Older Commercial Drivers: Do They Pose a Safety Risk?

DETAILS

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COMMERCIAL TRUCK AND BUS SAFETY SYNTHESIS PROGRAM

CTBSSP **SYNTHESIS 18**

Older Commercial Drivers: Do They Pose a Safety Risk?

A Synthesis of Safety Practice

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COMMERCIAL TRUCK AND BUS SAFETY SYNTHESIS PROGRAM

Safety is a principal focus of government agencies and private-sector organizations concerned with transportation. The Federal Motor Carrier Safety Administration (FMCSA) was established within the Department of Transportation on January 1, 2000, pursuant to the Motor Carrier Safety Improvement Act of 1999. Formerly a part of the Federal Highway Administration, the FMCSA's primary mission is to prevent commercial motor vehicle-related fatalities and injuries. Administration activities contribute to ensuring safety in motor carrier operations through strong enforcement of safety regulations, targeting high-risk carriers and commercial motor vehicle drivers; improving safety information systems and commercial motor vehicle technologies; strengthening commercial motor vehicle equipment and operating standards; and increasing safety awareness. To accomplish these activities, the Administration works with federal, state, and local enforcement agencies, the motor carrier industry, labor, safety interest groups, and others. In addition to safety, security-related issues are also receiving significant attention in light of the terrorist events of September 11, 2001.

Administrators, commercial truck and bus carriers, government regulators, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and underevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information available on nearly every subject of concern to commercial truck and bus safety. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the commercial truck and bus industry, the Commercial Truck and Bus Safety Synthesis Program (CTBSSP) was established by the FMCSA to undertake a series of studies to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern. Reports from this endeavor constitute the CTBSSP Synthesis series, which collects and assembles the various forms of information into single concise documents pertaining to specific commercial truck and bus safety problems or sets of closely related problems

The CTBSSP, administered by the Transportation Research Board, began in early 2002 in support of the FMCSA's safety research programs. The program initiates three to four synthesis studies annually that address concerns in the area of commercial truck and bus safety. A synthesis report is a document that summarizes existing practice in a specific technical area based typically on a literature search and a survey of relevant organizations (e.g., state DOTs, enforcement agencies, commercial truck and bus companies, or other organizations appropriate for the specific topic). The primary users of the syntheses are practitioners who work on issues or problems using diverse approaches in their individual settings. The program is modeled after the successful synthesis programs currently operated as part of the National Cooperative Highway Research Program (NCHRP) and the Transit Cooperative Research Program (TCRP).

This synthesis series reports on various practices, making recommendations where appropriate. Each document is a compendium of the best knowledge available on measures found to be successful in resolving specific problems. To develop these syntheses in a comprehensive manner and to ensure inclusion of significant knowledge, available information assembled from numerous sources, including a large number of relevant organizations, is analyzed.

For each topic, the project objectives are (1) to locate and assemble documented information (2) to learn what practice has been used for solving or alleviating problems; (3) to identify all ongoing research; (4) to learn what problems remain largely unsolved; and (5) to organize, evaluate, and document the useful information that is acquired. Each synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation.

The CTBSSP is governed by a Program Oversight Panel consisting of individuals knowledgeable in the area of commercial truck and bus safety from a number of perspectives—commercial truck and bus carriers, key industry trade associations, state regulatory agencies, safety organizations, academia, and related federal agencies. Major responsibilities of the panel are to (1) provide general oversight of the CTBSSP and its procedures, (2) annually select synthesis topics, (3) refine synthesis scopes, (4) select researchers to prepare each synthesis, (5) review products, and (6) make publication recommendations.

Each year, potential synthesis topics are solicited through a broad industry-wide process. Based on the topics received, the Program Oversight Panel selects new synthesis topics based on the level of funding provided by the FMCSA. In late 2002, the Program Oversight Panel selected two task-order contractor teams through a competitive process to conduct syntheses for Fiscal Years 2003 through 2005.

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FOREWORD

Administrators, commercial truck and bus carriers, government regulators, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and underevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

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For each topic, the project objectives are (1) to locate and assemble documented information; (2) to learn what practices have been used for solving or alleviating problems; (3) to identify relevant, ongoing research; (4) to learn what problems remain largely unsolved; and (5) to organize, evaluate, and document the useful information that is acquired. Each synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation.

PREFACE

By Donna L. Vlasak
Senior Program Officer
Transportation Research Board

This synthesis provides a knowledge base regarding age-related changes in the basic functional abilities needed to drive safely that can assist industry and labor practitioners in promoting safer commercial operations. Managers of bus and truck fleets, academic and trade association researchers, and federal and state agency officials with responsibility for developing effective regulatory and incentive programs may find this report useful.

The synthesis team conducted a literature review about changes in medical (functional) fitness to drive that affect older drivers generally, and older commercial drivers, specifically. Although research data on older drivers and older drivers in general was found to be broad, findings for older commercial drivers appeared to be limited. One 1995 study proved useful to this synthesis study. As surveys with carriers and others in the trucking industry regarding older drivers' information yielded a low response rate, in-person telephone interviews were conducted with six carriers to gather more detailed information from industry safety managers.

Gene Bergoffen, MaineWay Services, Inc.; John F. Brock, Windwalker Corporation; and Loren Staplin, TransAnalytics, LLC, collected and synthesized the information and wrote the report. The Commercial Truck and Bus Safety Synthesis Program Oversight Committee members are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

OLDER COMMERCIAL DRIVERS: DO THEY POSE A SAFETY RISK?

SUMMARY

This report presents the results of TRB CTBSSP Project MC-18: *Older Commercial Drivers: Do They Pose a Safety Risk?* It provides a knowledge base regarding age-related changes in the basic functional abilities needed to drive safely that can assist industry and labor practitioners in promoting safer commercial operations. It may also inform the broader commercial vehicle safety community and the FMCSA in developing policies and regulations that protect public safety without penalizing drivers on the basis of their age.

This report contains the following sections:

- A statement of the background and the problem that brought about this project.
- A literature review on changes in medical (functional) fitness to drive that affect older drivers generally and older commercial drivers specifically.
- The results of a series of structured interviews with carriers and others in the trucking industry regarding older commercial drivers.
- Conclusions.

The synthesis team conducted a comprehensive literature review on the topic of age as it pertains to driving. The team also conducted surveys of commercial truck carriers, motor coach companies, school bus associations and companies, industry organizations (e.g., the American Trucking Associations), insurance companies, state departments of transportation, and other relevant organizations. However, recent surveys of the trucking industry have been hampered by low response levels. With the concurrence of both the TRB and FMCSA, the team opted for in-person and telephone interviews to determine whether industry safety managers and state motor vehicle administrators think a need exists for any unique testing of older commercial motor vehicle drivers.

The literature review worked from general findings about the physiological and psychological effects of aging, to the specific literature pertaining to aging effects on driving, and, finally, to any specific literature on older commercial drivers. The review also looked for any current documentation of older commercial driver safety data, any policies or local regulations pertaining to older commercial drivers, and any findings in Europe, Asia, or Australia relevant to this synthesis. To the extent that medical conditions and medications are singled out for discussion in this review, it is based on their prevalence in the overall aging population, not on the results of epidemiological research conducted strictly within the older commercial driver population.

A principal audience for the synthesis study will be managers of bus and truck fleets. However, the results will be of special interest to academic and trade association researchers in the field of motor carrier safety, and federal and state agency officials with responsibility for developing effective regulatory and incentive programs to enhance commercial motor vehicle safety.

The literature review makes clear that aging has a profound effect on the human mind and body, with a present emphasis on changes known to impair drivers' capabilities in

ways that are recognized as crash risk factors. However, much of that literature is based on research performed on significantly older persons than one finds in the commercial driver population. Even for the general driving population, it is uncommon to find studies that show a significant increase in crash risk for persons age 70 or younger. The literature review also suggests that, even with the physical and cognitive changes in older persons, older drivers can often compensate for those changes by making better decisions and demonstrating better judgment while driving. The Llaneras et al. (1995) research, which studied active Commercial Driver License (CDL) drivers of all ages, showed that drivers over age 60 made fewer errors and had fewer near misses than their younger counterparts. Although this study was conducted in a driving simulator, feedback from industry indicates that these data support the general view of the older commercial driver.

Although the research data on older persons and older drivers in general are quite broad, the research findings for older *commercial* drivers are quite limited. The Llaneras et al. (1995) study noted previously strongly suggests that healthy, active older commercial drivers need not provide an exaggerated risk to traffic safety. Although counterintuitive, both the research and the large truck crash data support this stance. Most important is the evidence showing that loss of function for any driver underlies a higher risk of crash causation, regardless of age.

The synthesis findings suggest that older persons who are currently commercial drivers pose no greater safety risk than their younger and middle-aged counterparts. Some decline—which varies greatly from individual to individual—in the visual, cognitive, and psychomotor abilities needed to drive safely is inevitable with normal aging, with the diseases that are more common among older people, and with the medications used to treat them. Therefore, as the number of older persons, including professional truck drivers, grows larger, it is important that crash data continue to be monitored for any trends that differ from these findings.

The need for minimum qualifications for medical fitness to drive that are evidence-based, and are fairly and consistently applied, is widely recognized. However, the literature review and interviews conducted for this study show no reason that older commercial drivers should be treated differently by CDL testing and licensing jurisdictions.

CHAPTER ONE

INTRODUCTION

This report presents the results of TRB CTBSSP Project MC-18 entitled *Older Commercial Drivers: Do They Pose a Safety Risk?* This report provides a knowledge base regarding age-related changes in the basic functional abilities needed to drive safely that can assist industry and labor practitioners in promoting safer commercial operations. It may also inform the broader commercial vehicle safety community and the FMCSA in developing policies and regulations that protect public safety without penalizing drivers on the basis of their age.

