risk of an (at-fault) crash among older drivers are head-neck mobility, and lower limb strength and flexibility (Staplin, Gish, & Wagner, 2003; Ball, Roenker, Wadley, Edwards, Roth, McGwin, Raleigh, Joyce, Cissell, & Dube, 2006).

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MEDICATION USE IN THE OLDER POPULATION AND EFFECTS ON DRIVING

This chapter addresses an issue of continual concern for law enforcement officers, physicians, attorneys, pharmacists, and traffic safety professionals (Couper & Logan, 2004): driving under the influence of psychoactive drugs. While the principal concern is with the impairments experienced by older drivers who use prescription and over-the-counter medications, much evidence of the prevalence and effects of drug use has been derived from studies of the general population. Where such studies are referenced below, the reader should note that age differences in the way drugs are metabolized will only magnify their impairing effects for older people.

Medications that have known effects on the central nervous system, blood sugar levels, blood pressure, vision, or otherwise have the potential to interfere with driving skills have been termed "potentially driver impairing" (PDI) medications (LeRoy & Morse, 2008). PDI effects include sedation, hypoglycemia, blurred vision, hypotension, dizziness, fainting (syncope), and loss of coordination (ataxia). Often, patients who take over-the-counter or prescription medications are not aware of the potential impact these medications can have on their ability to drive a vehicle safely.

The most detailed information about the medications used in the ambulatory, community-dwelling population of Americans is available for people 65 and older. This is attributed to the increasing number of medical conditions they develop as they age and the increasing number of medications used to treat these conditions. In addition, older adults experience more adverse drug events (e.g., falls and hospitalizations) due to age differences in the way they metabolize medication.

Although the focus of this chapter is a synthesis of the research on medication classes and traffic safety risk, it begins by describing the prevalence of medication use in the community-dwelling older population. Less is known, however, about the prevalence of driving while under the influence of legally prescribed medications taken as directed, and this information is difficult to ascertain for a variety of reasons. As noted by the National Transportation Safety Board and the Food and Drug Administration (FDA) (2001) only a small percentage of people are ever tested for the presence of over-the-counter medicines and prescription drugs following a crash. The majority of the research available on the prevalence of driving under the influence of drugs is limited to illicit drugs or prescription drugs of abuse. Chemical tests of drivers in North American crashes are performed most often for narcotics, benzodiazepines, barbiturates, cocaine, amphetamines, and cannabis (Jones, Shinar, & Walsh, 2003).

Similarly, the magnitude of impairing drug use by drivers may be underestimated because of the procedures used in DUI enforcement, whereby a positive alcohol test usually means that no further investigation into the subject's medication use takes place (Schwilke, dos Santos, & Logan, 2006). Their data suggests that individuals with impairing amounts of alcohol in their systems may more often have impairing drugs in their systems than is documented, which could have contributed to their driving impairment. If the patterns of drug and alcohol use in their sample population (370 drivers age 15 to 93 who died within 4 hours of a traffic crash) carry over into the general impaired driving population, as many as 40% of all individuals arrested for alcohol-related driving offenses could be at least partially under the influence of drugs.

In a survey by Adams (1995) 38% of the older community dwellers reported concurrent use of alcohol and high-risk medications (e.g., antidepressants, antihypertensives, sedative-hypnotics). Six% reported consuming seven or more drinks per week while taking high-risk medications.

Given the prevalence of prescription and over-the-counter drug use described below, the high rate of polypharmacy in the older adult population, and the fact that 85% of the U. S. population that is of driving age (16 to 85+) holds a driver's license (FHWA, 2005), it is reasonable to conclude that a large percentage of the driving population could be at risk of medication-impaired driving.

MEDICATION USE IN THE COMMUNITY-DWELLING OLDER POPULATION

In 1998, older people made up approximately 12% of the U. S. population, but they consumed 32% of all prescription drugs (Rathmore, Mehta, Boyko, and Schulman, 1998). Furthermore, prescription drug use in the older population is increasing at a faster rate than in the population under 65 (Thomas, Ritter, & Wallack, 2001). Using prescription claims data, Thomas et al. (2001) found that the average number of therapeutic classes for which older people receive drugs is 4.66, compared to 2.99 for people under 65.

According to Memmott (2003), 69% of people over the of 65 regularly use over-the-counter (OTC) medications; approximately 40% of the drugs taken by older people are OTC medications. Bikowski, Ripsin, and Lorraine (2001) cite evidence that, on average, an ambulatory older patient takes 3.4 OTC medications daily.

A cohort study of nearly 28,000 Medicare+Choice enrollees cared for by a multispecialty practice (an ambulatory clinic setting) between 1999 and 2000, found that 75% of the sample received prescriptions for 6 or more medications (Gurwitz, Field, Harrold, Rothschild, Debellis, Seger, et al., 2003). Forty-nine percent of the sample was prescribed medications in four or more therapeutic categories.

Thomas et al. (2001) focused on therapeutic categories of drugs used by older people with high prescription drug expenditures ($3,000+). In this group, 90% used cardiovascular medications; and among these patients, over 50% also took a gastrointestinal medication, 50% took a lipid-lowering medication, and almost half took antidepressants or antiarthritis medications. This example calls attention to the issue of polypharmacy among older adults.

The risks of polypharmacy include an increase in the number of potentially inappropriate prescriptions, cognitive disorders, falls, hip fractures, depression, incontinence, and an increased risk of motor vehicle crashes (Gurwitz, Soumerari, & Avorn, 1990; LeRoy & Morse, 2008). As LeRoy and Morse (2008) report, the following factors account for the increase in the number of potential drug interactions in older adults:

- An increase in the number of drugs taken daily;
- Alterations in pharmacokinetics (the process by which a drug is absorbed, distributed, metabolized, and eliminated by the body);
- Long-term drug use;

- Alteration in gut surface area;
- Decrease in gastric motility;
- Decreased gastric acid secretion;
- Multiple drugs competing for binding sites on serum albumin;
- Multiple drugs competing for metabolic enzymes;
- Increase in the proportion of fat to body mass;
- Decreased body water;
- Reduced liver size with diminished ability to metabolize drugs; and
- Less efficient renal clearance of drugs.

LeRoy and Morse further state that symptoms of drug-induced poisonings, overdoses, drug interactions, or side effects are often interpreted as normal signs of aging and thus fail to be associated with pharmaceutical causes. Some of these symptoms include disorientation, tremors, lethargy, depression, and forgetfulness. Side effects are extensions of anticipated pharmacologic effects or side effects of normal doses of drugs that are particularly relevant to older adult drivers. These include dizziness, drowsiness, tremors, rigidity, confusion, hypoglycemia, hypotension, and blurred vision.

Information for several of the medication classes described below came from the conclusions of an international panel of experts in the fields of psychopharmacology, behavioral psychology, drug chemistry, forensic toxicology, and medicine, plus law enforcement personnel trained in the recognition of drug effects on drivers in the field. This panel met in 2000 to review developments in the fields of drugs and human performance over the last 10 years; to identify specific effects that drugs have on driving; and to develop guidance for others when dealing with drug-impaired driving problems. The information from this panel was summarized by Couper and Logan (2004) in a document called *Drugs and Human Performance Fact Sheets*, for a project sponsored by the National Safety Council, Committee on Alcohol and Other Drugs; the State of Washington Traffic Safety Commission; and the National Highway Traffic Safety Administration.

Data describing the crash risk associated with therapeutic classes of prescription drugs are presented where available. LeRoy and Morse (2008) used an administrative pharmaceutical claims database in a project for NHTSA, to determine how often various combinations of medications showed up among members who had experienced a motor vehicle crash versus those who had not experienced a crash. Their study evaluated the medication use of 33,519 members who had motor vehicle crashes (5,378 of whom were 50+) and the medication use of 100,000 matched controls (three for each case, matched on age and gender) who had not crashed.

In the LeRoy and Morse (2008) analysis, drivers were 1.2 to 7.5 times more likely to have been crash involved if they had taken medications in 35 of 90 potentially driver impairing (PDI) medication classes. Of these 35 pharmacologic classes highlighted in their research, 27 have specific warnings about sedation, dizziness, drowsiness, and the need for caution when driving, especially until the effects of the medication on driving are known. They calculated an odds ratio that describes how much more likely it is that a driver who *did* receive a prescription was involved in a motor vehicle crash than a driver of the same age and gender who did *not* receive a prescription for the medication (within a 90-day window of the crash). For example, an odds ratio of 1.2 can be interpreted as a 20% increase in the risk of crashing for drivers taking specific medications, compared to drivers not taking those medications. An odds ratio of 7.0

would mean that the risk of crashing was increased by 7 times.

Various, widely recognized limitations in the conclusions that can be drawn from the findings of case-control studies should be reiterated. First, while such studies can determine an *association* between a factor and an outcome, they cannot determine that the factor *caused* the outcome. It is difficult and often impossible to separate the study factor of interest (e.g., taking a medication) from other confounding factors that could also have been responsible for the outcome. Confounding factors include things such as having a medical condition or multiple medical conditions, severity of medical condition(s), drug interaction conflicts, number of miles driven, use of other medications or alcohol, length of exposure to the medication of interest, etc. Second, they do not give any indication of the absolute risk of the factor being studied. Finally, there may be differences between the cases and the controls chosen, even though care is taken to match them on specific characteristics.

Other information provided in this chapter was synthesized from published research on simulator and on-the-road studies of medications and driving. Information about prescription drug mechanisms of action, side effects, and patient information were taken from *Basic and Clinical Pharmacology* (2004) as well as the Medline Plus[2] and Epocrates[3] web sites. This chapter is organized according to potentially driver impairing therapeutic drug classes within the following major categories:

- Central Nervous System (CNS) Depressants;
- Cardiovascular/Renal Medications;
- Hematologic Agents;
- Respiratory Tract Medications;
- Hormones;
- Gastrointestinal Agents;
- Pain Relievers;
- Neurological Medications;
- Ophthalmics;
- Antiparasitics; and
- CNS Stimulants.

CENTRAL NERVOUS SYSTEM DEPRESSANTS

CNS depressants are used to treat anxiety, insomnia, and muscle spasticity by depressing brain activity and inducing a drowsy or calming effect. Initial side effects may include drowsiness, dizziness and decreased coordination; however, over time patients typically develop some level of tolerance to these symptoms. CNS depressants include a wide variety of medications such as those listed at the top of the following page:

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[2] A service of the National Library of Medicine (NLM) and the National Institutes of Health (NIH), available at www.nlm.nih.gov/medlineplus/druginformation.html.

[3] Epocrates Rx, a free download with information on dosing, interactions, and adverse reactions, safety monitoring, pharmacology for 3,300 brand name and generic drugs, accessible at www.epocrates.com.

- Barbiturates—e.g., amobarbital (Amytal) and secobarbital (Seconal),
- Benzodiazepines—e.g., alprazolam (Xanax) and diazepam (Valium), as well as
- Newer anxiolytic/hypnotic non-benzodiazepine type CNS depressants—e.g., buspirone (BuSpar) and zolpidem (Ambien).

Barbiturates

Barbiturates such as phenobarbital have been used in clinical practice since the beginning of the 20th century and have been widely used for a range of indications including the treatment of anxiety, insomnia, and seizure disorders, and as muscle relaxants and anesthetic agents. Benzodiazepines and the newer non-benzodiazepines are preferred to barbiturates for insomnia and anxiety for a number of reasons; specifically, they offer a therapeutic effect farther below a toxic dose, and patients develop a tolerance more slowly than to barbiturates. However, barbiturates still remain an important class of medications, and were associated with the highest risk of motor vehicle crashes among the 90 prescription drug classes studied by LeRoy and Morse (2008). With an OR of 7.5, the risk of crashing for drivers taking barbiturates was more than 7 times greater than the risk for drivers not taking these medications.

Barbiturates decrease anxiety and increase feelings of fatigue, dizziness, lightheadedness and lethargy. Patient information cautions that even when taken at bedtime, barbiturates may cause some people to feel drowsy or less alert upon arising. Patients are advised to make sure they know how the medicine affects them before they drive or do anything else that could be dangerous if they are dizzy or are not alert. Acute doses of barbiturates have been found to impair performance on standard tests of eye-hand coordination and symbol-digit substitution tests, and decrease the number of items recalled in memory recognition tests (Pickworth, Rohrer, & Fant, 1997). Additionally, as the cognitive tasks were made more challenging, impairments were detected at lower doses of the barbiturate. Researchers have also observed that both alcohol and barbiturates produce similar dose-related effects on all psychomotor and cognitive measures (Mintzer, Guarino, Kirk, Roache, & Griffiths, 1997).

Benzodiazepines

Benzodiazepines (BZDs) are used primarily to relieve anxiety, although some are used to treat other conditions such as insomnia, alcohol withdrawal symptoms, muscle spasms, panic disorders, and seizure disorders (Jones, Shinar, & Walsh, 2003). The most common side effect of benzodiazepines is sedation. Other PDI side effects may include blurred vision as well as burning and tearing of the eyes, dizziness, weakness, clumsiness, and unsteadiness or ataxic gait.

Benzodiazepines that sustain their effects (and their side effects) for more than 9 hours are called long half-life benzodiazepines. Examples of long half-life BZDs include alprazolam (Xanax), chlordiazepoxide (Librium), clorazepate (Tranxene), diazepam (Valium), lorazepam (Ativan), oxazepam (Serax), and prazepam (Centrax). Shorter half-life BZDs generally reach their peak within 2 hours. These medications include estazolam (ProSom), flurazepam (Dalmane), quazepam (Doral), temazepam (Restoril) and triazolam (Halcion).

The duration of hypnotic effect and the profile of unwanted effects may be influenced by the distribution and elimination half-lives of the administered medication and any active metabolites formed. When half-lives are long, the medication or metabolite may accumulate during periods of nightly administration and be associated with impairments of cognitive and motor performance during waking hours. If half-lives are short, the medication and metabolites will be cleared before the next dose is ingested, and carry-over effects related to sedation or CNS depression should be minimal or absent (RxMed, 2005). Berghaus and Friedel (1997), in Jones et al. (2003), analyzed the% of studies that showed impairment in driving-related psychomotor and perceptual tasks as a function of time since administration of certain benzodiazepines. Their findings, which are not specific to older drivers, are summarized below.

- Clobazam (at 10 or 20 mg) and temazepam (10 mg) generally yielded no significant impairments at all.
- Studies with midazolam, diazepam, oxazepam, triazolam, and lormetazepam showed impairments for 5 to 6 hours.
- High-dose long-life benzodiazepines showed significant impairments lasting up to 18 to 24 hours. This included nitrazepam (10 mg), flunitrazepam (2 mg), and flurazepam (30 mg).

Furthermore, benzodiazepines or active metabolites with very long elimination half-lives can accumulate with chronic dosing and produce prolonged effects, especially in older or obese patients, or those with liver disease; or, with concurrent use of other medications that compete for hepatic oxidation. The updated Beers criteria[4] indicate that short- and intermediate-acting benzodiazepines are preferred over long-acting benzodiazepines, if a benzodiazepine is required for an older patient (Fick, Cooper, Wade, Waller, Maclean, & Beers, 2003). However, most clinicians will use selective serotonin reuptake inhibitors (SSRIs) for the treatment of chronic anxiety since they have been found to be useful in this situation and with fewer side effects.

Deleterious effects of benzodiazepines on a wide variety of driver performance tasks have been demonstrated. Simulator and driving studies have shown that a single dose of diazepam (Valium) decreases a driver's ability to maintain vehicle lane position. Drivers' eye-hand coordination, reaction times, ability to perform multiple tasks, and retrieve information were also impaired (Couper & Logan, 2004). Subjects' on-road driving performance the morning after using benzodiazepines as hypnotics showed impairment comparable to a blood alcohol content (BAC) of .05 to .10 grams per deciliter (O'Hanlon, Brookhuis, Louwerens, et al., 1986). In LeRoy and Morse's research, drivers taking BZDs were twice as likely to have a motor vehicle crash (OR=2.0) than drivers not taking these medications.

In an older driver test group (age 67 to84 years), during the first 7 days of exposure to a long half-life benzodiazepine, there was an almost 50% increase in the rate of involvement in injurious motor vehicle crashes compared to a group of age-matched controls who had no exposure to benzodiazepines in the prior year (Hemmelgarn, Suissa, Huang, Boivin, & Pinard,

[4] Criteria used to identify potentially inappropriate medication use in the population of older people. These criteria consider (1) medications or medication classes that *should generally be avoided* in people 65 years or older because they are either ineffective or they pose unnecessarily high risk for older people and a safer alternative is available and (2) medications that should not be used in older people known to have *specific medical conditions*." The recent update of the Beers criteria found 48 individual drugs or classes of drugs to avoid in older adults and 20 diseases/conditions and medications that should be avoided in older people with these conditions.

1997). The risk remained significant (although somewhat reduced) for continuous use of longer duration up to 1 year. In contrast, no increased risk was observed after the initiation of treatment with short half-life benzodiazepines for the first 7 days of use, or over longer durations of use.

Walsh, de Gier, Christopherson, and Verstraete (2004) state that based on the present knowledge, benzodiazepines constitute a considerable risk to traffic safety, both in therapeutic doses and to a much larger degree at higher doses. When evaluating the driving risk for benzodiazepines, it is also important to consider the high prevalence of benzodiazepine use among older people (Hemmelgarn et al., 1997).

Anti-Anxiety/Hypnotic – Non-Benzodiazepine Agents

Meprobamate, the metabolite of carisoprodol, is a non-benzodiazepine anti-anxiety medication developed in the 1950's. Although it was marketed as being safer, meprobamate (e.g., Equagesic) has most of the pharmacological effects and dangers of the barbiturates even though it is less sedating at effective doses. Its half-life is between 6 and 17 hours, and accumulation of meprobamate during chronic therapy may occur as a result of this long half-life. There are limited performance effect studies for this medication; however, a single dose of meprobamate has been shown to be capable of causing significant impairment in divided attention, coordination, balance and reaction time. It is likely that decrements in psychomotor performance would be even more pronounced with chronic dosing.

Following administration of meprobamate in the treatment of anxiety, peak plasma concentrations are typically around 10 mg/L, but can range between 3 and 26 mg/L (Couper & Logan, 2004). Signs of impairment have been observed for drivers arrested for DUI and using meprobamate at blood concentrations as low as 1 mg/L (Logan, Case, & Gordon, 2000). In the research by Logan et al. (2000), the most severe driving impairment and the most overt symptoms of intoxication occurred in drivers whose combined carisoprodol and meprobamate blood concentrations were greater than 10 mg/L. Many of these drivers were involved in hit-and-run crashes, where they appeared to be unaware that they had hit another vehicle. Other observed driving behaviors included extreme lane excursions, weaving, and slow speed.

Sedative/Hypnotics – Non-Barbiturate

In the 1990s a newer class of medications, known as "non-benzodiazepine, benzodiazepine receptor agonists" (e.g., Ambien, Lunesta, Sonata) were introduced for the treatment of insomnia. These agents selectively bind to the BZD_1 receptor, reducing anxiolytic effects with a lower risk of abuse or dependence and fewer adverse effects than benzodiazepines. PDI side effects may include dizziness and drowsiness. Use of these medications increased the crash risk by 48% in the analysis by LeRoy and Morse (2008). Patient information advises that the medication should be taken before bedtime, and carryover effects may last into the next day. Patients are advised by the manufacturer to use caution when driving.

During a 1.5-hour driving test given 10 to 12 hours after the administration of Zolpidem (Ambien), no significant adverse effects were observed. However, impairments in coordination, cognition, and reaction time were seen when the driving test was completed within the first 4 to 5 hours of administration of single doses of 10-20 mg (Couper & Logan, 2004).

Meeker and Baselt (1996) reported on six cases of driving under the influence of zolpidem, with BACs ranging from .10 to .73 g/dL. The drivers were involved in crashes or were driving erratically, and symptoms included slow and slurred speech, ataxia (clumsiness and unsteadiness), unsteady gait, confusion, and disorientation.

Liddicoat and Harding (2006) reported on 6 individuals arrested for driving under the influence of zolpidem, with concentrations ranging from 190 to 4400 ng/mL. Therapeutic serum levels range from 29 to 272 ng/mL; 5 of the 6 cases had serum levels above therapeutic levels. All drivers tested negative for the presence of alcohol. Three drivers had taken SSRI antidepressants along with the zolpidem. Drivers' physical abilities were described as: slow to respond, swaying with an unsteady gait, confusion, disorientation, blurred and double vision, did not recall recent events, and poor comprehension. Driving behaviors included near-crashes, crashes into a parked car or other stationary object, drove over curb (all 4 wheels), erratic driving, weaving, lane crossings, incorrect stopping position at traffic signal, and failure to proceed when signal turned green. The researchers determined that because zolpidem has a very short half life and a quick elimination period, these drivers were not taking the drug as directed (before bedtime) or were taking large doses of it. If taken as directed, there would be no drug left in the blood after eight hours of sleep, or at least a very low amount of the drug.

A simulator study investigated the driving abilities of patients diagnosed with primary insomnia, after repeated dosing of sedative hypnotic prescription drugs (Staner, Ertlé, Boeijinga, Rinaudo, Arnal, Muzet, & Luthringer, 2005). Single and repeated (7 day) doses of zolpidem (10 mg), zopiclone (7.5 mg), or a placebo were administered to 23 patients with an average age of 38.8 years (s.d.=2 years). Treatments were administered at bedtime from day 1 to day 7, and its effect was assessed at the beginning (day 2) and at the end (day 8) of each treatment period after a night spent in the sleep laboratory. Driving simulator tests took place 9 to 11 hours post-dose.

Patients taking zopiclone (the European analog of the U. S. drug eszopiclone or Lunesta) had significantly more simulator crashes than patients taking the placebo. Zolpidem (Ambien) had no effect on the driving performance measures. Zopiclone had significant next-day effects (9 to 11 hours post dosages) on EEG correlates of vigilance level (benzodiazepine-like alterations in beta and alpha brain waves), a phenomenon referred to as "pharmacological dissociation." Zolpidem did not alter next-day physiological EEG rhythms 9 to 11 hours post-dose when taken as prescribed. The authors suggest that the poor driving performance associated with zopiclone during the driving simulation test was related to its prolonged CNS effects. The residual effects of the hypnotics increased with increases in their half-life. The average half-life of zopiclone is 5 hours, compared to 1.9 hours for zolpidem.

There have been recent anecdotal reports of "sleep driving" after taking zolpidem. In 2007, the FDA required a "black box" warning to alert patients of this danger. Presumably, if one takes the medication, as directed (just before bed), this is not a likely occurrence. But a patient who stays awake for any period of time may unconsciously attempt to drive. Couper and Logan (2004) conclude that a single 7.5 mg dose of zopiclone can cause severe residual effects on actual driving at 5 and 10 hours post-dose. Zolpidem (10 mg dose) causes significant effects on driving within 5 hours of use. Zaleplon (Sonata) causes significant impairment within 3 hours of use (10 mg), but no significant impairment after 4 hours.

Antidepressants

In addition to their primary use to relieve mental depression, antidepressants are often used in the treatment of other conditions including bipolar disorder, chronic pain, and anxiety disorders. Since the introduction of the first-generation antidepressants (tricyclics and monamine oxidase inhibitors), the number of new classes of antidepressant medications has grown dramatically. Newer classes of medications include the selective serotonin reuptake inhibitors (SSRIs), serotonin-norepinephrine reuptake inhibitors (SNRIs), and serotonin -2 antagonist-reuptake inhibitors (SARIs). Today, antidepressants are among the most commonly prescribed medications by both psychiatrists and general practitioners.

Researchers who have reviewed controlled experimental studies with drivers have concluded that impaired performance is associated with the use of most sedative tricyclic antidepressants (Walsh et al., 2004; European Monitoring Centre for Drugs and Drug Addiction, 1999). Epidemiological studies focusing on older drivers have documented increased crash risks for users of cyclic antidepressants, with a relative risk of 2.3 (Leveille, Buchner, Koepsell, McCloskey, Wolf, & Gagne, 1994). New generation antidepressants do not seem to interfere with performance, however, except when used at higher doses (Walsh et al., 2004).

Although some research has found the newer selective antidepressants (e.g., Lexapro, Zoloft, Effexor, Paxil, Wellbutrin) to be free of detrimental effects on driving when taken at recommended therapeutic doses (Ramaekers, 2003), a more recent analysis using a pharmaceutical claims database for patients who have experienced a motor vehicle crash has found that crash likelihood was increased 19 to 78% for drivers taking medications in these classes (LeRoy & Morse, 2008). Caution is also recommended when these medications are used in combination with other sedating medications such as sedative hypnotics, narcotics, or antihistamines (Judd, 1985).

A recent review notes a large number of clinically significant drug interactions with antidepressants in older people (Spina & Scordo, 2002). For example, tricyclic antidepressants and monoamine oxidase inhibitors have a high potential for pharmacodynamic drug interactions with a range of drugs, including benzodiazepines, antipsychotic agents, and other antidepressants. The newer antidepressants, such as SSRIs, SNRIs, and so-called dual-action compounds (*e.g.*, mirtazapine) exhibit fewer drug interactions[5] than the sedating antidepressants and long-acting benzodiazepines, but pharmacokinetic drug interactions may be seen (Sheikh, 2004). Some medications that may be prescribed along with antidepressants that may increase

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[5] Drugs can interact with each other at numerous sites in the body, including the small intestine, bloodstream, liver, and kidneys. The two main types of drug interactions are pharmacokinetic and pharmacodynamic (Cadieux, 1999). Pharmacokinetic interactions occur when one medication (the precipitant drug) affects the plasma concentration, half-life, or both, of another medication (the object drug) by altering its absorption, distribution, metabolism, or elimination. Competition for protein binding in the plasma and inhibition of catabolic enzymes in the liver are examples of such interactions. For object drugs with narrow therapeutic indexes (eg, tricyclic antidepressants [TCAs], anticoagulants, antiarrhythmic agents), even small elevations in plasma concentration can cause potentially serious adverse reactions. Pharmacodynamic interactions occur when one drug affects the ability of another to associate with its therapeutic target or receptor. Some compounds compete directly for binding to a receptor, while others indirectly affect the ability of an object drug to interact with its site of action. The former phenomenon is common with medications that bind to multiple receptor types (eg, first-generation TCAs).

the risk of dizziness, syncope, falling, and motor vehicle crashes include antipsychotics, anxiolytics, hypnotics, opioid analgesics, and diuretics and other antihypertensive medications.

Tricyclic Antidepressants and Related Non-Selective Re-Uptake Inhibitors. Tricyclic antidepressants such as nortriptyline (Aventyl), imipramine (Tofranil), amitriptyline (Elavil), and doxepin (Sinequan) have many PDI side effects including blurred vision, sedation, cognitive and memory difficulties, muscle weakness and hypotension. This class of antidepressants has been associated with a 41% increase in motor vehicle crash rate (LeRoy & Morse, 2008). Drivers taking antidepressant-tranquilizer combinations (e.g., Etrafon that combines amitriptyline and perphenazine) had a likelihood of crashing that was more than 4 times higher than that of drivers not taking these medications (OR=4.5). Similarly, tricyclic antidepressant-benzodiazepine combinations (Limbitrol DS) increased crash likelihood by 4 times (LeRoy & Morse, 2008).

Because tricyclic antidepressants cause sedation and may also cause dizziness, patients are cautioned against driving until they know how the medication affects them, and to avoid driving when they experience these side effects. Wang, Kosinski, Schwartzberg, and Shanklin (2003) recommend that whenever possible tricyclic antidepressants should be avoided in patients who wish to continue driving. However, if non-impairing alternatives are not available, patients should be advised of the potential side effects, and to temporarily cease driving during the initial phase of medication initiation or following dosage adjustments. In addition, patients should also be advised that they may experience impairment *even in the absence of subjective symptoms*.

Experimental driving studies have shown that sedating antidepressants, such as tricyclic antidepressants, may impair critical driving skills and thereby increase the risk of being involved in a traffic accident. Ramaekers (2003) found that acute doses of sedating antidepressants produced effects in lanekeeping ability that were comparable to those seen in subjects with a BAC of.08 g/d. But, it was also shown that the effects on driving were not significant after subjects had been dosed for at least one week, or if the dose was given at nighttime and performance was measured the next day. It is important to note that the subjects were young, healthy adults with no concomitant medications. It also deserves mention that administering these medications for the treatment of depression may have a net safety benefit by reducing the negative effects of the symptoms of depression on driving performance (Hobi, Gastpar, Gastpar, Gilsdorf, Kielholz, & Schwarz, 1982).

Selective Serotonin Reuptake Inhibitors (SSRIs). Selective Serotonin Reuptake Inhibitors (SSRIs) are used to treat depression, and work by increasing the amount of serotonin, a natural substance in the brain that helps maintain mental balance. Examples of SSRIs include citalopram (Celexa), paroxetine (Paxil), fluoxetine (Prozac), escitalopram (Lexapro), and sertraline (Zoloft). Each medication in this class contains a warning that it may cause drowsiness, and advises against driving until patients know how the drug affects them. Other listed side effects that could impair driving ability may include tremor; uncontrollable shaking of the hands; pain, burning, or tingling in the hands or feet; nervousness; muscle or joint pain; difficulty falling asleep or staying asleep; dizziness; muscle weakness or tightness; difficulty concentrating; forgetfulness; sensitivity to light; and although uncommon, hallucinations.

Wang et al. (2003) indicate that PDI side effects tend to be mild and well tolerated, while recommending that physicians counsel their patients about their potential to affect driving performance. In contrast, LeRoy and Morse (2008) found that a 59% increased risk of a motor vehicle crash was associated with the use of these medications.

Seratonin-2 Antagonist/Reuptake Inhibitors (SARIs). Seratonin-2 antagonist/reuptake inhibitors (SARIs) modulate the amount of serotonin in the brain to help relieve depression, by inhibiting norepinephrine and serotonin reuptake and antagonizing serotonin 5-HT2 receptors. Examples of medications in this class include trazodone (Desyrel) and nefazodone (Serzone). Trazodone patient information warns of drowsiness and impaired judgment, and cautions against driving until patients know how this drug affects them. Nefazodone warns of dizziness, drowsiness, and blurred vision, and also cautions against driving until patients know how the drug affects them. Other PDI side effects of SARIs may include clumsiness or unsteadiness, weakness, nervousness, decreased ability to concentrate or remember things, confusion, difficulty falling asleep or staying asleep, and muscle pain.

Researchers have evaluated the acute and subchronic effects of two doses of nefazodone (100 and 200 mg twice daily for 7 days) on actual driving performance, as well as on psychomotor tests and sleep latency tests in the laboratory (van Laar, van Willigenburg, & Volkerts, 1995). A single administration of each dose did not impair highway driving performance and had no (or minor) effects on psychomotor performance. After repeated dosing with 200 mg twice daily (but not with the 100-mg dose) there was slight impairment in subjects' lanekeeping ability while driving on the highway. Dose-related impairments of cognitive and memory functions were found. The higher the steady-state plasma concentrations, the poorer the reaction time on a memory scanning task. Nefazodone did not appear to induce daytime sleepiness, as measured by the sleep latency tests.

LeRoy and Morse (2008) found that drivers taking prescription drugs in this class experienced a 90% increase in the risk of a motor vehicle crash (OR=1.90) compared to drivers not taking medications in this class.

Serotonin-Norepinephrine Reuptake Inhibitors (SNRIs). Serotonin-Norepinephrine Reuptake Inhibitors (SNRIs) are used to treat depression by increasing the amounts of serotonin and norepinephrine, natural substances in the brain that help to maintain mental balance. Examples include venlafaxine (Effexor), which is also used to treat anxiety disorder and social anxiety disorder, and duloxetine (Cymbalta), which is also used to treat pain and tingling caused by diabetic neuropathy. Both contain a warning about drowsiness and caution against driving until the effects of the medication are known. Other PDI side effects may include weakness or tiredness, excitement or anxiety, nervousness, insomnia, dizziness, blurred vision, and muscle pain or cramps.

While O'Hanlon, Robbe, Vermeeren, van Leeuwen, and Danjou (1998) found that venlafaxine (in fixed doses of 37.5 mg twice a day, and incremental doses of 37.5 – 75.0 mg twice a day) did not generally affect driving ability, LeRoy and Morse (2008) found that motor vehicle crash experience increased 78% for drivers taking SNRIs compared with drivers not taking these medications.

Norepinephrine and Dopamine Reuptake Inhibitors. Bupropion (Wellbutrin, Zyban) is used to treat depression, as well as to help people stop smoking. Patient information indicates that bupropion may cause drowsiness, and cautions against driving until drug effects are known.

Other PDI side effects may include restlessness, excitement, dizziness, tremor, and insomnia (leading to daytime drowsiness). Although LeRoy and Morse (2008) found an increased crash risk associated with the use of this medication (OR=1.19), it had the lowest odds ratio of the antidepressant PDI medications evaluated in their case-control study.

Alpha-2 Receptor Antagonists. Mirtazapine (Remeron) is used to treat depression by antagonizing alpha2-adrenergic and serotonin 5-HT2 receptors (tetracyclic). Wang et al. (2003) state that it is typically taken only at night due to its sedating effects, and has been shown to cause substantial impairments for many hours after dosing. Patient information warns about drowsiness and cautions against driving until the effects of the drug are known. Other PDI side effects may include dizziness, anxiousness, and confusion. LeRoy and Morse (2008) found that drivers taking mirtazapine experienced an 88% increase in crash risk compared with drivers not taking this medication. Wang et al., recommend that this medication be avoided whenever possible in patients who wish to continue driving.