This report provides:

- A statement of the background and the problem that brought about this project.
- A literature review on changes in medical (functional) fitness to drive that affect older drivers generally and older commercial drivers specifically.
- The results of a series of interviews with carriers and others in the trucking industry regarding older commercial drivers.
- Conclusions and suggestions.

BACKGROUND

In 1995, the FHWA Office of Motor Carriers (now the FMCSA), released the final report of a major study on older commercial vehicle drivers (Llaneras et al. 1995). This study found that older commercial drivers who scored more poorly on a series of cognitive, psychomotor, and perceptual screening tests did as well or better than their younger counterparts when tested in a driving simulator. That same study also tested various interventions to improve older driver in-cab performance. These data were intriguing but limited to a small number of participating commercial drivers. This synthesis report summarizes the literature on factors that predict crash risk among older drivers in general and older commercial drivers in particular.

As stated in the original Request for Proposals for CTBSSP MC-18, a recent study on the truck driver shortage showed nearly 3% of the total truck driver population in the year 2000 to be older than age 65. By 2004, according to the study, that percentage had risen to 3.7%. If this trend continues, more than 5.5% of the truck driver population would be over age 65 by 2014. These changes may be seen against the backdrop of changes in the overall driver population, which is expected to include 20% to 25% drivers over age 65 at the quarter-century mark.

Further, the industry-wide average truck driver age continues to increase at a greater rate than that of the overall workforce. Over 8 years beginning in 1994, it rose by 2.7 years, whereas the average age of the entire labor force rose only 1.7 years.

The report referenced earlier (Llaneras et al. 1995), as well as a broader body of literature addressing noncommercial drivers [see Staplin et al. 2003 (*b*)], support the premise of the MC-18 Request for Proposal that declines in visual, mental, and physical abilities are more pronounced with aging.

The Age Discrimination in Employment Act affects the results of this synthesis. This 1967 act specifically prohibits age discrimination in, among other areas, hiring, promotions, wages, or firing/layoffs. In the team's interviews with various truck carriers, it was obvious that companies wanted to be very clear that they were not in violation of either the letter or spirit of this law.

OBJECTIVES AND SCOPE

The synthesis team conducted a comprehensive literature review on the topic of age as it pertains to driving. The team also planned to conduct surveys of commercial truck carriers, motor coach companies, school bus associations and companies, industry organizations (e.g., ATA), insurance companies, state departments of transportation (DOTs), and other relevant organizations. However, recent surveys of the trucking industry have been hampered by low response levels. With the concurrence of both TRB and the FMCSA, the team opted for in-person and telephone interviews to determine whether industry safety managers and state motor vehicle administrators perceive that a need exists for any unique testing of older commercial drivers.

The literature review worked from general findings about the physiological and psychological effects of aging, to the specific literature pertaining to aging effects on driving, and finally to any specific literature on older commercial drivers. The review also looked for any current documentation of older commercial driver safety data, any policies or local regulations pertaining to older commercial drivers, and any findings in Europe, Asia, or Australia relevant to this synthesis. To the extent that medical conditions and medications are singled out for discussion in this review, it is based on their prevalence in the overall aging population, not on the results of epidemiological research conducted strictly within the older commercial driver population.

A principal audience for the synthesis study will be managers of bus and truck fleets. However, the results will be of special interest to academic and trade association researchers in the field of motor carrier safety, and federal and state agency officials with responsibility for developing effective regulatory and incentive programs to enhance commercial motor vehicle safety.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

Given the perennial shortage of qualified operators for heavy commercial vehicles and the enhanced risk management skills of more mature, experienced drivers, there are clear advantages to the industry of retaining individuals who remain healthy into their 50s, 60s, and beyond. The overall aging of the U.S. population means that a larger proportion of these workers will be older as well, and this trend will only be accentuated as economic challenges compel people to remain in their jobs past the traditional retirement age. The consequences of this societal shift for commercial motor vehicle operations specifically, and for the safety of the nation's highways more generally, hinges on our emerging understanding of how our ability to perform critical driving skills changes as we get older and how this knowledge is applied to ensure that commercial drivers are medically fit regardless of their age.

An essential starting point in this review is that research has shown that the status of an (older) individual's visual, mental, and physical functions determines the safety risk that he or she poses, regardless of age. And while it is true that normal aging is broadly associated with many declines in functional status, there are tremendous individual differences. Some 70-year-olds are every bit as capable to safely operate a commercial vehicle as their 50-year-old coworkers. In this review, numerous references will attest to a significant decline in critical functional abilities with advancing age, but neither a person's age nor his or her medical diagnosis determines fitness to drive; rather, it is that person's functional status.

The following discussion first addresses medical conditions that can lead to diminished capability and driver impairment, and which become increasingly prevalent with advancing age. Next, the extent to which older persons use medications—and in particular, classes of drugs that have been identified as "potentially driver impairing"—to treat these conditions, will be considered. It then reviews research that has revealed which visual, perceptual/cognitive, and physical/psychomotor deficits most strongly predict a significant loss in driver competence (performance) or an increase in crash involvement. A concluding section focuses on potential countermeasures to mitigate age-related changes that compromise safe driving, including a case study describing a prevention strategy used by a fleet operator that employs a high percentage of older drivers, plus a study of how in-vehicle compensatory aids and training may be used to enhance driver performance.

MEDICAL CONDITIONS AND OLDER DRIVER SAFETY

Individuals may experience impairments in their ability to drive safely owing 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, it is important to consider the manner and extent to which underlying medical conditions can compromise critical safe driving abilities. Accordingly, the focus of this section is on diseases and medical conditions prevalent among older adults: diseases that scientific evidence has linked to driving impairment and that are likely to define priorities for detection by physicians because of their effects on specific visual, perceptual-cognitive, and psychomotor functions.

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.

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. The most common symptoms of cataracts include blurry vision, double vision, faded colors, poor night vision, and halos around lights. It is estimated that 20.5 million people in the United States older than age 40 have a cataract in one eye, a number that will increase to 30.1 million by 2020 (Eye Diseases Prevalence Research Group 2004).

In the physician's office, impaired vision attributable 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 et al. 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 et al. (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. Fortunately, cataract surgery can restore function and lead to measurable gains in safety for older drivers, as discussed here.

Next, glaucoma is a relatively common medical condition resulting in vision loss for older persons. Characterized by elevated intraocular pressure, glaucoma destroys the optic nerve. It is one of the leading causes of blindness according to the American Academy of Ophthalmology; yet almost half of those afflicted are unaware of their condition. This is because many 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. By 2020, the number of persons with the disease is expected to rise to more than 3 million (Eye Diseases Prevalence Research Group 2004).

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 et al. 1998) and the Glaucoma Symptom Scale (Lee et al. 1998).

Multiple studies have addressed the safety of older persons with glaucoma. A 5-year retrospective study in Canada compared patients in a glaucoma clinic with controls. The glaucoma patients were at higher risk for motor vehicle crashes, including at-fault crashes (Haymes et al. 2007). Other studies have also shown an increase in crash risk in patients with glaucoma (Hu et al. 1998; Owsley et al. 1998; Szlyk et al. 2005); but some have not (McCloskey et al. 1994; McGwin et al. 2004). 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 (McGwin et al. 2004; Szlyk et al. 2005).

Another disease affecting visual function among large numbers of older persons is macular degeneration (MD). This condition affects the central region (macula) of the retina, where the highest density of photoreceptors—as required for good acuity; that is, the ability to resolve fine detail—is found. 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. Because of its increasing prevalence with advancing age, this disease is often labeled "age-related macular degeneration" (ARMD). The Eye Diseases Prevalence Research Group (2004) estimates that 1.5%, 1.75 million of Americans over age 40 has MD in one eye. By 2020, the total number of people with MD is expected to approach 3 million.

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. Other questionnaires, such as the National Eye Institute Vision Function Questionnaire-25, include items that screen for ARMD (DeCarlo et al. 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 et al. 1993, 1995), although 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

The medical conditions that most commonly affect cognitive abilities needed to drive safely are dementia, stroke, and sleep apnea. In this context, 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 loss and other cognitive impairment—for example, a loss of "executive functioning," or the ability to think abstractly and to plan, initiate, sequence, monitor, and stop complex behavior—than would be expected owing to normal aging processes.

Common effects of *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 a 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 underestimate the risks involved in activities, such as driving. Impulsivity can lead to problematic behaviors, such as prematurely pulling out into traffic or running a red light.

The most troubling of the dementias is Alzheimer's disease (AD). Alzheimer's disease is the most common cause of dementia, with prevalence estimated at 13% for Americans age 65 and older (Alzheimer's Association 2007). In 2007, 2% of Americans ages 65 to 74 had AD, compared with 19% of those ages 75 to 84, and 42% of those ages 85 and older. With the increase in the number of baby boomers turning age 60 (a rate of approximately 330 every hour), the number of Americans age 65 and older with AD could increase from 11 million to 16 million by the year 2050 (Alzheimer's Association 2007). These estimates reflect the prevalence of AD, regardless of whether a diagnosis of AD 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 diagnosed with AD or another dementia had this condition noted in their medical record.

Impairments in critical driving skills may be among the first signs of AD (Silverstein 2008). In a review of the literature on crash rates for control drivers and drivers with AD, Carr (1997) found that there is a twofold increased crash rate for drivers with dementia when compared with 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 AD or other dementias in these studies ranged from 0.04 to 0.14.

In a retrospective study in British Columbia, the driving records of 165 older drivers 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 et al. 1993). Crash records showed that the dementia group drivers were involved in 86 crashes during the driving period. This result is 2.5 times more than that found for the general driving population.

Drivers with dementia are at the highest risk for crashes in the advanced stages of their disease. 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. 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 five and beyond, 0.129. When the data for the first 3 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.