Antipsychotics

Antipsychotics are generally used to treat schizophrenia and psychosis in dementia, which can include hallucinations, delusions, and hostility. Other uses include control of severe nausea and vomiting, severe hiccups, and moderate to severe pain in hospitalized patients, and to treat severe behavioral problems in children who have autistic disorders. The antipsychotic agents are divided into chemical classes. Most, if not all, of the antipsychotic medications have a strong potential to impair driving performance through various central nervous system effects. The traditional antipsychotics (e.g., haloperidol and thioridazine) are heavily sedating, and all produce extrapyramidal side effects (Wang et al., 2003). The extrapyramidal system is a neural network located in the brain that is part of the motor system involved in the coordination of movement. Although the modern or “atypical” medications have a lower tendency to cause extrapyramidal side effects, they are sedating and can cause dizziness and orthostatic hypotension—a drop in blood pressure upon rapid change in body position (from sitting to standing, for example) that may lead to fainting.

Phenothiazines. The phenothiazines are the oldest group of antipsychotics and include chlorpromazine (Thorazine), mesoridazine (Serentil), prochlorperazine (Compazine), and thioridazine (Mellaril). These medications may cause some people to become drowsy or to be less alert than they are normally. Even when taken at bedtime, patients may feel drowsy or less alert upon arising. Patient information cautions against driving until the effects of the medication are known. In addition, phenothiazines may cause blurred vision, difficulty in reading, visual field loss, color vision changes, inability to move the eyes, and increased blinking or spasms of the eyelid, particularly during the first few weeks of treatment. Patient information cautions against driving if vision is impaired. The side-effect profile of medications in this class is extensive and includes tardive dyskinesia (involuntary irregular muscle movements), neuroleptic malignant syndrome (with severe muscle stiffness and severe confusion), muscle spasms, twitching, and uncontrollable twisting movements of the arms, legs, neck or trunk.

Although the actions and the side-effects associated with these drugs would predict a greatly increased motor vehicle crash likelihood, the analyses of LeRoy and Morse (2008) revealed that medications in this class were associated with only a modest 5% increase in motor vehicle crashes (OR=1.05). Judd (1985) noted that despite the extremely widespread use of antipsychotics, there is little evidence that this class of psychoactive medications is significantly implicated in vehicular crashes or deaths. In his review of epidemiologic evidence of crashes and medications, he concluded that "*the acute administration of antipsychotics in normal individuals induces sedation and performance decrements in visual-motor coordination and specific attention behaviors, which have a deleterious effect on driving. However, antipsychotics are rarely used on an acute basis, and tolerance to sedation and decreased alertness does occur during chronic treatment*." Judd (1985) cautions that antipsychotic medications have the capacity to increase the effects of alcohol, sedative hypnotics, narcotics, and antihistamines; therefore, combinations of antipsychotics with these other drugs increases driving-related impairment. LeRoy and Morse (2008) found that tricyclic antidepressant/phenothiazine combinations were associated with a 4.5 fold increase in motor vehicle crash risk.

Dopamine Agonists – Thioxanthenes. Thiothixene (Navane) selectively antagonize dopamine D2 receptors in the treatment of nervous, mental, and emotional conditions. This class carries the same patient cautions about drowsiness and lowered alertness levels as the phenothiazines. Prescription drugs in this class may also cause tardive dyskinesia (movement disorders) and neuroleptic malignant syndrome. This is a neurological disorder, most often caused by an adverse reaction to neuroleptic or antipsychotic drugs that typically develops within two weeks of the initial treatment with the drug, but may develop at any time the drug is being taken, with the following symptoms: muscle rigidity, fever, autonomic instability and cognitive changes such as delirium. Other PDI side effects may include inability to move eyes and blurred vision among other eye problems, loss of balance control, muscle spasms (especially in the back and neck), arm and leg stiffness, trembling and shaking of fingers and hands, twisting body movements, and uncontrolled movements of the arms and legs. Thioxanthenes were associated with a 3-fold increase in the risk of a motor vehicle crash in the research performed by LeRoy and Morse (2008).

Atypical Antipsychotics – Dopamine and Serotonin Antagonists. During the 1990's the atypical antipsychotics such as risperidone (Risperdal), quetiapine (Seroquel), olanzapine (Zyprexa), ziprasidone (Geodon) and clozapine (Clozaril) were introduced and have found favor due to their lowered tendency to cause extrapyramidal side effects (movement disorders). Side effects reported for the various atypical antipsychotics are medication specific; however, general side effects include drowsiness and blurred vision. Other PDI side effects may include dizziness, anxiety and agitation, lowered alertness, stiffness of arms and legs, trembling or shaking of hands and fingers, and muscle pain. Manufacturers advise patients to use caution when driving until they know how the medication affects them, as it may cause drowsiness and affect judgment. Clozapine carries a warning not to drive while taking this medicine. The odds ratio showed that the risk of motor vehicle crashes associated with the use of atypical antipsychotics was less than it was with the use of thioxanthenes and phenothiazine-tricyclic antidepressant combinations, but was still significant at 2.20 (LeRoy & Morse, 2008).

Antiemetic/Antivertigo Agents

Medications such as meclizine (Antivert), promethazine (Pentazine), and scopolamine patch (Transderm Scop) are used to prevent and treat nausea, vomiting, and dizziness caused by motion sickness. Prochlorperazine (Compazine) and ondansetron (Zofran) are used to treat nausea and vomiting caused by radiation therapy, cancer chemotherapy, surgery, and other conditions. Trimethobenzamide (Tigan) controls nausea and vomiting for patients with the flu and other illnesses. Potentially driver impairing side effects may include significant drowsiness, lowered alertness, blurred vision, disorientation, and muscle cramps. Several drugs in this class contain patient advisories to postpone driving until medication effects are known. Wang et al. (2003) report that significant impairment may be present even in the absence of subjective symptoms. In a driving study by Betts, Harris, and Gadd (1991) subjects taking 5 mg of prochlorperazine 3 times daily showed increased carelessness and significant slowing on a maneuvering task. Also, these subjects were not aware of their driving impairments. In LeRoy and Morse's analysis (2008), patients taking antiemetic/antivertigo agents experienced a 63% increase in motor vehicle crash risk compared to patients not taking these medications.

CARDIOVASCULAR/RENAL MEDICATIONS

Antihypertensives

Antihypertensives represent a broad class of agents that are used to lower blood pressure as well as treat a variety of other cardiovascular conditions and which, as a class, demonstrated an increased odds ratio for a motor vehicle crash (LeRoy & Morse, 2008). The most common side effects of these medications are symptoms related to their hypotensive properties such as dizziness, drowsiness, and weakness, all of which may impair driver performance. Antihypertensives that work centrally (e.g., the sympatholytic agents such as clonidine or methyldopa) may also cause insomnia, confusion, and nervousness (Wang et al., 2003).

<u>Diuretics</u>. Diuretics are among the oldest known medications for treating hypertension. They work in the tubules of the kidneys to remove salt and fluids from the body. Frequently, diuretics are used in low doses in combination with other antihypertensive medications. An increased risk of motor vehicle crashes has been associated with three classes of diuretics: *loop diuretics*, *potassium sparing diuretics*, and *potassium sparing diuretics in combination*. Drivers taking these medications had a 20 to 35% increased incidence of crash involvement compared to drivers not taking these drugs (LeRoy & Morse, 2008). Potentially driver-impairing (PDI) side effects associated with loop diuretics (e.g., Lasix, Bumex, Edecrin, Demadex) include dizziness, weakness, drowsiness, fainting, and blurred vision. PDI side effects associated with potassium sparing diuretics (e.g., Aldactone, Inspra, Dyrenium) include dizziness, drowsiness, and excessive tiredness. Potassium sparing diuretics in combination with hydrochlorothiazide (another diuretic) include Dyazide, Maxzide, Aldactazide, and Moduretic, among others. PDI side effects include dizziness, drowsiness, weakness, and fainting. Patient warnings about drowsiness and the ability to operate a car safely accompany several medications in this class.

<u>Angiotensin-Converting Enzyme (ACE) Inhibitors</u>. ACE Inhibitors (e.g., Lisinopril, Accupril, Altace) decrease the activity of angiotensin and as a result blood vessels dilate and blood pressure is reduced. Researchers found that drivers taking ACE inhibitors experienced a motor vehicle crash risk that was 23% greater (OR=1.23) than that of drivers not taking these medications (LeRoy & Morse, 2008). Dizziness, drowsiness, excessive tiredness, weakness, and lightheadedness are potential side effects that could impair driving performance.

Calcium Channel Blockers. Calcium channel blockers (e.g., Norvasc, Verapamil, Diltiazem) block the entry of calcium into the muscle cells of the heart and arteries, decreasing the contraction of the heart and dilating the arteries. In one analysis, drivers taking these medications had a 25% greater motor vehicle crash risk than drivers not taking these medications (LeRoy & Morse, 2008). PDI side effects of these medications include dizziness, lightheadedness, drowsiness, and excessive tiredness.

Sympatholytic Agents. Clonidine (Catapres), methyldopa (Aldoril), and guanabenz (Wytensin) are examples of centrally acting antihypertensives classified as sympatholytic agents. These agents stimulate the alpha-receptors in the brain. The result of this stimulation is a decrease in sympathetic nervous system outflow and the relaxation of the peripheral arteries throughout the body. LeRoy and Morse (2008) found that drivers taking sympatholytic hypotensives had a 79% increased risk of motor vehicle crash involvement (OR=1.79) compared to drivers not taking these drugs. PDI side effects of medications in this class may include drowsiness, muscle weakness, and dizziness. Because these drugs cause drowsiness, they contain a warning not to drive a car until patients know how the drug affects them. Aldoril's warning states that patients should abstain from driving a car for 48 to 72 hours after beginning to take the medication, or after the dose is increased.

Vasodilators

Nitroglycerin (Nitrostat, Transderm-Nitro, NitroQuick) relaxes smooth muscles and widens blood vessels to produce relief of chest pain, decrease blood pressure and increase heart rate. Common PDI side effects of nitroglycerin include dizziness and drowsiness; these symptoms, as well as the underlying medical condition, have been shown to impact driver performance (LeRoy & Morse, 2008). Although rare, blurred vision may occur as a side effect. In LeRoy and Morse's analysis, drivers taking vasodilators had a 31% increased risk of motor vehicle collisions compared to drivers not taking medications in this class. Patient information accompanying nitroglycerin warns about dizziness and drowsiness and cautions against driving until patients know how the drug affects them.

Antiarrhythmics

Antiarrhythmics are used to treat irregular heartbeats. Examples include quinidine, mexiletine (Mexitil), procainamide (Procanbid), disopyramide (Norpace), amiodarone (Cordarone, Pacerone). They improve the heart's rhythm by relaxing an overactive heart. PDI side effects may include dizziness, difficulty sleeping, fatigue, weakness of arms or legs, blurred vision, decreased peripheral vision, blue-green rings or halos around lights, lowered alertness, trembling or shaking of the hands, and numbness or tingling in the fingers or toes. Several medications in this class contain a warning relating to dizziness, lightheadedness, and lowered alertness, and caution patients to understand how the drug affects them before they drive a car. LeRoy and Morse (2008) found that drivers taking antiarrhythmics had a motor vehicle crash risk that was 46% higher that that for drivers not taking medications in this class.

Digitalis Glycosides

Digoxin (Digitek, Lanoxin) is an approved treatment for congestive heart failure and certain cardiac arrhythmias. PDI side effects may include dizziness or lightheadedness, drowsiness, and vision changes. Because of the potential for dizziness and drowsiness, the patient information accompanying digoxin advises against driving a car until the drug effects on the patient are known. In the study by LeRoy and Morse (2008), drivers taking prescription drugs in this class had a 29% increased risk of motor vehicle crashes compared to drivers not taking these drugs.

Digoxin has a low safety profile because the therapeutic and toxic serum levels are known to be close. Digoxin toxicity is a result of both dosing and cumulative effects. It is estimated that up to 20% of patients who receive digoxin demonstrate some level of toxicity. Up to 95% of patients with toxic levels of digoxin demonstrate visual symptoms (Piltz, Wertenbaker, Lance, et al., 1993). Digoxin's visual side effects overlap with those of amiodarone (Cordarone, Pacerone), and include color vision deficits (commonly yellow-brown) and visual-field defects. Unique to digoxin is a reported side effect of a white or colored "snowy" or "frosted" appearance to vision (Castellas, Teitelbaum, & Tresley, 2002).

A number of medications can also significantly increase serum levels of digoxin, easily inducing toxic levels. These include amiodarone, furosemide, nifedipine, verapamil, and quinidine. Amiodarone, in particular, can increase serum digoxin concentrations 70 to 100%, with substantial variability (American Society of Health-System Pharmacists, 2001).

Cardiac polypharmacy has been associated with color vision and acuity changes in older people (Castellas et al., 2002). The addition of amiodarone therapy in patients using digoxin has been associated with visual "shining," glare, color vision anomalies, and decreased visual acuity.

HEMATOLOGIC AGENTS

Hematologic agents encompass several categories of medications including:

- Oral anticoagulants – coumarin type or vitamin K antagonists (e.g., Coumadin));
- Heparin and related preparations (e.g., Lovenox, Arixtra, Innohep);
- Platelet aggregation inhibitors (e.g., Plavix, Aggrenox); and
- Platelet reducing agents (e.g., Agrylin).

Medications in each of these classes have not been studied specifically for their impact on driver performance measures; however each class is associated with an increased risk of a motor vehicle crash in the epidemiological research of LeRoy and Morse (2008). Drivers taking platelet reducing agents had a motor vehicle crash risk that was 3 times higher than that for drivers not taking these drugs. PDI side effects associated with platelet reducing agents may include dizziness and weakness. Drivers taking heparin and related products were twice as likely to be crash-involved than drivers not taking heparin. PDI side effects associated with heparin and related preparations include dizziness; unusual tiredness or weakness; moderate to severe pain or numbness in the arms, legs, hands, or feet; and joint pain, stiffness, or swelling.

The odds ratios of crashing are lower for the coumarin type oral anticoagulants (1.31) and the platelet aggregation inhibitors (1.69). Patients taking oral coagulants such as Coumadin do not typically experience side effects that would impair driver performance; however, the conditions that this class of medications are used to treat can themselves be driver impairing. PDI effects associated with platelet aggregation inhibitors may include dizziness, tiredness, and muscle and joint pain.

RESPIRATORY TRACT MEDICATIONS

Antihistamines

There are more than 60 antihistamines available for oral administration. These medications are being used by an estimated 40 million people in the United States daily. Many are available without a prescription. Not only are antihistamines used to treat allergic conditions such as rhinitis and the respiratory symptoms associated with colds and the flu, they are also used to treat motion sickness, vertigo, vascular headaches, nausea, itching, anxiety, and insomnia (Moskowitz & Wilkinson, 2004). Such widespread use highlights the increased potential safety risk to drivers.

Antihistamines are generally categorized as first-generation versus second-generation (and later), which indicates whether they have ingredients that cause greater or lesser sedation. First-generation antihistamines contain compounds called anticholinergics, which tend to produce the side effects (e.g., drowsiness, impaired thinking, and dizziness) that differentiate this group from second-generation antihistamines. The newer, second-generation antihistamines do not contain anticholinergics, and so do not usually cause sedation at recommended doses.

Only 20% of patients with allergic rhinitis seek professional care, and in turn receive prescription antihistamines (many of which are non-sedating). Most patients with allergies turn to nonprescription medications for self-treatment of their symptoms (Casale, Blaiss, Gelfand, Gilmore, Harvey, Hindmarch, Simons, Spangler, Szefler, Terndrup, Waldman, Weiler, & Wong, 2003). With the exception of *loratadine* (a second-generation non-sedating prescription medication that became available OTC in 2002), OTC allergy medications contain first-generation antihistamines, commonly referred to as sedating antihistamines (e.g., *diphenhydramine*, *chlorpheniramine*, and *brompheniramine*).

First-generation antihistamines, such as diphenhydramine (Benadryl), chlorpheniramine (Chlor-Trimeton), clemastine (Dayhist, Tavist), hydroxyzine (Atarax), brompheniramine (Dimetapp); dexbrompheniramine (Drixoral); cyproheptadine (Periactin); doxylamine (in nighttime cold medicines such as Tylenol Cold and Flu Nighttime, Nyquil); phenindamine (Nolahist); pyrilamine (Codal DM); and triprolidine (Actifed) freely pass the blood-brain barrier and have an attraction to central H_1 receptors. This lack of specificity directly correlates to increased sedation and anticholinergic effects. Many of the first-generation antihistamines have half-lives as long as 24 hours and unwanted side effects may be experienced into the next day, as an “antihistamine hangover.” In addition, because older antihistamines are sedating, they also disrupt the normal sleep architecture, most notably, reducing rapid eye movement (REM) sleep. Altered nighttime sleep patterns lead to daytime fatigue and sleepiness (Casale et al., 2003). Driving while fatigued can result in performance impairments similar to those observed while under the influence of alcohol.

Second- and third-generation antihistamines developed over the past ten years, such as cetirizine (Zyrtec), loratadine (Claritin) and fexofenadine (Allegra), are far more selective for peripheral H_1 receptors and, correspondingly, this class has a far-improved side-effect profile. Second- and third-generation antihistamines do not tend to distribute into the central nervous system at standard doses, and are therefore *relatively* non-sedating (Moskowitz & Wilkinson, 2004). However, taking a second generation antihistamine at higher-than-recommended doses can produce a detectable level of sedation (Wang et al., 2003). Being relatively devoid of sedation and CNS impairment, second- and third-generation antihistamines are less likely to impair driving than first-generation antihistamines.

Studies have demonstrated that first-generation antihistamines at a single therapeutic dose can significantly impair cognitive and psychomotor performance. Weiler, Bloomfield, Woodworth, Grant, Layton, Brown, McKenzie, Baker and Watson (2000) used the Iowa Driving Simulator (IDS) in a randomized, double-blind study to measure "coherence" – a subject's ability to continuously match variations in the speed of a car he/she is following – among individuals dosed with one of the following:

- Diphenhydramine (Benadryl 50 mg) — a first-generation antihistamine available over the counter.
- Alcohol (.10 BAC).
- Fexofenadine (Allegra 60 mg) — a second-generation antihistamine available by prescription.
- Placebo (a pill containing no medication or active ingredient, used as a control).

Secondary measures obtained in the IDS included lane keeping (steering instability and crossing the centerline) and the time that it took to respond to a vehicle that unexpectedly blocked the lane ahead. Subjects also provided self-reports of drowsiness.

The principal conclusions in the Weiler et al. (2000) report were that subjects were better able to match the speed of the car ahead, drove farther behind that car, and had better steering control after taking alcohol or fexofenadine than after taking diphenhydramine. Alcohol impaired the secondary tasks, especially response time to the blocking vehicle, but overall driving performance was poorest among the study participants who took the diphenhydramine. Self-reports of drowsiness were not a good predictor of impairment on the primary or secondary tasks in this study, suggesting that "*drivers cannot use drowsiness to indicate when they should not drive*." Based on these results, the report authors issue a special caution regarding the use of "first-generation" (sedating) antihistamines, suggesting that they "… *may have an even greater impact than does alcohol on the complex task of operating an automobile.*" However, as cautioned by Moskowitz and Wilkinson (2004), while second-generation antihistamines represent a major triumph for the pharmaceutical industry in reducing potential side effects, there remains some evidence that all antihistamines may cause sedation and objective skills impairment, at least in some cases and for some individuals.

Moskowitz and Wilkinson (2004) evaluated the results of 130 experimental studies measuring the effects of first- and second-generation H_1 antagonists on behavioral and cognitive performance skills important for driving, and subjective measures of sedation. Results are summarized below.

- Impairment of actual, on-road driving was found in 89% of the studies evaluating first-generation antihistamines, and 10% of the studies evaluating second-generating antihistamines. All of the first-generation antihistamines studied (chlorpheniramine, clemastine, diphenhydramine, hydroxyzine, and triprolidine) showed on-road driving impairment. In contrast, the only two second-generation antihistamines that showed on-road driving impairments were cetirizine and terfenadine. In one of the studies, the effects of cetirizine (Zyrtec) on driving performance after a single 10 mg dose resembled those of alcohol. Subjects taking Zyrtec drove with significantly greater variability in speed and lateral position (weaving) when compared to a placebo (Ramaekers, Uiterwijk, & O'Hanlon, 1992). Neither fexofenadine (Allegra) nor loratadine (Claritin) were associated with impaired on-road driving performance. Vermeeren and O'Hanlon (1998) concluded that fexofenadine had no effect on driving performance after being taken in the recommended dosage of 60 mg twice daily.

- Divided attention tasks consisting of tracking and visual search are also impaired by first-generation antihistamines. First-generation drugs impaired divided attention tasks in 69% of the studies evaluated, whereas second-generation drugs impaired divided attention tasks in only 13% of the studies.

- First-generation antihistamines also impaired sustained attention (vigilance) in 86% of the studies. None of the second-generation antihistamines showed evidence of impaired vigilance.

- In terms of tracking performance, all five of the first-generation antihistamines demonstrated significant impairment; in 69% of the studies evaluated, first-generation antihistamines impaired tracking ability. Only two of the second-generation antihistamines tested (Zyrtec and Allegra) impaired tracking performance; tracking was impaired in 19% of the studies evaluating second-generation antihistamines.

- Reaction time was significantly slowed in 48% of the studies evaluating first-generation antihistamines; this compares to 11% of the studies evaluating second-generation antihistamines. Zyrtec was the only second-generation antihistamine that showed significant impairment in reaction time. Tashiro, Horikawa, Mochizuki, Sakurada, Kato, Inokuchi, Ridout, Hindmarch, and Yanai (2005) analyzed brake reaction time for subjects performing a divided attention test and found that subjects taking a second-generation antihistamine (Allegra) showed no difference compared to placebo, while subjects taking a first-generation antihistamine (hydroxyzine HC1 30 mg—a non-benzodiazepine anxiolytic/hypnotic, also used as a sedating antihistamine) had significantly slowed brake reaction times.

- In terms of objective sedation measures, such as the multiple sleep latency test that uses EEG frequencies to detect the onset of sleep, 100% of the studies evaluating first-generation drugs showed significant sedation compared to only 9% of the studies evaluating second-generation antihistamines. The only second-generation antihistamine that showed significant objective sedation was Zyrtec.

- In terms of subjective sedation, Moskowitz and Wilkinson (2004) found that the older antihistamines were associated with subjective sedation in 67% of the studies evaluated, and the newer antihistamines were associated with subjective sedation in 5% of the studies. Each of the five first-generation antihistamines produced significant feelings of sleepiness, whereas Zyrtec was the only second-generation antihistamine associated with subjects' feelings of sleepiness. Tashiro et al. (2005) found that in tests of subjective sleepiness, subjects given hydroxyzine (Atarax) were significantly less alert/more sedated than those who were administered fexofenadine (Allegra) or the placebo. There were no significant differences in subjective alertness/sleepiness between fexofenadine and the placebo groups. Significantly, Wang et al. (2003) report that subjects may experience impairment in the absence of any reported subjective symptoms of impairment.

From their review, Moskowitz and Wilkinson (2004) concluded that the proper selection of a second-generation antihistamine will produce little impairment in the performance of skills necessary for safe driving, and only a small effect on traffic crashes. Of particular note, the United States Federal Aviation Administration has authorized the use of fexofenadine and loratadine by pilots when needed. According to Casale et al. (2003), 32 driver licensing agencies in the United States have special laws that include medication use in defining impaired driving, and patients would be considered impaired under these laws if they drove vehicles while taking any of the first-generation antihistamines or cetirizine.

In the case-control study by LeRoy and Morse (2008), patients taking antihistamines (prescription) evidenced a 55% higher risk of motor vehicle crashes (OR=1.55) compared with drivers who were not taking antihistamines. First- versus second-generation antihistamines were *not* distinguished in their research. The top medications used in this class by the crash-involved drivers were Norel DM, Rondec DM, and ED-A-Hist (which include chlorpheniramine, a first-generation antihistamine). PDI side effects of these medications include drowsiness, fatigue, dizziness, nervousness, insomnia, weakness, tremors, and blurred vision. Patient information accompanying these medications advises of the side effects of dizziness and drowsiness, and cautions against driving if these side effects occur.

Bronchodilators

Bronchodilators are either short- or long-acting and are intended to improve airflow. The adrenoreceptor agonists work primarily by relaxing airway smooth muscles and inhibiting the release of bronchoconstricting substances from mast cells. Beta adrenergic selective agents have been widely used in the treatment of asthma and include albuterol (Proventil, Ventolin, Volmax), pirbuterol (Maxair), salmeterol (Serevent), formoterol (Foradil), and levalbuterol (Xopenex). This class of medication is known to produce short-term and long-term side effects such as increased heart rate, lightheadedness, anxiety, arrhythmias, nervousness, muscle pain or cramps, and extreme tiredness that are dose dependent. These systemic side effects, as well as the disease state that they are used to treat, play a role in this class of medication's elevated risk of motor vehicle crashes (LeRoy & Morse, 2008). Compared to drivers not taking these medications, drivers taking beta-adrenergic agents were 35% more likely to be involved in a crash (OR=1.35), and drivers taking combined beta-adrenergic and glucocorticoid products, such as Advair, were at more than twice the risk of crash involvement (OR=2.4).

Non-Narcotic Antitussives

Prescription non-narcotic antitussives such as benzonatate (Tessalon, Tessalon Pereles) relieve symptomatic coughs due to the common cold, flu, pneumonia, and bronchitis by acting directly on the lungs and breathing passages, and minimally on the cough center of the brain. Common side-effects that may affect driving performance include mild dizziness, mild drowsiness, and burning sensation in the eyes. Uncommon side effects include confusion and hallucinations. In research conducted by LeRoy and Morse (2008), drivers using Tessalon were 2.23 times more likely to be involved in a motor vehicle crash than drivers not using this medication. Physicians usually recommend that these agents be taken only at night, because a cough may be a productive, natural response that should not be suppressed during the day.

HOROMONES/HORMONAL MECHANISM OF ACTION

Hypoglycemics

In addition to insulin, there are five classes of oral diabetes medications, which help in lowering blood glucose levels by different mechanisms. Blood sugar control can be achieved with the use of a single agent, or a combination, with or without insulin. These five classes are:

- Sulfonylureas – stimulate the pancreas to make more insulin (Glucotrol, Micronase, Amaryl);
- Biguanides (non-sulfonylureas) – turn off the liver's production of excess glucose (Glucophage);
- Thiazolidinediones – increase the body's sensitivity to insulin (Avandia, Actos);
- Meglitinides – stimulate the body's sensitivity to insulin (Prandin); and
- Alpha-glucosidase inhibitors – decreases the intestines absorption of carbohydrate (Precose, Glyset).

Of the hypoglycemics, insulin (e.g., Lantus, Humalog, Novolin) was associated with the highest odds ratio (OR=1.80) for a motor vehicle crash in the study by LeRoy and Morse (2008). The other hypoglycemic agents studied had odds ratios ranging from 1.35 to 1.50. Common side effects associated with hypoglycemics are gastrointestinal upset, bloating, diarrhea and loss of appetite, none of which would predict a direct relationship with impaired driving. Uncommon side effects may include shortness of breath, dizziness, and blurred vision, which would fall into the PDI category.

Within this class of medication, compliance may have more to do with PDI effects than metabolic effects of the drug. Taking too much insulin or delaying or missing a scheduled meal or snack can cause low blood sugar (hypoglycemia), and can result in shakiness, dizziness, confusion, difficulty concentrating, drowsiness, weakness, clumsy or jerky movements, and seizures. These symptoms are driver impairing. Low blood sugar, left untreated, can lead to unconsciousness. High blood sugar (hyperglycemia) results from too little insulin, and also has symptoms that may impair driving, such as weakness, blurred vision, and decreased consciousness. These symptoms may result from skipping an insulin dose or from overeating.

A study has identified a direct relationship between the medications used in the treatment of diabetes and an increased risk of impairment resulting in falls (Lee, Kwok, Leung, & Woo, 2006). This study is relevant to the topic of driving, because vehicle crash involvement in older people has been significantly associated with a recent history of falls (see Staplin, Lococo, Stewart, & Decina, 1999). As falling and crashing are two adverse mobility outcomes, they may share the same underlying causes. Among the medications studied by Lee et al., only anti-diabetics showed a moderate association with *recurrent* falls (OR=2.9). The study cohort contained a large proportion of diabetic patients not on drug treatment (25.7%); this permitted direct comparisons between individuals with anti-diabetic medication and those without this medication. The study indicated that anti-diabetic medications were related to recurrent falls but the medical condition itself, i.e., being diabetic, was not. Thus, hypoglycemic side effects of drugs could be the cause of falls among older diabetics.

GASTROINTESTINAL AGENTS

Gastric Acid Secretion Reducers

Prescription gastrointestinal agents such as esomeprazole (Nexium), lansoprazole (Prevacid), and pantoprazole (Protonix) block gastric acid secretion. The medications in this class vary in level of potency and carry the general patient caution label of "use caution when driving as this medication may cause some drowsiness or dizziness." Empirical studies documenting the effects of prescription gastric acid secretion reducers on driving are not available; however LeRoy and Morse (2008) found a 55% higher risk of a motor vehicle crash for drivers using these medications compared with drivers not using them.

Three other medications are available as OTC antihistamines to treat gastrointestinal disturbances such as heartburn, indigestion, hyperacidity, and dyspepsia. These are cimetidine (Tagamet HB), ranitidine (Zantac 75) and famotidine (Pepcid AC). The literature on the sedating and performance effects of cimetidine is controversial (Department for Transport, 2004). Moscati and Moore (1990) compared 300 mg of cimetidine with 50 mg of diphenhydramine, and found that cimetidine caused drowsiness, but not to the level produced by diphenhydramine. Other studies found that doses up to 400 mg of cimetidine did not produce significant effects on alertness or on the performance of psychomotor and cognitive tasks. Nevertheless, listed side effects of cimetidine that may impair driver performance include dizziness, confusion, and drowsiness.

Watson, Weiss, and Harter (2000) found that patients given famotidine (20 mg given intra-muscularly) showed none of the signs of sedation that are associated with diphenhydramine (50 mg). Famotidine lists dizziness as a potential side effect, but not drowsiness. Ranitidine does not appear to cause sedation or impairment of psychomotor and cognitive tasks, at doses up to 4 times the individual recommended dose sold OTC (Department for Transport, 2004). However, ranitidine increases blood alcohol level in social drinkers, leading to impairment at normally "safe" levels of alcohol consumption. Therefore, combining ranitidine and drinking even small amounts of alcohol could cause patients to unknowingly break the law, and jeopardize their ability to drive safely.

Because ranitidine and famotidine do not produce the sedative effects produced by cimetidine, particularly at the low dosages available OTC, they likely would be recommended over cimetidine for people performing skilled activities. Still, the Department for Transport

(2004) in the United Kingdom recommends caution for older people taking these medications, since renal function does decrease elimination and increases the potential for side effects.

Anticholinergics/Antispasmodics

The anticholinergic/antispasmodics are a group of medications that include the natural belladonna alkaloids (atropine, belladonna, hyoscyamine, and scopolamine) and related products. They are used to relieve cramps or spasms of the stomach, intestines, and bladder. Some are used together with antacids or other medicines to treat peptic ulcer, and others are used to prevent nausea, vomiting, and motion sickness. LeRoy and Morse (2008) found an 85% higher risk of a motor vehicle crash associated with the belladonna alkaloids (e.g., Antispasmodic, Donnatal, NuLev). PDI side effects of belladonna alkaloids include confusion, blurred vision, dizziness, and drowsiness. Patient information accompanying these medications includes a warning about driving until drug effects are known.

Other anticholinergics/antispasmodics such as dicyclomine (Bentyl) may cause confusion, dizziness, drowsiness, tingling, weakness, blurred vision, and double vision. Patients are cautioned about driving until drug effects are known. LeRoy and Morse (2008) found that the crash risk increased by 20% (odds ratio = 1.2) for drivers taking anticholinergics/antispasmodics compared to drivers not taking these medications.

PAIN RELIEVERS

Narcotic Analgesics

Every year, millions of prescriptions for narcotic analgesics are written for patients as a means to manage chronic and acute pain (Byas-Smith, Chapman, Reed, & Cotsonis, 2005). Narcotic analgesics are opioid derivatives that selectively bind to the opioid receptors of the central nervous system and carry the general warning to use caution when driving due to the CNS depressant effects. Side effects may include dizziness, lightheadedness, feeling faint, drowsiness, and unusual tiredness or weakness. Blurred or double vision are less common, but may occur. Wang et al. (2003) report that patients using narcotic analgesics may be impaired even in the absence of subjective symptoms of impairment.

There are four broad classes of opioids:

- Endogenous opioid peptides produced in the body: endorphins;
- Opium alkaloids: morphine, codeine;
- Semi-synthetic opioids : oxycodone, hydrocodone, hydromorphone; and
- Fully synthetic opioids: meperidine, methadone, fentanyl, propoxyphene, butorphanol, tramadol.

With over 2.2 times the risk of crash involvement for drivers using narcotic analgesics compared with drivers not using these medications (LeRoy & Morse, 2008), studies have demonstrated the impairing psychomotor effects of narcotic analgesics in acute, “narcotic-naïve” patients. It is commonly accepted that opioid-naïve patients should be instructed not to drive. However, there is controversy surrounding what recommendations should be made to patients taking stable opioid doses (Fishbain, Cutler, Rosomoff, & Rosomoff, 2003). Patients with chronic pain on a stable opioid analgesic regimen may be capable of operating a motor vehicle safely during daytime, good-weather conditions (Byas-Smith et al., 2005).

Acute Dosing. Laboratory studies have shown that non-tolerant individuals receiving single doses of methadone have experienced dose-dependent impairments in reaction time, visual acuity, information processing, and sedation (Couper & Logan, 2004). In a driving simulator study of the effects of codeine on the driving performance of narcotic-naïve subjects, subjects under the influence of codeine had more collisions, drove off the road more often, and neglected more of the instructions than a group of subjects not under the influence (Linnoila & Hakkinen, 1974).

In research conducted by Verster, Veldhuijzen, and Volkerts (2006) subjects were given either oxycodone/paracetamol 5/325 mg; oxycodone/paracetamol 10/650 mg; or placebo, and were road tested 1 hour after dosing. Each subject participated in each medicine or control treatment, separated by a 7-day washout period. Oxycodone is an opioid agonist that is often prescribed in combination with paracetamol to reduce the opioid dosage while retaining the analgesic efficacy, to reduce opioid-related adverse effects. The recommended dosage is 5 mg oxycodone with 325 mg paracetamol. Drive test results showed no significant differences between the opioid treatments and the placebo; however, there was a significant difference in drivers' ability to keep the vehicle centered within the lane between the high dose and the low dose of the opioid medication. The difference between the high dose and the placebo was not significant, and is less than that observed with BACs of .05 g/dL. There were also no significant differences between the opioid treatments and the placebo on any of the laboratory tests (memory scanning, a tracking task, and a divided attention task), although performance was worse under both opioid treatment conditions than the placebo condition.

Compared to the placebo, subjective mental effort during driving was significantly elevated after the high dose of the opioid, but not after the low dose of the drug. Also, a significant dose-response relationship on mental effort was found for the opioid drug. Verster et al. suggest that the lack of impairment they observed on the drive test may have been related to the participants reporting increased effort during driving while under the influence of this medication. Finally, compared to the placebo, subjective alertness was significantly decreased for both doses of the opioid, and there was also a significant dose-response relationship. Further, after the drive test, self-reported level of sedation was significantly increased in the high-dose opioid condition, as was dysphoria (a feeling of emotional and/or mental discomfort, restlessness, malaise, and depression). There was a significant dose-response relationship for the opioid medications on the dysphoria scores.

Stable Dosing. Fishbain, Cutler, Rosomoff, and Rosomoff (2003) conducted a structured, evidence-based review of the literature between 1966 and 2001 to determine whether opioids affect the driving ability of patients who are on stable doses of this medication or who would be presumed to have developed some tolerance to the sedative effects of opioids. This review suggested that driving-related skills are not impaired in patients stabilized on long-term opioid therapy when used alone, and noted that the following advice should being given to patients (Fishbain, 2003):

- Do not drive after initiating narcotic therapy or after a dose increase, for 4-5 days.
- Do not drive if feeling sedated.

- Report cognitive decline, sedation or unsteadiness to your prescriber, so that a reduction in dosage can be initiated.
- Do not use alcohol.
- Avoid taking over-the-counter antihistamines.
- Do not change your medication regimen without consulting your prescriber.

In conclusion, opioids do represent a risk to traffic safety based on present knowledge; however, the degree of impairment is dependent on the particular opioid, dose, and history of use (Walsh et al., 2004).

Non-Steroidal Anti-Inflammatory Drugs

Nonsteroidal anti-inflammatory drugs (also called NSAIDs) are used to relieve some symptoms caused by arthritis (rheumatism), such as inflammation, swelling, stiffness, and joint pain. The common non-steroidal anti-inflammatory prescription drugs, such as Motrin and Naprosyn, block the action of both cyclooxygenase (COX) -1 and COX-2 enzymes. The more selective COX-2 inhibitors (Celebrex, Mobic) only block the enzymes at the site of inflammation and therefore have a decreased side-effect profile.

In general this class of medications is rarely associated with impaired driver performance; however, there have been isolated reports of confusion after taking phenylbutazone (Wang et al., 2003). Certain side effects—such as confusion, swelling of the face, feet, or lower legs—may be especially likely to occur in older patients, who are usually more sensitive than younger adults to the effects of nonsteroidal anti-inflammatory drugs.

When PDI side effects occur, they consist of drowsiness, dizziness, lightheadedness, lowered alertness, and blurred vision. Because of these potential side effects, patients are cautioned to make sure they know how the medication affects them before operating a motor vehicle. LeRoy and Morse (2008) found a 58% increase in crash risk for drivers taking NSAIDs compared to drivers not taking these medications.

The frequency of side-effects from OTC NSAIDs varies between the specific agents; in general, drowsiness and dizziness are possible side effects. While naproxen (Aleve) and ibuprofen (Advil) do not have warnings on their labeling to patients that they can cause drowsiness or impair driver performance, drowsiness and dizziness are listed adverse effects in the pharmacy literature. Again, these effects are more likely to be experienced by older people, when higher-than-recommended doses are taken or when they are combined with other impairing medications. Some pain medications such as Tylenol PM contains 25 or 50 mg of diphenhydramine, which causes drowsiness. The Tylenol PM warning label directs patients not to drive after taking this medication; this is due to the diphenhydramine contained in the product, not the acetaminophen. Acetaminophen does not cause drowsiness and thus does not impair a person's ability to drive.

Skeletal Muscle Relaxants

Skeletal muscle relaxants by convention have been classified into one group; however, they are actually a heterogeneous group of medications commonly used to treat two different types of underlying conditions - spasticity from upper motor neuron syndromes, and muscular pain or spasms from peripheral musculoskeletal conditions. Medications classified as skeletal muscle relaxants are baclofen (Lioresal), carisoprodol (Soma), chlorzoxazone (Paraflex), cyclobenzaprine (Flexeril), dantrolene (Dantrium), metaxalone (Skelaxin), methocarbamol (Robaxin), orphenadrine (Norflex), and tizanidine (Zanaflex).

The manufacturers of these drugs suggest that patients be warned that their mental and/or physical abilities required for driving an automobile may be impaired, and that they should not drive until they know how the drug affects them. As a class, skeletal muscle relaxants have CNS-related side effects: drowsiness, dizziness, decreased alertness, blurred vision, and clumsiness. Their use was associated with a 2-fold increase in the risk of motor vehicle crashes (OR= 2.09) by LeRoy and Morse (2008). Muscle relaxants are included on the Beers List of potentially inappropriate medications in older adults. They are poorly tolerated by older patients, because they cause anticholinergic adverse effects, sedation, and weakness. Also, their effectiveness at doses tolerated by older patients is questionable (Fick et al., 2003).

Carisoprodol has a short half-life, approximately 100 minutes. At a single 700 mg dose, it did not significantly affect psychomotor and cognitive test performance within 3 hours of dosing. However, with chronic dosing, it is likely that decrements in psychomotor performance would be more pronounced. Similarly, in individuals with impaired kidney or liver function, the altered metabolism of carisoprodol would result in a half life of 2 to 3 times that of normal individuals (Couper & Logan, 2004). In a study of DUI cases where carisoprodol was detected in concentrations at or above the recommended therapeutic dose, all subjects were involved in crashes or were observed to exhibit severe weaving on the road. In some cases, subjects had been involved in hit-and-run crashes, where they struck other vehicles or fixed objects without appearing to be aware they had hit anything (Logan, Case, & Gordon, 2000).

It is the consensus of experts that a single therapeutic dose of carisoprodol is unlikely to cause significant performance impairment in normal individuals. However, chronic doses of this medication may produce moderate to severe impairment of psychomotor skills associated with safe driving (Couper & Logan, 2004).

NEUROLOGICALS

Anti-Parkinsonism

Many medications and classes of medications are used in the treatment of Parkinson’s disease symptoms, including tremors, stiffness, and slowness of movement. Parkinson's disease symptoms are caused primarily by a dopamine deficiency and medications that compensate for the dopamine deficiency such as carbidopa/levodopa (Sinemet), pramipexole (Mirapex), ropinirole (Requip), entacapone (Comtan), and pergolide (Permax) are routinely used alone or in combination. Amantadine (Symmetrel), an antiviral medication, is also used to treat stiffness and shaking associated with Parkinson’s disease, although the mechanism of action is unknown. Common known side effects of these medications that may impact driving ability are excessive daytime sleepiness, dizziness, blurred vision, involuntary movements, hallucinations, and confusion. These medications carry a warning about the side effect of drowsiness, which may cause patients to fall asleep during activities of daily living. This class of medications used to treat Parkinson’s disease was associated with a 62% increase in the risk of motor vehicle crash involvement (LeRoy & Morse, 2008).

Homann, Wenzel, Suppan, Ivanic, Kriechbaum, Crevenna, and Ott (2002) reviewed research published between July 1999 and May 2001 on the prevalence of sleep attacks in patients taking dopamine agonists for Parkinson's disease (PD). They found that up to 30% of patients taking these medications had sleep attacks, with men comprising two-thirds of the cases. Sleep attacks are defined as events of overwhelming sleepiness that occur without warning or with a warning symptom that is too short to act upon. Patients having sleep attacks ranged in age from 34 to 87. Duration of the disease ranged from 1 to 20 years, and although in 2 patients sleep events happened upon first exposure to the medications, in the others they occurred with drug exposures ranging from 2 weeks to 20 years. Sleep events occurred in 124 patients: 96 included sleep attacks, 4 had sleep episodes where onset was not sudden but it was irresistible, and 23 had events that were not defined in the publication. These sleep events were associated with the following PD medications: levodopa alone (8 patients); ergot agonists (apomorphine in 2 patients, bromocriptine in 13 patients, cabergoline in 1 patient, lisuride or piribedil in 23 patients, pergolide in 5 patients); and non-ergot agonists (pramipexole in 32 patients and ropinirole in 38 patients). Sleep events happened at both high and low doses of the drugs. In 17 of the 124 cases, the sleep event happened during driving, leading to motor vehicle crashes in 10 cases.

It is not known whether the cause of the sleep attacks is drug-related or disease related, because PD patients experience alterations in their sleep patterns that results in daytime sleepiness (Comella, 2002). Dopaminergic agents also induce sleepiness. Patients are advised by the drug manufacturers to avoid driving until they know how the medication affects them, particularly during the first 3 to 5 days of therapy and any time the dose is increased. However, patients should be made aware of the following (Shire BioChem, Inc, 2004; Comella, 2002):

- Patients being treated with dopaminergic agents have reported suddenly falling asleep while engaged in activities of daily living. This includes driving a car, and it has sometimes resulted in crashes.

- Although some patients reported feeling sleepy, others had no warning signs such as excessive drowsiness, and believed they were alert immediately prior to the event.

- Sudden sleep attacks are not limited to the initiation of drug therapy.

- Patients considered to be at risk for falling asleep behind the wheel should be cautioned strongly to avoid driving.

Anticonvulsants

Anticonvulsants belong to a diverse class of medications developed to prevent epileptic seizures. Barbiturates and benzodiazepines, already discussed, are commonly used to prevent and treat seizure disorders, as are clonazepam (Klonopin), gabapentin (Neurontin), topiramate (Topamax), valproic acid (Depacon), oxcarbazepine (Trileptal), phenytoin (Phenytek), carbamazepine (Carbatrol), and lamotrigine (Lamictal). The goal of anticonvulsant therapy is to suppress abnormal nerve activity in the brain and due to this effect, anticonvulsants are also prescribed for the treatment of conditions such as bipolar disorder, anxiety, and aggression. Potential driver impairing side effects of these drugs include drowsiness, fatigue, dizziness, blurred vision, double vision, irregular eye movements, confusion, inability to concentrate, shakiness, loss of balance or coordination, memory problems, and decreased alertness. Anticonvulsants were associated with nearly twice the risk (OR=1.97) of a motor vehicle crash (LeRoy & Morse, 2008). Wang et al. (2003) note that individually, anticonvulsants may be mildly impairing; however, these medications are typically used in combination with antidepressants, antipsychotics and/or anxiolytics, which magnifies impairment of psychomotor performance.

Topiramate received FDA approval for prevention of migraine headaches in August 2004, and is being prescribed for off-label uses such as psychiatric and eating disorders, neuropathic pain, and alcohol and drug dependency (Gordon & Logan, 2006). In forensic toxicology investigations of topiramate-positive drivers, psychomotor impairment was evident with blood concentrations within normal therapeutic range. As an example, a 31-year-old female was prescribed topiramate for an eating disorder. She drove off the highway and crashed into the median. Responding officers noted thick slurred speech, heavy eyelids and dilated pupils. She had a lack of coordination and could not stand unassisted and was arrested for DUI. The only drug identified in her blood was topiramate at therapeutic levels (8.1 mg/L). Gordon and Logan note that as anti-epileptic medications are increasingly used to treat psychiatric disorders, their prevalence in impaired driving cases has increased. For psychiatric patients, there must be specific instructions about the dangers of driving while taking these medications.

OPHTHALMICS

Eye Antihistamines

Eye antihistamines are used to relieve the itching of the eye due to allergic conjunctivitis (pink eye). Medications in this class include levocabastine (Livostin), ketotifen (Zaditor), epinastine (Elestat), azelastine (Optivar), and olopatadine (Patanol). Side effects may include blurred vision, eye burning or stinging, and excessive tiredness. Although there are no warnings from the drug manufacturers regarding side effects and driving safety, LeRoy and Morse (2008) found a 67% increase in crash risk associated with the use of these medications.

Eye Sulfonamides

Sulfonamide ophthalmic preparations are used to treat infections of the eye. Medications in this class include sulfacetamide (AK-Sulf, Bleph-10, Cetamide, Ocu-Sul) and sulfisoxazole (Gantrisin). Common side effects include itching, redness, and swelling. The drug manufacturer cautions that sulfacetamide ophthalmic may cause blurred vision, and to avoid driving if this side effect is experienced. LeRoy and Morse (2008) found a 76% increase in crash risk associated with the use of these medications.

ANTIPARACITICS

Antiparasitics as a general class are not potentially driver impairing, with the exception of the antimalarials (LeRoy & Morse, 2008). Antimalarial drugs include hydroxychloroquine (Plaquenil), mefloquine (Lariam), atovaquone and proguanil (Malarone), chloroquine phosphate oral (Aralen), and quinine. Plaquenil is also used to treat lupus and rheumatoid arthritis. Side effects of drugs in this class include dizziness, drowsiness, muscle pain, decreased visual accommodation, and visual field defects. Some of the medications in this class contain a warning related to vision changes, dizziness, and drowsiness and the ability to operate a motor vehicle safely. LeRoy and Morse (2008) found a 34% increase in crash risk associated with the use of these medications.

CNS STIMULANTS

Anti-narcolepsy and anti-hyperkinesis medications are classified as CNS stimulants and fall into one of four classes:

- Mixed amphetamine salts (Adderall);
- Dextroamphetamine (Dexedrine);
- Methylphenidate (Ritalin); and
- Pemoline (Cylert).

CNS stimulants increase activity in certain areas of the brain and are associated with side effects that may impair driving performance, such as overconfidence, nervousness, anxiety, insomnia, and rebound effects as the stimulant's effect wears off (Wang et al., 2003). In epidemiological studies of run-off-the road crashes, the driving behavior of people taking amphetamine- and methamphetamine-type CNS stimulants has been characterized as high-speed, diminished divided attention, inattentive, failing to stop, and high-risk (Couper & Logan, 2004). Observed behaviors include driving over the lane lines, erratic driving, and crashes.

Overall, CNS stimulants are most commonly associated with physiological reactions, with observable behavioral impairments being less frequent (Jones et al., 2003). At lower doses, amphetamines have few effects on cognitive functioning and may result in enhancement of some psychomotor tasks. But as noted above, risk-taking and inappropriate responses increase at higher-than-therapeutic doses (Couper & Logan, 2004).

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DEMENTIA AND DIMINISHED DRIVING SKILLS

This chapter summarizes current knowledge regarding the impact of Alzheimer's disease and other dementias on driving performance, including evidence that dementing disorders may contribute substantially to the increased crash risk of aging drivers. At the same time, diagnosis is not an adequate predictor of function, and there is great heterogeneity in the rate of progress as well as the cognitive strengths and weaknesses among patients with dementing disorders. One consequence is that performance-based guidelines for driving competence are essential, rather than dependence on diagnostic labels (Beattie, Tallman, Tuokko, & Weir, 1991). Given the likely increases in both the incidence and prevalence of dementing disorders with the aging of the population, it is significant that many cases remain undiagnosed, as discussed below. This means that epidemiological data describing crash risk factors, from population-based studies, may reflect an unknown but potentially substantial influence of driving with dementia.

A better understanding of dementia and its impact on the ability to drive safely thus defines a clear and continuing research priority. Diagnostic criteria, co-existing medical conditions, and comparative analyses of crash rates are examined in the following pages before a more in-depth discussion of the methods and results of studies addressing the driving errors and crash characteristics of people with dementia. The chapter concludes with a consideration of changes in driving habits associated with the presence and progression of dementia.

SIGNS, SYMPTOMS, AND CLINICAL DIAGNOSTIC CRITERIA

The essential feature of a dementia is the development of multiple cognitive deficits that include memory impairment <u>and</u> at least one of the following cognitive disturbances: aphasia, apraxia, agnosia, or a disturbance in executive functioning. The cognitive deficits must be sufficiently severe to cause impairment in occupational or social functioning (e.g., going to school, working, shopping, dressing, bathing, handling finances, and other activities of daily living) and must represent a decline from a previously higher level of functioning. Dementia must be distinguished from the normal decline in cognitive functioning that occurs with aging. The diagnosis of dementia is warranted only if there is demonstrable evidence of greater memory and other cognitive impairment than would be expected due to normal aging processes and the symptoms cause impairment in social or occupational functioning. A diagnosis of dementia should not be made if the cognitive deficits occur exclusively during the course of a delirium (American Psychiatric Association, 1994).

The paragraphs immediately following present the diagnostic features from the *DSM IV,* and expand upon these to describe the types of driving difficulties that might be expected in a person with dementia.

"Memory impairment" is required to make the diagnosis of a dementia and is a prominent early symptom. People with dementia become impaired in their ability to learn new material, or they forget previously learned material. Most individuals with dementia have both forms of memory impairment, although it is difficult to demonstrate the loss of previously learned material early in the course of the disorder. They may lose valuables like wallets and keys, forget food cooking on the stove, and become lost in familiar neighborhoods. In advanced stages of dementia, memory impairment is so severe that the person forgets his or her occupation, schooling, birthday, family members, and sometimes even their own name. Within the context of driving, memory impairment has ramifications in particular when there are changes in familiar environments, such as detour or speed limit signs. It may also affect the ability of a person to retain information from a complex sign such as “NO LEFT TURN BETWEEN 7-9 AM ON WEEKDAYS.”

“Aphasia” is a deterioration of language function, and may be manifested by difficulty producing the names of individuals and objects. The speech of individuals with aphasia may become vague or empty, with long circumlocutory phrases and excessive use of indefinite references, such as “thing” and “it.” Comprehension of spoken and written language and repetition of language may also be compromised. In the advanced stages of dementia, individuals may be mute, or have a speech pattern characterized by echoing what is heard or repeating sounds or words over and over. When one loses the ability to understand language, then signs with words may become meaningless. Aphasia will impair a driver’s ability to comply with regulatory traffic sign messages and make appropriate responses to warning and guide signs.

“Apraxia” is impairment in the ability to execute motor activities despite intact motor abilities, sensory function, and comprehension of the required task. Individuals with dementia may be impaired in their ability to pantomime the use of objects (e.g., combing hair) or to execute known motor acts (e.g., waving goodbye). Apraxia may contribute to deficits in cooking, dressing, and drawing. Within the driving context, the greatest concern may be impairment in the use of vehicle controls (e.g., pedal confusion and signaling errors).

“Agnosia” is a failure to recognize or identify objects despite intact sensory function. For example, the individual may have normal visual acuity but lose the ability to recognize objects such as chairs or pencils. Eventually, they may be unable to recognize family members or even their own reflection in the mirror. Similarly, they may have normal tactile sensation, but be unable to identify objects placed in their hands by touch alone. When one loses the ability to see the environment in a structured way, then the relationships between the streets, the cars and the signals may become distorted and driving is likely to become extremely dangerous.

“Executive functioning” involves the ability to think abstractly and to plan, initiate, sequence, monitor, and stop complex behavior. Impairment in abstract thinking may be manifested by the individual having difficulty coping with novel tasks and avoiding situations that require the processing of new and complex information. Executive dysfunction is also evident in a reduced ability to shift mental sets, to generate novel verbal or nonverbal information, and to execute serial motor activities. Impaired abstract thinking may impair a driver’s ability to understand how symbols such as picture signs relate to actual driving behavior. Difficulty switching from one task to another will result in increased crash risk for drivers dealing with complex traffic situations (e.g., intersections).

Associated features common in dementia include spatial disorientation and difficulty with spatial tasks, poor judgment, and poor insight. Impaired judgment refers to the inability to make correct decisions, such as when it is safe to turn across the intersection. Although this function is difficult to measure in the clinical setting, it may be one of the most relevant of disturbances for the demented driver. Individuals may exhibit little or no awareness of memory loss or other cognitive abnormalities. They may make unrealistic assessments of their abilities and make plans that are not congruent with their deficits and prognosis. They may underestimate the risks involved in activities, such as driving. Impulsivity can lead to dangerous behaviors, such as prematurely pulling out into traffic or running a red light.

The different types of dementia are classified according to the specific cause of the multiple cognitive deficits. The *DSM IV* categorizes the dementias according to the following types: dementia of the Alzheimer's type, vascular dementia, dementia due to HIV disease, dementia due to head trauma, dementia due to Parkinson's disease, dementia due to Huntington's disease, dementia due to Pick's disease, dementia due to Creutzfeldt-Jakob disease, dementia due to other general medical conditions, substance-induced persisting dementia, and dementia not otherwise specified (when a specific etiology for the multiple cognitive deficits cannot be determined). The most common cause of dementia is Alzheimer's disease, followed by vascular disease, and then by multiple etiologies.

Valcour, Masaki, and Blanchette (2002) found that primary care physicians are unaware of cognitive impairments in most of their patients who drive. In a study of 297 participants 65 and older who were consecutive patients in an internal medicine group practice in Hawaii, only 5% (1 of 21) of the drivers with "intermediate" performance on a cognitive abilities screening instrument, and 11% (1 of 9) with "poor" performance on the instrument were recognized by their physicians as having cognitive problems. Furthermore, 25 subjects in the study met criteria for dementia, of which 3 reported they currently drove. Only one of these three subjects was recognized by their physician as having cognitive problems.

The most troubling of the dementias is Alzheimer's disease . Alzheimer's disease is the most common cause of dementia, with prevalence estimated at 13% for Americans65 and older (Alzheimer's Association, 2007). The prevalence increases with increasing age, although a small percentage of people younger than65 are affected by early-onset Alzheimer's disease. In 2007, 2% of Americans65-74 had Alzheimer's, compared with 19% of those 75 to 84, and 42% of those85 and older. With the increase in the number of baby boomers turning60 (a rate of approximately 330 every hour), the number of Americans65 and older with Alzheimer's disease could increase from 11 million to 16 million by the year 2050 (Alzheimer's Association, 2007). These estimates reflect the prevalence of Alzheimer's, regardless of whether a diagnosis of Alzheimer's has been made or is noted in their medical record. The Alzheimer's Association notes that in one study, less than one-fifth of those with Alzheimer's or another dementia had a diagnosis of the condition in their medical record. Impairments in critical driving skills may be among the first signs of the disease (Silverstein, 2007).

In addition to the cognitive deficits listed as criteria for diagnosing dementia, Alzheimer's is characterized by its gradual onset and continuing cognitive decline. The course is associated with a loss of 3 to 4 points per year on a standard assessment such as the Mini-Mental State Exam (American Psychiatric Association, 1994). In the first few years of illness, few motor and sensory signs are associated with dementia of the Alzheimer's type; instead, early deficits in recent memory are seen, followed by the development of aphasia, apraxia, and agnosia after several years. Later in the course, myoclonus (brief, involuntary muscle twitches) and gait disorder may appear. Reisberg, Ferris, de Leon, and Crook (1982) developed a scale to track the course of Alzheimer's disease in individuals and to define its stages within the broad three stages of "mild," "moderate," and "severe." The seven major clinically distinguishable stages, shown in Table 1, range from "no cognitive decline" to "very severe cognitive decline."

Table 1. Global Deterioration Scale
(Source: Reisberg, Ferris, de Leon, and Crook, 1982)

Stage		Example of Deficits
1	No cognitive decline either by subjective complaint or a clinical interview	
2	Very mild cognitive decline	Subjective complaints of memory loss only e.g. forgetting where one has placed familiar objects. No objective evidence of loss on clinical interview.
3	Mild cognitive decline	Decreased performance in demanding employment and social settings. Objective evidence of impairment only obtained in intensive interview.
4	Moderate cognitive decline	Decreased knowledge of current events. Decreased ability to perform complex tasks. Decreased ability to market, handle finances.
5	Moderately severe cognitive decline	Unable to recall a major aspect of current life. May have difficulty with choice of clothing; can no longer survive without some assistance.
6	Severe cognitive decline	Largely unaware of recent life events. Increasing difficulties with dressing and bathing. Eventually develop problems with toileting. Emotional changes, such as agitated behavior, may emerge.
7	Very severe cognitive decline	All verbal abilities are lost. Incontinence is present, progressive loss of basic psychomotor skills.

A commonly used tool in both research and clinical settings to characterize the level of cognitive and functional performance in patients suspected of having Alzheimer's disease or other dementia is the Clinical Dementia Rating (CDR) scale (Morris, 1993). It characterizes six domains of cognitive and functional performance: memory, orientation, judgment and problem solving, community affairs, home and hobbies, and personal care. The necessary information to make each rating is obtained through a semi-structured interview of the patient and a reliable informant or collateral source (e.g., a family member). The CDR table provides descriptive anchors that guide the clinician in making appropriate ratings based on interview data and clinical judgment. In addition to ratings on a 5-point scale for each domain (except personal care, which is rated on a 4-point scale) an overall CDR score is derived by standard algorithm. This score is useful for globally staging the level of impairment: 0 = No impairment, 0.5 = Very Mild Dementia, 1 = Mild Dementia, 2 = Moderate Dementia, and 3 = Severe Dementia.

The duration of Alzheimer's disease ranges from 3 to 20 years (Alzheimer's Association, 2007). People with Alzheimer's disease die an average of 8 to 10 years following the onset of symptoms (American Psychiatric Association, 1994). The FDA has approved five drugs for the treatment of Alzheimer's disease: four for use in the mild to moderate stages (tacine or Cognex, donepezil or Aricept, rivastigmine or Exelon, and galantamine or Razadyne) and one for treatment of symptoms in the moderate to severe stages (memantine or Namenda). These drugs slow worsening of symptoms temporarily (6 to 12 months) for roughly half of the individuals who take them (Alzheimer's Association, 2007). All 5 drugs contain a caution stating that "this drug can cause side effects that may impair your thinking or reactions. Be careful if you drive or do anything that requires you to be awake and alert." A side effect listed as "serious" for all 5 drugs is seizures; other "serious" potentially driver impairing (PDI) side effects for a subset of the five include syncope, hypotension, paranoia, hallucinations, and worsening of Parkinson's disease. Side effects listed as "common" and are PDI for these drugs include: dizziness, agitation, confusion, insomnia, fatigue, somnolence, tremor, confusion, and hypertension.

CO-EXISTING MEDICAL CONDITIONS

Maslow (2004) provides data from Bynum et al. (2004) describing coexisting medical conditions in the population of people with Alzheimer's disease. Bynum et al. (2004) used data provided by the U. S. Centers for Medicare and Medicaid (CMS database) to conduct a cross-sectional analysis of 1 year of claims data for Medicare beneficiaries 65 and older comparing medical expenditures and hospitalizations by patients with claims for dementia and those without claims for dementia. Their sample of 1,238,895 individuals was a nationally representative 5% random sample of Medicare beneficiaries in 1999. Their findings are shown in Table 2.

Table 2. Percentage of Medicare Beneficiaries Age 65+ With Alzheimer's Disease and Other Dementias and a Specified Coexisting Medical Condition. (Source: Bynum et al., 2004 in Maslow, 2004).

Co-Existing Condition	Percentage With the Condition
Hypertension	52
Coronary heart disease	30
Congestive heart failure	28
Cardiac dysrhythmias	25
Diabetes	22
Osteoarthritis	20
Peripheral and visceral atherosclerosis	19
Affective disorders, including depression	18
Chronic obstructive pulmonary disease	17
Thyroid disorders	16
Disorders of lipid metabolism	13
Cancer	11
Osteoporosis	10
Late effects of cerebrovascular disease (stroke)	10

This is noteworthy as each medical condition alone has potentially driver impairing consequences, and the coexisting medical conditions and medications used to treat them may increase the severity of the dementia symptoms. Maslow (2004) indicates that some coexisting conditions actually cause dementia. For example, cardiovascular conditions such as stroke, hypertension, and cardiorespiratory diseases can cause vascular dementia. Cardiovascular conditions can also accelerate the development, expression, and progression of Alzheimer's disease. Dementia may also make it difficult or impossible for the day-to-day management of coexisting medical conditions, for example, complying with a prescribed medication regime, if a patient has no family members to oversee medication compliance, accurate dosing, and other instructions for proper administration (e.g., as for Fosamax, an osteoporosis medication: take with water, and stay upright for at least 30 minutes after taking it).

DEMENTIA AND CRASH RISK

In a review of the literature on crash rates for control drivers and drivers with Alzheimer's disease, Carr (1997) found that although a majority of the demented drivers (greater than 70%) in these studies do not experience a crash, there is a twofold increased crash rate for drivers with dementia when compared to controls. Crash rates for control subjects in studies on dementia and driving ranged from 0.02 to 0.08 per driver per year. The crash rate for drivers with Alzheimer's disease or other dementias in these studies ranged from 0.04 to 0.14.

Demented drivers are at increased risk for crashes especially in the advanced stages of their disease (Waller, 1967; Friedland, Koss, Kumar, Gaine, Metzler, Haxby, & Moore, 1988; Lucas-Blaustein, Filipp, Dungan, & Tune, 1988; Drachman & Swearer, 1993; Carr, 1997). In a questionnaire survey of 130 Alzheimer's disease patients and 112 age-matched, nondemented control subjects, Drachman and Swearer (1993) found that for all years of driving following the onset of dementia, AD patients had a mean of 0.091 reported crashes per year compared with 0.040 reported crashes per year for controls in the same time period. Although the AD patients had slightly twice as many reported crashes per year as the controls, this rate is less than the average of 0.148 reported crashes per year for registered 16- to 24-year-old males.

The average number of crashes per year changed with each year of driving following the onset of AD, with considerably lower reported crash rates during the initial years of dementia. In year one, the crash rate was 0.068; in year two, 0.097; in year three, 0.093; in year four, 0.159; and in year 5 and beyond, 0.129. For comparison, registered drivers of all age have an average of 0.067 reported crashes per driver per year, drivers 16 to 25 have a rate of 0.125 reported crashes per driver per year, while registered drivers 65 and older have an annual average of 0.037 reported crashes per driver per year. When the data for the first three years post-AD are combined, the crash rate is 0.072. The AD patients incurred their first crash an average of 2.20 years post-AD.

Thus, this study indicates that throughout the first three years the crash rate for AD patients is only slightly higher than that for drivers of all ages in the United States, and remains well below that of young adults 16 to 24. Although the course of AD may vary considerably, these findings suggest that the increase in crash risk develops toward the end of the third year, and more than doubles in the fourth year. Drachman and Swearer (1993) therefore suggest that patients who have had AD for more than two years should have their driving ability closely monitored if they are to continue driving, as the overall risk to society during the first two years is well within the accepted range for other drivers. They also note that mental status evaluations may be useful in identifying older drivers who are beginning to show evidence of cognitive decline, but on-road or off-road tests, especially those requiring the driver to follow sequential directions, are more likely to measure the skills required for driving.

In a retrospective study, the driving records of 165 older drivers in British Columbia classified as having dementia were examined to determine whether cognitively impaired individuals experience a higher crash rate than their age- and sex-equivalent counterparts in the general population (Cooper, Tallman, Tuokko, & Beattie, 1993). The diagnosis of dementia was based on the consensus of a multidisciplinary team using criteria defined by the DSM III-R (American Psychiatric Association, 1987). The average age at assessment was 69.2 years. The average severity of dementia was mild (mean = 3.18 on the Functional Rating Scale). Driver record data were extracted by the Traffic Safety Research Department of the Insurance Corporation of British Columbia (ICBC) using the provincial Motor Vehicle Branch (MVB) Drivers File and the MVB Accident Database and the ICBC Claims Database. These records were compared with those of a stratified random sample selected from the population of drivers in British Columbia, based on gender, exact year of age, and the area of the province in which the clinic patient lived. Since the period of time of interest was that between the time of symptom onset and cessation of driving for the demented sample, each matched pair of clinic and control drivers had the same period assigned, which was somewhat different from that attached to any other pair; this period of time varied from 6 to 70 months. Crash records showed that the dementia group drivers were involved in 86 crashes during the driving period. This result is 2.5 times that found for the general driving population sample.