Next, 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 U.S. experience a first stroke, and 200,000 experience a recurrent attack; stroke is the leading cause of serious disability in the United States (American Heart Association 2006).

Although stroke symptoms can include vision and motor impairments, stroke-related sensory loss (numbness or loss of sensation) and cognitive impairments are most likely to cause problems with driving. These include memory loss, hemianopia (inattention or 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). Muscle weakness or paralysis is also a possible consequence of stroke.

The evidence of crash involvement with stroke survivors remains inconclusive. Sims et al. (2000) reported that a history of stroke or TIA (a transient ischemic attack, or "ministroke," that produces stroke-like symptoms) 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 with controls was found by Koepsell et al. (1994), but not by Salzberg and Moffat (1998). An additional perspective on these findings is provided by the reality that a significant number (approximately 42%) of community-dwelling stroke patients continue to drive (Legh-Smith et al. 1986). Most notable is the finding by Fisk et al. (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 undertreated) condition with potentially serious consequences for driving safety. A prevalence rate of 4% for men and 2% for women has been reported (Young et al. 1993). Some patients experience a related condition, "hypopnea," or repeated episodes in which airflow is reduced during sleep.

The (daytime) functional impairments of apnea–hypopnea include drowsiness and sleepiness, memory loss, impaired concentration and coordination, anxiety, and depression. Questionnaires have been used in the diagnosis of sleep apnea, including the Berlin Questionnaire (Netzer et al. 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, is the "gold standard" for diagnosis.

Studies have linked crash risk to the amount of sleep that was previously obtained (Garharino et al. 2001); and anecdotal reports of drowsy driving as a crash-contributing factor easily exceed 100,000 per year. Maycock (1996) has correlated scores on the Epworth sleepiness scale with crash risk. Sleep apnea patients, specifically, have been associated with a twofold to a sevenfold increase in crash risk, depending on the study (Teran-Santos et al. 1999). These drivers are also at significantly higher risk of serious injury in crashes (*Medical News Today* 2007). 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 persons may have a neurological origin (e.g., Parkinson's disease) or may be the result of musculoskeletal diseases—especially arthritis—that result in weakness, frailty, and/or restricted range of motion. According to a Parkinson's Disease Foundation report (2004), the muscle tightness resulting from this disease can slow reactions to hazards and changing traffic patterns. However, it is the side effects of medications commonly used to treat Parkinson's that may be of greatest concern. 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.

The prevalence of arthritis among individuals in the United States is pronounced, with more than 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. Clinicians may diagnose arthritis through physical examination; a diagnosis of osteoarthritis is confirmed through X-ray imaging.

A diagnosis of arthritis, plus the use of nonsteroidal anti-inflammatory drugs (NSAIDs), was significantly associated with at-fault crash risk by McGwin et al. (2000). However, according to Henriskkson (2008), patients driving cars that have been adapted for their musculoskeletal restrictions are not at increased risk of a crash. As discussed in another section, two areas of functional loss related to musculoskeletal disease that significantly predict the risk of an (at-fault) crash among older drivers are head-neck mobility and lower limb strength and flexibility [Staplin et al. 2003(*a*); Ball et al. 2006].

The potential scope of a review of material on this topic is enormous. Certain rare conditions that may result in loss of consciousness, such as epilepsy and syncope, have been excluded from this discussion. The effects of alcohol on driving also have been excluded. Another omitted disease that is becoming increasingly prevalent among older persons, diabetes mellitus, deserves special attention. Although some studies have suggested that diabetics experience an elevated crash risk, a Utah-based Crash Outcome Data Evaluation System (CODES) analysis including more than 10,000 drivers with diabetes mellitus and no other known medical condition showed that the effect size was modest, and disappeared among drivers with higher levels of impairment and greater restrictions on driving (Vernon et al. 2001). Thus, a diagnosis for diabetes alone may have little value in explaining safety outcomes. There is also reason to believe that the medications used to treat diabetes, rather than the medical condition itself, is of greatest concern. The interested reader is urged to consult more exhaustive summaries such as the NHTSA compendium *Medical Conditions and Driving: a Review of the Literature* (Dobbs 2005).

MEDICATION USE AND SAFETY CONCERNS AMONG OLDER DRIVERS

Medications that have known effects on the central nervous system (CNS), blood sugar levels, blood pressure, vision, or other functions have the potential to interfere with driving skills and as such have been termed "potentially driver-impairing" (PDI) medications (LeRoy and Morse 2008). PDI effects include sedation, low blood sugar levels (hypoglycemia), blurred vision, low blood pressure (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 that these medications can have on their ability to drive a vehicle safely. Adverse drug events leading to hospitalization are more common among older adults, reflecting their increased use of single and multiple medications (polypharmacy) as well as age differences in the way they metabolize medication.

In 1998, older persons made up approximately 12% of the U.S. population, but they consumed 32% of all prescription drugs (Rathmore et al. 1998). Using prescription claims data, Thomas et al. (2001) found that the average number of therapeutic classes for which older persons receive drugs is 4.66, compared with 2.99 for persons under age 65. Specifically, the claims data for older persons revealed that 90% used cardiovascular medications, and among these patients more than 50% also took a gastrointestinal medication, 50% took a lipid-lowering medication, and almost half took antidepressants or anti-arthritis medications.

Consistent findings emerged from a cohort study of nearly 28,000 Medicare+Choice enrollees, which found that 75% of the sample received prescriptions for six or more medications (Gurwitz et al. 2003) and 49% of the sample was prescribed medications in four or more therapeutic categories. A national survey by Gurwitz (2004) found that among noninstitutionalized adults age 65 and older in the United States, 90% use at least one prescription medication each week, 40% use five or more, and 12% regularly use 10 or more.

The risks of polypharmacy include an increase not only in the number of potentially inappropriate prescriptions, but also in cognitive disorders, depression, and an increased risk of motor vehicle crashes, as discussed later. As LeRoy and Morse (2008) reported, 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.
- Less efficient renal clearance of drugs.

The side effects of normal doses of drugs that are particularly relevant to older adult drivers include dizziness, drowsiness, tremors, rigidity, confusion, hypoglycemia, hypotension, and blurred vision.

Data describing the crash risk associated with therapeutic classes of prescription drugs are rare, and are not specific to commercial vehicle operations. LeRoy and Morse (2008) used an administrative pharmaceutical claims database to determine how often various medications and combinations of medications showed up among members who had experienced a motor vehicle crash compared with those who had not experienced a crash. The study evaluated the medication use of 33,519 members with crashes (5,378 of whom were age 50 or older) and of 100,000 controls (three for each case) matched on age and gender without crash involvement. The cases must have sustained an injury severe enough to result in a hospital treatment and an associated insurance payment, and must have had at least 6 months of continuous coverage before the date of the crash/injury. Information in this patient-level database allowed a determination of which medications were current at the date of the crash.

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 PDI medication classes. Of the 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 are known.

A subsequent data mining project looked specifically at the relationship between driver age, PDI drug use, and crash involvement (Staplin et al. 2008). This study revealed that the (mean) number of "current" (at time of crash) PDI medications taken by drivers in different age groups increased sharply for those ages 50 and older versus the ages 16–49 group, continued to climb as the database was truncated at successively older 5-year cohorts, then leveled off when the age-65-and-older threshold was reached. These findings are summarized in Table 1 for all *crash-involved* drivers:

TABLE 1

MEAN NUMBER OF PDI MEDICATIONS AT TIME OF CRASH, BY DRIVER AGE

	Driver age group						
	16-49	50+	55+	60+	65+	70+	75+
Number in database	18,837	3,737	2,212	1,208	643	474	299
Mean number of PDI medications	0.42	1.28	1.43	1.56	1.63	1.66	1.64

As indicated in the following figures, the rate of use of multiple PDI medications by crash-involved drivers climbs with age until leveling off at the ages 65–69 cohort. Another perspective on these data is provided by the following graphics, which look more narrowly at the contrast between zero, one, and multiple drug usage. Figure 1 presents these relationships in a bar graph, whereas Figure 2 focuses more closely on the changes in multiple drug use with driver age.

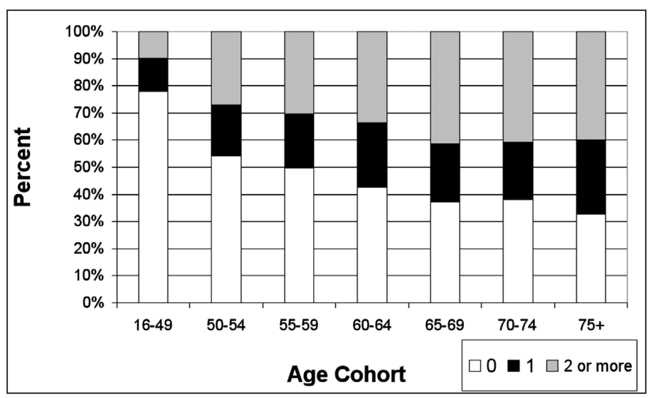

FIGURE 1 Proportion of crash-involved drivers within each age cohort taking none, versus one, versus multiple (two or more) PDI medications at time of crash.

These graphs suggest that the number/proportion of crash-involved drivers taking multiple (two or more) medications increases significantly with increasing age. A chi-square analysis confirmed that the observed values for "0," "1," and "2 or more" medications by different age groups, as shown in Figure 1, significantly exceed the expected values ($p < 0.001$). This test result may be explained by the lower-than-expected use of PDI medications by the ages 16–49 groups and the higher-than-expected use by the older driver cohorts.