DEMENTIA, DRIVING ERRORS, AND CRASH CHARACTERISTICS

As noted by Adler, Rotunda, & Dysken (2005), although road tests have face validity and seem essential to answering questions about driving ability, on-road driving evaluations are employed in less than half of the studies on driving and dementia, and of those that incorporate road tests, the protocols vary considerably and generally do not include demanding or non-routine driving situations. Because driving is an overlearned task, standard road tests with step-by-step instructions do not necessarily test the skills of or expose error types commonly made by experienced drivers. However, most of the research shows that drivers with AD perform more poorly on road tests than drivers without AD, little is known about their reactions to hazardous situations in rear-world driving situations. Although driving simulator studies have shed some light on this issue, the artificial nature of a driving simulator and the time required for a driver with Alzheimer's disease to become comfortable operating it raises questions about whether driving simulation is a valid substitution for an on-road test for drivers with cognitive impairment. These caveats notwithstanding, findings of both on-road and simulator studies describing the driving errors made by dementia subjects are presented below.

Driving problems may be an early sign of dementia, because of the great demands for selective attention, judgment, and visual interpretation. Demented drivers may become lost in familiar areas; they may become confused by detours or heavy traffic; they may misinterpret signs and signals; or they may accelerate when they intend to brake (Kaszniak, Keyl, & Albert, 1991). Other errors made by demented drivers and the situations in which they occur are described by Hunt (1994) and include: stopping in the middle of traffic when driving in situations that demand complex or rapid cognitive processing and problem solving, when to an observer, there is no reason to stop; failing to yield the right of way or inappropriately attempting to proceed on a green light when turning left at an intersection when the sign reads, "left turn on arrow only;" and incorrectly interpreting verbal commands or suggestions from a passenger (e.g., directions, reminders to check traffic before making a lane change) or not interpreting them in time for the proper action to occur.

Appropriate responses to traffic situations rely largely on intact attention and visuospatial skills. Demented drivers make a variety of typical errors while driving. The relationship between specific cognitive deficits and specific driving errors remains to be determined. Distractibility is likely to contribute substantially to errors in driving, especially at intersections and sites of merging traffic. Visuospatial skills are likely to relate to the ability of the driver to maintain appropriate vehicle placement or to judge distance and space relationships, such as required when monitoring oncoming cars or entering parking spaces (Doege & Engelberg, 1986). Isolated memory loss may be relevant only when there is a change in routine, such as a detour or a sign to decrease speed for construction ahead. Isolated language impairment, especially a diminished reading comprehension, should have little impact in familiar settings. However, in unfamiliar settings there may be difficulty in interpreting important road signs. Simple reaction time is unlikely to play a major independent role in driving safety (Dubinsky, Gray, Husted, Busenbark, Vetere-Overfield, Wiltfong, Parrish, & Koller, 1991).

Whelihan, DiCarlo, and Paul (2004) found that performance on tests measuring executive functioning and visual attention for a group 23 patients with questionable dementia (CDR score of 0.5) and 23 age-matched controls classified those who passed and failed a road test with 80% accuracy. In a meta-analysis of studies to examine the relationship between neuropsychological functioning and driving ability for adults with dementia, Reger et al. (2004) found that neurological tests overall correlated poorly with on-road tests within samples of dementia (when control subjects were eliminated). However, the neuropsychological tests that tested the specific domains of visuospatial skills and attention-concentration showed significant relationships with on-road test performance.

As reported on by Silverstein (2007), consensus of an expert panel on fitness to drive in early dementia was that poor judgment or impaired decision making, and impaired visuo-spatial abilities manifested across most driving maneuvers. The skills identified by the panel that are most compromised in early dementia are: wayfinding, observing, changing lanes, gap acceptance, passing, stopping/braking, yielding, responding to signals/signs, maintaining speed, backing up, signaling, maintaining lane position, following, seat belt use, and use of headlights.

Drivers with dementia have difficulty recognizing traffic signs (Brashear et al., 1998; Carr, Madden, & Cohen, 1991; Hunt, Morris, Edwards, & Wilson , 1993; Carr, LaBarge, Dunnigan, & Storandt, 1998). In a paper-and-pencil test of traffic sign recognition similar to the one administered to license renewal applicants in Indiana, Brashear et al. (1998) found that older drivers with AD (CDR score $\leq$1) were able to correctly identify an average of 5.95 of the 10 signs presented. The response format was multiple choice. In comparison, normal healthy older controls were able to correctly identify an average of 8.8. Of particular concern to traffic safety is the low percentage of dementia subjects who correctly identified the No Passing Zone sign (45%), the No Right Turn Sign (51%), the Yield sign (61%), and the Stop sign (76%). Correct identification by controls for these signs was: No Passing Zone (84%), No Right Turn (79%), Yield (89%), and Stop (98%). A score of 7 or more is required to pass the re-licensing exam. In this study, 57% of the subjects with dementia and 11% of the controls would have failed the Bureau of Motor Vehicles relicensing exam. The control subjects were selected among the caregivers who accompanied the dementia subjects to the Alzheimer's disease center; those performing poorly on the test may have been identified as "normal" when in fact, when in fact, there were not, as the criteria for selection were not strict, and no testing other than the sign test was administered to them. It should be notes that the signs used in the study were presented in black and white, which may have added to the poor recognition performance, however the shapes alone for 3 of the 4 signs should have provided a clue to their meaning as they are icons. Also, the comparative percentof control subjects who could correctly identify the meaning provides evidence of diminished capability for subjects with AD.

Deficits in executive control over attention to switch between the two tasks of searching for signs and controlling a vehicle were exhibited by a group of study participants with Alzheimer' s disease (Rizzo, Anderson, & Dawson, 2004). Drivers with mild Alzheimer's disease detected significantly fewer traffic signs and landmark signs than healthy age-matched controls while driving an instrumented vehicle along a route that used 45 minutes of drive time. The Alzheimer's group also committed more at-fault safety errors (erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior) than controls, during the landmark and traffic sign identification task portions of the drive, as well as when no secondary task was administered. A subset of the drivers with Alzheimer's disease made no safety errors, suggesting that some individuals with mild dementia remain fit drivers.

In a related study to assess navigation and safety errors during a route-following task in drivers with mild Alzheimer's disease, drivers with mild AD (n=32) made more incorrect turns, got lost more often, and made more at-fault safety errors than normal older controls (n=136) during the navigation portion of a 45-minute on-road drive test (Uc, Rizzo, Anderson, Shi, & Dawson, 2004). The navigation task required drivers to remember and execute a series of turns onto specific roads. The navigation instructions (e.g., turn right out of the hospital driveway, turn left on Hawkins Drive, right on Melrose Avenue, left on Koser Avenue, and left on George Street) were read to the subject just before beginning the experimental drive, and were repeated with corrections until the driver recited the instructions correctly twice in a row. Drivers with AD required more trials to learn the route correctly than the control subjects. There was no difference between the groups in at-fault safety errors, however, on a straight segment of the drive during which time no secondary navigation task was administered. There was also no difference between the groups on times lost, when controlling for familiarity with the neighborhood. In this study, incorrect turns were defined as turning too soon, too late, or in the wrong direction. "Times lost" was defined as incorrect turns after which the driver did not recognize and correct the error. At-fault safety errors were defined as erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior.

Rizzo et al. (2004) state that the route-following test engages anterograde verbal memory (the ability to learn and recall novel information from a point in time forward), visual perception and attention, recognition of landmarks such as street signs, and visuospatial abilities (such as right/left discrimination and executing remembered turns in the correct direction). The route-following task also requires drivers to monitor their navigation errors and correct them to resume the correct route. Self-monitoring and correction require executive functions; mental rotation of imagined space; and recognition of recently encountered landmarks from an altered perspective, and comparison with the mental model developed from the initial sequence of verbal instruction. Drivers underwent neurological testing during the week preceding the drive task. Measures of verbal and visual memory, executive function, visual perception, visual attention, visuoconstructional abilities, and overall cognitive function correlated significantly with the route following task outcome measures. Near and far visual acuity did not predict route-following task outcome, nor did correction render group differences insignificant. Thus, it is the higher-order visual and visual attentional processes, and visuospatial abilities that relate to safe driving performance when engaging in cognitively challenging driving tasks such as route-finding and navigation. The authors indicate that the greater number of safety errors made by the

AD group likely results from the increased cognitive load caused by performing the route-following task rather than differences between groups in their basic ability to control the vehicle.

Rizzo, McGehee, Dawson, and Anderson (2001) analyzed the driving performance of 18 licensed drivers (mean age 73) with mild to moderate cognitive impairment due to Alzheimer's disease using the Iowa Driving Simulator and compared their performance to 12 nondemented drivers (mean age 70). They found that drivers with AD were more likely to crash at intersections than drivers without AD, and that these crashes often occur because drivers fail to notice other drivers, or notice them too late to make an appropriate response. An intersection incursion was programmed into a 15-mile simulated driving circuit, within 3.6 seconds of the driver's time to reaching the intersection. The surprise event required immediate decision making and action by the subjects to avoid the crash, optimally consisting of releasing the accelerator, applying the brake, and making steering corrections as needed to stay within the lane (safe avoidance) or swerving onto the shoulder of the road or into the left lane (unsafe avoidance).

Six of the 18 subjects with AD (33%) experienced crashes during the intersection incursion. None of the control drivers crashed. Driving performance on the road segments preceding the intersection showed no safety errors related to lane crossings, shoulder crossings, speeding, or tailgating, indicating that all drivers had mastered control of the simulated vehicle. Measures of lateral and longitudinal vehicle control on the uneventful segments varied within restricted ranges and did not differ significantly between the drivers with AD and the controls. Analysis of the 5-second time period before the crash revealed that one driver was looking straight out the windshield but took no action to avoid the crash (looked but did not see), and struck the intruding vehicle at 60 mph. The other 5 subjects who crashed either reacted inappropriately or reacted too late to avoid the collision (e.g., didn't press the brake pedal until 1 second from the intersection and steered left into the oncoming lane 1 second before the intersection). For the 12 AD subjects who did not crash, 4 made an unsafe avoidance response and 8 made a safe avoidance response. For the 12 controls who did not crash, 2 made an unsafe avoidance and 10 made a safe avoidance.

Neuropsychological tests that significantly predicted crashes were those that measured visuospatial impairment, disordered attention, reduced processing of visual motion cues, and overall cognitive decline (e.g., Controlled Oral Word Association, Rey-Osterrieth Complex Figure Test, WAIS-R Block Design, Trail Making Test Part B, and Motion Direction Discrimination). The finding that 12 of the 18 AD subjects did not crash and none committed safety errors on the uneventful segments of the drive suggests that some drivers with mild AD remain safe drivers.

In an earlier study using the Iowa Driving Simulator, Rizzo, Reinach, McGehee, and Dawson (1997) found that older drivers with AD were also more likely to have rear-end collisions than older drivers without dementia. In that study, 6 of the 21 subjects (29%) experienced a rear-end crash in the simulator compared to none of the 18 control subjects. Behaviors within the 5 seconds preceding the crash included looking without seeing and failing to respond at all, as well as failing to react in time to avoid a collision. Only 1 crash occurred on an uneventful segment of the drive, when a driver lost control of the vehicle while distracted.

Bieliauskas, Roper, Trobe, Green, and Lacy (1998) recorded the errors made by 9 drivers with Alzheimer's disease and 9 age-matched controls as they performed a 30-minute drive through lightly traveled urban streets. Six error types were recorded by professional driving instructors who accompanied the study participants: (1) *turn*—failure to use the proper signal; (2) *speed*—failure to maintain the posted speed limit within 5 mph; (3) *path*—failure to stay within a lane; (4) *observation*—failure to make necessary observations (directly or using rear-view mirrors) on turns, at a stop or yield sign, or prior to making requested lane changes; (5) *limit line*—failure to position the car directly at a stop sign or turn signal; and (6) *gap acceptance*—failure to allow for a safe distance before merging into traffic. No subjects completed the road test free of errors, however, only turning errors were committed by the majority of subjects. The frequency of occurrence of other errors was 50% or less overall; therefore errors other than turning were summed for data analysis purposes. Significant group differences were found in the number of turn errors, other errors, and total errors. Participants with Alzheimer's made an average of 7.2 turn errors compared to 1.2 turn errors made by controls. The Alzheimer's group made an average of 4.1 "other errors," compared to 2.8 "other errors" made by the control group. The average total number of errors made by the Alzheimer's group and control group was 11.3 and 4.0, respectively.

Cooper et al. (1993) found marked differences in crash characteristics between the clinic group of drivers with dementia and the matched control group drivers from the general population. The demented drivers were *less* likely to have had their crashes at intersections than were the control group drivers (53% versus 87%, respectively). However, the clinic patients who had crashes at intersections were turning 42% of the time, whereas the control group drivers were turning in only 23% of their intersection crash involvements. The dementia group was twice as likely to have their crashes on wet roads (42%) as the control group (20%). The contributing factors to the crashes experienced by the dementia group drivers more often included improper turning or passing, following too closely, unsafe backing, or driving without due care or attention. This group was, however *underrepresented* with respect to right-of-way infractions such as failure to yield or disobeying a traffic control device (17% versus 53% for the control group drivers). The dementia group drivers were judged to be at fault in 92% of the crashes in which they were involved, compared to only 67% of their matched controls. Over 80% of the dementia group who experienced a crash event (and who were almost always at fault) continued driving for up to 3 years following the event, and during this time, over one-third had at least one more crash.

The recommendation that a diagnosis of dementia can be used to determine driver license revocation is premature and raises major concerns (cf. Drachman, 1988). The Friedland et al. (1988) and Lucas-Blaustein et al. (1988) papers recommended that patients with a diagnosis of Alzheimer's disease should not drive. But their studies are limited by small sample sizes, retrospective design, and lack of data regarding amount and type of driving exposure. The Lucas-Blaustein study did not use controls. The Friedland study used community volunteer controls who appeared to be better than average drivers when comparing their reported crashes with population data (Kaszniak et al., 1991). Additionally, it has been reported that a substantial minority (almost one third) of drivers with Alzheimer's disease may have preserved driving skills until advanced stages of their illness (O'Neill, 1992).

In this regard, Hunt (1991) examined the driving skills of people in the questionable and mild stages of senile dementia of the Alzheimer's type (SDAT) using an in-car, on-the-road assessment to study the differences in performance when compared with that of healthy older controls, and to assess whether those with SDAT lack insight into their driving skills. In this study, thirty-nine subjects with a mean age of 73 were assessed for the presence and level of SDAT using the clinical dementia rating scale (CDR). Thirteen subjects who received a score of 0 (no dementia) served as controls, and were compared to 14 mildly demented subjects (score = 1) and 12 questionably demented subjects (score = 0.5) who were matched for age, gender, education and driving experience.

The in-car driving skills were assessed during a one-hour trial by an investigator sitting in the back seat. An experienced driving instructor sat in the front passenger seat in a vehicle instrumented with a dual braking system to give directions and perform safety steering and braking if necessary. The self-assessment of driving skills included true/false questions about present driving skills and a self-rating of driving ability. The results of the on-the-road evaluation showed that all 13 of the control subjects passed the driving exam, as did all subjects with questionable dementia. However, 50% of the subjects with mild dementia failed the exam. The impaired subjects required repeated step-by-step directions while driving through the pre-designed route consisting of urban streets and highways, compared to what was required by control and questionably demented subjects to complete the course. The impaired drivers also needed verbal cues to signal when changing lanes throughout the driving task, whereas the unimpaired drivers may have initially forgotten, but would remember to signal on subsequent lane changes. Fifty percent of the impaired group, when they did signal, did so too late. Two of the impaired subjects stopped at green lights, and one stopped at a light to see what other drivers were doing. Almost half of the impaired group did not check their blind spots, compared to one-quarter of the questionably demented, and one-tenth of the control group. Additionally, impaired judgment by the demented group was noted by subjects coasting to near stop in moving traffic, drifting into other lanes, making sudden stops for no apparent reason, driving while pressing the brake and accelerator simultaneously, and failing to realize why other drivers honked at them.

Demented subjects' perception of their driving ability did not correspond either to that of their caregivers (as assessed by questionnaire) nor their actual driving performance. Eighty-six percent of the mildly demented subjects reported no problems with their driving ability. Seventy-one percent of the caregivers for this group reported concern about the subject's driving ability. They also reported that the subject is slower in reacting to dangerous driving situations (79%), and finds it difficult to join traffic (64%).

Based on these results, Hunt (1991) suggested that SDAT subjects are less likely to report driving problems than unimpaired drivers, and thus in-car assessment may be essential in determining driving fitness. Additionally, this report advocates measures of dementia *severity* rather than use of the SDAT diagnosis alone in determining licensing restrictions, because some people with mild dementia still demonstrate driving fitness.

In a later study, Hunt, Murphy, Carr, Duchek, Buckles, and Morris (1997) found that turn signal use or nonuse does not discriminate between safe and unsafe drivers, nor between healthy older drivers and drivers with dementia of the Alzheimer’s type (DAT), as neither group used their signals appropriately. Turn signal use does discriminate between safe and unsafe drivers when the turn signal is employed only after a turn is made, or when a driver fails to use a turn signal when cued to do so.

Another finding from the study by Hunt et al. (1997) was that driving performance in people with DAT may vary from day to day, as a result of fluctuations in cognitive performance because of stress or fatigue (“good day” versus “bad day”), as well as from differences in the availability of environmental cues. As an example, a driver failed to stop at a stop sign and would have hit a pedestrian had the examiner not intervened. On the 1-month follow-up road test, the driver stopped at stop signs and for pedestrians. On the initial test, there was no preceding traffic for the driver to respond to; her driving behaviors were self generated. On the follow-up test, another vehicle preceded her at each setting, and stopped appropriately for each stop sign and pedestrian. Hunt et al. note that cognitively impaired drivers seek the actions of other drivers to follow the flow of traffic. They slow down at green lights to determine how other drivers are proceeding before they continue. This may have both positive and negative outcomes. An example of a dangerous outcome from copying preceding drivers’ behavior would be an unsafe turn in front of oncoming traffic at a permitted left turn signal. Drivers ahead of the driver with DAT may observe a safe gap in oncoming traffic, and make the left turn safely. The driver with DAT may follow the preceding drivers without considering oncoming traffic.

As noted by Duchek, Hunt, Ball, Buckles, and Morris (1997), although many of the skills involved in maneuvering a vehicle may be well automated, there are times when unpredictable events occur and attentional control must be exerted. It is under such circumstances where breakdowns in driving performance would manifest themselves in drivers with dementia of the Alzheimer’s type.

Duchek, Carr, Hunt, Roe, Xiong, Shah, and Morris (2003) studied the driving performance of 58 healthy controls (mean age 77), 21 participants with very mild dementia of the Alzheimer type (DAT) with a mean age of 74, and 29 participants with mild DAT, with a mean age of 74 years. Dementia level was assessed with the Clinical Dementia Rating (CDR) Scale. Participants were recruited from the Alzheimer’s Disease Research Center at Washington University School of Medicine, who knew that their driving skills would be assessed. They were screened for depression, reversible dementias, and other disorders that could produce cognitive impairment. Almost half of the potential subject pool declined participation in the study (28% with CDR = 0; 44.9% with CDR = 0.5; and 27.1% with CDR = 1). No significant differences were found in age, education, gender, and Short Blessed test of cognitive abilities (a 6-item test of orientation, concentration and memory) between study participants and those who declined participation.

Driving performance in the Duchek et al. (2003) study was assessed using the Washington University Road Test in a standard car with dual brakes. This open-course test was conducted in traffic during a 45-minute drive, and assessed the following driving skills: maintaining speed, obeying traffic signs, signaling, turning, yielding right of way, changing lanes, reacting to other drivers, and negotiating intersections. These skills were scored on a 2- or 3-point scale yielding a quantitative driving score between 0 and 108 (perfect performance) by a driving instructor who sat in the front passenger seat and the study investigator who sat in the back seat. In addition, the two raters independently assigned a global rating of safe, marginal, or unsafe as an expert clinical impression of driving performance. The inter-rater reliability of the global rating was high (k=0.85).

Subjects participated in 4 road tests, administered at 6-month intervals for a 2-year period to investigate longitudinal driving performance. At the time of the first test session, 41% of older subjects with mild dementia of the Alzheimer’s type (CDR = 1) failed the in-traffic road test, compared to 14% of older subjects with very mild AD (CDR = 0.5) and 3% of healthy older subjects (CDR = 0). Subjects who failed the road test did not undergo subsequent testing. A global rating of "safe" (driving behavior unlikely to produce any risk of a crash) was assigned to 78% of the CDR 0 subjects (no dementia), 62% of the CDR 0.5 subjects (very mild dementia), and 41% of CDR 1 subjects (mild dementia). A global rating of "marginal" (driving behavior posed a small to moderate risk of crashing) was assigned to 19% of CDR 0 subjects, 24% of CDR .05 subjects, and 17% of CDR 1 subjects. Two driving behaviors—lane change and using signals—were impaired with increasing dementia severity.

Only three driving behaviors showed a significant decline from the first to the second test administration—*qualitative judgments* (e.g., comprehension of directions, attention to task, awareness), *reacts to others* (e.g., an awareness of how one's driving affects others), and *speed control*. These were independent of CDR group status. The authors note that these behaviors represent the more complex cognitive skills involved in driving (e.g., awareness of the driving environment and decision making) rather than the specific mechanics of driving, such as signaling. These three behaviors were also highly correlated with the global ratings during the first test administration.

Analysis of driving performance over time indicated that subjects without AD took significantly longer to receive a rating of not safe than subjects with mild dementia. Subjects with very mild dementia fell somewhere between the healthy and mild dementia groups. The majority of drivers with mild AD were judged unsafe either at the first test administration, or during follow-up testing within the two-year period. The study authors recommend that the diagnosis of DAT should prompt an individualized, standardized evaluation of driving skills early in the disease process that should be reevaluated and monitored every 6 months to determine precisely when driving performance is no longer safe. This is because some individuals with very mild DAT and a few individuals with mild DAT retained safe driving skills after repeated times of testing over the 2-year period, suggesting that guidelines recommending that all CDR 1 patients cease driving may be too restrictive.

Dey (2004) examined the on-road driving performance and neuropsychological test performance of 42 patients diagnosed with Alzheimer's disease, who were undergoing an evaluation of their ability to continue to drive safely. The objective of the study was to test the hypothesis that driving ability diminishes with increased dementia severity. Clients' mean age was 77 years, and 59.5% were males. The neuropsychological tests included the Mattis Dementia Rating Scale, Boston Naming Test, Trail Making A and B tests, the Benton Facial Recognition Test, and the Clinical Dementia Rating. The road test consisted of 38 maneuvers that evaluated skills such as left turns, observing traffic signs and signals, and signaling for lane changes. The test route required 30 minutes to complete, and included business and residential areas, as well as entering and exiting a State highway. The 38 maneuvers were classified into 7 categories: Signals (maneuvers that involve signaling before merging into traffic or while changing lanes); Checks (checking mirrors, blindspots, and checking for traffic situations before merging into traffic); Speed (ability to maintain appropriate speed while driving straight); Traffic Signs (capacity to follow traffic lights and signals); General Awareness (awareness of other vehicles or pedestrians); Lane Keeping (capacity to maintain lanes while driving); and Turning (maneuvers that deal with making left and right turns and maintaining lane and appropriate speed while turning).

Each maneuver was scored independently by an occupational therapist and a professional driving evaluator, using a “0” to indicate no error or a “2” to signify an error. A global “pass” or “fail” rating was assigned to each participant, based on the OT’s scores for the road test. Sixty-two percent failed the driving test and 38% passed. The only significant correlations between the neuropsychological tests and driving performance were for the Benton Faces test (a test of visuoperceptual abilities), Trails B time, and Trails A percentile. People who performed poorly on the Benton Faces test (indicating increased dementia severity) showed higher driving impairment as evidenced from the OT total score, and significant impairment in 3 of the 7 driving categories: signals, appropriate speed, and awareness of others. Clients who took longer on the Trails B test, and those in the lower Trails A percentile (also indicative of increased dementia severity) showed impaired performance only for maneuvers that involved signaling before merging in traffic or while changing lanes.

Wild and Cotrell (2003) used an on-road standardized driving test to compare actual driving performance to self-reported and caregivers’ perceptions of driving ability for a sample of 15 healthy older subjects and 15 older subjects with mild Alzheimer’s disease (mean age = 72.7 years). Caregivers generally included spouses or other family members living with the driver, or close friends (in the case of a subset of the healthy elderly). Criteria for participation by the healthy older controls (recruited from the Oregon Brain Aging Study) was a Clinical Dementia Rating (CDR) score of 0, independence in daily activities, no chronic medical conditions, and not taking any medications that affect cognition. Alzheimer’s disease patients were recruited from the Aging and Alzheimer Disease Clinics and the Portland VA Medical Center. Nine of the Alzheimer’s disease patients had a CDR score of 0.5 and 6 of the AD patients had a CDR score of 1. All subjects were required to have a valid automobile driver’s license, health and automobile insurance, and drive a minimum of once a week.

The on-road driving evaluation in the Wild and Cotrell (2003) study was conducted by a certified driver rehabilitation specialist (CDRS) in a dual-controlled automobile, on a standardized test route in a residential neighborhood in an area unfamiliar to participants. The route included intersections, lane changes, stop signs, and traffic signals, and segments at pre-determined intervals when the evaluator engaged the subjects in conversation to determine ability to attend to driving, navigation, and engaging in conversation simultaneously. The driving evaluation began with a 30-minute familiarization with the test car, followed by approximately 60 minutes of on-road test time. Drivers were evaluated using a 10-item assessment that is an abbreviated version of the assessment used at the Portland, Oregon, Veteran’s Administration Medical Center. Items were selected to represent the most frequent driving errors and causes of crashes among patients with AD as well as older drivers in general; many of the items follow the Oregon DMV guidelines for driving evaluations. The 10 items, listed below, were rated on a 5-point scale from “very good” to “very poor.”

- Manages intersections.
- Manages lane changes.
- Maintains lane position.
- Maintains proper speed.
- Follows at a safe distance.
- Signals in time.
- Uses mirrors appropriately.
- Responds to road conditions.

- Responds to warning road signs.
- Handles conversational distraction.

The AD patients performed significantly worse than the healthy older controls on all 10 driving behaviors, as rated by the experienced CDRS, who was blinded to the subjects' cognitive status and group membership. AD patients rated their driving performance significantly better than the evaluator's ratings on 7 of the 10 items (ratings were statistically equal for maintains lane position, follows at a safe distance, and handles conversational distraction). Healthy controls evaluated their performance better than that of the driving evaluator on only one item (manages intersections), and significantly worse on one other item (handles conversational distraction). AD patients' self reports of driving ability mirrored healthy older drivers' self reports of driving ability for 9 of the 10 items, indicating that patients with AD are not cognizant of their diminished driving capabilities. Caregivers' perceptions of their Alzheimer's patient's driving ability were similar to the evaluator's assessments in all but two areas: managing intersections and responding to warning road signs, indicating that caregivers of patients with Alzheimer's are generally able to recognize the need for remedial interventions.

Dobbs (1997) and Dobbs, Heller, and Schopflocher (1998) found that specific error types discriminated drivers with dementia from healthy older and younger drivers. The following groups were studied:

- 155 cognitively impaired seniors who were current drivers, the majority of whom carried a diagnosis of AD, with mean age of 72 years, and an average MMSE score of 23.4;
- 60 mature healthy current drivers, with an average age of 69, and an average MMSE score of 28.5; and
- 30 young healthy controls, with an average age of 36, and an average MMSE score of 29.6.

A road test was administered by two experienced driving instructors from the Canadian Automobile Association. Testing was conducted in a mid-sized American car equipped with dual brakes. The test consisted of 37 maneuvers, required 40 minutes to administer, and was conducted on commercial and residential streets, and an urban freeway. Maneuvers were selected to maximize those implicated in older-driver crashes. Some instructions for downstream maneuvers were given; other maneuvers required planning (e.g., a lane change prior to a turn); and some maneuvers required working memory skills (e.g., turn left after two blocks). There was also a "take me to" instruction. Errors were assigned a severity score of 5, 10, or 51, with 51 being an automatic failure, based on that typical in North American licensing exams. Errors were totaled, and an accumulation of more than 50 resulted in a failing score.

The proportion of drivers who failed the driving evaluation using the conventional scoring criteria in the research by Dobbs et al. (1998) was 72% for the patient group, 41% for the older control group, and 43 for the young control group. The researchers determined that some errors are made by experienced drivers, and although they could result in a citation, they do not signal a decline in mental competence, but rather indicate poor driving habits.

Re-examination of the data indicated that the occurrence of a hazardous error was the best single indicator of membership in the dementia patient group. Half of the hazardous errors occurred while the vehicle was changing lanes, merging, or approaching intersections. A significant number of hazardous errors also occurred during left turns (21%) and failing to stop

(15%). Other hazardous errors occurred during right turns (6%) and during stopping maneuvers (8%). Several other categories of driving errors discriminated between the patient group and the control group. Definitions and examples of error categories were as follows.

- <u>Hazardous or potentially catastrophic driving errors</u>: clearly dangerous errors, regardless of the maneuver involved, (e.g., wrong-way on a freeway, stop at green light), and would result in a crash if examiner did not intervene or traffic did not adjust.

- <u>Discriminating driving errors</u>: potentially dangerous errors that signal declining driving skill. These included: minor positioning errors (driving too close to lane markings); turning position errors (wide turns or cut turns); scanning errors (no shoulder checks); overcautiousness (driving too slow); and signal errors (signaling too late or too early).

- <u>Non-Discriminating driving errors</u>: errors made equally often by good and bad drivers, reflecting bad habits as opposed to declining ability. These included extreme positioning errors (driving on the shoulder); stop position errors (stopping too close or too far back); aggressive maneuvers (risky turns); rolled stops (failing to come to a complete stop at a sign/signal); speed error (driving over the posted speed limit); vehicle control (shaky steering); and poor habits (one-hand steering).

Dobbs et al. (1998) found that the hazardous errors and four discriminating error categories (minor positioning errors, overcautiousness, turn position errors, and scanning errors) accounted for 57% in the variance associated with global ratings of driving performance provided by the expert driving instructors. Recalculating the severity scores by error type to re-evaluate the number of drivers failing the test resulted in 68% of the patients, 25% of the normal older controls, and 3% of the young controls failing the test, which was more in line with their expectations.

In the Dobbs (1997) analysis, hazardous errors were renamed as criterion errors and their commission results in an automatic fail. A combined criterion of one or more criterion errors and/or discriminating point total exceeding criterion, resulted in a failure on the road test. Using the joint criterion, all of the young normal drivers passed the road test, approximately 95% of the mature control group drivers passed the road test, and only 25% of the cognitively impaired (patient) group passed the road test. Hazardous or potentially catastrophic errors were made exclusively by drivers with dementia; a small subset (4) of older “healthy” drivers committed these errors, but 3 of these drivers were later discovered to have indications of dementia or other cognitively impairing conditions. These errors differentiated the cognitively impaired group of drivers from the normal drivers. Discriminating driving errors were committed by drivers in all three groups; however, they were rarely made by the young drivers, made more often by the older control drivers, and most frequently by the mentally impaired older drivers.

CHANGES IN DRIVING HABITS ASSOCIATED WITH DEMENTIA

Research relating driving cessation to the onset of Alzheimer's disease is equivocal. There are a number of studies that suggest that patients with Alzheimer's disease tend to drive until a crash occurs (Shemon & Christensen, 1989; Carr et al.,1990; Logsdon and Teri, 1990; Gilley, Wilson, Bennett, Stebbins, Bernard, Whalen, & Fox, 1991; & O'Neill, 1992). Additional research indicates that some drivers with Alzheimer's disease engage in self-regulation, and still others cease driving altogether. Carr, Jackson, and Alquire (1990) described a geriatric clinic population in which 23% of the patients were active drivers at the time of the evaluation. Of the patients who drove, 60% had cognitive impairments and 40% were diagnosed with dementia of the Alzheimer's type. Men continued to drive in the face of declining function significantly more often than did women (Carr et al., 1990). Cotrell and Wild (1999) found that drivers with dementia who ceased driving, often did so long after their caregivers thought that they should stop driving. The time period between cessation and the point at which their spouses thought the drivers should stop driving ranged from 0.5 months to 48 months.

In the Drachman and Swearer (1993) survey, 97 of the 130 AD patients who still drove, had done so for a period of 0.16 to 8.0 years (mean = 2.41 $\pm$ 1.78 years) post-AD. Thirty of the 97 AD patients were involved in 33 reported and unreported crashes while driving post-AD. Of the 58 patients who stopped driving post-AD, 5 did so because of crashes. At three years after the onset of dementia, 50% of the patients had stopped driving. In this same survey, it was discovered that after the onset of AD, 65% of the patients drove fewer miles, 34% drove the same amount of miles, and 1% drove more miles than they had before the onset of AD. Twenty-eight percent limited their driving to near home only, and 51% drove in familiar areas only. Twenty-one percent continued to drive anywhere. Forty-one percent of the AD patients who were still driving at the time of the survey were estimated to drive fewer than 5,000 miles per year, while 36% drove between 5,000 and 10,000 miles per year, and 23% drove more than 10,000 miles per year.

Cotrell and Wild (1999) found that drivers with AD who are aware of their attentional deficits are more likely to implement driving restrictions and to cease driving than drivers who are not aware. The mean age of the 35 patients in their study was 73.6 years; 63% had mild impairment, 25% had questionable dementia and 11% had moderate dementia. A 16-item discrepancy questionnaire addressing abilities in remote memory, recent memory, attention, and performance of everyday activities was completed by patients with AD and their caregivers (spouses). Patients rated themselves as significantly less impaired than their caregivers in all abilities except remote memory. Total discrepancy scores were significantly related to scores on the MMSE, indicating that insight becomes more impaired as mental status declines.

During the initial interview, 19 of the 35 patients were still driving. A comparison of the discrepancy scores for drivers and non-drivers found that only the attention subscore was significant, with patients no longer driving having greater disagreement with their caregivers' assessment of their attentional abilities than patients who were still driving. A second interview with 14 caregivers was conducted 12 to 18 months following the initial interview. Ten of the 14 patients had stopped driving by the time the second interview was conducted. For 7 of the 10 patients who stopped driving, either the patient or caregiver made the decision (as opposed to a physician or the Department of Motor Vehicles). Eighty-six percent of the caregivers (12 of the 14) reported that the patient drove less following the onset of dementia-related problems. Of the

12 who modified their driving behavior, 11 did so voluntarily, with 8 initiating the restrictions themselves and 3 making changes at the suggestion of the caregiver.

The most frequent change made by patients was avoiding unfamiliar routes; the least frequently made change was driving with a co-pilot. Restrictions implemented by patients and the percentage of patients who "always" or "sometimes" implemented them were as follows: avoids night driving (93%); avoids long distances (67%); avoids unfamiliar routes (64%); avoids heavy traffic (64%); drives at slower speeds (57%); avoids bad weather (50%); avoids highway driving (50%); drives with co-pilot (38%). Four behaviors had frequencies that clustered in the "always" and "never" categories and were used to analyze the relationships between restricted behavior and patient awareness of abilities: avoids bad weather; avoids unfamiliar routes; avoids heavy traffic; and drives at slower speeds.

Only the subtest of awareness (attentional abilities) was significantly associated with self-imposed driving restrictions. Awareness of attention was related to only two of the four driving restrictions: avoiding unfamiliar routes and avoiding heavy traffic. Drivers who had greater awareness tended to restrict their driving; drivers with poor awareness did not restrict their driving. Awareness of attention was not related to avoiding bad weather or driving at slower speeds. Awareness of remote memory abilities, recent memory abilities, and ability to perform everyday activities were not related to self-imposed driving restrictions.

Recent findings are presented by Silverstein (2007) who reports that 30 to 45% of people with dementia continue to drive (Carr et al., 2006; Ducheck et al., 2003; Foley et al., 2000; & Lloyd et al., 2001). Estimates of the length of time drivers with dementia continue to drive following their diagnosis range from 3 to over 5 years, with approximately half ceasing to drive within 3 years of the disease onset (Carr, 1997).

In the study by Foley, Masaki, Ross, and White (2000), driving prevalence in a population of men in the Honolulu-Asia Aging Study declined with declines in the level of cognitive functioning. In this study, a family informant provided information for 643 subjects (74 to 95, mean age = 81 years) regarding whether or not they were still driving, and the age at which they ceased driving. Cognitive status was measured with the CDR. Of the 162 men with no cognitive impairment, 78% continued to drive. Of the 287 men with poor cognitive functioning but without clinical dementia, 62% continued to drive. Of the 96 men with very mild dementia (CDR score of 0.5), 46% were still driving. Of the 98 men with mild dementia (CDR score of 1.0), only 22% were still driving. Based on information provided by the caregivers in the neurologist's notes, there were few incidences of crashes among the men with dementia: only 1 of the 59 men still driving had crashed, and only 6 of the 57 who had ceased driving within the previous 2 years had crashed. Also, approximately 10% of the informants for the 59 demented subjects still driving mentioned that the subject always drove with a co-pilot (who was often the spouse of the demented person). Foley et al. also found that in addition to good cognition (no diagnosis of dementia), men with good balance, strong grip, faster walking speed, and no vision impairment were 2 to 4 times more likely to continue driving than those with problems in these areas.

Adler and Kuskowski (2003) studied the process of driving cessation in a group of 53 older men with dementia, recruited from a Veteran's Affairs memory loss clinic. They completed a 44-item questionnaire during a baseline phase regarding driving history, driving habits, and expectations about driving cessation, and also underwent a Mini Mental Status Examination. Family members serving as collaterals also completed a questionnaire at baseline, providing corroborating information. Collaterals completed a second questionnaire 25 to 39 months later to provide information about current driving status. The average age of the men with dementia at the time they completed an initial questionnaire was 75, and the duration of the disease ranged from 1 to 182 months, with a median of 36 months. The average number of days per week they drove was 5.5.

At follow-up, 43 patients remained in the study (8 had died, and two were excluded because they were the only 2 females, precluding an examination of gender effects). At the time the second questionnaire was completed, 46.5% of the patients continued to drive, at an average frequency of 2.4 days per week. In a multivariate logistic regression model to predict driving status at follow up, only age and MMSE at baseline were significant. Those with lower MMSE scores and older age at baseline were more likely to have ceased driving 3 years later. Interestingly, although 23 drivers (53.5%) had given up driving, only 4 drivers (9.3%) at baseline had made plans for future driving cessation.

Collaterals reported that the decision to stop driving was abrupt, and most often prompted by the advice of a physician (56.5%), followed by the collateral—usually a spouse of grown child (30%), the DMV (21.7%), and suggestions by other family and friends (13%). This is despite the fact that at baseline, drivers considered physicians' opinions about driving to be the least important, and that they, themselves should be responsible for deciding when to stop driving. The decision to stop driving was never made after a crash or a close call for the 23 subjects who ceased driving. The most frequent reason drivers gave up their licenses was memory loss (78%), followed by other health problems (26%), and decreased ability to drive (13%).

In an earlier study, Adler, Rottunda, and Kiskowski (1999) administered a survey to 75 male drivers over the age of 60 (range 64 to 88) with a diagnosis of dementia and 75 family members serving as collateral information sources. The purpose of the survey was to obtain information about the patients' driving history, current driving habits, changes in driving pattern within the past year, expectations about driving cessation, and how the decision to stop driving should be made. Thirty-eight of the drivers were diagnosed with probable Alzheimer's disease and 37 were diagnosed with other dementias. The average length of memory problems was 43.9 months. MMSE[6] scores and ranged from 11 to 28, with a mean of 21.4. Drivers with dementia drove an average of 5 days per week; 37% reported driving daily. Family members corroborated this information.

Conditions under which drivers with dementia reported frequently driving (and percentage of the sample) included: driving at night (25%), driving on the freeway (43%), driving in rush hour (21%), errands (55%), and driving alone (53%). There was close collateral-patient agreement to these responses. Over half of the driver-collateral pairs (68%) agreed that the dementia patient had changed his driving habits in the past year. The driving situations and percentages of drivers reporting changes were: night driving (33%); freeway driving (17.3%);

[6] The maximum score on the Mini Mental Status Exam (MMSE) is 30. In general, scores fall into four categories: 24 – 30: "normal" range; 20 – 23: mild cognitive impairment or possible early-stage/mild Alzheimer's disease; 10 – 19: middle-stage/moderate Alzheimer's disease; 0 – 9: late-stage/severe Alzheimer's disease

rush hour (20%); bad weather (20%); drives if no other driver available (23%); and drives less often (36%).

In response to the question posed by Adler et al. (1999) of whether the patient with dementia would need to discontinue driving at some point in the future because of cognitive changes, 65% of the drivers and 43% of the collateral sources believed the driver with dementia would be able to continue driving throughout the course of the disease. When asked who could best make the decision to stop driving and provided with the alternatives of self, physician, other healthcare professional, State DMV, or family member, both the patients (57%) and their collaterals (35%) indicated the driver with dementia could best make the decision to discontinue driving. These responses indicate a lack of insight regarding driving risk and the progressive nature of dementia by the collaterals, denial or minimization of memory deficits by drivers with dementia, and the inability of caregivers to objectively evaluate driving skills (particularly for caregivers who do not drive.

To determine compliance with physician recommendations, drivers were asked whether they would be willing to take a State driver's test if requested by the physician. Eighty-eight percent of the drivers indicated a willingness to take the test. When asked whether they would discontinue driving at the request of the physician, 79% expressed willingness to comply with the physician's recommendation, however, 46% indicated that they would be reluctant to discontinue driving based solely on the physician's recommendation. The authors note that based on their clinical experience, lack of insight coupled with poor judgment and a loss of reasoning ability may impede a person's ability to follow through with a recommendation from a physician to cease driving.

Brown, Ott, Papandonatos, Yunxia, Ready, and Morris (2005) also found that caregivers/informants' ratings of an AD patient's driving safety, while more stringent than an that of the individual with AD, are not significantly related to performance on an on-road driving test. Brown et al. compared an experienced driving instructor's ratings of safety with those of a neurologist (specializing in dementia), a family member who had spent time with the AD patient more than once weekly and had accompanied the participant while driving at least once monthly during the preceding 12-month period, and the patient him or herself. Of the patients with very mild AD (CDR score of 0.5), 94% rated their driving ability as "safe," while the percentage of patients rated as "safe" was 76% by the informants, 69% by the neurologist, and 46% by the driving instructor. Of the patients with mild AD (CDR score of 1), 94% rated their driving ability as "safe," while the percentage of patients rated as "safe" was 50% by the informants, 56% by the neurologist, and 41% by the driving instructor. The experienced driving instructor made the most stringent assessment of driving ability, despite being blinded to patients' status as a healthy older driver, a driver with very mild AD, or a driver with mild AD. The neurologist's assessment (made based on an extensive clinical interview and multiple clinical tests) was significantly related to the on-road driving score obtained by the experienced driving instructor. This finding supports the idea that physicians with considerable experience in dementia may be able to approximately gauge driving abilities in patients with dementia.

Follow-on research by Ott et al. (2005) confirmed that physicians with specialized training in dementia, regardless of their years of clinical experience, were more accurate in their predictions of driving performance (as measured by a driving instructor on a road test) than the general practitioner and geriatric nurse practitioner in their study. In their assessments, based on a chart review of patients with probable and mild dementia, the most accurate raters (a senior geriatric neurologist, a geriatric neurology fellow, and a geriatric psychology fellow) emphasized dementia duration; dementia severity measured using the CDR and MMSE, specific neuropsychological tests of praxis, visuospatial ability, executive function, and attention; and crash and violation history. The least accurate raters placed greater emphasis on history of illness and aspects of the physical exam.

The findings by Brown et al. (2005) also indicate that informants either do not have adequate knowledge about the effects of AD on driving performance, or are uncomfortable with being the primary driver if the driver with AD ceases to drive, and therefore may overestimate a person's ability to drive safely. In a meta-analysis examining the relationship between neuropsychological functioning and driving ability for adults with dementia, Reger et al. (2004) found that caregivers' reports of driving ability do not correlate with patients' memory, executive, or language functioning. Only changes in mental status and visuospatial skills indicate that caregivers are more likely to report reduced driving skills.

Brown and Ott (2004) reported that study findings are mixed regarding the predictability of family members' reports of an AD patient's capacity to drive and performance on a road test. However, when detailed questions are asked of caregivers, they have been found to be a valid source for assessing AD patients' capacity to drive. For example, caregiver responses to 12 questions developed by Brashear, Unverzagt, Kuhn et al. (2002) covering the patient's driving habits, whether the caregiver thought the patient was a safe driver, and attentiveness on the road predicted passing versus failing an on-road driving evaluation. The questions specifically addressed: becoming lost; running red lights; obeying stop signs; staying in lane; finding vehicle controls; confusion on 1-way streets; turning the wrong way onto an interstate; driving too slowly or speeding on the road or interstate; and almost hitting another vehicle, object, or person. Total score on the driving questions correctly identified 83% of the patients who failed the road test.

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BEHAVIORAL COUNTERMEASURES TO REDUCE CRASH RISK

OVERVIEW

This chapter focuses on countermeasures to improve the safe operation of motor vehicles by older drivers, including as wide a range of interventions as possible while limiting discussion to those for which research to evaluate their effectiveness has been reported. Under the broad heading of "behavioral" countermeasures, the following discussion includes:

- Strategies to limit exposure to risky situations, both self-imposed and via license restrictions.
- Educational programs to enhance knowledge of safe driving practices (on-road, simulator, and classroom programs).
- Physical training—exercises to improve strength and flexibility.
- Perceptual training—exercises to improve visual attention.
- Use of passengers as copilots.
- Aftermarket rearview mirrors to increase the field of view and/or to eliminate blind spots.
- Use of corrective lenses, including bioptic telescopes.
- Treatment of eye diseases including glaucoma and cataracts.
- Compensatory scanning to accommodate visual field defects.
- In-vehicle technologies for navigation assistance, vision enhancement, collision avoidance, adaptive cruise control, and emergency management.

It should be noted that a number of additional interventions, in the form of adaptive equipment typically employed with older patients by a driver rehabilitation specialist (DRS), were identified in this review; but research studies documenting their effectiveness were elusive. This includes spinner knobs, pedal extenders, left-foot accelerators, and seat cushions.

Next, countermeasures were targeted in this chapter with a broad cross-section of the older adult population in mind. This is not to say that particular interventions will not be applied to subpopulations with particular needs. But no *special* consideration of interventions to aid drivers with dementia is found here. Man-Son-Hing, Marshall, Molnar, and Wilson (2007) identified six potential compensation strategies for drivers with dementia, and performed a systematic review of the literature for studies assessing the efficacy of retraining/education programs; copilots; on-board navigation and crash warning systems; restricted licensing; self- and family-imposed driving restrictions; and prescription medications to enhance cognition (e.g., acetylcholinesterase inhibitors). As per these authors, none of the above strategies are reasonable, evidence-based options. While there is evidence that restricted licenses can reduce crash rates (Marshall, Spasoff, Nair, & van Walraven, 2002) and that families can influence those with dementia to drive less and in less risky situations (Cotrell & Wild, 1999), it will continue to be problematic to evaluate the effectiveness of countermeasures for those with a progressive disease such as dementia. Our limited understanding about the relationship between dementia and driving performance (or crash risk) reinforces the recommendation by Man-Son-Hing et al. (2007), plus many other researchers and clinicians, to conduct repeated on-road driving evaluations to determine continued fitness to drive.

STRATEGIES TO LIMIT EXPOSURE

Self Regulation

There have been a number of investigations relating the likelihood that an (older) individual will restrict or cease driving to his/her functional status, medical symptoms or conditions, mental health status, socioeconomic status, and other variables (cf. Keay, Munoz, Turano, Munro, Duncan, Baldwin, Jasti, Gower, & West, 2008). This discussion, however, will focus primarily upon studies that have examined whether a traffic safety outcome is associated with self-regulation of driving, regardless of the events or conditions precipitating a reduction in exposure.

Ball, Owsley, Stalvey, Roenker, Sloane, and Graves (1998) studied 257 drivers 56 to 90 (mean age =70). State recorded at-fault crash history was obtained for the prior 5-year period, and crash frequency was categorized into 4 levels: no crashes, 1-3 crashes, and 4+ crashes. Visual functions were measured, including contrast sensitivity, visual fields, overall eye health, and acuity, and categorized by impaired versus unimpaired. Cognitive functions were also measured using the Mattis Organic Mental Syndrome Examination [MOMSSE] and the Useful Field of View test. Driving exposure was gauged according to responses on the Driving Habits Questionnaire, to determine the amount of avoidance of the following situations: night, high-traffic roads, rush-hour traffic, high-speed interstates/ expressways, alone, left-hand turns across oncoming traffic, and rain. The response options covered a range of 1 to 5 (1=never, 2=rarely, 3=sometimes, 4=often, and 5=always).

Most older drivers in this sample (>80%) reported frequent avoidance of driving at night and in rush-hour traffic. There was wide variability in the frequency of avoidance for the other driving situations. Generally, those with the most severe impairments reported the most avoidance. However, Ball et al. (1998) concluded that some older drivers with impaired mental status do not avoid challenging driving situations, presumably because they fail to recognize that they have impairments that would make avoidance a prudent decision.

Subjects in the Ball et al. (1998) study who reported more avoidance of driving in the rain, during rush hour, and making left turns had a higher number of at-fault crashes. An effort was made to relate avoidance with at-fault crashes in the subsequent 3 years; however, a significant number of older drivers in the sample stopped driving or died during the subsequent 3 years, and thus no relationship between average avoidance score and the number of future crashes was demonstrated.

In a Victoria, Australia, telephone survey of 656 drivers 55 and older, Charlton, Oxley, Fildes, Newstead, O'Hare, and Koppel (2003) found that older drivers who had been involved in a crash in the prior 2-year period (regardless of fault) were <u>more likely</u> to avoid any of seven specific driving situations queried than older drivers who had not been crash involved (OR = 1.5). Also, half of the respondents said they have difficulty or lack confidence in a given situation, but do not self regulate in that situation. Self-regulation and *prospective* crash involvement were not evaluated in this research.

Overall, the majority of drivers surveyed by Charlton et al. indicated that they did not avoid the various driving situations. The driving situations queried in this research and percentage of drivers indicating avoidance are as follows: rain (14%), merging into traffic (6%), busy traffic (22%), night (25%), night when wet (26%), changing lanes (15%), and intersections (10%). Of those who indicated they avoid intersections, 77% indicated they avoided intersections without traffic lights, and 30% avoided intersections without fully controlled right-hand turn arrows (in Australia, right-hand turns are turns against opposing traffic). The most frequently reported reasons for avoiding intersections were concerns for safety and crash avoidance. Females were significantly more likely than males to avoid driving in the rain, merging, driving at night, and driving at night when wet. There were no gender differences for avoidance of busy traffic and changing lanes. Drivers75 and older were significantly more likely to avoid merging into traffic, night driving, and driving at night when wet than drivers 55 to 64 and drivers65 to 74. No differences in age group were observed for avoidance of driving in the rain, intersections, and changing lanes, and a difference of borderline significance was observed for avoidance of busy traffic (less avoidance for drivers 55 to 64 than for the two older groups). Fourteen percent of the respondents also indicated avoiding freeways.

Hennessy (1995) evaluated the association between vision test performance and crash history in the prior 3-year period for 3,669 drivers 26 to 70, as well as the mediating effects of self restriction. The Driving Habits Survey was used to measure level of self restriction (never, sometimes, often, or always) for the following forms of self restriction: night driving, avoidance of rain or fog, avoidance of sunrise or sunset, avoidance of driving alone, avoidance of left turns, and avoidance of heavy traffic. Overall, he found that for drivers 70 and older, self restriction is less than adequate compensation for worsening impairments of multiple visual abilities critical to safe driving.

For drivers 70+, Hennessy found that avoiding left turns significantly moderated the relationship between crashes and performance on the visual fields test, as well as the relationship between crashes and speed of processing. However, avoiding left turns was <u>not</u> predictive of fewer crashes; older drivers with poor visual field performance or poor speed of processing *and* who often or always avoid left turns had a *higher* crash rate relative to drivers with good visual fields or good speed of processing. Hennessy (1995) also observed that, while avoiding heavy traffic compensated in part for the reduced contrast sensitivity found in older drivers, none of the forms of self restriction mediated the crash rate of drivers with poor divided attention capability; he states that this is consistent with the "inadequate-compensation" hypothesis.

The only study that evaluated the effect of self regulation (reduced exposure and avoidance of challenging driving situations) on prospective crashes, found no safety benefit of self regulatory behavior (Owsley, McGwin, Phillips, McNeal, & Stalvey, 2004). In this study, 403 older drivers (mean age 73) with a visual acuity deficit (20/30 to 20/60) or slowed processing speed (a 40% or greater reduction in the useful field of view), or both, and who were the drivers in police-reported crashes in the prior year were randomly assigned to either "eye care as usual" or to an "educational intervention plus eye care as usual" group. MMSE scores for both groups were within normal limits with respect to age and educational composition for adults aged 60 and older (all were 23 or greater); and depressive symptom scores, health status, visual function, social desirability Marlowe-Crowe scale), and driving exposure were comparable in the two groups.

In this study, usual care consisted of a comprehensive eye examination. The educational intervention, "Knowledge Enhances Your Safety" (KEYS), consisted of two, one-on-one educational sessions on the effects of visual impairment on driving safety, tailored to each driver's impairment type. The first session lasted 2 hours and included information to increase the driver's self awareness of his/her visual impairment, how the impairment causes driving performance problems and increases crash risk, a discussion of challenging driving situations for older people and how vision is challenged in these situations, and strategies to avoid such driving situations (e.g., driving during the day, in non-rush hour, avoiding left turns across oncoming traffic, avoiding adverse weather, etc.) Participants set specific goals in a personal written contract listing ways they would try to modify their driving behavior. The second session lasted for 1 hour and was conducted 1 month after the first session as a "booster" session, and to discuss progress toward the written goals. Subjects in both groups completed questionnaires at baseline, and at follow-up periods of 6, 12, 18, and 24 months assessing avoidance of challenging driving situations on a 5-point scale from 1=never to 5 = always (e.g., at night, in rain, in rush hour, heavy traffic roads), and self regulation strategies on a 4-point scale from 1=never to 4 = often (e.g., driving at times other that rush hour, scheduling outings during daylight hours, and making right-hand turns around the block to avoid left turns across traffic) at 6 and 18 months. Crash involvement during the 2-year follow-up period was obtained by the State Department of Public Safety, and was expressed in terms of crashes per person-years of driving in the subsequent 2-year period (whichever came first: 2 years, date of death, date of driving cessation) and crashes per person-miles, based on self-reported weekly mileage obtained at the 6, 12, 18, and 24-month follow-up interviews.

Study findings indicated that both groups of drivers decreased their average weekly mileage over the course of the 2-year period, but the rate of decline in the group with the educational intervention was significantly greater. In addition, the driving avoidance and self-regulation scores—which were equivalent for the intervention group and the usual care group at baseline—were significantly higher for the intervention group than the usual care group at each follow up visit. This indicates that the educational intervention was successful at decreasing exposure and increasing avoidance of challenging driving situations (as measured by self report). However, regardless of how crash outcomes were measured, there were no significant differences in the rates of crash involvement between the usual care and intervention groups.

The study authors note that given the self-report nature of the driving exposure measure, there may have been some question as to whether these drivers actually drove less after the intervention, or whether social desirability was operative. Owsley et al. (2004) state that this explanation is unlikely because baseline social desirability scores between the two groups were similar, and because exposure expressed as person-years driving is not a self-reported measure. They conclude that the behavior changes may not have been frequent enough or sufficiently large to generate a measurable protective effect against crash involvement.

The authors did not report on the amount of avoidance or the frequency of self-regulation by type of challenging driving situation, they only reported the results based on composite scores. It may be that drivers performed frequent avoidance of some, but not all challenging driving situations, and were not therefore restricting appropriately. An alternative explanation (not reported by the study authors) for why the intervention did not reduce crash rates is that drivers who said they avoided challenging situations and frequently engaged in self-regulatory strategies, really did not employ these strategies, even though they decreased their weekly mileage. Regardless of the fact that social desirability scores were similar at baseline, this explanation seems plausible, given that part of the intervention consisted of a written contract listing the ways that they would try to modify their driving behavior. Drivers may have said they practiced frequent self-restriction and avoidance because it was expected of them. Another explanation for why crash rate was not affected by the educational intervention may be that the crashes were not restricted to at-fault crashes, which may have been a more sensitive measure of effectiveness.

De Raedt and Ponjaert-Kristoffersen (2000) found that drivers who performed poorly on a road test but were free of at-fault crashes in the prior 12-month period used significantly more strategic compensation tactics (avoidance of difficult traffic situations) than poor-performing drivers with a history of at-fault crashes. Poor-performing crash-free drivers also used significantly more tactical compensation then poor-performing crash-involved drivers. There was no significant difference in either strategic or tactical compensation for crash-free and crash-involved drivers whose driving performance was rated as “average” or “good.” The subjects in this study included 84 licensed, active older drivers (65 to 96, mean age 78.6) who were referred to the Belgian Road Safety Institute for a fitness-to-drive evaluation either by their physician or by their insurance company following one or more crashes or because they changed insurance companies. Subjects were free of neurological disorders that could affect their neuropsychological functioning, and those suspected of having dementia were excluded. Subjects’ performance on a road test (quartile scores) was used to distinguish between “bad,” “average” and “good” drivers. Subjects also provided a self-report of the number of at-fault crashes during the prior 12-month period, and completed a questionnaire to determine strategic compensation (avoidance of 16 difficult traffic situations, such as driving in rush hour, in complex environments, etc.). Tactical compensation was evaluated during the road test using four specific observations: distance from the car in front (on a 5-point scale from too close to too far), choice of speed (on a 5-point scale from too fast to too slow), anticipation behavior in changing traffic situations (on a 4-point scale from unsatisfactory to good), and anticipation behavior during changing road conditions (same 4-point scale).

The number of crashes per subject in the De Raedt and Ponjaert-Kristoffersen (2000) study ranged from 0 to 4. Sixty-three percent of the subjects reported at-fault crashes over the previous year. The road test was administered by two driving instructors from the Belgian fitness-to-drive evaluation center, in a car equipped with a dual brake. The 45-minute road test was conducted over a standardized 21.7-mi (35-km) route in and outside of town areas in Brussels and on a highway, and included maneuvers such as lane changing, turning left, and merging with traffic. Examiners completed a detailed evaluation grid that consisted of 11 dimensions, as follows. Each dimension was rated on two or more 3- and 4-point subscales.

(1) Lateral position on the road: Lateral positioning and steady steering control.
(2) Lane position change: Lane choice.
(3) Distance from the car in front: Style and adaptation.
(4) Speed: Style and adaptation.
(5) Visual behavior and communication: Eye/hand movements, and contact with other road users.
(6) Traffic signals: Perception and reaction.
(7) Mechanical operations: Fluency and timeliness of steering and pedal control.

(8) Anticipation: Tactical anticipatory behavior in changing situations.
(9) Understanding, perception, and quality of traffic participation: Insight, sense of context, and practical implementation.
(10) Turning left: Specific situation, into main road.
(11) Joining the traffic stream: Specific situation on the highway.

Study findings indicated that older people with poor driving performance (assessed during a road test where they are placed in complex situations) are able to remain crash free by using strategic and tactical compensation strategies. The "bad" driver group had the highest scores for strategic compensation, indicating that *only bad drivers select traffic situations below their capacities*. In this study, there was no correlation between strategic compensation and mileage in the group of "bad" drivers, indicating that *successful compensation does not mean reduced mobility, but only reduced exposure to difficult situations*. "Average" and "good" drivers used more tactical compensation (driving slow, keeping further away from the car in front, anticipation) than "bad" drivers, and the tactical driving style adaptations were successful in avoiding crashes. Tactical compensation scores were high for all groups except for the "bad" driver group, which had a significantly lower score. The "bad" driver group with no crashes had significantly higher tactical compensation scores than the "bad" drivers with crashes. The authors conclude that it would be advisable to include an evaluation of compensation abilities in fitness-to-drive evaluations, and that special courses could be developed to enhance the use of such strategies.

License Restrictions

In a study of route-following in older drivers with Alzheimer's disease, Rizzo et al. (2004) found that although drivers with mild dementia were more likely to get lost than normal older controls, drivers with dementia who reported familiarity with the area of town where the navigation task was conducted did not get lost. This finding corroborates research suggesting that drivers with early AD may have trouble learning routes, but are able to navigate accurately on familiar old routes. The study authors suggest that their findings support consideration of graded licensure policies that allow driving in familiar neighborhoods for drivers with mild dementia.

Diller, Cook, Leonard, Reading, Dean, and Vernon (1999) evaluated the medical conditions program by comparing the crash and citation rates per eligible licensed days for restricted and unrestricted drivers who had single medical conditions, by functional ability category (levels 3-5 versus 6-11) to the rates of control drivers (drivers licensed without a medical condition) matched on age group, gender, and county of residence. In Utah, driver license applicants must complete a general questionnaire designed to identify medical conditions related to physical, mental, and emotional health. Applicants who report a medical condition are placed into at least one of 12 functional ability categories (diabetes mellitus and other metabolic conditions; cardiovascular; pulmonary; neurologic; epilepsy and other episodic conditions; learning/memory/communications; psychiatric or emotional conditions; alcohol and other drugs; visual acuity; musculoskeletal abnormalities/chronic medical debilities; functional motor ability; and hearing) and further by functional ability level (1-12) within the functional category.

The intent of this Utah program is to create the least restrictive program possible that is consistent with public safety. Passenger vehicle drivers in functional ability profile levels 1-5 may drive without restrictions (speed, area, time of day, licensed passenger). Although severity of impairments increase with increases in assigned functional profile level, drivers in levels 4 and 5 are deemed safe to drive without license restriction, but may be required for reexam/medical review at intervals shorter than the standard renewal period, depending on their functional (medical) category. Drivers assigned to functional ability profile level 6 have a speed restriction placed on their licenses. A profile level of 7 indicates that the driving risk posed by the functional impairment justifies a speed and area limitation. A profile level of 8 indicates a speed, area, and time of day limitation. Drivers in profile level 9 must be accompanied by a licensed driver, and may have speed, area, and/or time of day limitations as recommended by their health care professional. Levels 10 and 11 are associated with special driving limitations recommended by health care providers or the Director of Licensing. A person assigned to level 12 may not drive until ability improves and functional ability can be assigned at a lower level.

Analysis by individual functional ability categories (medical conditions), showed great variation, but overall, Diller et al. (1999) found that unrestricted drivers licensed with single medical conditions had higher rates of citation, crash, and at-fault crashes than the chosen comparison drivers. Restricted drivers licensed with single medical conditions during the study period had higher rates of crash and at-fault crashes than unrestricted program drivers, but similar rates of citation. Thus, restrictions led to equivalent citation rates but did not have the same effect on crash rates. This means that participation in the program does not completely negate the effects of the medical condition related to driving. It does not mean that the program is not beneficial to public safety, according to the study authors, but instead that the existing program should be changed to reduce the excess risk of drivers with medical conditions to approximate the risks of the general public.

Diller et al. state that it is not appropriate to compare the results of restricted drivers to the results of unrestricted drivers to analyze the effectiveness of the program, because doing so could lead to incorrect conclusions that the differences are due solely to the program. Drivers who are restricted may have much different exposure rates because of the program itself, or because of their illness or condition. Accurate (objective) measures of exposure were not available. Also, by nature of the licensing program, restricted drivers are more medically frail and unstable, depending on their condition. It is also unknown to what degree drivers may have “doctor shopped” to obtain a lower (better) functional ability level, and to what degree drivers complied with their restrictions. Finally, it is unknown to what degree drivers self report their medical conditions, which is the mechanism for their entrance into the DMV medical program.

EDUCATION

Kua et al. (2007) reviewed four randomized clinical trials (RCTs) evaluating the effectiveness of educational interventions in improving driving related skills in older drivers. These studies were uncovered during their comprehensive search of the literature between 1966 and 2006. They concluded that there is moderate evidence from two “high” quality RCTs (Owsley et al., 2003; Owsley et al., 2004) and one “fair” quality RCT (McCoy et al., 1993) that an educational intervention curriculum improves driving awareness and driving behavior. However, they found moderate evidence from one “high” quality RCT that an educational intervention does <u>not</u> reduce crashes (Bédard et al., 2004). They also identified a descriptive study (Janke, 1994) that found that participants in an educational driving program had significantly lower citation rates than those who did not participate, but a slightly higher crash rate; and a pre-post study design (Eby et al., 2003) indicating that a driving workbook intervention significantly increased self-awareness and general driving knowledge. Kua et al. (2007) concluded that given the variations in the definition of safe driving as well as measures used, it is difficult to compare findings across studies regarding the effectiveness of educational interventions for older drivers.

Several additional studies were uncovered during the literature review for the current project. Two randomized controlled studies found that an educational program consisting of classroom and on-road training improved the performance of older drivers (Marottoli (2007; Bédard, Porter, Marshall, Isherwood, Riendeau, Weaver, Tuokko, Molnar, & Miller-Polgar, 2008). Several summaries of the AARP Driving Safety Program (DSP), using self reports of program participants, have found that the course persuaded drivers to adopt safer practices to compensate for age-related declines in safe driving abilities. Finally, Nasvadi and Vavrik (2007) found that participation in a mature driver retraining course resulted in an *increased* number of crashes for men75 and older, but had no effect on subsequent crashes for younger men or women of all ages.

Attributes of these educational interventions and research outcomes are provided below.

KEYS Educational Curriculum (Knowledge Enhances Your Safety)

Owsley, McGwin, Phillips, McNeal, and Stalvey (2004) and Owsley, Stalvey, and Phillips (2003) evaluated the effectiveness of a one-on-one educational intervention tailored to each participants' visual impairment, and found that although self-reported avoidance of challenging driving situations and performance of self-regulatory practices increased in the intervention group and self-reported driving exposure decreased compared to the control group, there was no difference between the groups in police-reported crash rate during the 2-year follow-up period (Owsley et al., 2004).