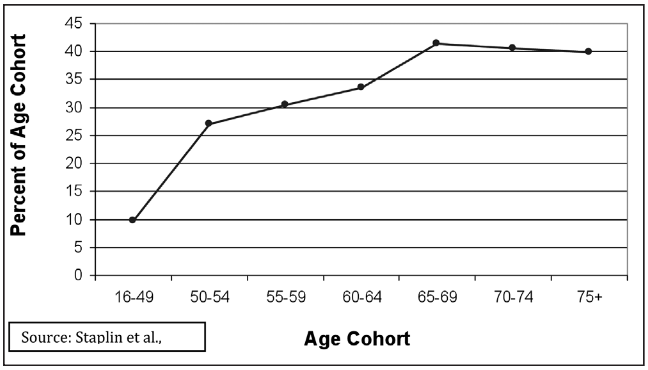

FIGURE 2 Proportion of crash-involved drivers in each age cohort taking multiple (two or more) PDI medications at time of crash.

It is important to recognize the limitations of case-control studies. Although 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 also could have been responsible for the outcome. Confounding factors include a medical condition or multiple medical conditions, severity of medical condition(s), drug interaction conflicts, driving exposure (number of miles driven), use of other medications or alcohol, and length of exposure to the medication of interest. Furthermore, that a person had a current prescription for a given medication does not guarantee that he or she was actually taking it on the day a crash occurred. Also, there may be differences between the cases and the controls chosen, even though care is taken to match them on specific characteristics. Nonetheless, these data are a "warning flag" about the increasing prevalence of single- and multiple-medication usage among older drivers. For reference, Leroy and Morse (2008) found the most frequently appearing drug combinations (in descending order of frequency) in the group of crash-involved drivers age 50 and older to be as follows:

- Narcotics + NSAIDs
- Skeletal muscle relaxants + NSAIDs
- Narcotics + skeletal muscle relaxants
- Narcotics + skeletal muscle relaxants + NSAIDs
- Narcotics + antibiotics
- Gastric acid secretion reducers + narcotics
- Anti-anxiety drugs + narcotics
- Selective serotonin reuptake inhibitor antidepressants + narcotics
- Narcotics + NSAIDs + antibiotics

In comparison, Wilkinson and Moskowitz (2001) reviewed 11 epidemiological studies of medication use and traffic safety risk (primarily in older drivers) in the United States and Canada between 1991 and 2000, and concluded that the prescription drugs most likely to be associated with motor vehicle crashes by older drivers include the same CNS medications found to increase risk in adults younger than age 65—namely, benzodiazepines (especially long-acting), cyclic antidepressants, and opioid analgesics.

An excellent summary of the effects of specific drugs on driving plus guidelines for dealing with drug-impaired driving problems can be found in the *Drugs and Human Performance Fact Sheets* developed by Couper and Logan (2004). This information reflects the conclusions of an international panel of experts in behavioral psychology, drug chemistry, forensic toxicology, medicine, and psychopharmacology as well as law enforcement personnel trained to recognize drug effects on drivers in the field.

AGE-RELATED FUNCTIONAL DEFICITS THAT PREDICT CRASH RISK

As emphasized earlier, a person's functional status—not his or her age—determines fitness to drive. Medical conditions and medication use deserve attention because of how they can compromise functional abilities, regardless of age. But even in the absence of these factors, the process of *normal aging* is accompanied by predictable functional deficits for the vast majority of the population—though individual differences will grow ever more pronounced among older cohorts of drivers. The following pages focus on age-related changes in the abilities that research has demonstrated are most critical for safe driving.

Wherever possible, evidence tying functional loss to crash involvement—in particular, to *at-fault* crash involvement—will be cited. This is most difficult when individuals with significant deficits have already been screened out of the driving population. For example, because the visual acuity test is already universally applied for private vehicle as well as commercial vehicle operators [*Ref.* 49 CFR 391.42 (b)(10) Has distant visual acuity of at least 20/40 (Snellen) in each eye without corrective lenses or visual acuity separately corrected to 20/40 (Snellen) or better with corrective lenses, distant binocular acuity of at least 20/40 (Snellen) in both eyes with or without corrective lenses, field of vision of at least 70º in the horizontal meridian in each eye, and the ability to recognize the colors of traffic signals and devices showing standard red, green, and amber], very few drivers on the road have a significant deficit in this ability and therefore crash analyses that compare them with drivers who have "good" vision are statistically untenable. With such a restriction in the range of acuity levels in the current fleet, only very weak relationships, if any, are found when analyzing differences in this functional ability to predict crash outcomes. In this case, differences in driver performance on a reliable road test offer the best evidence available.

Performance decrements are often presumed to mediate crash risk, and crash studies typically involve large samples, lengthy intervals, and considerable expense. This helps explain why the bulk of research in this area is cross-sectional and part-task, whether it is carried out in a laboratory, a simulator, or on a closed course. Fortunately, the growing concern with medical and functional fitness to drive in an aging population has focused increasing resources on this problem in recent years, making it possible to point with greater confidence to a relatively small set of functional abilities that appear to predict crashes most strongly.

Deficits in Sensory Ability

Sensing (detecting) hazards is critical to safe driving. If a conflict with a pedestrian, another vehicle, or an obstruction in the roadway is not sensed or detected, the driver will not recognize the hazard and may fail to execute the control movements necessary to avoid it. Alternately, if a hazard is sensed late, the subsequent perceptual/cognitive and psychomotor stages of information processing will also be delayed, slowing the driver's response.

The technical literature commonly describes driving as primarily a visual task in the sense that an alert individual can obtain all the information he or she needs to safely operate a motor vehicle through visual inputs. But the role of hearing cannot be discounted for commercial drivers, particularly in local and short-haul operations that take place in congested urban settings and include frequent backing maneuvers using vehicles from which visibility is severely limited. Robinson et al. (1997) investigated the functional requirements for safe commercial vehicle operation and, after gaining a detailed understanding of what commercial drivers must do to safely perform their jobs, identified a number of specific tasks for which hearing is critical. These researchers concluded that an FHWA hearing requirement is necessary, and provided recommendations not only for hearing standards [See 49 CFR Part 391.41 (b) (11) First perceives a forced whispered voice in the better ear at not less than 5 feet with or without the use of a hearing aid or, if tested by use of an audiometric device, does not have an average hearing loss in the better ear greater than 40 decibels at 500 Hz, 1,000 Hz, and 2,000 Hz with or without a hearing aid when the audiometric device is properly calibrated [American National Standard (formerly ASA Standard) Z24.5–1951] but also for improved testing methods to address the questionable reliability of the "whisper test." Pure tone audiometric tests were recommended for assessing hearing level in the future, with different sensitivities required at different frequencies as opposed to an average hearing level.

The Robinson et al. (1997) research was performed in four phases, including a literature review; the most extensive commercial driving task analysis ever undertaken; field measurements of driver hearing, truck-cab noise, and noise exposure; and evaluations of the audibility of speech, warning signals, and other sounds during commercial operations. According to this literature review, prior studies comparing the safety records of hearing-impaired with those of nonimpaired drivers of private (noncommercial) vehicles have found that hearing-impaired drivers had roughly 1.8 times the number of accidents as nonhearing-impaired drivers. This finding was fairly consistent across the studies reviewed in this area.

Another study, *Hearing Disorders and Commercial Motor Vehicle Drivers*, has suggested that when visual information is diminished, an auditory warning becomes more important to prevent crashes (Songer et al. 1993). In addition, sounds sometimes give drivers the first awareness that a problem or condition demanding a timely driver response exists, including both emergency sounds such as sirens and warnings of equipment failure.

Attempts to quantify the safety impact of hearing loss for commercial vehicle operators remain inconclusive, as the FHWA hearing standard ensures that the same "restriction of range" for this functional ability applies as in the case of visual acuity. But in the private vehicle fleet, where this driver ability is not regulated, a relative risk associated with hearing loss has been demonstrated. This elevated crash involvement for hearing-impaired drivers of private vehicles raises concern about the consequences of a sensory deficit that can delay hazard perception for operators of commercial vehicles, with their larger sizes, heavier weights, and longer braking distances.

In consideration of visual deficits, the existing standard and associated "restriction-of-range" problem in studies examining the relationship between (static) visual acuity and motor vehicle crashes and convictions has already been noted. One study on this subject carried out by Rogers and Janke (1992) compared the driving records of heavy-vehicle operators whose vision was unimpaired with the records of heavy-vehicle operators who were found to have a deficit in static acuity. Overall, the visually impaired drivers were found to have a higher incidence of crashes and convictions than the unimpaired drivers. However, when the visually impaired group was further subdivided into those who were moderately impaired and those who were severely impaired, the incidence of crashes for moderately impaired and unimpaired drivers did not differ significantly regardless of age. Indeed, the older drivers in the broader visually impaired sample had lower conviction and crash rates, despite their overall poorer visual acuity as a group.

Given the desire to predict future crash risk based on functional status measurement, it is a stronger research design to use prospective rather than retrospective crash data. Several studies involving older drivers of private vehicles have used this approach. Rubin et al. (2007) found no association between static acuity and future crashes in a population-based, prospective study, using 1,801 current drivers ages 65 to 85. Another investigation found no significant relationship between impaired acuity (defined as resolution worse than 20/40) and injurious crash risk in a prospective cohort study with 3 years of follow-up crash data, using 294 drivers ages 55 to 87 (Owsley et al. 1998).

Dynamic visual acuity—the ability to resolve the details of a moving (instead of a stationary) target—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 greater demands for dynamic visual acuity. For many years, a slight advantage for dynamic visual acuity versus static visual acuity has been observed in crash studies; but the correlations between dynamic visual acuity and crash rates have also been consistently weak. As reported by Hills and Burg (1977), this correlation was too low ($r = 0.054$) to be of any practical significance for identifying at-risk drivers.