AARP Driver Safety Program (formerly 55-Alive Program)

Most AARP Driver Safety program (DSP) courses are taught in two, 4-hour sessions, although an on-line course is available for those wishing to take the course over the Internet. The course teaches participants the effects of aging on driving behaviors and how to adjust driving behaviors to accommodate these changes.

Skufca (2008) reported on the results of a survey completed by a random sample of 5,340 participants who took the DSP between May and August 2007. Respondents were asked to comment on 17 key driving behaviors and to indicate whether or not they had changed any behaviors as a result of taking the course. Ninety-five percent of the participants indicated they had changed at least one behavior, with many indicating they had changed multiple behaviors. The average number of behaviors changed was six. The behaviors surveyed and the percent of respondents indicating change was as follows: always checking blind spots (74%), following distance and space cushion (65%), keeping your eyes moving/scanning traffic (60%), always using safety belts (50%), paying more attention when entering or exiting highways (49%), yielding right of way (44%), being aware of where you park (37%), limiting driving in bad weather (36%), limiting use of cell phones while driving (31%), looking for safety features when buying a car (30%), turning in general (29%), using anti-lock brakes properly (27%), limiting times when you drive (20%), avoiding left turns (20%), learning medication effects on driving (20%), limiting your travel on highways and freeways (18%), and considering limiting or stopping driving (5%).

Respondents were also asked about various activities and medical screenings they had engaged in since attending the class. The most frequent response was having vision checked (61%), followed by working independently on flexibility/strength training (24%), speaking to a doctor about the effects of medication on driving fitness (6%), and working with a specialist to improve physical abilities (6%). Similar results were reported by Kutner (2006) in her summary of the 2005 AARP DSP, finding that 83% of the 3,512 graduates surveyed reported that the information learned in the DSP helped prevent their involvement in a traffic incident.

In a study to determine differences between older people who participate in the AARP DSP and those who do not, Kutner (2006) found that participants are more likely than non-participants to believe that their driving could be improved and that the DSP course could help them. The study respondents were drawn from Massachusetts—the only State in the United States that does not provide an insurance discount for taking the AARP DSP. DSP non-participants were more likely than DSP participants to be extremely confident in their driving ability, find driving as an extremely enjoyable activity, and drive more days per week. There were also demographic differences between participants and non-participants, as follows: participants were more likely to be75 or older than non-participants (41% versus 17%), have lower annual household incomes (41% below $40,000 versus 26%), be unemployed (87% versus 52%), and have health status rated lower than "excellent" or "very good" (56% versus 63%).

In terms of self-reported crashes, there were no differences between participants and non-participants in the prior 12-month period. For both participants and non-participants, less than 1 in 10 reported that they had been involved in a crash as the driver, and only 4% had received a moving violation or citation. Approximately two-thirds of both groups reported that the number of near-miss crashes they had avoided in the past 12 months stayed about the same.

Participants and non-participants reported concerns about the same driving situations; however, participants had higher levels of concern than non-participants. The situations with the highest levels of concern for both groups were driving in bad weather, night driving, and driving in unfamiliar areas. The situation with the largest difference in concern was making left turns, with 11% of non-participants indicating concern compared to 34% of participants. Non-participants were more likely to agree with the statement, "I don't need to take a driver safety course; I'm a very safe driver" than participants. Participants were more likely than non-participants to agree with the following statements: "It's important for me to feel that I'm doing what I can to make sure my driving skills stay sharp," "I am interested in how I can improve my driving," Changes in health status or medications are important signs for me to think about taking a DSP," and "I am concerned about the impact that my driving has on the safety of other drivers on the road."

Bédard, Isherwood, Moore, Gibbons, and Lindstrom (2004) evaluated the effectiveness of the Canada Safety Council adaptation of the 55-Alive program developed by AARP. They compared on-road driving evaluation scores before and two months after treatment group drivers received the training, and compared these scores to those of a control group of drivers who did not undergo training. The control and intervention groups were equivalent on age, gender, and baseline driving scores. Scores on the second evaluation were higher than on the baseline evaluation for the whole sample of participants, and the number who passed the second evaluation increased significantly by 64%. However, there was no significant difference between the treatment and intervention group on the mean change scores from the first to the second evaluation. Explanations provided by the study authors for the improvement by both groups include: feedback that may have been given by the evaluator during the first evaluation; practice effect (drivers were tested on the same route in the driving school car); sharing of educational material between groups who frequented the same senior centers; inability of the driving evaluation to test safety strategies acquired in the course; and insufficient intensity of the course (possibly requiring more classroom hours and on-road training).

Nasvadi and Vavrik (2007) conducted a study to examine the self-selection bias of seniors who attend driver education programs, examine the changes in crash rate of older drivers after attending a driver education program, and identify the compensation strategies used by participants who take such programs. Quantitative data (driving records) included police-attended crashes as well as minor crashes and moving violations. Qualitative data were obtained by focus group interviews.

In the first phase of the study, a retrospective cohort design was used to compare the crash rates of 884 older drivers who attended a 55 Alive/Mature Driving course between January 1, 2000, and July 31, 2003, (delivered by the British Columbia Safety Council) to a matched control group (age, gender, and postal code) of 884 older drivers who did not attend the educational program. Driving record data were extracted for subjects and controls for a 2-year period prior to the data of attendance at the course, and only crashes where the driver was deemed at least 25% liable were included. Females comprised 63.9% of the sample (mean age 75.5 years) and males 36.1% of the sample (mean age 76.6 years). During the 2-year period prior to attendance at the 55 Alive/Mature Driving program, significantly more subjects were involved both “all” and “police-attended” crashes than controls (16% versus 10% and 5% versus 2%), but there were no significant differences between the groups in number of drivers with violations. Both men and women who attended the course had significantly more total crashes than their control counterparts; however, only women who took the course had more police-attended crashes than those who did not. Results of phase 1 of the study confirmed the self-selection bias among older drivers who attend remedial driver education courses, namely that they are more likely to have been involved in at-fault collisions prior to the course than drivers who do not take the course.

In the second phase of the study, Nasvadi and Vavrik (2007) compared the crash rate of drivers who attended the 55 Alive program with a control group who did not take the program, but was matched on crash rate prior to the intervention. This matched pre- and post- comparison design was implemented to accurately measure the impact of the program, as involvement in a crash increases the likelihood of a subsequent crash, and may therefore mask a decline in crashes if compared to the general population. Results indicated that more subjects (n=74) than controls (n=65) were involved in crashes in the subsequent 2-year period, but this difference was not significant. However, when stratifying the data by age category (55 to 74 and 75+), older men and women who attended the 55-Alive Mature Driving course had a 1.5 times greater odds of being involved in a crash than their matched controls, and these results were marginally significant (p= .078). For women separately, there was no difference between subjects and controls for the number of post-course crashes, regardless of age category. For men, however, drivers 75 and older who attended the educational program were 3.8 times more likely to be involved in a crash (p=.05). Younger male drivers had fewer post-course crashes than controls, but the difference was not significant. Thus, results of the second phase of the study showed a negative effect of attending the educational program on the crash rate of men over 75 but not for men 55 to 74 or women 55 to 74 and 75 and older.

Focus groups were conducted with 25 men 63 to 90 who had taken the 55-Alive course in the final phase of the study by Nasvadi and Vavrik (2007), to discern possible reasons for the increase in crashes for older men following their participation in the course. There were 7 men who had no crashes either before or after the course ("perfects"), 7 men who had crashes prior to taking the course, but none after taking the course ("pre-crashers), and 11 men who had crashes both before and after taking the course ("crashers"). The mean age for drivers in each group was not statistically different. Differences in attitudes, beliefs, and compensation strategies were evident for the "crashers," which may explain why some older men continue to have crashes following their attendance at older driver refresher courses.

First, the crashers offered no other reason for attending the course besides appeasing their wives. Drivers in the other groups indicated they were encouraged to attend by their wives, but they also said that unexpected driving events made them want to re-evaluate their driving skills and increase their knowledge about how to improve their driving. Crashers were also unable to recall items learned in the course, indicating low motivation for attending, whereas perfects and pre-crashers were able to recall learning about the specific topics taught in the course, such as road signs, checking blind spots, keeping safe gaps, etc. Crashers also expressed strong confidence in their driving, and most said they would not change their travel-related goals, such as taking a longer route to avoid left turns or restricting driving to familiar areas. Many pre-crashers and perfects, on the other hand, stated they had stopped driving at night, and two had stopped driving altogether due to medical conditions. Perfects drove fewer days per week than crashers. When asked about challenging driving situations, crashers blamed other drivers or external events, whereas perfects and pre-crashers talked about driving difficulties due to aging and their own shortcomings. Crashers expressed stronger emotions about driving than the men in the other two groups, and expressed a determination to continue to drive as they had always driven in the past.

The authors conclude that the most likely explanation for the higher cash rate of older men following course attendance is failure to implement the knowledge presented in the course, continued driving exposure, and lack of awareness of declining driving skills. In designing educational programs aimed at older drivers, more success may result by including components that deal with recognizing culpability for driving incidents, because some older drivers continue to believe that others are at fault for crashes, and are therefore unwilling or unable to change their own driving habits.

Mature Driver Improvement Program

Janke (1994) compared the crash (total, fatal, and injury) and citation rates of 5 cohorts of drivers 55 and older who had graduated from the Mature Driver Improvement course in California between 1988 and 1992 to a comparison group of drivers who did not attend the course. The course was 400 minutes (6.6 hours) of in-classroom instruction on age-related physical changes and driving performance; rules of the road; defensive driving countermeasures; effects of alcohol and medications on driving performance; trip planning; and decision-making in dangerous, hazardous, and unforeseen conditions (e.g., fog, slippery surfaces, what to do when the vehicle stalls, etc.). Analysis of the unadjusted rates (not adjusted for age, gender, license class, and prior driving history) found that the driver education group had significantly lower citation rates across the cohorts and evaluation intervals (6, 18, and 30 months following course completion). However, there were no significant differences on total crashes or on fatal/injury crashes between the intervention and control groups. Analysis of the adjusted crash rates showed significant differences between the intervention and control group for two cohorts, one favoring the treatment group and one favoring the control group after 6 months.

A separate analysis of these two cohorts' 6-month data indicated that program completion was associated with more total fatal injury crashes and fewer citations. Janke speculated that completion of the course may have increased graduates' knowledge of traffic laws and their confidence behind the wheel, which may have helped them reduce the number of citations (unlawful driving); but at the same time may have prompted them to increase the amount of driving and thus their exposure to challenging situations, leading to more crashes.

AAA Safe Driving for Mature Operators

McCoy et al. (1993) found that interventions that included the use of the *AAA Safe Driving for Mature Operators* course increased older driver's on-road performance as measured by the DPM by 3.7 to 13.9 percentage points. Education alone increased performance by 3.7 percentage points; education with physical therapy increased DPM performance by 8.7 points, and education with perceptual therapy increased DPM performance by 13.9 percentage points.

The AAA educational course was taught by an officer of the Nebraska Highway Patrol who usually teaches the AAA course in the Omaha area. The course consisted of 8 hours of classroom instruction presented in 1 session. Each subject received a course manual that covered the information presented by the course instructor. The physical therapy intervention was a set of seven self-administered home-based exercises to improve posture, trunk rotation, neck flexibility, and shoulder flexibility. It was performed 4 times per week for a period of 8 weeks. The perceptual therapy was a set of self-administered home-based exercises designed to improve the following components of visual perception: spatial relationships, visual discrimination, figure-ground, visual closure, and visual memory. Subjects were given workbooks that contained the exercises and instructions for completing them. They performed these exercises for 20 minutes a day, 4 times per week, for 8 weeks.

Driving Decisions Workbook

Eby, Molnar, Shope, Vivoda, and Fordyce (2003) evaluated the effectiveness of a self-assessment instrument in increasing older drivers' self awareness and general knowledge of their safe driving abilities, and how well responses on the instrument correlated with on-road driving performance, as a preliminary assessment of the workbook's validity. Ninety-nine drivers ages 65 to 90 participated, recruited from retirement communities, senior centers, health-care facilities, and supermarkets. The self-assessment instrument is a workbook organized around the 5 broad sections of medical conditions and medication use, visual abilities, cognitive abilities, motor abilities, and experiences/attitudes/behaviors, for a total of 37 individual assessment areas. Each assessment area is presented on a separate page and contains between one and six question items. For each item, lines connect the response choices that suggest a potential problem with safe driving to appropriate feedback. Participants first completed the workbook, which took an average of 30 minutes. They then completed a 27-item questionnaire to identify self-reported increases in self awareness and general knowledge as the result of completing the workbook, as well as its perceived usefulness. Subjects then participated in an on-road driving assessment on a 7-mi (11.3-km) course featuring 28 structured maneuvers at specific locations (e.g., controlled right and left turns, uncontrolled right and left turns, and lane change) that took 15 minutes to complete. An examiner riding in the front seat of the subject's vehicle scored up to 17 performance tasks (e.g., use of signals, checking mirrors, vehicle speed, and lane positioning) using standard scoring criteria.

Approximately 75% of subjects indicated that the workbook made them more aware of changes that can affect driving, and 14% discovered a change in themselves that they had not been aware of before completing the workbook. Approximately 40% reported that completion of the workbook made them think about taking a driving refresher course, and 35% reported that they would be more likely to have a physician check their vision, cognition, or psychomotor abilities as a result of completing the workbook. In rating the overall usefulness of the workbook, 50% found it to be "very useful," while 40% found it to be "somewhat useful." Correlations between the overall workbook score and the on-road score were positive and statistically significant, indicating that as the number of potential problem areas identified by the workbook increased, the number of performance tasks with problems observed during the road test also tended to increase. The correlations for the abilities subdomains showed that the responses for cognition and psychomotor abilities were significantly related to driving performance, but the vision domain was not. While the health domain was not significantly related to driving performance, the subdomain of health conditions was. Thus, the workbook was effective in improving older drivers' self awareness of changes in driving abilities related to aging and the effects of these changes on driving. The study also showed that the workbook was effective in encouraging people to seek second-tier assessment, and in encouraging older people to consider changing their driving habits. The study did not assess whether drivers followed through on their plans to seek further assessment and change their driving behavior.

Combined Classroom Driver Safety Training With On-Road Driver Training

Bédard et al. (2008) expanded on their 2004 study to include the measurement of knowledge before and after driver training, as well as the addition of an on-road instruction component to the in-class component. They examined changes in safe driving knowledge and on-road driving performance following an intervention that included both in-class and on-road training components. Participants included drivers 65 to 87 with MMSE scores at least 24, to rule out cognitive impairment.

The intervention in this study consisted of the Canadian Safety Council's adaptation of the AARP 55-Alive Mature Driving Program, presented in two sessions that lasted for 4 hours. In addition, participants were given the opportunity to reinforce the concepts learned in the classroom by engaging in two 30- to 40-minute sessions with a certified instructor, driving either in their own vehicles or in a dual-brake vehicle. The instructor provided participants with constructive feedback on their driving habits. The measures of effectiveness were:
(1) scores on a 15-item multiple choice safe driving knowledge questionnaire given before the classroom session and again after completion of the classroom sessions, but before the on-road training sessions (for the treatment group); and (2) performance on a standardized on-road

driving evaluation given before the intervention and again 4- to 8-weeks post-intervention (both the treatment and control group). Five driving actions were evaluated:
(1) starting/stopping/slowing; (2) signal violations/right of way/inattention; (3) moving in the roadway; (4) speed/passing; and (5) turning.

Results of the Bédard et al. (2008) study indicated a significant improvement in knowledge of safe driving practices, with an increase from 61% of the questions answered correctly at baseline to 81% answered correctly at follow-up. Driving performance improved significantly for the intervention group (fewer violations were made) compared to the control group, but only for the category of moving in the roadway. Examples of violations in this category included straddling the traffic lane, failing to check traffic when changing lanes, wandering, and failing to drive in the proper lane.

Marottoli (2007) conducted a randomized, controlled trial with blinded endpoint assessment to determine whether an educational intervention consisting of classroom and on-road training focused on commonly encountered problem areas for older drivers, could enhance driving performance among 126 active drivers 70 or older. Intervention drivers participated in two, 4-hour classroom sessions based on the AAA Driver Improvement Program (Safe Driving for Mature Operators) and two 1-hour on-road driving sessions focused on common problem driving areas for older drivers. The classroom sessions followed the outline and videos of the AAA program, but were supplemented with the following additional topics: a review of all road signs, neck rotation for head checks, checking blind spots, the use of side mirrors, steering-wheel hand placement, steps for changing lanes and merging in traffic, right-on-red rules, limiting distractions and focusing on driving, search strategies for intersections, scanning to the rear, backing-up strategies, the consistent use of turn signals, and strategies for left turns across traffic or how to avoid such turns.

The on-road instruction was based on common errors made by older drivers (from a literature review, and the earlier study by Marottoli et al., 2007). The most common errors made by drivers in the earlier study were failure to scan side to side, to the rear, and make head checks; failure to use a seat belt, keep the car centered in the lane, maintain a safe following distance, and use directional signals; and errors in backing up, making lane changes, and in speed regulation. The topics therefore that were included in the on-road instruction were vehicle orientation (adjusting seat position and mirrors, seat belt, head restraints, hand position, and distance from wheel); parking lot maneuvers (parking, backing up, using mirrors, looking over shoulder); maneuvers for low volume streets (K-turns, intersection strategies such as stopping position, search strategies, signaling, yielding to pedestrians, and left turns across traffic); maneuvers for moderate- and high-volume roads (looking 30 seconds ahead, watching for pedestrians and vehicles changing directions or slowing down, strategies for stop lights, turning strategies, lane change strategies, speed and space management, mirrors and head checks, and signaling); and maneuvers on highways (entering, exiting, merging, changing lanes, mirror and head checks, blind spots, speed regulation, space management). The first session also addressed any errors the driver made during the baseline assessment.

Control drivers received one-on-one sessions about vehicle maintenance and safety devices, home safety, and environmental safety. These were conducted in the participants' homes and included education on falls and tripping hazards, lighting, handrails, appropriate footwear, crime prevention, tire pressure, vehicle lights and mirrors, pedestrian issues, etc. This protocol involving driving, safety, and mobility was chosen for control subjects to maximize participant recruitment and retention in the study, have minimal effect on the primary outcome of the study (driving performance), and minimize costs.

Outcome measures in the Marottoli (2007) study included on-road driving performance at baseline and 8 weeks post-intervention, for both the intervention and control group. Also, a knowledge test was given at baseline and 8-weeks post-intervention for both groups consisting of 20 multiple-choice questions based on the AAA road knowledge questions and 8 road-sign questions. The road test covered 10 miles, included a 1.7-mile highway segment, and took 45 minutes to complete. It included urban and residential areas with low-, medium-, and high-traffic densities, with speed limits ranging from 10 to 35 mph on access roads and city streets to 55 mph on the highway. There were 63 intersections on the route (32 crossing and 31 T-type); 45 were signalized, 2 were controlled by flashing lights, and 11 were controlled by stop signs. There were 15 right and 15 left turns, 12 merges, and several opportunities to make a right on red at a traffic signal.

Mean baseline road test scores were comparable in the intervention and control groups, for those who drove daily or less than daily (60.9 versus 60.7, respectively, out of 72 points). Intervention drivers showed a mean increase in road test score of 8.5% compared to a 4.2% increase for control subjects. The improvement in on-road test performance at 8 weeks for the intervention group was 2.87 points higher (least-squares mean change) on a 72-point scale than that in the control group. This difference was significant, and translates to a 9.5% decrease in crash risk over a 2-year period (unpublished data from populations studied earlier by the author). The items showing the most improvement with intervention were: scanning to the rear, lane selection, right turns, and judgment. Intervention drivers showed a mean increase in knowledge test score of 22.5% compared to a 6.2% increase for control subjects. The improvement in written-test performance at 8 weeks was 3.45 points higher (least-squares mean change) on a 28-point scale for the intervention group than for the control group, which was also significant.

The study author concluded that the intervention consisting of classroom and on-road instruction was effective in improving driving performance and written test scores (knowledge), relative to the control group (a non-referral volunteer sample drawn from general-medicine-clinic waiting areas and the community at large). Thus, the study findings have broad potential applicability. However, Marottoli (2007) notes that the study was not powered or designed to look at crashes, injuries, fatalities, changes in driving patterns, or duration of effects so there are unanswered questions regarding the actual safety implications of the intervention.

PHYSICAL TRAINING

Kua, Korner-Bitensky, Desrosiers, Man-Son-Hing, and Marshall (2007) uncovered two studies in the research literature between 1996 and 2006 on the effectiveness of physical retraining for improving driving-related skills in people 55 and older (Ostrow, Shaffron, McPherson, 1992; and McCoy, Tarawneh, Bishu, Ashman, & Foster, 1993). Both studies were rated as “fair quality” randomized clinical trials, using the Physiotherapy Evidence Database; Kua et al. (2007) concluded from these two studies that there is limited evidence that physical retraining interventions improve driving-related skills in older drivers. An additional study, a randomized controlled trial rated as “high quality” was uncovered during the literature search in the present project, providing moderate evidence of the effectiveness of a physical conditioning program in improved on-road driving performance for older people (Marottoli et al., 2007). A final comment on the benefit of aerobic fitness training on cognitive ability is included, based on work by several researchers (Colcombe et al., 2006; Rovio et al., 2005; Abbott et al., 2004).

In the study by Marottoli et al. (2007) drivers 70 and older who drove at least 5 days per week, had binocular visual acuity of 20/40 or better, a MMSE score of 24 or better, with no medical conditions that might deteriorate over the study period or acute medical illness at the time of the screening, but had at least two physical impairments were randomly assigned to either an intervention group or a control group. Physical impairments included: inability to turn one's head to touch shoulders (neck rotation), turn one's trunk to touch the wall behind shoulders (trunk rotation), lift shoulders to touch hands behind one's head (shoulder abduction), clear a 4-inch card placed beneath the foot (hip flexion), greater than 18.5 seconds to place 5 small objects in a cup using tweasers (manual dexterity), and greater than 11 seconds to walk 10 feet and back as quickly as possible (gait speed). The intervention was a weekly in-home visit by a physical therapist for 12 weeks, who guided participants through a graduated exercise program targeting the following physical domains and abilities potentially relevant to driving:

- Axial/extremity conditioning (cervical, trunk, and axial rotation; cervical flexion and extension; shoulder flexion and abduction; hip flexion and abduction; knee flexion and extension; ankle dorisflexion and plantarflexion).
- Upper extremity coordination/dexterity and hand strength.
- Gait and foot abnormalties.

Each of the coordination domains consisted of three progressive levels of exercises. The therapist gradually increased the number of repetitions for each exercise, once the participant demonstrated the ability to perform the exercises safely and correctly. Exercise programs were designed to take 15 minutes and participants were asked to perform the exercises once daily for 7 days each week. Intervention participants reported completing the exercises a median of 5.4 days per week. The control group received monthly in-home education modules about home safety, fall prevention, and vehicle care. The intervention group also received these modules to ensure that the materials did not influence study outcomes.

Study outcomes included a change in on-road driving performance at 3 months relative to baseline using a 36-item scale based on the driving evaluation used by the Connecticut DMV, with scores ranging from 0 (worst) to 72 (best). Secondary driving performance measures were the evaluator's overall rating of driving performance on a 4-point scale ranging from 1 (no problem) to 4 (major problems), and critical errors observed during the evaluation (ranging from 0 to 3) including inattention, turning or changing lanes without looking, and disobeying signs or signals.

Significant improvements were demonstrated in road test scores for the treatment group compared to the control group (2.43 points), with the largest improvements in the worst-performing group of treatment subjects at the baseline driving evaluation relative to the worst-performing control group at baseline (4.81 points). The 2.43 point difference (least squares mean change) translates to an 8% lower crash occurrence over 2 years, and the 4.81 point difference (least squares mean change) translates to a 16% lower crash occurrence over 2 years.[7] Participants in the intervention group also demonstrated 37% fewer critical errors than the

[7] Using data from a similar cohort of 552 drivers followed prospectively by the researchers, but no citation provided; data available on request to the Principal Investigator: R. Marottoli)

control group during the 3-month follow-up road test; which nearly reached significance (p<.076). The difference in number of critical errors at baseline was not significant (p<.38). There was no significant difference between groups in driving evaluator overall rating.

In the study by Ostrow, Shaffron, and McPherson (1992), 32 subjects ages 60 to 85 were stratified by gender and randomly assigned to an experimental or control group. Drivers in the experimental group received an 8-week range of motion exercise program that could be practiced at home, consisting of chin flexion/extension, neck rotations, head side bending, chin tucks, rotating the shoulders backward, and trunk rotations. Drivers in the exercise group met weekly with a clinician who introduced new elements of the exercise program, reviewed previously learned skills, and monitored the subjects' compliance with the program. They also kept a daily log to record their compliance, and the frequency and extent of their driving. Subjects in the control group did not receive the exercise intervention. Instead, they kept a log of the frequency and extent of their driving, and as an incentive to participate in the study, received in-car instruction after the project was completed.

Range of motion was measured at baseline, and again at 8 and 11 weeks, along with 9 in-car driving measures adapted from the Automobile Driver on-Road Performance test (ADOPT), developed by Edwards, McKnight, and McPherson (1981). Only trunk rotation and shoulder flexibility showed significant improvements across the three testing sessions in the experimental subjects' range of motion scores. Subjects in the experimental group improved on trunk rotation during the first 6 weeks of the program, but showed less improvement during the latter two weeks of the intervention. The control group deteriorated on trunk rotation during the first 6 weeks. Although the control group improved slightly on shoulder flexibility over the course of the study, experimental group subjects improved significantly on shoulder flexibility at each testing session. Experimental subjects improved their on-road observing performance during the last two weeks of the intervention (defined operationally as the percentage of appropriate responses made for observing to the rear, observing to the side, observing the rear quarter, and looking back while driving), while the control subjects declined on this skill during the last two weeks of the study. Control subjects improved, however, on their handling position scores (distance of the tires from the curb after parallel parking) while the performance of the experimental group declined during the first 6 weeks of the intervention. There were no significant differences between the groups in days or average number of miles of driving per week. It was concluded from the study findings that the range of motion exercises improved driver's flexibility and translated to enhancement of driving skills that demand an adequate range of motion, such as observing to the sides and rear of the vehicle.

As a part of a larger study, McCoy, Tarawneh, Bishu, Ashman, and Foster (1993) investigated whether physical therapy would improve older drivers' on-road driving performance. Driving performance was measured for 9 subjects age 75 or older before and after a physical therapy regime using the Driving Performance Test (DPT) developed at Michigan State University (Vandosall & Rudisill, 1979). Physical therapy consisted of a set of seven self-administered, home-based exercises designed to improve posture, trunk rotation, neck flexibility, and shoulder flexibility. The exercises were done 4 times per week for 8 weeks, following a 1-hour training session. Physical therapy improved the DPM performance by 6.8 percentage points, which was statistically significant. Seven other subjects in the study received physical therapy in combination with driver education, and showed improvements in DPT performance of 8.7%. The authors note that the percentage improvement is an indication of the resultant improvement in the safety or older drivers, not necessarily the reduction in older drivers' crashes provided by the countermeasure. The cost of the physical therapy averaged $5.35 per person, and included the 1-hour training sessions and the instructional brochures and exercise workbooks.

Evidence is mounting that physical aerobic activity can increase cognitive function, and even provide a protective effect against dementia. In a study by Colcombe et al. (2006), subjects who participated in aerobic exercise showed increased brain volumes in regions associated with age-related decline in both structure and cognition. In their study, 59 healthy but sedentary community-dwelling volunteers ages 60 to 79 participated in a 6-month randomized clinical trial. Half of the older adults were assigned to an aerobic training group walking 3 times per week for 45-minute periods) and the other half participated in a toning and stretching control group (non-aerobic stretching exercises 3 times per week). Twenty younger adults served as controls on the measure of effectiveness (magnetic resonance imaging) and did not participate in the exercise intervention.

Significant increases in brain volume, in both gray and white matter regions were found in the older adults who participated in the aerobic fitness training, but not in the adults who participated in the stretching and toning exercises (nonaerobic) or in the younger controls. During their magnetic resonance imaging protocol, participants performed a focused attention task that required them to focus on a single central object while ignoring irrelevant distractor objects that flanked the target item. Older adults who participated in the walking protocol were better able to ignore the misleading flanking items, but the control adults were not (Kramer, Erickson, & Colcombe, 2006).

In a review of the literature on fitness training and cognitive functioning among non-demented older adults, Colcombe and Kramer (2003) found that although fitness training broadly influences a variety of cognitive processes, the largest positive effects were observed for executive control processes. Executive control processes include components of cognition such as planning, scheduling, working memory, inhibitory processes, and multi-tasking—and are many of the processes that show substantial age-related decline. They also found that the effects of fitness training were larger when programs of aerobic training were combined with strength and flexibility training.

Abbott, White, Ross, Masaki, Curb, and Petrovitch (2004) found that walking is associated with a reduced risk of dementia. They studied the distance walked per day for 2,257 physically capable, non-smoking Japanese-American men 71 to 93. After adjusting for age, men who walked less than a quarter mile per day experienced a 1.8-fold excess risk of dementia compared with men who walked over two miles per day. These associations persisted after accounting for other factors, including the possibility that limited amounts of walking could be the result of a decline in physical function due to preclinical dementia.

Similarly, Rovio et al. (2005) found that those who exercised during their middle-life (age 30, 40, and 50) were 60% less likely to develop Alzheimer’s disease in old age (age 65 to 79) than sedentary adults, and 50% less likely to develop other forms of dementia and memory loss. In this study of 1,449 older people, exercise was defined as leisure time physical activity lasting at least 20 to 30 minutes at least twice a week and intense enough to cause breathlessness and sweating. The benefits were apparent even after adjusting for medical and lifestyle factors such as heart/blood vessel disease, locomotor disorders, smoking, alcohol consumption, age, gender, education. The benefits were especially pronounced among those who carried the APO-E4 gene that is known to increase a person's risk of developing Alzheimer's disease in old age.

VISUAL PERCEPTION TRAINING

Kua et al. (2007) reviewed two randomized clinical trials (RCTs) evaluating the effectiveness of visual perception interventions in improving driving related skills in older drivers. They concluded that there is limited evidence from two "fair" quality RCTs (Roenker, Cissel, Ball, Wadley, & Edwards, 2003; McCoy et al., 1993) that visual perception interventions improve driving related skills in older drivers. These two studies are described below, in addition to studies uncovered in the current project evaluating the effectiveness of speed-of-processing training on cognitive and everyday functioning (Ball, Edwards, & Ross, 2007) and a cost-benefit analysis conducted by Viamonte, Ball, and Kilgore (2006) for providing speed-of-processing training to older drivers at license renewal.

Visual-Perceptual Therapy

McCoy et al. (1993) evaluated the effectiveness of a perceptual therapy intervention for 9 older drivers (ages 65 to 88) in improving their on-road driving performance, compared to a control group of 9 older subjects who did not receive the intervention. Baseline driving performance and follow-performance at 2 months post-intervention were assessed using the Driver Performance Measurement (DPM) technique developed at Michigan State University. The perceptual therapy consisted of a set of self-administered home-based exercises designed to improve the following five components of visual perception: spatial relationships, visual discrimination, figure-ground, visual closure, and visual memory. The therapy consisted of 568 exercises, organized into five sections in a workbook, one for each component of visual perception, arranged in order of degree of difficulty, from the simplest to the most difficult. The subjects were instructed to spend about 4 minutes on each section during a 20-minute session, doing as many exercises as possible working at their own pace. The exercises were to be done for 20-minutes, four times a week, for 8 weeks. If they completed the exercises in one of the sections before the end of 8 weeks, they were instructed to start the section over from the beginning. Before the start of the exercise program, subjects were given a 1-hour training session, during which time they practiced the exercises for each of the five components.

The mean difference in DPM was 7.7 percentage points higher at follow-up than at baseline, indicating an improvement in performance for the perceptual therapy intervention group. The mean difference for the control group was -0.4 (no improvement in performance). A pair-wise comparison showed these differences to be statistically significant, indicating that visual perceptual therapy was effective in improving driving performance for the intervention group, relative to the control group.

It should be noted that McCoy et al. (1993) also evaluated the effectiveness of an educational intervention and a physical therapy intervention (both described earlier in this review) and found that all three countermeasures (visual perception, education, and physical therapy) were equally effective, with an average improvement in DPM score of 7.9% each; and there were no significant differences in the magnitude of improvement for one intervention versus another, or between different combinations of interventions.

Speed-of-Processing Training

Roenker et al. (2003) conducted a study to determine if speed-of-processing training, which has been found to expand the size of the useful field of view, also produces an improvement in driving performance. The participants were licensed drivers with an average age of 71 years (range 55-86). Three groups of drivers participated: 25 drivers with an intact field of view (reduction of less than 30%) who did not undergo any training (low-risk reference group); 22 drivers with a reduction in useful field of view of 30% or greater who underwent simulator training (traditional driver training control group); and 48 drivers with a reduction in useful field of view of 30% or greater who underwent speed-of-processing training (the training of interest). Simulator training consisted of two, 2-hour educational sessions with groups of 3 to 4 participants each, using a non-interactive Doron driving simulator. Simulator education consisted of a general review of rules of the road and instruction about safe driving practices and crash avoidance. Participants practiced with the simulator, using films that demonstrated techniques for crash avoidance, managing intersections, and scanning. The last hour of instruction was a demonstration by the driving instructor of many skills described in the films. Speed-of-processing training was conducted on an individual basis using a touch-screen computer. All three subtasks were trained to criteria, with an average of 1,040 training trials completed, and an average training time of 4.5 hours. Pre- and post-training measures of effectiveness included simple and choice reaction time, a useful field of view measure, and an on-road driving test. Training effectiveness was also assessed on all measures at 18 months.