Another visual ability that declines with age, and appears to be more strongly related to motor vehicle crash risk, is contrast sensitivity. Tests of this ability 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 have less distinct edges. Contrast sensitivity makes it possible to drive in rain or fog, at twilight, or in other poor visibility conditions. It is also especially important for detecting curbs, barriers, or objects that do not stand out sharply from their background, including pedestrians at night, lane and road edge boundaries that are not marked conspicuously with fresh paint, and reflectors. Under the same lighting conditions, the median 75-year-old requires at least twice the contrast in a scene to see as well as a 55-year-old (Brabyn et al. 2000).

In a population-based study with older drivers, Rubin et al. (2007) found that reduced contrast sensitivity was associated with poor driving performance, self-reported driving difficulty, self restriction, and prior crash involvement; however, the association with future crashes was not significant after adjusting for miles driven. Yet in Brown and others' 1993 study of 1,475 ITT Hartford Insurance Company policyholders (ages 50–80+), who were divided into two groups based on the presence or absence of recent at-fault crashes, the Pelli–Robson contrast sensitivity test consistently yielded the highest correlation to crashes ($r = -0.11$, $p < 0.05$). These researchers noted that because 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.

In a study by Wood (2002) of visual impairment, age, and driving performance, contrast sensitivity as measured by the Pelli–Robson test chart emerged as a significant predictor of the ability to recognize and avoid road hazards. Specifically, a correlation of $r = 0.57$ described the association between contrast sensitivity level and detection of 1 × 2.2-m sheets of 80-cm-thick gray foam rubber placed on the roadway. These targets represented objects that were large relative to the resolution limits of the eye—so performance was not related to acuity—but were of low contrast. Wood (2002) concludes that older drivers, even in the early stages of an ocular disease that produces contrast sensitivity deficits, are likely to have significant problems with seeing and avoiding potholes, highway debris, speed bumps, pedestrians, and other vehicles, especially when driving in poor visibility conditions such as rain or fog.

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 ($r_s = 0.44$, $p < 0.0001$). Subjects with better contrast sensitivity were able to identify a higher percentage of the signs than subjects with poorer contrast sensitivity. Although this deficit could affect all drivers, its impact on commercial vehicle operators is arguably more important.

Finally, in a study of 12,400 Pennsylvania drivers ages 16 to 75+, Decina and Staplin (1993) did not find a significant relationship between contrast sensitivity and crash rates in a 3.67-year retrospective analysis. Neither was visual acuity nor horizontal field measures, in isolation, significantly related to crash involvement. However, they did find that a composite measure including contrast sensitivity, binocular visual acuity, and horizontal field measurement was significantly related to crash involvement for drivers age 66 and older. Failure on a combined criterion that incorporates a binocular acuity standard of 20/40, a horizontal visual field standard of 140 degrees, *and* below-normal scores for one or more of the three spatial frequencies of sine wave gratings in a contrast sensitivity test using a countertop vision tester produced the strongest relationship linking poor vision and high crash involvement, especially for the ages 66–75 and age 76+ driver groups (Decina and Staplin 1993).

These findings raise the issue of visual field loss among older drivers. It has long been established that the isopters, or borders, of the visual field are constricted as a consequence of aging, with older adults exhibiting a generalized loss in sensitivity throughout the central 30 degrees of vision and a slightly greater sensitivity reduction in more peripheral areas (Jaffe et al. 1986; Johnson et al. 1989). As with visual acuity, a minimum visual field size is required under 49 CFR Part 391.41, as cited earlier, with the same consequences for analyses relating visual field loss to safety outcomes for (older) commercial drivers.

Historically, studies among drivers of all ages examining visual field sensitivity and crashes have typically failed to find a relationship between them (Council and Allen 1974;

Shinar et al. 1977; Waller et al. 1980); this includes an early study involving bus and truck drivers (Henderson and Burg 1974). 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. More recent research suggests that the effect of a visual field loss on driving is strongly related to its location, with the greatest safety risk resulting from losses in the central field and in the horizontal meridian (Lovsund et al. 1991), including the lower periphery (Rubin et al. 2007).

Even as the relationship between visual field loss and crash risk remains difficult to quantify, given existing controls to remove those with severe deficits from the fleet, 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." This is actually a perceptual-cognitive ability, for which reliable age differences *and* a significant relationship with at-fault crashes have been demonstrated, as discussed in the following section.

To conclude the review of functional changes in vision with advancing age that have a potential impact on traffic safety, the regulatory requirement to "recognize the colors of traffic signals" must be acknowledged. A differential increase in blue–yellow errors as a function of age is most prominent (e.g., Verriest et al. 1982); the mean error for naive subjects older than age 70 is greater than 100, compared with a mean error score of 37 for the ages 20 to 30 group on the Farnsworth Munsell 100 hue test.

Traffic safety researchers including Temple (1989), Brown et al. (1993), and Tarawneh et al. (1993) have reported that correlations of deficiencies in color vision with on-road driving performance were not significant. Where significant correlations with simulator performance could be demonstrated, such findings have not suggested any practical consequence for performance of critical driving tasks. Also, color vision was not significantly correlated with older drivers' prior at-fault crashes in studies by Owsley et al. (1991) or by Ball et al. (1994). In other words, available data do not indicate that an increase in crash risk specifically as the result of deficits in color vision will be a major concern, with the aging of the commercial driver population.

Deficits in Perceptual-Cognitive Ability

Vision, and to a lesser extent hearing, are essential to provide drivers with the information they need to make decisions and execute timely vehicle control movements, yet from moment to moment these decisions and actions critically depend on a core set of perceptual-cognitive abilities. These abilities are needed to filter, attend to, and make sense of the sensory inputs a driver receives from his/her eyes and ears. Key perceptual-cognitive abilities include (1) working memory, including speed of processing; (2) attentional processes, including selective and divided attention; and (3) visuospatial abilities, such as pattern perception and visualization of missing information. These abilities have been empirically validated as significant predictors of *at-fault* crash risk among older (private vehicle) drivers, but they have strong construct validity as crash predictors for commercial vehicle operators as well.

One other cognitive ability with strong construct validity as a crash predictor is *executive function*. In technical literature, this term is variously used to encompass the evaluative aspects of cognition, such as planning and judgment, as well as the process through which the memory, attentional, and visuospatial abilities noted earlier are integrated to support driver decision making. This review will not focus explicitly on executive function, however, for several reasons. First, this construct remains only vaguely defined, and accordingly there are no methodologies for testing it that are widely accepted and which produce reliable results with a clearly established relationship to safety measures. Perhaps more important, this review targets potential safety concerns with the workforce of normally aging commercial operators, not those older individuals with symptoms of dementia; that is, the group where evidence of deterioration in executive function is most prominent.

Working memory 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. As a practical example, this ability comes into play when a driver is fully engaged in vehicle guidance and maintaining a safe headway in relation to a lead vehicle, while at the same time recalling information about the route he or she wishes to follow and the next navigational landmark for which to watch.

One way that researchers have operationalized working memory is to provide drivers with a to-be-remembered set of words, number, or ideas; confirm that they have learned this material; then require performance of another task that interferes with rehearsal of the new information; and finally ask that they recall what they memorized earlier. Using this type of "delayed recall" measure with a sample of 1,876 Maryland drivers age 55 and older, Staplin et al. [2003 (*b*)] found that those who scored poorly (2 out of 3 verbal stimuli recalled incorrectly after a 5-minute 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 et al. 2003(*a*)].

Similarly, Johansson et al. (1996) used a five-item delayed recall test, where the subject was required to name and recall five objects viewed on a desk after a 10-minute period, in a case-control study to compare 23 cases with crashes and 29 control subjects with no crashes in the past 5 years. Results showed that the crashed drivers had poorer five-item recall ($p < 0.003$). And, in McKnight and McKnight's (1999) study of 407 drivers age 62 and older, split into incident-involved and nonincident-involved groups, measures of delayed short-term memory showed a significant and fairly strong correlation with unsafe driving ($r^2 = 0.32$).

Salthouse and Babcock (1991) reported that age-related variance in working memory was largely accounted for by measures of *processing speed*. In other words, age-related decline in working memory is not the result of differences in the capacity of working memory, but rather in that older adults require more time to retrieve information from memory (Waugh et al. 1978). Given this limitation, and that information in immediate memory has a limited "life span," older adults will be penalized on tasks that require substantial attentional resources, or on tasks that require the reorganization of "to-be-remembered" information. As a consequence, older drivers will be at greater risk in situations such as intersections that require rapid mental operations for appropriate vehicle control, especially when simultaneously required to perform such operations and retain other (e.g., navigational) information for future use.

Using the Visual Attention Analyzer, Useful Field of View subtest 1, Hennessy (1995) found that speed of processing deficits in a sample of 1,235 California drivers accelerated after age 70. Comparing performance on this test to California Department of Motor Vehicle crash records, poor performance on the speed of processing subtest accounted for 2.8% of the variance in crash involvement ($p < 0.05$) for drivers age 70 and older, without adjusting for demographics or driving exposure. After adjusting for age, gender, and driving exposure in the group of drivers age 70 and older, performance on the speed of processing subtest accounted for 4.1% of the variance in crash involvement.

The impact of the decline in speed of processing with advancing age derives from its cross-cutting nature—it appears to mediate a number of other cognitive functions—and from its prevalence among older drivers. While keeping in mind that individual differences in (cognitive) ability increase with age, 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 70s and beyond (Cerella 1985).

Next, two complementary functions that are essential to safe driving performance and have been associated with significant age differences are *selective attention* and *divided attention*. 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. 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.

Pietras et al. (2006) found that older drivers with selective attention deficits had shorter time-to-collision values (5.60 s vs. 6.86 s), took longer to cross the roadway (5.42 s vs. 4.84 s), and had shorter safety cushions (the difference between time-to-collision and time to cross the roadway) than older drivers with no impairment in their selective attention capabilities. Their traffic entry judgments were made from an instrumented vehicle parked in an entry driveway perpendicular to a busy two-way, four-lane highway. Oncoming traffic entered the view of the participant approximately 1,000 ft 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.

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. Driving involves complex scenes with moving and/or distracting stimuli, plus the necessity of constantly dividing one's attention between central and peripheral vision. These attributes are not present in conventional visual field sensitivity tests. Another approach examining the "functional" or "useful" field of view involves the detection, localization, and identification of targets against complex visual backgrounds, often with distractors in the scene, and a limited time to process the display. Tests assessing the useful field of view are better predictors of driving problems than are standard visual field tests.

Ball et al. (1994) found that drivers with restrictions in their 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 $r = 0.55$. In an analysis of 278 drivers from this sample, McGwin et al. (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 with drivers with less than 40% reduction when the dependent measure was state-recorded crashes. 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 was 85.4%, with a sensitivity of 86.3% and a specificity of 84.3%.

Age-related deficits in selective attention may also explain older driver failure to detect pedestrians and other vehicles at intersections. Caird et al. (2005) used a change blindness method in their laboratory to assess turn decision accuracy. Change blindness—the inability to detect changes made to an object or scene during a flicker, or blink—was used in this study to assess visual attention. The study sample included 62 drivers distributed across four age groups: 18 to 25, 26 to 64, 65 to 73, and 75+. For intersections where pedestrians appeared, drivers age 65 and older had especially low accuracy scores compared with younger drivers, even when the pedestrians were in a crosswalk. Failure to detect the pedestrians may have led older drivers to decide that 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.

Drivers' difficulties in negotiating intersections also may reflect the divided attention demands they face in these situations. In their study of 1,876 Maryland drivers age 55 and older, referenced earlier, Staplin et al. [2003(*b*)] found that older subjects who scored poorly (took 300 msec or longer) on the useful-field-of-view subtest that measures divided attention 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 subtest were 2.48 times more likely to be involved in a crash and 1.67 times more likely to be cited for a moving violation. In the updated crash analysis conducted by Staplin et al. [2003(*a*)] that added 12 more months of prospective crash data, the odds ratio for at-fault crashes was 2.23.

Rubin et al. (2007) examined the relation of selective attention, divided attention, and processing speed to prospective crash involvement in a sample of 857 older drivers. Overall, they found that a useful field of view reduction 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, $p < 0.01$). After adjustment for miles driven, the hazard ratio increased to 2.21 (95% CI = 1.32–3.39, $p < 0.01$). 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, $p < 0.0001$). The hazard ratio for processing speed was 1.27 ($p < 0.04$), and for selective attention was 1.45 ($p < 0.22$).

An additional aspect of perceptual-cognitive function that has been identified as a significant predictor of crash risk is visuospatial ability. The ability to visualize missing information is valuable in many situations: when a stop sign is partially obscured by foliage; when only an arm or leg of a pedestrian stepping out from behind a parked car is visible to an approaching motorist; or when the leading edge of a potential conflict vehicle first appears at an intersection with a road or driveway where the sight triangle is restricted.

The Goode et al. (1998) study included two measures of *visuospatial* ability, the Rey–Osterrieth Complex Figures test, which involves first copying a complex figure and then attempting to draw the figure from memory, and the Visual Reproduction subtest of the Wechsler Memory Scale (WMS-VR), which requires memorization of a visual stimulus and construction of the stimulus from memory. Performance on these measures distinguished between 124 older drivers who had experienced one or more state-recorded at-fault crashes in the prior 5-year period from 115 crash-free older drivers. The WMS-VR had a sensitivity of 66.1% and a specificity of 52.2%. The Rey–Osterrieth test had a sensitivity of 50% and a specificity of 61.7%.

Lundberg et al. (1998) also employed the Rey–Osterrieth test to compare older, crash-involved drivers who had suspended licenses because of serious moving violations (running red lights, not yielding right-of-way rules, and not heeding stop signs) with older, non–crash–involved drivers whose licenses had been suspended for violations, and with older control drivers with clean driving records. The former group performed significantly worse on the visuospatial memory component of this test.

In the research with older Maryland drivers reported by Staplin et al. [2003(*b*)], those who scored poorly on the Motor Free Visual Perception Test–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. This measure depends on the visualization of missing information, by requiring the identification of which of four incomplete figures (line drawings) could be completed to match an example figure. Crash and violation history were obtained from the state motor vehicle administration. 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 a subsequent analysis by Staplin et al. [2003(*a*)] that looked at 32 months of prospective, plus 1 year of retrospective driving history data, drivers age 55 and older performing below the cut point for this measure were at 3.6 times greater risk of an at-fault crash.

Deficits in Psychomotor Ability

The physical capabilities (psychomotor 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. National estimates of the prevalence of age-associated functional impairments for physical mobility are available from studies such as the *National Health Interview Survey* (Pleis and Lethbridge-Çejku 2007). In the *National Health Interview Survey*, age was positively associated with an arthritis diagnosis and the presence of chronic joint symptoms. Forty-four percent of adults age 75 and older had chronic joint symptoms, and those ages 65 to 74 had an almost equal amount (43%); whereas percentages for those ages 45 to 64 dropped to 34%, and to 15% for those ages 18 to 44.

The relevance of such physical limitations for safe driving is indicated in a general sense by the findings of Diller et al. (1999). These researchers 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.

The specific age-related changes in psychomotor function of greatest concern for safe driving appear to be a loss of leg strength and range of motion, and reduced head/neck flexibility. These physical deficits have been linked to difficulties with pedal (brake) control and with visual search to the sides and rear of the vehicle, respectively; and associated increases in crash risk have been documented. Thus, despite the reduced physical demands for operating modern passenger and commercial motor vehicles, concerns remain about the safety impact of changes in physical function.

Zhang et al. (2007), in a study including studies of 1,039 drivers age 67 and older, found that those who reported three or more complaints of pain in the feet, hips, legs, or current treatment for arthritis, had significantly slower brake reaction speeds than drivers with no complaints of pain in these areas, in terms of both initial reaction speed and physical response speed. 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 it took for the foot to start moving from the accelerator until 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.

A study of 283 community-dwelling individuals ages 72 to 92 found that a measure of leg strength and mobility, the rapid-pace walk, was a significant ($p < 0.05$) predictor of who reported an "adverse driving event" in the year following testing (Marottoli et al. 1994). Adverse events included crashes, violations, and being stopped by police.

Next, the extent and effect of restricted head movement were investigated by Isler et al. (1997), for drivers in four age groups: under age 30, ages 40 to 59, ages 60 to 69, and age 70 and older. Their methodology required drivers arriving at the decision point of a T-intersection to judge the distance and speed of traffic approaching on the intersecting roadway, to find a safe gap in which to merge. In this situation, considerable head movement was needed to bring intersecting traffic into central vision, to support these perceptual judgments; and the oldest subjects exhibited an average decrement of approximately one-third of head range of movement compared with the youngest group of subjects. As a consequence, the oldest drivers could not bring oncoming traffic into central vision at distances exceeding 65 ft (20 m) without additional eye movements. Unfortunately, in addition to their restricted head movements, the oldest drivers also had restricted horizontal peripheral vision. 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.

Finally, there is solid evidence about the safety impact of these age-related physical limitations from the Maryland Pilot Older Driver Study [Staplin et al. 2003(*b*)]. This research included the rapid-pace walk as a measure of leg strength and mobility, plus a measure of head/neck rotation designed to determine whether an individual could look directly over his or her shoulder as needed to safely change lanes or merge; for the latter measure, the lower torso was fixed in place with a seatbelt, as when driving. Both of these measures were significant predictors of at-fault crashes in an observation period that included 1 year of retrospective crash data plus an average prospective observation interval of 20 months, for 1,876 drivers age 55 and older; their respective odds ratios were 2.64 (leg strength/mobility) and 2.56 (head/neck rotation).

STRATEGIES TO MAINTAIN SAFETY WITH AN AGING DRIVER POPULATION

Individual drivers, their employers, and society as a whole will benefit as new approaches are implemented to maintain safety in an aging workforce. Initiatives in three broad areas may hold promise in this regard: *remediation, accommodation,* and *prevention*.

The first option centers on deficits linked to a specific medical condition for which there is an intervention with proven effectiveness. These interventions should generalize well to commercial drivers, allowing them to realize the same benefits as those demonstrated for the general driving population. The second option targets individuals with identified deficits, employing strategies to help offset a particular diminished capability to an extent that they can continue to drive safely. The last option posits safety benefits from the use of validated screening tools to provide early warning of age-related declines in key safe driving abilities, to improve the potential for remediation or accommodation, while identifying operators who need an in-depth medical evaluation to allow determination of their health and/or job status. Evidence keyed to commercial driving applications, though limited, may be cited for the latter options.

Remediation

The option to remediate functional deficits tied to elevated crash risk is a preferable option, where available. A comprehensive review of countermeasure options targeting age-related functional decline completed in 2009 (Stutts et al. 2009) points to effective interventions for remediation of certain visual and psychomotor limitations experienced by normally aging drivers. The remediation of cognitive impairment is more problematic, though recent studies offer some promise in this area.

The most widely available, affordable, and effective countermeasure to improve vision is a refractive correction. Although no before–after studies to measure the safety gains from this intervention could be identified, it may be advocated simply based on the prevalence of the problem (acuity deficit) and the inexpensiveness of the solution. One of the early findings of the Salisbury Eye Study was that among the proportion of older individuals who had worse than 20/40 vision, more than half of them could be corrected just with glasses. A new development in this area also deserves mention: wavefront lenses. This technology provides higher-definition vision in the daytime and can significantly improve driver responses under nighttime conditions. According to research by the developer, drivers' ability to identify pedestrians at night increased by an average of 330 msec, or 30 ft sooner at 55 mi/h, when using wavefront lenses compared with conventional lenses (Haddrill 2008).