The reaction time measures were collected in the driving simulator. For simple RT, participants watched a light arrangement containing six colored lights. Color-matched pairs of lights blinked on and off in random order. Participants were instructed to brake as quickly as possible when two red lights (simulated brake lights) were illuminated. For complex RT, participants watched a film that included road signs (pedestrian, bicycle, right turn arrows, and left turn arrows) with and without slashes through them. They were instructed to react only to signs without slashes, and to brake when they saw pedestrian and bicycle signs, or by turning the steering wheel right or left according to the arrow signs.

The on-road test in the study performed by Roenker et al. (2003) was designed based upon a review of crash literature, traditional drivers' tests, and fitness-to-drive evaluations. They employed an on-road course, consisting of two loops through a 7-mile urban/suburban route. Repetition of the route was conducted to provide an opportunity for a range of traffic conditions to occur. The evaluation, performed in a car modified with a passenger-side brake pedal, was conducted during daylight hours, and required 50 to 60 minutes to complete. The route permitted observation of maneuvers identified in the literature as especially difficult for older drivers (e.g., left turns across traffic). For each location where a potentially difficult maneuver was attempted, two back-seat raters coded the extent to which the driver's behavior constituted a dangerous maneuver—one which either required the driving instructor to take control of the car or one where other vehicles had to alter their course in order to avoid a collision. Three raters were trained on a total of 455 items until all scoring criteria could be consistently applied by all raters (interrater reliability was $r \geq .92$).

The following driving behaviors were rated on a scale of 0 (very unsafe) to 2 (safe or appropriate) in this research: maintaining lane position, activating signals, stopping smoothly, searching (additional mirrors were placed in the car to assist the raters in detecting eye movement), selecting gaps, accelerating and decelerating smoothly, turning, maintaining speed, maintaining position in traffic, and dangerous maneuvers. Stopping at a stop sign was rated on a four-point scale, where running the stop sign = -1, rolling through a stop sign = 0, stopping at an inappropriate position = 1, and 2 = an appropriate stop. After the drive, the raters also provided a global rating of the drive ranging from 1 (drive aborted/very unsafe) to 6 (very competent/safe).

The driver performance data were reduced by grouping a total of 455 items into 13 composites, based on the behaviors being rated. Four composites—gap selection, acceleration, deceleration, and right-of-way—were subsequently dropped from the analysis due to ceiling effects (performance was nearly perfect on most observation opportunities). In addition, the composite measure for "search" was dropped for lack of sufficient data, reflecting difficulty in reliably scoring this behavior. The remaining eight composites, listed below, were scored according to the multi-level rating system described earlier, except for dangerous maneuvers, which was scored as an actual number of observed events.

- Position in traffic – relative position to surrounding traffic while moving.
- Signals – proper and timely use of turn signals.
- Speed – vehicle speed control relative to posted speed limits.
- Stop position – vehicle position when required to stop at a traffic control device.
- Tracking – position of vehicle in the proper lane.
- Turning – position of vehicle when turning.
- Changing lanes – changing lanes on a multi-lane road.
- Dangerous maneuvers – based on the observations of raters at 17 potentially dangerous locations during the test (6 unprotected turns across traffic, 9 left-turn entrances to a high-traffic road, and 2 opportunities for inappropriate stopping in traffic to make a right turn)

Global ratings increased for all three groups from baseline to the immediate post-test. The low-risk reference group's baseline ratings were higher than the baseline ratings for both the simulator and speed-of-processing trained groups. At the immediate post-test, there were no significant differences in global scores between the three groups. After 18 months, the simulator-trained groups' global ratings returned to their baseline level, while the global scores for the low-risk reference group and speed-of-processing group remained high. Five of the eight driving composites yielded significant group-by-time interactions.

For the *dangerous maneuvers interaction*, the low-risk reference group had fewer dangerous maneuvers than the two training groups at baseline; however the number of dangerous maneuvers for both training groups dropped during the immediate post-test and was significantly different from the reference group. At the 18-month follow-up test, both the reference group and the simulator-trained group performed significantly more dangerous maneuvers than the speed-of-processing trained group. For the *turn signals interaction*, the reference group was more consistent in their use of turn signals than either of the two training groups at baseline. At the immediate post-test, the reference group's use declined, but the simulator group's use improved. These changes did not persist; at 18 months, both groups returned to baseline levels of signal use. The speed-of-processing group's signal use remained constant across the three driving tests.

For the *turning interaction*, the reference group performed better at turning into the proper lane than either of the two training groups at baseline. The simulator-trained group showed improvement at the immediate post-test. The three groups did not differ at the 18-month follow-up. For the *changing lanes interaction*, the three groups did not differ at baseline in their ability to correctly change lanes in traffic. At immediate posttest, there was a decline in performance by the reference group, relative to the two training groups. At the 18-month follow-up, the reference group returned to baseline levels, and the simulator trained group's performance was significantly lower than both the reference group and the speed-of-processing group. The speed-of-processing trained group's performance remained constant across the three assessments.

For the *position in traffic interaction*, the three groups were equivalent in their ability to maintain the proper distance between vehicles in traffic, during the baseline and immediate post-tests. There was a general improvement in all groups' performance from baseline to immediate post-test. At the 18-month follow-up, the speed of processing-trained group was significantly inferior to both the reference and the simulator-trained groups. The improvement in performance was maintained for the reference group and the simulator-trained group.

The simple RT measure showed no group differences or training effects across time, indicating that this measure was insensitive. The choice RT measure showed main effects for group, time, as well as an interaction. The reference group demonstrated faster complex RT (shorter times) than the two training groups at each assessment. The simulator trained group's complex RT remained stable across the three assessments. The speed-of-processing trained group showed an initial drop (faster performance) at the immediate post-test (below that of the simulator-trained group), which was maintained at baseline.

The findings of Roenker et al. (2003) indicate that both speed-of-processing training and traditional driving simulator training can each enhance the driving performance of "at risk" drivers, but the nature of the improvement differs. The simulator group did not improve on speeded reactions, but improved on specific maneuvers on which they were trained (turning into the correct lane and signaling). The improvements were not maintained over time, however. The speed-of-processing group and the reference group did not improve their turning and signaling performance, but they improved on untrained tasks that rely on visual attention and higher-order processing speed: choice reaction time and fewer dangerous maneuvers. These improvements were still present at the 18-month follow-up assessment, for most, but not all participants.

Ball, Edwards, and Ross (2007) evaluated the results of six studies assessing the effects of speed-of-processing training on cognitive and everyday functions. Training was delivered with the Visual Awareness, Inc., UFOV speed of processing training program, with 3 studies using customized training techniques with task difficulty tailored to each trainee's abilities for all training sessions, and 3 studies using a standardized training protocol followed by customized training. They found the largest training effect sizes when the training was customized to the ability level of the participant, as opposed to when standardized training tasks were used in at least half of the sessions. They also found that although training is particularly beneficial to people with initial processing speed impairment, higher functioning people showed improvements in the more challenging tasks. Across the six studies, age and education were not associated with speed-of-processing training gain; however, the fact that 90% of the subjects had completed high school or higher may have reduced the power to detect a significant effect. Subjects in these studies had an education level that ranged from 4th grade to doctorate level, and age ranged from 55 to 95.

Speed-of-processing training transferred to improvements in safe driving performance (Roenker et al., 2003), as well as improvements in the speed required to perform certain instrumental activities of daily living (Edwards, Wadley, Myers, Roenker, Cissel, & Ball, 2002; Edwards, Wadley, Vance, Roenker, & Ball, 2005). In the Edwards et al. (2005) study, significant improvements were seen on the timed instrumental activities of daily living test for the speed-of-process-trained group, regardless of whether training was delivered one-on-one or in a group format, relative to a control group that received training in how to use the internet (e.g., using email and accessing web pages).

COMPENSATORY SCANNING FOR VISUAL FIELD DEFECTS

Strokes/cerebral vascular accidents are a major cause of hemianopsia, which is a loss of the visual field on one side, starting at the midline and generally sparing the central vision. Hemianopic field loss is detected in 36% of right-brain strokes and 25% of left-brain strokes. Unilateral inattention (visual field neglect) has been detected in 82% of right-brain strokes and 65% of left-brain strokes (Gottlieb & Miesner, 2004). Visual field defects can also occur due to ocular pathology, such as age-related macular degeneration, glaucoma, or retinitis pigmentosa. Compensatory viewing strategies for drivers with peripheral visual field defects (inability to notice objects in the periphery) consist of scanning to enlarge the field of view. Compensatory viewing strategies for drivers with central visual field defects (inability to notice objects in the fixation area) consists of eccentric fixation as well as scanning to assure that no information is concealed by the area of decreased vision (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2001).

Coeckelbergh et al. (2001) conducted a study to determine the effect of training in the use of compensatory viewing strategies on fitness to drive in 51 drivers with visual field defects due to ocular pathology, such as age-related macular degeneration, glaucoma, or retinitis pigmentosa. Drivers with severe cognitive impairments including hemi-spatial neglect were excluded from participation. To be included in the study, visual field defects had to be present, but visual acuity was required to be at least 20/200. Optical devices such as bioptic telescope or bioptic amorphic lenses were not used. All subjects had been referred to the training program by an official driving examiner of the Dutch driving license authority, because they failed the on-road driving examination. Subjects ranged in age from 37 to 86 (mean age 63). Seventeen subjects had a central visual field defect; their acuity was below 20/40, but their horizontal field extended beyond 120 degrees. Twenty-one subjects had a peripheral visual field defect; their acuity was greater than 20/40, but their horizontal visual field was constricted (< 120 degrees).

Pre- and post-training driving tests were conducted, both in a simulator and on the road. A second set of post-tests was given 3 months after training to investigate long-term effects of training. The on-road driving test was conducted by a driver license examiner, to determine whether the individuals adapted their behavior to compensate for their visual impairment. A standard checklist was used to score lateral position, steering control, viewing behavior, lane choice, car following, speed, detection of traffic signals, mechanical operation, overtaking, anticipatory behavior, communicating with other road users, turning left, and changing lanes; the test is the means used by the Dutch Central Bureau of Driving Licenses to examine drivers who do not quite meet the vision requirements for driving. Compensatory viewing efficiency was also assessed at baseline, immediately following training, and at 3 months post training using an

Attended Field of View (AFOV) test on a computer that measures speed of visual search.

Subjects were randomly allocated to one of three training programs: laboratory training, mobility training, or motor traffic training. Each training program consisted of 12 sessions, with one session conducted per week, each session lasting 90 minutes. In laboratory training, compensatory viewing strategies were taught in the laboratory on a computer without any reference to a driving situation. In the motor traffic training, compensatory viewing strategies were trained while driving a car. This training was conducted by a driving instructor who had knowledge of the nature and implications of visual field defects. Mobility training was an intermediate training program, where compensatory viewing strategies were taught in a real-world traffic situation but while walking and cycling. In mobility training, the relationship to a traffic situation is more direct than in the laboratory training, but subjects practice the new skills under time pressure constraints that are lower than those while driving.

Training significantly improved visual search speed, as measured by the AFOV, from baseline to the first post-training assessment, and remained stable at the 3-month follow up. There were no significant differences in AFOV scores as a function of training program.

Motor traffic visual scanning training significantly increased viewing behavior assessed on-road at baseline, relative to the laboratory and mobility training, which showed no differences from the baseline on-road assessment. At the 3-month follow-up, there was no significant difference between training groups in on-road viewing behavior. The difference between training programs disappeared at the 3-month follow-up, because performance of motor-traffic-trained subjects decreased, while performance of laboratory- and mobility-trained subjects improved. Viewing behavior scores for the on-road test did not differ between the central and peripheral field defect groups.

Training significantly increased the number of head movements and the distance from an intersection where subjects started to make head movements, as assessed in the driving simulator. The number of head movements remained stable from the post-test assessment to the 3-month follow up assessment. The distance to the next intersection at which subjects started to make head movements increased significantly after training, but was slightly reduced at the 3-month follow up. There were no significant differences in these measures as a function of training program. Viewing behavior scores for the simulator test did not differ between the central and peripheral field defect groups.

Training significantly increased the number of subjects who passed the practical fitness to drive test, from 25.5% at baseline, to 39.2% immediately after training, and to 45.1% at the 3-month follow up. The percentage of subjects who passed the on-road driving test did not vary as a function of training program. The percentage of subjects who passed the on-road driving test was not significantly related to the type of visual field defect.

The authors concluded that the compensatory viewing behavior can be improved by training for people with visual field defects, and that enhancing compensatory viewing behavior has a positive effect on practical fitness to drive. The finding that training was strongest for subjects in the motor traffic training group suggests that training is task specific, and that generalization to more complex tasks is limited.

CATARACT SURGERY

Cataracts cause acuity and contrast sensitivity deficits, and increased disability glare (Owsley, McGwin, Sloane, Wells, Stalvey, & Gauthereaux, 2002). They are treatable by surgical removal of the crystalline lens followed by intraocular lens (IOL) insertion.

Monestam and Wachtmeister (1997) compared acuity and self-estimated visual problems while driving of 208 patients before and after cataract surgery. Prior to lens removal surgery, 82% of the patients reported visual problems while driving, while post-operatively, only 5% did so. Problems in distance judgment fell from 37% to 6%. Prior to surgery, 23% had driven with acuity below the legal limit, whereas after surgery, only 4% were in this category.

McGwin, Scilley, Brown, and Owsley (2003) evaluated the impact of cataract surgery on 156 older adults' (age 55+) self-reported visual difficulties, and compared the difficulties with those of 89 older adults with cataracts who declined cataract surgery. Visual acuity, contrast sensitivity, and disability glare tests were administered at baseline (prior to surgery) and again at a 1-year follow-up visit. In addition, the Activities of Daily Vision Scale (ADVS) was completed at baseline and follow-up. The ADVS is a questionnaire used to assess the extent to which patients with cataract experience difficulty with the visual aspects of daily living, including driving. It consists of 22 items addressing visual difficulties in everyday tasks, with responses ranging on a 5-point scale from "no difficulty" to "unable to do the activity because of visual problems." Item responses are organized responses into 5 subscales: daytime driving, night driving, near vision, far vision, and glare disability. Each subscale is scored between 100 (no visual difficulty) to 0 (inability to perform the activity because of visual difficulty).

Subjects who elected to have surgery scored 20 points lower on the ADVS on the day and night driving subscales than those who declined surgery. In addition, baseline visual acuity, contrast sensitivity, and disability glare were all significantly worse in those electing surgery than those declining surgery, although both groups had cataracts and had received a recommendation for cataract surgery by their eyecare specialist because of reduced vision. In the surgery group, 44% of the subjects had surgery in one eye, while 56% had surgery in both eyes. In the surgery group, visual acuity, contrast sensitivity, and disability glare significantly improved postoperatively. In the no-surgery group, vision declined slightly or remained the same. In the surgery group, the *ADVS scores for all subscales after surgery were significantly higher* than before surgery, while there was no difference in the ADVS scores for the no-surgery group.

The ADVS change scores in the surgery group were significantly correlated with changes in visual acuity, contrast sensitivity, and disability glare, independent of age, sex, race, education, chronic medical conditions, and ocular comorbidities. Multiple linear regression models showed that:

- Visual acuity in the first surgery eye had a significant, independent association with the change in overall ADVS score and with the change in night driving and glare disabilities subscales.
- The change in contrast sensitivity was associated with change in the night driving subscale only.

- Change in disability glare in the second surgery eye was significantly associated with the overall ADVS change score as well as the change scores of the night driving, near vision, and glare disability subscales.
- The change in vision scores (adjusted for baseline demographic and health variables) accounted for 60% of the variance on the night driving subscale.

Owsley et al. (2002) conducted a prospective cohort study of 277 patients 55 to 84 with cataracts to determine the impact of cataract surgery on the crash risk of older adults in the 4-year period following surgery (n=174), compared to that of older adults who elected not to have the surgery (n=103). For the surgery group, 55.7% had surgery in both eyes. Analyses corrected for group differences in number of subjects, person-miles of travel, race, visual acuity, and contrast sensitivity, and found that the relative risk of a crash following surgery was 0.47 compared to the no-surgery group. In other words, patients with a cataract who underwent cataract surgery and IOL implantation had half the rate of crash involvement during the follow-up period than cataract patients who did not undergo surgery. This relative risk estimate translates to an absolute rate reduction of 4.74 crashes per million miles of travel from a base rate of 8.95 crashes per million miles of travel (the crash rate among the no-surgery group).

Crash rates in the 5-year period before enrollment in the study were compared to crash rates in the follow-up period for the surgery group and no-surgery group. For the no-surgery group, there was a 72% increase in crash rate, which was statistically significant. For the surgery group, there was a non-significant increase in crash rate of 27%. Self-reported annual mileage declined over the course of the study for both groups in an equal manner. Self-reported driving difficulty was obtained at baseline, and at the 1-year and 2-year follow-up visit, using the Driving Habits Questionnaire, which assessed the difficulty of driving during the previous 3 months in 8 challenging situations (e.g., night, rain, left turns, rush hour) on a 5-point scale, from no difficulty to no longer drive in that situation. A composite score of driving difficulty was computed across items and scaled on a 100-point scale.

The no-surgery group's self-reported difficulty remained consistently low over the 2-year follow-up period. At baseline, the surgery group reported significantly more difficulty driving than the non-surgery group. By the first year post surgery, both groups were relatively equal. By the second year post surgery, the surgery group reported significantly less difficulty than the non-surgery group. Study results therefore indicate that cataract surgery slows the rate of increasing crash rate associated with aging. It is unknown whether cataract surgery in one eye is sufficient to prevent the increase in crash rate, or whether cataract removal from a second eye provides further benefits for driver safety, as the study was not designed to answer these questions.

Wood and Carberry (2006) found that bilateral cataract surgery resulted in significant improvements in on-road driving performance, which were attributed to improvements in contrast sensitivity. They evaluated 29 patients with cataract (and no other ocular disease) ages 50 to 89 and 18 control subjects ages 53 to 78 free of ocular pathology and with normal visual acuity (better than 20/25). Vision and driving performance were assessed at baseline (1 month prior to surgery on the first eye) and at 1-month following surgery on the second eye. Approximately 80 days separated the first and second surgeries. Control subjects were assessed during the same time periods. Vision tests included acuity, contrast sensitivity, disability glare sensitivity, and kinetic fields. Driving performance was assessed on a closed-route circuit 5.1

meters in length and representative of rural roads. The assessment provided a relatively high degree of complexity, involving tasks of recognition, divided attention, gap perception, speed, and maneuvering. The outcome measures included sign recognition, road hazard recognition, road hazard avoidance, correct gap judgments, divided attention, maneuvering time, and time to complete the course.

Baseline driving performance of the subjects with cataracts was significantly worse that that of controls for road sign recognition, road hazard recognition and avoidance, as well as for an index of overall performance. Although the mean age of the cataract group was 5 years more than the non-cataract group, the association between the change in overall driving score and age was nonsignificant. Driving performance improved significantly for the cataract group, to the level of performance of the no-cataract group for overall driving score, road sign recognition, and road hazards recognized and avoided. Both the patients with cataracts and controls showed a significant improvement in the number of reaction lights seen over the two visits (divided attention task), but there was no group by session interaction, which indicates that for this task, improvements may have resulted from the effects of repeated testing rather than improvements in driving function after cataract surgery.

In terms of vision performance, at the first visit, cataract patients had significantly poorer performance on all measures than the no-cataract group, except for visual acuity in the second to-be-operated eye. Disability glare performance on the Berkely Glare test was excluded from further analyses of vision and driving after cataract surgery, because at the first visit, only 20 cataract subjects could be assigned a score binocularly and only 13 monocularly. Vision performance improved significantly for the patients with cataract after surgery for binocular visual acuity, visual acuity in the first and second operated eye, binocular contrast sensitivity, contrast sensitivity in the first and second operated eye, and disability glare in the first operated eye (measured with the Brightness Acuity Tester).

Bivariate correlations showed that changes in overall driving score were significantly predicted by changes in visual acuity in the first operated eye, and changes in contrast sensitivity binocularly and in each eye individually. In the final multiple regression model, the difference in contrast sensitivity scores in the second operated eye (better eye) was the only vision measure that remained in the model, showing that it alone was the single best predictor of the change in driving performance after bilateral cataract surgery.

BIOPTIC TELESCOPIC LENSES FOR CENTRAL VISUAL FIELD LOSS

Presently, bioptic telescopic lenses (BTL) may be used for driving, at least under certain circumstances, in 42 States (FHWA, in press). A bioptic telescopic lens is a lens system with a telescope attached to a pair of glasses, mounted above the normal line of sight. This allows a trained user the opportunity to detect objects or movement within the driving scene using the wide field of view available through the regular spectacle lens (the “carrier” lens) and to resolve fine details such as road sign messages and traffic light status by glancing briefly and intermittently into and out of the miniature telescopic unit (by a downward tilt of the head).

Janke and Kazarian (1983) compared the 2-year crash records of 229 low-vision drivers who used BTL with that of 21,064 comparison drivers, and found that the BTL’s crash rate per mile driven is more than 1.5 times the population rate. They mention that the 2-year crash rates of drivers with medical condition other than impaired vision are 2.3 to 4.8 times the population rate, which argues against banning the licensure of BTL drivers, but suggests that greater licensing control and greater use of license restrictions may be appropriate.

Clark (1996) conducted a 2-year study of the crash and citation rates for 393 drivers with valid licenses who were required to wear bioptic telescopic lenses while driving to a randomly selected comparison group of 20,587 drivers with valid licenses. Adjusting for age and gender, total and fatal/injury crash rates for the BTL drivers were 1.9 times higher than the rates for the comparison group. Conversely, total citation rate for the BTL wears was 0.7 of that for the comparison group. These differences were significant. These findings indicate that BTL drivers as a group are at greater risk of a crash than are non-BTL drivers, but their lower citation rates indicate that they are compensating for their increased risk by driving less and/or more lawfully. The inadequacy of their reduced exposure in avoiding crashes suggests that their perceptual deficit was substantial. The study also found that only 35% of the drivers had a sunrise-to-sunset license restriction code.

Szlyk, Seiple, Laderman, Kelsch, Stelmack, and McMahon (2000) conducted a study to evaluate a vision rehabilitation program for training individuals with central vision loss to use a bioptic telescope for improving life skills (including driving), and to compare outcomes for subjects who were given bioptic telescopes and training with subjects who were prescribed telescopic lenses without training. Their subjects ranged in age from 16 to 78, and were randomly assigned to one of three groups: 1) an immediate training group that received bioptic lenses and training within the first 3-month period of the 6-month study; 2) a delayed training group that received lenses and training in the second 3-month period of the 6-month study; and 3) a no-training group that received the lenses but no training. The first group was used to measure the effect of lenses and the effect of training from baseline to 3-months, and the sustainability of the training at 6 months. The second group was used as a test-retest sample to measure any differences in performance between baseline and at 3 months without any intervention. The third group was used to compare the effects of telescope use without training, by comparing its performance to that of Group 1's performance. Functional assessments and driving related skills were measured at baseline, at 3 months, and at 6 months.

Training consisted of 5 weekly sessions of 3 hours each of laboratory-based training focusing on skills in the categories of recognition, mobility, peripheral identification, scanning, tracking, and visual memory. A main emphasis was on the use of the lens as a spotting device (i.e., to spend the majority of the time viewing through the carrier lens with brief and systematic glances into the bioptic lens). This was followed by 8 weekly on-road driving training sessions, again emphasizing that the bioptic lenses were to be used for brief spotting to gain information.

Szlyk et al. (2000) found that the mean change across all tasks averaged an 11.9% improvement for Group 2 from baseline to the 3-month assessment (and before they received their intervention). This indicates that change in performance occurred due to time or testing alone. The values for the individual items served as a criterion to judge improvements due to the interventions (bioptic lenses and training). The immediate training group showed substantial improvements in all 6 visual skill categories from baseline to the 3-month assessment, as did the delayed training group from their 3-month to their 6-month assessment. Both groups showed the highest average percentage of tasks improved within the scanning category and the lowest within the peripheral identification category. Performance for the immediate training group was sustained at the 6-month assessment.

Comparison between the trained groups (Groups 1 and 2) with the untrained group (Group 3) found that the trained groups showed significantly greater improvement compared to the untrained group for recognition, peripheral identification, and scanning, but not for mobility, tracking, or visual memory. When the tasks evaluating driving-related skills were analyzed separately, there was a significant difference between the trained and untrained groups. The immediate training group showed a 62% increase in improvement in driving-related tasks, compared to a 66% increase for the delayed training group and a 55% increase for the no training group. This indicates that the telescopic lenses increased performance, but the effect was greater when training was provided. The results provide a recommendation for training in the effective use of bioptic telescopic lenses, especially for use in driving, for individuals with central visual field loss. In terms of user satisfaction, 82% of the subjects reported that they were "very satisfied" to "extremely satisfied" with the bioptic lenses, and 18% indicated that they were "satisfied." Eighty-two% indicated that they planned to apply for a restricted license to drive with the bioptic telescopic lenses.

Bowers, Apfelbaum, and Peli (2005) note that opponents of bioptic driving argue that visually impaired drivers obtain a bioptic telescope solely as a means of meeting the DMVs visual requirements for licensure, and then do not use the device for driving. They conducted a telephone interview study of the driving habits of 58 bioptic users ages 17 to 86 (mean = 47) across the United States (largely from West Virginia, Massachusetts, and New Hampshire, but also representing 12 other States) who had driven with a bioptic for at least 3 months within the previous 3 years. The Driving Habits Questionnaire was used, supplemented with additional questions. Fifty percent of the sample had participated in a formal bioptic training program, either a full-scale program with behind-the-wheel training (31%) or a more limited program as passenger-in-car training, but no BTW (19%). An additional 17% reported taking driving lessons with the bioptic from an instructor with experience teaching drivers with disabilities.

Sixty-two percent of interviewees reported using the bioptic lenses all of the time while driving, while 10% wore it rarely or not at all when driving. Subjects estimated that approximately 5% of their time was spent viewing through the telescope while driving. Seventy-four% indicated that the telescope was very helpful and 17% that it was moderately helpful. Ninety percent indicated that that would use the bioptic for driving, even if it were not required for driving licensure. All subjects used the telescope to read road signs, and reading road signs was rated the most difficult task to perform without the use of bioptics. The task with the fewest number of subjects using the telescopes (30%), seeing brake/signal lights or judging the distance to the car ahead of them, was judged as the easiest to perform without using the telescope.

When asked about these potential difficulties of using a bioptic telescope while driving—awareness of traffic outside the field of the telescope, and difficulty lining up the telescope with the object of interest—the majority (85%) reported no difficulty with these tasks. Only 16% of the subjects reported any situations where the telescope hindered their performance. These included the weight of the telescope, solar glare at sunrise and sunset through the telescope, limit in visual field of the carrier lens by the optic when parallel parking, and problems due to lack of training and experience. In terms of driving avoidance, the only situations where 50% or more of the bioptic drivers reported difficulty or avoidance was in rain, in bright sunlight (there was a high percentage of albinos in the sample), and at night (but it was noted that 22% had a daytime-only license restriction).

BIOPTIC AMORPHIC LENSES FOR PERIPHERAL VISUAL FIELD LOSS

Szlyk, Seiple, Laderman, Kelsch, Ho, and McMahon (1998) conducted a study using outcome measures described in their earlier study (Szlyk et al., 2000), but with patients with peripheral visual field loss due to retinitis pigmentosa, choroideremia, and Usher's syndrome Type II. The study was conducted to determine whether training in the use of bioptic amorphic lenses could expand the field of view for driving and other everyday activities. Amorphic lenses are spectacle-mounted cylindrical reversed telescopes that increase the peripheral visual field by minifying the horizontal meridian.

In an earlier study using amorphic lenses as full-field systems and no formal training, Szlyk et al. reported that only 20% of the original sample completed the 2-week trial and reported increased mobility with the lenses, while the remaining 80% became dizzy and disoriented while wearing the lenses and did not complete the study (Hoeft et al., 1985). To counter these effects, Szlyk et al. (1998) used a bioptic form of an amorphic lens system, with the amorphic lens mounted inferiorly on both the left and right carrier lenses, and provided a 12-week training curriculum in the use of the amorphic system for navigation, mobility, and driving an automobile. Patients' distance prescriptions were incorporated into the carrier lens as well as into the amorphic lens.

Patients were trained to spend the majority of the time viewing through the carrier lens, and use the amorphic lens for transiently spotting and localizing peripheral visual field information. Two types of training were used: four 3-hour sessions of orientation and mobility training, and eight 2-hour sessions of driving training. Orientation and mobility training consisted of locating objects, tracking stimuli, scanning skills, and visual memory using Benell's Sports Vision 35-mm Training Slides in the laboratory, as well as training to navigate complex environments on indoor and outdoor courses (locating specific room and directional signs within the hallways, walking stairs, crossing streets, tracking passing cars, negotiating crowded public places, and locating items on store shelves). For the driving training, the subject was given tasks to accomplish while driving, such as locating addresses and informational signs. Training also focused on reading dashboard displays, maintaining proper lane position, selecting appropriate gaps, locating relevant peripheral traffic control signs, improving visual memory skills, using mirrors, and navigating complex traffic situations as a passenger.

Fifteen patients ages 27 to 67 were divided into two groups. Subjects in the immediate-training group were given the amorphic bioptic lenses and were trained during the first 3 months of the 6-month study; they served as a training effectiveness group, as well as a sustainability of training group. The delayed-training group received the lenses and training in the second 3-month period; they served as a test-retest reliability group for the baseline and 3-month evaluations, and as a training effectiveness group from month 3 to month 6. Results indicated that following training, patients showed improvements in all visual skill categories, with an overall improvement of 37%. Skills were maintained during the second-three month period for the immediate-trained group.

The driving skills assessments in this research were keyed to the visual skills of recognition, peripheral detection, scanning, tracking, visual memory, and mobility; results were combined across assessment types (on road, simulator, clinical vision, and orientation and mobility assessment). An example of a recognition task while driving included speed monitoring and maintenance of proper distances when following other vehicles. An example of a mobility test was navigation of complex traffic situations on the road course. Peripheral detection was assessed using lane position and the patient's ability to locate landmarks and signs, and mirror use. Scanning tests included frequency and effectiveness of spotting through the lenses while driving on the road course. Visual memory skills were assessed, by asking the subject to recall critical information viewed while driving (e.g., reporting the current speed limit).

The study authors indicate that the question of whether patients can drive safely with the lenses remains for further research. Specific effects of the lenses and training on driving skills *per se* (i.e., as opposed to the visual skills noted above), or on a global driving score, were not reported. However, 86% of the subjects in this study reported that they were "satisfied to extremely satisfied" with their lenses and improvement in visual function, although they expressed concerns with their weight and cosmetic appearance, and high cost if they had to be replaced.

PASSENGERS AS CO-PILOTS

In the dementia and driving literature, there is some evidence that caregivers (usually the spouse) attempt to serve as co-pilots for drivers with dementia as a countermeasure for diminished cognition and judgment/decision making (Cotrell & Wild, 1999; Bédard, Molloy, & Lever, 1997; Shua-Haim & Gross, 1996). Man-Son-Hing et al. (2007) explain that this strategy is not a reasonable, evidence-based option, because most crashes happen without adequate time to provide instructions to the drivers. A case study and a retrospective crash analysis examining the effectiveness of co-pilots for drivers with dementia are presented below, followed by two crash analyses evaluating the impact of passengers on the safety of the general population of older drivers. While one passenger who serves as a copilot for a driver with declining cognitive capabilities may have a protective effect on crash risk, the presence of passengers has mixed results on the crash risk of the general population of older drivers. Passengers who serve as copilots to drivers with dementia may behave differently than passengers who are not actively serving in the role of driving assistants.

In a sample of 321 new referrals to a geriatric clinic for assessment and management of cognitive impairment, Bédard, Molloy, and Lever (1997) found that those whose caregivers allowed them to drive alone were twice as likely to have experienced a crash in the prior 5 years of driving than patients whose caregivers required them to drive with a passenger. Crash data were self-reported by the patients' caregivers in this study. Although the study design does not establish a causal relationship, it was suggested that the presence of a reliable passenger could help delay license revocation among cognitively impaired older drivers, in light of the findings that 25% of those who drove alone had a crash compared to 13% who drove with a passenger. It should be noted that those who drove alone were younger by an average of 4 years (mean age 68.7 years versus 73.3) and had average mental status scores that were 5 points higher (mean MMSE score 25.4 versus 20.4) than those who drove with a passenger. These differences were statistically significant. The mean duration of symptoms did not differ significantly, however between those who drove alone and those who did not (5.6 years versus 5.2). There were equal percentages of drivers diagnosed with Alzheimer's disease according to standard diagnostic criteria in both groups (41% versus 42%). Data were not collected to describe annual miles driven, or roadway types or other conditions under which driving occurred. It may be the case that the younger, higher cognitively functioning subjects drove more miles, explaining the higher crash frequency in this group, rather than passengers providing a protective effect for the non-crash group.