Age-related deficits in contrast sensitivity may also be remediated in many cases where this loss results from cataract formation. A reduction in crash risk following cataract removal surgery has been demonstrated (Owsley et al. 2002), including evidence that drivers with a cataract who underwent surgery and intraocular lens implantation had half the crash rate of drivers with cataract who did not undergo surgery (4.74 crashes per million miles of travel versus 8.95); this effect is most likely attributable to improvement in contrast sensitivity (Owsley et al. 2001). 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, which included the ability to detect and avoid hazards. Monestam and Wochmeister (1997) found that more than 20% of older adults returned to driving after cataract surgery. Conversely, those (older) adults who delay cataract surgery appear to be at greater risk of losing driving privileges (Leinonen and Laatikainen 1999).

The potential to remediate other conditions that impair vision is more limited. For MD, laser therapy can stabilize the condition in exudative cases, and certain medications have shown promise in actually improving vision for patients with this disease (Smith et al. 2007). For glaucoma, treatment can be either medical (eye drops) or surgical (laser); in either approach, the goal is to lower intraocular pressure, but the realistic expectation for these interventions is to slow the progression of the disease rather than to remediate it.

With regard to age-related physical limitations that have been linked to higher crash risk, it appears that deficits resulting from certain chronic conditions may be remediated through strength and flexibility exercises. Significant improvements in trunk rotation and shoulder flexibility following an 8-week exercise program led subjects measured at baselines 8 and 11 weeks to look more frequently to the sides and rear of their vehicle than control drivers who did not participate in the program (Ostrow et al. 1992).

Marottoli et al. (2007) reported on a study in which older drivers received a 12-week program of in-home exercises to do 15 minutes each day, 7 days a week, with a weekly in-home visit by a physical therapist. Exercises focused on axial/extremity condition, upper extremity coordination/dexterity, and gait abnormalities. On-road driving performance was measured at baseline and post-intervention for the treatment group and a control group. There was significant improvement in the targeted physical abilities for the treatment group compared with the control group, which translated to an 8% to 16% lower crash occurrence over a 2-year period. At follow-up, the intervention group also made 37% fewer critical errors (inattention, turning or changing lanes without looking, disobeying traffic signs or signals) than the control group.

In the arena of cognitive remediation, there is preliminary evidence that speed of processing training can yield sustained gains in performance on measures of visual attention, that translate to improved performance behind the wheel. Roenker et al. (2003) used a standardized on-road driving course to compare the performance of older drivers who completed a computer-based speed of processing regimen with two control groups on a number of risky maneuvers, including six opportunities for unprotected turns across traffic and nine left-turn entrances to a high-traffic road. The controls were a placebo group and a group who completed training on a part-task fixed-base driving simulator. After 18 months, the speed-of-processing training group maintained superior performance, compared with both control groups. The potential for this intervention to ameliorate crash risk among normally aging (i.e., not demented) older drivers will be examined carefully in future research.

Accommodation

The accommodation of age-related functional deficits can be accomplished through the use of *in-vehicle aids*, or through *education and training*. In-vehicle aids compensate for a diminished capability to execute some critical driving skill. A diminished sensory capability may be accommodated by aids that make information more accessible to the driver; aids that prioritize information or otherwise reduce task demands may, to some extent, compensate for diminished cognitive capability; and aids that assist in vehicle control actions may compensate for certain physical limitations. Training interventions, by comparison, are designed to enhance driver performance as the result of new knowledge or directed practice in a critical driving skill.

There is a vast literature describing adaptive equipment for private vehicles; the field of driver rehabilitation is among the fastest-growing subdisciplines for occupational therapists (see Stav et al. 2006). Similarly, reviews of programs and techniques for commercial driver training are widely accessible (e.g., Staplin et al. 2004). But only a single investigation has explicitly examined the efficacy of strategies to accommodate deficits in visual, cognitive, and psychomotor abilities known to influence performance or predict crash risk among older commercial drivers (Llaneras et al. 1998). A detailed review of this study follows.

The Llaneras et al. study was designed to first evaluate the independent effects of selected functional abilities on driving performance and safety, and then to develop and evaluate interventions targeted to key abilities for which deficiencies are common among older commercial drivers. The emphasis on independent effects is important, as a deficit in any single ability that significantly predicts performance or safety outcomes can establish the need for a countermeasure, and provide a theoretical basis to guide its development. Specific abilities measured by the research team included static and dynamic visual acuity, contrast sensitivity, useful field of view, field dependence, depth perception, selective attention, attention sharing, information processing, decision making, reaction time, multi-limb coordination, control movement precision, tracking, and range of motion. A detailed description of the methodologies used to obtain these measures of functional ability is presented in Llaneras et al. (1998).

The study sample included 107 commercially licensed (current CDL) truck drivers in five age cohorts: under age 50, ages 50 to 54, ages 55 to 59, ages 60 to 64, and age 65 and older. The age range in the sample was age 31 to age 76; these subjects had an average of 27 years of driving experience, including both long-haul and local, and averaged 61,000 miles per year. More than a dozen companies plus a number of independent owner–operators were represented in the sample.

Of the 15 abilities assessed for the study sample, 13 were found to degrade significantly with age. As a rule, differences were greatest when comparing the under age 50 group with the age 65 and older group. There were two notable exceptions among the psychomotor tests and the cognitive tests. Test results for multi-limb coordination showed that the age 65 and older group had the best performance of any age cohort; more than any other measure, this may be related to an integrated driving activity and the authors suggested that "experience may have compensated for any age-induced decrements." Also, the results for decision making showed that speed (measured by choice reaction time) decreases significantly with chronological age, but accuracy does not decrease. Each of the perceptual abilities measured showed a decline with advancing age, with the strongest bivariate correlation ($r = -0.51$) between age and useful field of view.

Driving performance data were collected using a TT150 Professional Truck Driving Simulator, configured as a cab-over, tandem-axel tractor with a 48-ft trailer carrying an 80,000-lb uniform load with a high center of gravity. Structured observations of driver behaviors (e.g., mirror checks, visual search, and speed control) by commercial drivers with 20 years of training experience, and performance measures obtained automatically by instruments in the simulator (speed and space management, fuel economy), were collected as study participants drove a standardized 10-mile course. This course included a variety of road conditions and driving tasks, such as turns at intersections, straight driving along interstate highways and along two-lane rural roads, lane changing, and responses to hazards (a sudden loss of air brake pressure).

Based on a step regression analysis using age and the results of the functional ability measures to predict scores on the driving performance measures obtained in the simulator, Llaneras et al. (1995) developed a model estimating the relative contributions of age versus functional change to an individual's overall driving skill and to performance on discrete tasks such as negotiating curves, executing turns, shifting, and fuel management. Within this model, a hierarchical analysis of direct, indirect, and total effects associated with age and with the strongest predictors within each domain of functional ability revealed that age does not directly influence the performance of commercial drivers, but exerts a moderate indirect effect through age-related changes in perceptual, cognitive, and psychomotor abilities. These analyses did reveal significant direct effects on driving performance for (1) psychomotor ability, as measured by range of motion scores; (2) cognitive ability, as measured by accuracy on attention sharing (divided attention) tasks; and (3) perceptual ability, as measured by depth perception, field dependence, and useful field of view scores. Within these functional domains, perceptual ability contributed the most to overall driving competence.

Finally, the extent to which four interventions targeted to age-related deficits in these most influential measures of functional ability could enhance driving performance was examined. The four interventions included three compensatory and one training intervention. The compensatory interventions were a prescriptive on-board navigational system using auditory commands, an advanced auditory warning system that monitors brake system status, and an automatic transmission. The training intervention included instruction and practice on visual search and scanning techniques keyed to the safe execution of turning maneuvers. A treatment group received all four interventions before driving a test course in the Commercial Truck Driving Simulator, while a matched comparison group relied on a paper map with written instructions (identical to the auditory instructions) for navigation, a dummy warning light on the simulator's instrument console for warning about an air brake pressure system malfunction, and a nine-speed manual transmission. In addition the comparison group was not exposed to the search-and-scanning training.

The individual effects of each intervention were assessed on the basis of unique performance variables associated with each countermeasure. For example, the effect of the auditory navigation system was assessed in terms of navigational errors, adjusting vehicle speed to external conditions, and adherence to traffic signs and signals; the effect of the auditory warning system was assessed by means of detection rates for a brake system malfunction; the effect of the automatic transmission was assessed in terms of variables including curve negotiation, executing turns, lane position, fuel management, and brake temperature; and search-and-scanning training effectiveness was assessed in terms of visual search behavior and mirror checks. Training effectiveness also was assessed in terms of several overlapping measures including executing turns and adherence to traffic signs and signals.

The results of this countermeasure evaluation study did not demonstrate benefits for every intervention on every dependent variable. Drivers equipped with the automatic transmission had superior performance during negotiation of curves, but worse fuel economy and higher brake temperatures. However, with respect to overall driving performance, and especially for the more safety-related outcome measures, this research, though exploratory, produced very encouraging findings. Llaneras et al. (1998) conclude that compensatory and training-oriented interventions can accommodate age-related declines in many critical driving abilities. They also suggest that, based on evidence from this work, older commercial drivers may benefit substantially from physical therapy to improve range of motion, and that interventions that improve perceptual ability may enhance the performance of commercial drivers age 55 and older.

Prevention: A Case Study

One additional recommendation from the research carried out by Llaneras et al. (1998) was to develop screening systems that incorporate measures of functional ability associated with safe driving. Such screening tools—if properly validated, easy to administer, standardized, and perceived to be fair by the drivers who are evaluated—could mark an important step toward the prevention of commercial motor vehicle crashes. If drivers in the early stages of functional loss can be reliably identified, this information might also make it possible for a larger percentage of aging operators to keep driving safely longer, by taking advantage of the remediation and accommodation options discussed earlier. A case study of an early adopter of driver functional screening provides an example of how such screening can be implemented.