Shua-Haim and Gross (1996), have observed the phenomenon of "co-pilots" in their patient population at a memory disorder clinic. They reported on two cases of older drivers with mild AD and two older drivers with moderate AD. All drove only when accompanied by other older drivers who either never drove or had ceased driving; these companions assisted with navigation tasks, traffic sign identification, and made judgments in challenging driving situations, with the goal of helping the demented driver overcome cognitive deficits that would limit their driving ability. In none of these cases was there a crash during the prior 1-year period. All driving was done only during daylight, and to nearby locations. Based on their observations, the authors recommend that State Departments of Motor Vehicles perform a behind-the-wheel test for such at-risk drivers along with their co-pilots. If the pair successfully completes the test, the DMV should restrict the area in which driving is permitted; restrict driving to daylight hours, optimal weather conditions, and during non-rush hours; and restrict driving on highways or busy roadways. These restrictions are suggested as an alternative to removal of their licenses, which would result in loss of the ability to live in the community for these drivers and for their co-pilots.

Because passengers may represent either a distraction or an advantage (e.g., a pair of extra eyes on the road), Hing, Stamatiadis, and Aultman-Hall (2003) examined whether the presence of different passenger groups in the vehicle improved the safety records of older drivers—specifically, the probability that the older driver is at fault in a crash. Four years of crash data from Kentucky were used in a quasi-induced exposure method to estimate the relative crash rates of older drivers (age 65-74 and 75 and older), in single- and multivehicle crashes, with different passenger groups, including drivers traveling alone. Results indicated that for both single and multivehicle crashes, the presence of 1 versus 2 or more passengers does not affect the crash rate of drivers 65 to 74 compared to their rate when driving alone. However, the presence of 2 or more passengers increases the crash rate of drivers 75+ in single-vehicle crashes (Relative Accident Involvement Ratio) 1.6 times over their rate when driving alone or with one passenger (RAIR = 1.3 in both cases). When all occupants of the vehicle are male and the driver is 75 or older, the crash involvement ratio is even higher (RAIR = 2.0) for single-vehicle crashes.

In multi-vehicle crashes, Hing et al. found that the presence of 2 passengers is the riskiest for drivers over age 75 (RAIR = 1.8), but even 1 passenger increases the risk slightly over driving alone (1.6 versus 1.5). Also for multivehicle crashes, drivers over 75 are more likely to cause a crash with two or more passengers when they are driving on curves, grades, and two-lane roads; however, they have a reduced risk with two passengers at nighttime (RAIR = 1.4) compared to one passenger at nighttime (RAIR = 1.7) or when driving alone at night (RAIR = 1.6). The finding that two or more passengers negatively affects the crash rate of drivers 75+ on less-than-ideal situations (curves and grades) suggests that they represent a distraction. However, at nighttime passengers may recognize the risks and be consciously trying to assist with the driving task. Since a middle-aged group of drivers was not included in this study, it was not possible to determine whether the observed trends are specific to older drivers or apply to all drivers.

Bédard and Meyers (2004) used data from the Fatality Analysis Reporting System (FARS) from 1975 to 1998 to examine the potential benefit or detriment of the presence of passengers for drivers 65 and older. They used data in the “driver-related factors” field to identify unsafe driver actions, and found that the association between the number of passengers and the risk of an unsafe action was dependent on the age of the driver. For drivers less than 20, the presence of any passenger was associated with an increase in unsafe actions linked to fatal crashes, with increasing numbers of passengers (from 1 to 4) increasing the risk. Relative to driving alone, where the odds ratio of an unsafe action is 1.0, drivers less than 20 had an OR of 1.32 when driving with 1 passenger, an OR of 1.70 with 2 passengers, an OR of 1.90 with 3 passengers, and an OR of 2.15 with 4 passengers. The association between number of passengers and unsafe driving actions remained, but weakened for the age group 20 to 29. For each decade after29, the presence of passengers became a protective effect. For drivers 65 to 79, the ORs by number of passengers were as follows: driving alone (1.0), 1 passenger (0.76), 2 passengers (0.74), 3 passengers (0.66), and 4 passengers (0.73).

Bédard and Meyers (2004) also examined the top 10 most frequent unsafe actions made by 73,565 drivers 65 and older. Overall, 65.2% made at least one unsafe action. Among “young-old” drivers 65-79, 61.5% made at least one unsafe action; 78.4% of “old-old” drivers 80 and older made at least one unsafe action. The top 10 unsafe actions, in order of frequency of occurrence among the older drivers involved in a crash with a fatality were: failing to obey signs/warnings/right-of-way, traveling off lane/road, speeding, other careless action, turning, inexperience, following, passing, driving the wrong way, and lane changing. Overall, the presence of passengers had a protective effect, leading to a reduction in unsafe actions of 25% for drivers 65 to 74 (OR = 0.75) and 11% for drivers 80 and older (OR=0.89).

More fine-grained analyses indicated that the presence of passengers was protective for some actions and detrimental for others. The presence of passengers was protective for unsafe actions related to traveling off the lane/road (OR=0.61 for young-old and 0.68 for old-old), speeding (OR = 0.74, 0.92), other careless action (OR = 0.84, 1.04), inexperience (OR = 0.52, 0.55), following (OR = 0.79, 0.90), and driving the wrong way (0.37, 0.36). It was neutral for passing (OR = 0.90, 0.95). It was detrimental for obeying signs/warnings/right of way (OR = 1.18, 1.27), turning (OR = 1.22, 1.11), and lane changing (OR = 1.31, 1.35). Thus, the presence of competent passengers acting as copilots may decrease unsafe behaviors by older drivers, but passengers also have the potential to be distractions. The methodology in Bédard and Meyers (2004) did not allow for the evaluation of the roles passengers played in these crashes.

NONPLANAR DRIVER-SIDE MIRRORS

Title 49, Part 571, Standard Number 111 of the Code of Federal Regulations requires the driver side mirror to be planar (flat), while the passenger side mirror may be convex or planar. In Europe, non-planar rearview mirrors are allowed on both the driver’s and passenger’s side of the vehicle. There is anecdotal evidence that drivers attach after-market convex mirrors on the driver side mirror to eliminate the blind spot, and there are multiple vendors who provide such after-market mirrors. Convex mirrors provide a wider field of view, but produce a minified image that may cause inaccurate judgments about the speed and distance of following/overtaking vehicles. No research was uncovered on the effectiveness or safety benefit of this behavioral adaptation, but research has been performed in the United States and Europe on the benefits and difficulties experienced by drivers using convex and multiradius mirrors on the driver’s side.

Staplin, Lococo, Sim, and Gish (1998) conducted a laboratory simulation and field study to explore the effects of three mirror types on older and younger drivers' judgment of the "least safe gap" to make a lane change in front of a vehicle approaching from the rear. The three mirrors included a planar mirror, a spherical-convex mirror with a curvature of 50 to 55 degrees, and an aspherical-multiradius mirror that provided a horizontal field of approximately 40 degrees. No training was conducted as part of the study, given the intent to represent the responses of naïve subjects who have installed an after-market device on their personal vehicles.

Two relative target approach speeds were tested: overtaking the subject's vehicle at a speed difference of 5 mph, and at a speed difference of 15 mph. Subjects made 6 responses to each mirror by speed differential test condition. Two age groups were tested: 6 drivers 65-75 (mean = 71.6) and 6 drivers 25-42 (mean = 32.3). Subjects viewed a large-screen video projection image of a vehicle approaching from behind in the laboratory simulation, starting at a separation distance of 1,000 feet. The same study design was repeated in the field. Subjects were stationary in both the laboratory and field trials.

Main effects were found in the laboratory for target speed, mirror type and age, but there were no significant interactions, although the age-by-mirror type interaction approached significance. Drivers accepted longer gaps for the higher speed. Longer gaps were accepted for the planar mirror. Older drivers accepted longer gaps than younger drivers. In the field, main effects were found for all variables, plus a significant interaction was found for age-by-mirror type. The performance of younger subjects remained stable across mirror type, for both overtaking vehicle speeds, while the older subjects selected distinctly larger gaps when viewing the target vehicle in the planar mirror. Self-reported mirror habits were also obtained in the study. All younger subjects indicated that they use the outside mirror first and then make a direct look behind them before changing lanes, while 67% of the older subjects responded in this manner. The remaining 33% of older subjects indicated they rely on the outside mirror only, when preparing for a lane change.

Another laboratory study was then conducted by Staplin et al. (1998) to determine latency of lane change decisions with 5 mirror designs, using a brief sampling scenario representing driver mirror use preceding a lane change in an imminent collision situation in moderate-to-dense traffic volumes. In this scenario, subjects attended and responded to brake light actuations on a lead vehicle, and performed a pursuit tracking task using the steering wheel. A yellow circle with a black X was presented at varying intervals following each trial onset to alert subjects to look into their side-view mirror and decide as quickly as possible if a lane change to the left was safe. Five different mirror types were used, with approximately the same reflective surface area, but covarying levels of horizontal field of view and apparent image size and/or distortion. The mirrors were: (1) planar; (2) spherically convex (80 inch radius of curvature); (3) side-by-side design #1 with a spherically convex (110 inch radius of curvature) on the inboard 40% of the surface, and aspherical on the outboard 60% of the surface; (4) an over-under-design with planar on top, and a spherical convex (25 inch radius of curvature) below; and (5) side-by-side design #2 with a spherical convex mirror (80 inch radius of curvature) on the inboard 75% of the surface area, and an aspherical on the outboard 25% of surface. Three driver age groups were tested, with 15 subjects in each group: 28 to 64; 65 to 74; and 75 and older. Trials were conducted with the target following vehicle and the observer both moving but with a constant separation distance, and also with the target following vehicle overtaking the observer to produce a changing separation distance.

For the lane change maneuver under the constant separation distance condition, the oldest subjects were especially slow to respond using the planar mirror for adjacent-lane targets positioned 1.5 to 3 car lengths back. However, all 15 subjects made the correct decision that it was unsafe to change lanes using the planar mirror for every adjacent-lane target that was 1 car length or more away. Contrasting results were found for every alternative mirror at every distance, where 1 or more older subjects incorrectly judged the danger of the maneuver. When a target vehicle was 100 feet away and overtaking at a 25 mph differential, none of the subjects made an unsafe decision to change lanes when using the flat mirror, but 1 to 2 older subjects made this serious driving error with each of the alternative mirrors. These data suggest that older drivers could have difficulty using non-planar mirror that could lead to a crash, if they did not supplement their decision with a direct look over their shoulder. As noted in the preceding study, one-third of the older subjects indicated that they rely solely on the mirror image when making a lane change decision.

De Vos (2000) conducted a study in the Netherlands to determine whether drivers with long-term experience with non-planar mirrors are able to estimate the distance and speed of a car closing in from the rear and the critical gap required to initiate a lane change as adequately as drivers using planar mirrors. In addition, the question of whether adequate gap estimation with non-planar mirrors affects processing effort (e.g., longer glance durations) was addressed. Results of an exploratory questionnaire using 25 younger drivers (age 50 and younger) and 22 older drivers (over 50) with vehicles equipped with either planar (21 subjects), spherical (20 subjects), or aspherical (6 subjects) driver-side mirrors indicated that when changing lanes, older drivers look over their shoulder less often than younger drivers. Also, when changing lanes, younger drivers using non-planar mirrors feel more safe and confident than users of planar mirrors, whereas older drivers using non-planar mirrors feel less safe and confident than older drivers who use planar mirrors. Younger drivers reported higher feelings of ability to judge distance than older drivers (irrespective of mirror type). In a large-sample questionnaire on mirror use using 116 younger drivers and 92 older drivers with vehicles equipped with either planar (71 subjects), spherical (89 subjects), or aspherical (48 subjects) mirrors, younger drivers with non-planar driver's side mirrors turn their head less often than younger drivers with flat mirrors. Older drivers with aspherical mirrors turn their head more often when compared to older drivers with flat or spherical mirrors. Drivers with aspherical or flat mirrors think they are better able to assess gaps than drivers with spherical convex mirrors. Less than half the drivers correctly knew the optical effects of their driver's side mirror and approximately one-third knew what optical type of mirror they had.

Next, de Vos (2000) conducted a field study with 36 drivers divided into two age groups (25-45 and 60 to 75) and three categories of own vehicle driver side mirror type (planar, spherical convex, and aspherical convex). Four mirror types were studied: (1) planar; (2) spherical convex with a radius of curvature of 1400 mm; (3) aspherical convex with a radius of curvature of the spherical part 1400 mm; and (4) aspherical convex with a radius of curvature of the spherical part of 2000 mm. During each trial, a following vehicle approached behind in an adjacent lane at either 50 km/h or 80 km/h, and drivers were asked to indicate the last safe moment they thought it was safe to change lanes in front of the vehicle. The inside rearview mirror was aimed at the experimenter in the passenger seat, so that the subject had to rely on the information presented in the driver's side mirror. A secondary task required drivers to indicate in which direction a gap appeared in circles painted on the road ahead of the driver, as they traveled at a speed of 30 km/h. Following the gap judgment, a curtain was placed over the driver side window, and the following vehicle positioned itself in one of five positions: (1) out of view; (2) adjacent lane just behind subject's vehicle, but no overlap, so still possible to move to adjacent lane; (3) just overlap with subject's vehicle (so not possible to change lanes); (4) in the blind spot area of the planar mirror; (5) in the direct field of view. The position just behind the subject's car and the position just overlapping the subject's car were included to test whether or not it is more difficult to discern these conditions in the case of non-planar mirrors. The blocking curtain was then dropped. In this detection task, drivers could look in the driver's side mirror and turn their head.

Results indicated that, in general, drivers accept smaller gaps in case of non-planar mirrors, due to the image size reduction. Drivers' experience with non-planar mirrors on their own vehicles did not compensate for the negative effect, with the exception of drivers who were accustomed to spherical convex mirrors; these drivers compensated for the image minification of spherical convex mirrors and accepted the same gaps with planar and spherical mirrors. Negative effects on the effort required to process the mirror information were not found. The results of the vehicle detection task showed that non-planar mirrors reduced the number of detection faults from 30% (planar mirror) to 10% (non-planar mirrors). When the most critical position (the blind spot was considered), the aspherical mirror showed greater improvement than the spherical convex mirror: 49% detection faults for the planar mirror, 25% for spherical mirror, 8% for aspherical 1400 mm mirror, and 10% for aspherical 2000 mm mirror. The improvement in detection performance with non-planar mirrors was less for older drivers than for younger drivers, leading to the conclusion that the images viewed in non-planar mirrors were more difficult for older drivers to interpret than the information provided by planar mirrors.

In comparing the relative benefit for non-planar mirrors of improved detection performance against the disadvantage of decreased gap margins, de Vos (2000) states that the ability of the driver in the adjacent lane to compensate for a driver ahead making an improper lane change must be considered. If a driver approaching from the rear sees that a driver is making an improper lane change (accepting an inappropriate gap), he or she can steer or brake to compensate. However, if a driver makes an inappropriate lane change into a space already occupied by another vehicle (failure in detection, due to a blind spot), the following or overtaking driver may be too close to compensate. Therefore, the author asserts that improved detection outweighs potential errors associated with inappropriate gap judgments, and concludes that the use of non-planar driver's side mirrors should provide a net safety benefit.

IN-VEHICLE TECHNOLOGIES

In-vehicle technologies (or telematics) to assist drivers include devices such as vision enhancement systems (e.g., head-up displays, or HUDs); navigation aids for route guidance; collision warning and avoidance systems; real-time traffic information systems; intelligent cruise control and headway maintenance systems; automated lane changing and parking systems; driver condition monitoring; and emergency management (mayday) systems. However, technology that has potential for increasing older drivers' safety also may cause difficulties for those with reduced cognitive capability since it can complicate the driving task by increasing demand for the driver's attention or distract and overwhelm the driver (Little, 2002), thereby reducing net response effectiveness and safety. As noted by Caird (2004), it is older drivers who are most likely both to benefit and to suffer from the (unintended) consequences of implementing such technologies in vehicles.

Although some older people embrace and experiment with new technologies, many are less confident in their ability to operate new systems. Issues that are likely to be recurrent for older drivers when using new technologies include an initial fear of the technology, difficulty in operating a device when driving, the legibility of visually displayed information, and a need for specific training. In their review of in-vehicle systems for older drivers, Mitchell and Suen (1998) note that depending on the design of these systems, they may assist in compensating for the adverse effects of aging and make driving easier and safer; however, if not well designed, they could increase the driver's workload and cause potentially dangerous distraction from the driving task. McCarthy (2005) states that systems that do not require driver decisions may prove to be more effective for older people. Baldwin (2002) recommends the use of the auditory channel for presenting essential collision avoidance warnings and navigational information to avoid overloading the visual processing abilities of older drivers, to reduce task switching time, and periods of time when drivers are required to take their eyes off the road.

Mitchell and Suen (1997) categorized various in-vehicle technologies by their potential to compensate for the effects of aging and impairment. The results of their analysis is summarized in Table 3 below.

Table 3. In-Vehicle Technologies With Potential to Assist Older Drivers With Selected Impairments.

Impairment	Problems	Technologies
Increased reaction time: inability to divide attention between tasks	Difficulty driving in unfamiliar or congested areas	Navigation/route guidance; traffic information; variable message signs
Deteriorating vision, particularly at night	Difficulty seeing pedestrians and other objects at night and difficulty reading signs	Night vision enhancement systems; in-vehicle signing
Difficulty judging speed and distance	Failure to perceive oncoming vehicles; crashes at intersections	Collision warning, automated lane changing and merging
Difficulty perceiving and analyzing situations	Failure to comply with yield signs and traffic signals; slow to appreciate hazards ahead	In-vehicle signing and warnings; intelligent cruise control
Difficulty turning head, reduced peripheral vision	Failure to notice obstacles while maneuvering; worries over merging and lane changing	Blind spot/obstacle detection; automated lane changing and merging
More prone to fatigue	Getting tired on long journeys	Intelligent cruise control; automated lane following
General effects of aging	Worries over inability to cope with a breakdown; worries about driving to unfamiliar places, driving at night, and driving in heavy traffic	Emergency callout (Mayday) systems; vehicle condition monitoring; navigation and route guidance systems; traffic information via on-board display of signs and warnings of hazards (e.g., HUD), and use of variable message signs
Impairments varying in severity from day to day; prone to fatigue	Concern over fitness to drive	Driver condition monitoring

In a study to determine the effects of distraction mitigation strategies on drivers' simulator performance while engaged in an in-vehicle information system task, Donmez, Boyle, and Lee (2006) found that the mitigation strategies had a positive effect on driver performance, but that older drivers do not benefit from the mitigation strategies as much as younger drivers do. In a strategy termed “locking,” drivers are prevented from continuing the distracting task (e.g., the in-vehicle display screen goes blank). In a strategy termed “advising,” drivers are merely alerted that they should stop the distracting task and attend to the road. Both visual and auditory distractions were employed in the study. It was found that visual distractions were more detrimental than auditory distractions for curve negotiation. Also, the locking strategy was more beneficial to older drivers than the advising strategy, in promoting timely braking responses in an imminent collision scenario.

Studies that have evaluated the use of specific technologies by older drivers are described in the following paragraphs.

Navigation Assistance Systems

Although drivers prefer navigation systems that can inform them of their current location visually, navigation systems that make exclusive use of the visual modality may cause attentional overload (Liu (2001). Baldwin (2002) states that auditory modalities for providing in-vehicle information have many advantages over visual displays, which are particularly relevant for older drivers. Citing the work of others, he reports that providing turn-by-turn navigation information via auditory channels results in reductions in visual processing demands and shorter travel times, fewer navigational errors, reductions in mental workload, and overall improvements in driving performance such as speed and headway maintenance, lane control, appropriate responses to external traffic cues, and vehicle handling (Dingus, Hulse, & Barfield, 1998; Kimura, Marunaka, & Sugiura, 1997; Srinivasan & Jovanis, 1997; Walker, Alicandri, Sedney, & Roberts, 1990; & Zaidel & Noy, 1997). Auditory displays, as opposed to visual displays, may particularly benefit older drivers who tend to spend more time focused on the roadway scene and less time scanning in-vehicle visual displays (Hanowski & Dingus, 2000) and who have greater resource costs associated with task switching. Because older drivers are likely to experience the interacting effects of age-related and noise-induced elevations of auditory thresholds, coupled with the influences of increased mental workload when using in-vehicle auditory displays, in-vehicle auditory displays should be designed to allow for the functional hearing abilities of older adults (Baldwin, 2001).

In a driving simulation study, Liu (2001) found that older and younger drivers using an auditory display as well as those using a multimodal display (auditory plus visual) produced better performance (response time, total number of correct turns, and subjective workload ratings) than those using a visual-only display. Overall, driving performance was least affected by the multimodal display. The multimodal display produced the fewest navigation-related errors and lower workload and stress ratings. An age effect was found, wherein the multimodal display significantly improved older drivers’ performance on a secondary push-button task, i.e., pushing one of two buttons on the steering wheel as quickly as possible after a warning, to indicate whether a message was for road conditions such as fog or road construction, or for vehicle conditions such as high engine temperature.

In a review of route guidance systems, McCarthy (2005) indicates that although these systems have been shown to reduce wrong turns and shorten travel time, older drivers have difficulty with this technology. In a study where drivers were asked to use a navigational device while driving, those over 65 demonstrated an increased number of safety-related driving errors (lane deviations, inappropriate glances longer than 2.5 seconds, inappropriate speed, and intersection-related errors), even though they traveled at a slower speed (Dingus, Hulse, Mollenhauer, Fleischman, McGehee, & Manakkal, 1997). The navigational formats were: TravTek simple turn-by-turn visual display, with and without voice guidance; TravTek route map visual display, with and without voice guidance; textual paper direction list; and conventional paper map. The supplementary voice guidance was provided in the form of up to three brief verbal messages pertaining to distance to the next maneuver and near turn information. Near turn information included the name of the turn street and type of maneuver (e.g., “make a hard left” or “bear right”).

When a route was provided *without* voice prompts, older drivers (> 65) made more inappropriate glances longer than 2.5 sec and more lane deviations than middle-aged (35-45) and younger (16-18) drivers. Older drivers benefited substantially (fewest lane deviations) when *turn-by-turn guidance using redundant information* (visual plus voice) was provided. Their errors were reduced to the level of errors made by younger drivers. Inappropriate glances lasting over 2.5 sec were more frequent among older drivers across all navigational display formats but these effects were more evident and significantly longer for the visual route map display condition, both with and without the voice guidance supplement, and for the paper directional list condition. Examining the lane deviations across age groups provides support for the benefit to older drivers of voice guided (verbal) in-vehicle navigation displays (Baldwin, 2002). Older drivers had significantly more lane deviations in both the paper map and paper directions conditions than younger drivers. However, older drivers exhibited very few lane deviations while using the visual turn-by-turn display with voice guidance. The middle-aged group had few lane deviations overall and their performance did not vary between display formats, while the younger group had a large number of lane deviations in only the route map without voice condition. As users of all ages gained experience with the TravTek system, their driving performance improved (less frequent glances at the display, shorter glance periods, fewer large steering wheel reversals, and fewer lane deviations).

Oxley and Mitchell (1995) found that navigation systems that diverted the driver’s attention for prolonged episodes resulted in drivers reducing speed and steering off course. As the complexity of route guidance increased, basic driving task performance declined, with larger declines shown by older than for younger drivers. Verwey (2000) also found that older drivers required more time to process information while using navigational systems compared to younger drivers. McKnight and McKnight (1992) observed the simulated driving performance of 150 drivers equally divided into the following age groups: less than 25, 25 to 50, and 50 and older. Participants were expected to respond appropriately to the traffic situations in the video presentations (e.g., making a turn) while interacting with navigation displays. Dependent measures included total time looking at the display and appropriate traffic responses. Older drivers failed to anticipate turns more frequently (34%) than did the middle-aged (28.4%) and younger drivers (28.6%). The cumulative glance duration to the navigation displays was highest for the older drivers (5.8%), compared with the middle aged (5.1%) and younger drivers (3.9%). Although not significant, the older group responded to traffic situations more accurately (41.5%) than did the middle aged (37.5%) and younger groups (36.2%). Dingus, Antin, Hulse, and Weirwille (1989) also found that older drivers spent more time looking at navigational displays (6.3% of the time) than younger drivers (3.5%). Barham, Alexamder, Ayala, and Oxley (1994) reported that driver eye glances to a route guidance system by their sample of 35 drivers 65 and older represented 7.5% of all glances, and that males made longer glances (mean = 0.73 s) than females (mean = 0.63 s). Researchers have found that older drivers made more glances, for longer durations, than did younger drivers (Hayes, Kurokawa, & Weirwille, 1989; Scialfa, Ho, Caird, & Graw, 1999); and this finding is independent of working memory deficits that might require a driver to look more frequently at a display to reacquire information

In a focus group study with 18 older drivers (64 to 82) familiar with the use of an in-vehicle navigation system, participants reported that they are eager to have both a navigational assistance unit and a human co-pilot who can help use the system while providing another set of eyes and ears to perceive and interpret information (Kostyniuk, Streff, & Eby, 1997). Participants also expressed a strong preference for hands-on training with the in-vehicle navigation system and some follow-up training after they had the unit for a few weeks. Campbell, Kinghorn, and Kantowitz (1995) reported that older focus group participants (age 55-85) found the features of a navigation system (TravTek) more difficult to use and less functional than did a group of younger drivers. However, their initial reticence to use a navigation system diminished as they gained more experience with the system. This highlights the point that until older drivers have adequate experience, they may be reluctant to use the technology.

Vision Enhancement Systems (VES)

Caird (2004) describes infrared vision enhancement systems (IVES) and ultraviolet vision enhancement systems (UVES) and how they work. IVES uses a sensor display to represent thermal differences between an object and its background, such as animals or a pedestrian on the road. A pedestrian with a thermal signature that is different from the background traffic/road environment could be detected at a greater distance because of target contrast differences. Such thermal energy differences between objects in the traffic environment are displayed either on the windshield, using a head-up display (HUD), or on a small display mounted in the dashboard. UVES technology, meanwhile, is designed to aid drivers in the (nighttime) detection of environmental features treated to increase their reflectance in the ultraviolet part of the spectrum, such as lane markings. Hypothetically, vision enhancement systems may assist with older drivers' loss of visual capability.

In a study using 4 older drivers and 4 younger drivers on a test track, with a mock-up VES system presenting images on a dash-mounted, 5-in CRT, Gish, Staplin, and Perel (1999) found no significant difference between target detection distances for older drivers for "VES on" versus "VES off" trials. However, the VES improved detection distances by 100 to 200 feet for younger observers. Reports from three of the four older drivers indicated that they did not use the display when it was on to detect targets; if they used it, they did so only to detect curves. This suggested that the added workload and risks associated with scanning down to the in-vehicle display were unacceptable to the older drivers. Oxley and Mitchell (1995) reported on the subjective perceptions of VES by older drivers; 100% of the sample of 31 UVES users and 15 IVES users indicated that the system was easy to use and that they may choose to drive at new times (73% UVES, 60% IVES). An unintended consequence of this technology could be an increase in older driver crashes by increasing their exposure during challenging driving situations.

Caird, Horrey, and Edwards conducted a simulator study with 24 younger (age 18 to 32) and 24 older (age 67 to 86) drivers, to compare driving performance using either a conformal vision enhancement system or a nonconformal vision enhancement system. Conformal systems overlay an image (in the case of a head-up display) that is directly superimposed on the object it is providing information about. In this study, conformal vision enhancement of moving and parked vehicles consisted of a horizontal blue bar superimposed on the bumpers of other vehicles. As the vehicles approached, the blue bar increased in size (corresponding to the increasing size of the bumper). Conformal enhancement of a traffic light at an intersection was accomplished by placing a blue bar behind the traffic light, such that it surrounded the light with a sort of halo.

By comparison, *non*conformal enhancement presents information without this cue of direct superimposition on the detection target. In this study, nonconformal enhancement of approaching and parked cars and traffic lights at an intersection consisted of blue bars presented on the head-up display 1.2 degrees below the line of sight and directly in front of the driver. For approaching and parked cars, the size of the bar increased correspondingly with the vehicle's bumper. The bar alerted the driver that a vehicle was approaching, but offered no cues as to the location of the vehicle (e.g., whether it was parked on the right, parked on the left, or approaching). To use the nonconformal information, participants had to scan the environment for a corresponding object. For enhancement of the traffic light with the nonconformal system, an expanding blue bar was placed on the road and a traffic light was superimposed on the bar. The color of the traffic light was not represented on the bar, and the bar was not positioned at the location of the light, but on the road in front of the driver.

Baseline driving trials were conducted in daylight scenarios without the VES. Next, practice trials were conducted in daylight scenarios either with the conformal or nonconformal display. Then driving trials were conducted either with the conformal or nonconformal system in daylight and fog scenarios. The surprise appearance of a pedestrian was presented to measure a participant's ability to respond to an unexpected event.

With the exception of the intersection scenario, differences between younger and older drivers were not found. Caird et al. (2001) found that for separation distance from parked cars, there were no significant main effects of age, VES type, or gender, but there was a significant effect of condition. Daytime separation with either VES type (mean = 4.9 ft [1.51 m]) was less than baseline separation with no VES (mean = 5.3 ft [1.61 m]), and also less than in the fog condition (mean = 5.3 ft [1.61 m]). For oncoming vehicle separation, age and gender were not significant, but participants who used the conformal display kept a greater separation distance under day and fog conditions than those who used the nonconformal display. When the pedestrian suddenly appeared between two parked cars, drivers using the conformal display had faster perception-response times than drivers using the nonconformal display, both in daytime and fog conditions. For the intersection scenario, the traffic light changed from green to yellow to red on 50% of the trials. Older drivers ran the stoplight more often than younger drivers, and drivers with the conformal system ran fewer lights than did drivers who used the nonconformal display.

When asked whether the VES helped them to notice hazards, both younger and older drivers responded that both types of VES made them more aware of other vehicles but not of unexpected hazards, such as pedestrians, and in fact participants mentioned that the pedestrian may not have been noticed as quickly because attention was focused on the enhancements. Many nonconformal VES users mentioned that the display obscured a portion of the roadway, and focus on the enhancements may reduce the use of perceptual cues such as the outlines of vehicles. They also mentioned a reduction in scene scanning. Drivers indicated that the VES would be useful when environmental conditions restrict visibility, such as night, snow, fog, and rain. They indicated that extremely heavy traffic and cluttered environments would be poor situations for VES use, as well as daytime driving. Less than 25% of the participants indicated they would use a VES with regularity if it were installed in their vehicle.

Collision Avoidance Systems

Collision avoidance systems warn the driver in advance of an impending emergency event. Caird (2004) notes that few evaluation studies have included a sample of older drivers, and those that do, don't analyze age effects. Dingus, McGhee, Manakkal, Jahns, Carney, and Hankey (1997) reported that younger drivers had shorter mean headways (2.01 s) than older drivers (2.58 s). They also found that older drivers were insensitive to system false alarms (they did not increase or decrease their headways as a response) whereas younger drivers tended to increase their headway when more false alarms were experienced.

Maltz, Sun, Wu, and Mourant (2004) found that drivers, both younger and older, benefited from the use of a headway and detection alerting device. Age had no effect on the amount of time drivers spent in the optimal following distance zone (2 to 4 seconds). Older drivers were less likely to respond to false alarms when they were distracted by an auditory task (listening to a book on tape) than when they were not distracted. However, younger drivers responded *more* to false alarms when they were distracted than when they were not distracted. This age effect occurred only when the headway and detection alerting device was highly reliable. Maltz et al. indicate that the explanation for older drivers ignoring more false alarms when they were distracted may be due to their greater difficulty dividing attention, particularly when the two tasks share the same output modality (auditory stimuli, in this case). Finally, Oxley and Mitchell (1995) tested a collision warning system in a driving simulator and found that it was effective in preventing older drivers from turning across traffic through gaps that were dangerously short. They also found that this technology was even more effective for a small sample of younger drivers than for the main sample of older drivers.

Adaptive (Intelligent) Cruise Control

Adaptive (also known as intelligent) cruise control is designed to reduce a driver's need to continuously control the accelerator to adjust speed and headway, especially during highway driving (Caird, 2004). At a predetermined limit, the system disengage, changes gears, or applies limited braking for the driver, as needed. It does not provide a warning when front separation is at its preset limit, nor does it take evasive action. In a large-scale field trial using 96 drivers in three age groups (young,20-30; middle-aged,40 to 50; and older,60 to 70), it was found that older drivers used the adaptive control more frequently than the younger and middle-aged drivers for speeds of 35 to 55 mph. Drivers could set headway limits of either 2.0 s, 1.6 s, or 1.0s. Younger drivers set the system for shorter headways and older drivers preferred the longer headways. Older women preferred longer headways and slower speed than other age/gender groups. Older drivers in general responded favorably to adaptive cruise control; only 5% of the drivers did not feel comfortable with the system and indicated that they would likely not use it in the future. Learning how to use the system required several hours, and integrating the adaptive cruise control into driver behavior took approximately 1 week.

Emergency Management Systems

Emergency management systems automatically report the location of a vehicle to an emergency center in the event of a breakdown, crash, or other emergency, and allow communication with that center. In the study by Oxley and Mitchell (1995), all older drivers who tested a prototype emergency alert system reported that it increased their confidence and feeling of security; 8 of the 22 older subjects indicated they would be more willing to drive at night, on highways, and in unfamiliar areas if they had such as system.

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