The subject of this case study is Corry Auto Dealers Exchange (Corry ADE), an auction business in northwest Pennsylvania (Erie County) that employs approximately 75 drivers, some holding a CDL. (This case study description is based on an April 3, 2009, interview with Tim Swift, Vice-President and General Manager of Corry Auto Dealers Exchange. Mr. Swift also became President of the National Independent Automobile Dealers Association in June 2008.) Their workforce, which includes a significant proportion of drivers age 50 and older, is involved in operations on their sale lot and in transporting vehicles to and from destinations around the Northeastern, Mid-Atlantic, and upper Midwest states.

There is a strong safety culture at Corry ADE. Signs emphasizing "Think Safety—It's Everybody's Job" are posted prominently around the premises. Safety videos provided by the National Auto Auction Association are used for driver training. In 2007, at the suggestion of their insurance agent and consultant for risk management, the firm instituted a routine functional screening program. This screening program is administered at the time of first hire, then annually, for all drivers regardless of age.

The screening program used by Corry ADE is a computer-based version of the test protocol validated against at-fault crashes for drivers age 55 and older in Maryland [see Staplin et al. 2003(*b*)]. It measures the following functional abilities: high and low contrast visual acuity; head/neck/torso flexibility (range of motion); leg strength and mobility; visual information processing; visual search (with divided attention); visualization of missing information; and working memory. These measures are administered by a company staff member who was a former safety instructor for the state of Pennsylvania; however, no special training, background, or credentials are necessary to run the screening program, which uses onscreen text with accompanying narration to present test instructions.

The screening program requires about half an hour, not counting practice time for drivers who are unfamiliar or uncomfortable with using a personal computer. Although this program can be administered using a touch screen interface, Corry ADE drivers use a mouse to respond to the various functional ability tests. Not surprisingly, older drivers are more likely to need practice with the mouse before completing the screening measures. As a practical matter, facility with a computer mouse can affect scores on only a single measure (visual search); but comfort with test methods helps ensure that (older) drivers do not perceive an age bias when functional screening is introduced.

The management of Corry ADE has implemented driver functional screening (as one component of their safety program) for 2 years, and sees a clear value in the information it provides. Analyses relating collisions, either on the lot or during transport of vehicles to or from other locations, to scores on the functional screening battery remain pending, however.

The information provided by functional screening has definite limitations. A poor screening outcome does not mean that an individual cannot drive safely; but it does indicate a priority for follow-up, and a focus for in-depth diagnostic testing to determine the reason for the functional loss, and the potential for treatment. Neither does a good screening outcome mean that a driver will not crash; but it provides some assurance that he or she is not at increased risk of crashing owing to functional impairment. With these limitations in mind, the potential benefits of driver functional screening to promote safety and advance risk management in commercial vehicle operations appear substantial.

CHAPTER THREE

TRUCK CARRIER INDUSTRY

LARGE TRUCK CRASH CAUSATION STUDY

Knipling (2009) reports that nearly all long-haul commercial drivers are between middle 20s to middle 60s in age. The older driver population of commercial vehicles is, therefore, younger than the older driver population at large. The *Large Truck Crash Causation Study* (LTCCS) (2007) reports that in multi-vehicle crashes, older commercial drivers (over age 51) were found at fault less than any other age group. Furthermore, of all 10-year age cohorts in the LTCCS, truck drivers ages 61 to 70 "had the lowest percentage of critical driver errors, by a wide margin" (Knipling 2009, p. 80).

INDUSTRY'S VIEW

Several carriers and other industry professionals were contacted to ascertain if the industry is treating older commercial drivers differently from other commercial drivers. The carriers and their representatives were promised anonymity because of the possible sensitivity of the subject matter.

Five of the carriers are national in scope. They have drivers on the road for extended lengths of time and operate in all the 48 contiguous states. The sixth company is a regional carrier whose drivers are rarely on the road for more than 4 days at a time. The primary person interviewed in every case was a human resources person. We also did a few informal interviews with current and former commercial drivers and safety experts.

For our questions, we identified the older driver as an active commercial driver over age 60. The questions were:

1. Do you have older drivers currently employed?
2. Do you have evidence that older drivers are over-involved in accidents or close calls?
3. Do you have any evidence that older drivers are more likely to be cited for driving or safety violations?
4. Do you assign routes to your older drivers differently than to your other drivers?
5. In your experience, do you believe that older drivers need to be regulated or licensed differently than young commercial drivers?

Somewhat surprisingly, of the six carriers interviewed none knew how many drivers it had over age 60. In all cases, human resource personnel stated that they did not keep age data. The few safety officers who were questioned reported that they rely on each driver's medical and driving records to make any decisions about driving assignments. Officially, at least, age of the driver is not part of the decision process.

There was remarkable unanimity across the interviewees. Officially, at least, older drivers are not seen as a unique subset of the commercial driver population. They are not treated differently in terms of hiring, assignments, or schedules. Some interviewees pointed out that older drivers tend to be the more senior drivers in the company and may, by virtue of seniority, have better assignments (i.e., assignments with less stress and more convenient schedules). There was no support for different licensing requirements for older drivers.

In general discussions with knowledgeable professionals in the carrier community, some observations were generally agreed. Because older drivers are most often also senior drivers, they may also be driving shorter or otherwise less demanding routes. Older drivers know when they are tired and adjust their driving accordingly. This observation is supported by the data that show older commercial drivers have fewer fatigue-related crashes and those that do occur tend to be in the afternoon rather than in the early morning hours (Knipling 2009). As one interviewee put it, "Experience and judgment trump any limitations that aging may cause."

We could find no evidence of any carrier hesitating to hire or keep older drivers. For the people managing the day-by-day operations of the trucking industry, older drivers are not perceived as providing additional risks to trucking safety.

CHAPTER FOUR

CONCLUSIONS

GENERAL FINDINGS ON OLDER DRIVERS

The literature review makes clear that aging has a profound effect on the human mind and body, with a present emphasis on changes known to impair drivers' capabilities in ways that are recognized as crash risk factors. However, much of that literature is based on research performed on significantly older persons than one finds in the commercial driver population. Even for the general driving population, it is uncommon to find studies showing a significant increase in crash risk for persons age 70 or younger.

The literature review also suggests that even with the physical and cognitive changes in older persons, older drivers can often compensate for those changes by making better decisions and demonstrating better judgment while driving. The Llaneras et al. (1995) research, which studied active Commercial Driver License (CDL) drivers of all ages, showed that drivers over age 60 made fewer errors and had fewer near misses than their younger counterparts. Although this study was conducted in a driving simulator, feedback from industry indicates that these data support the general view of the older commercial driver.

GENERAL FINDINGS ON OLDER COMMERCIAL DRIVERS

Although the research data on older persons and, older drivers in general, are quite broad, the research findings for older *commercial* drivers are quite limited. The Llaneras et al. (1995) study noted earlier strongly suggests that healthy, active older commercial drivers need not provide an exaggerated risk to traffic safety. Although counterintuitive, both the research and the large truck crash data support this stance. Most important is the evidence showing that loss of function for *any* driver underlies a higher risk of crash causation, regardless of age.

SUMMARY

This draft final report presents the results of CTBSSP MC-18 entitled: *Older Commercial Drivers: Do They Pose a Safety Risk?* This report provides a knowledge base regarding age-related changes in the basic functional abilities needed to drive safely that can assist industry and labor practitioners in promoting safer commercial operations. It may also inform the broader commercial vehicle safety community and the FMCSA in developing policies and regulations that protect public safety without penalizing drivers on the basis of their age.

This report provides the following:

- Statement of the background and the problem that brought about this particular project.
- A literature review on changes in medical (functional) fitness to drive that affect older drivers generally and older commercial drivers specifically.
- The results of a series of structured interviews with carriers and others in the trucking industry regarding older commercial drivers.
- Conclusions and suggestions.

The synthesis team conducted a comprehensive literature review on the topic of age as it pertains to driving. The team also planned surveys of commercial truck carriers, motor coach companies, school bus associations and companies, industry organizations (e.g., ATA), insurance companies, state departments of transportation, and other relevant organizations. However, recent surveys of the trucking industry have been hampered by low response levels. With the concurrence of the synthesis sponsor, the FMCSA, the team opted for in-person and telephone interviews to determine whether industry safety managers and state motor vehicle administrators perceive a need for any unique testing of older commercial drivers.

The literature review worked from general findings about the physiological and psychological effects of aging, to the specific literature pertaining to aging effects on driving, and finally to specific literature on older commercial drivers. The review also looked for current documentation of older commercial driver safety data, policies, or local regulations pertaining to older commercial drivers, and any findings in Europe, Asia, or Australia relevant to this synthesis. To the extent that medical conditions and medications are singled out for discussion in this review, it is based on their prevalence in the overall aging population, not on the results of epidemiological research conducted strictly within the older commercial driver population.

The literature review makes clear that aging has a profound effect on the human mind and body, with a present emphasis on changes known to impair drivers' capabilities in ways that are recognized as crash risk factors. However, much of that literature is based on research performed on significantly older persons than one finds in the commercial driver population. Even for the general driving population, it is uncommon to find studies showing a significant increase in crash risk for persons age 70 or younger.

The literature review also suggests that, even with the physical and cognitive changes in older persons, older drivers can often compensate for those changes by making better decisions and demonstrating better judgment while driving. The Llaneras et al. (1995) research, which studied active CDL drivers of all ages, showed that drivers over age 60 made fewer errors and had fewer near misses than their younger counterparts. Although this study was conducted in a driving simulator, feedback from industry indicates that these data support the general view of the older commercial driver.

Although the research data on older persons and older drivers in general are quite broad, the research findings for older *commercial* drivers is quite limited. The Llaneras et al. (1995) study noted previously strongly suggests that healthy, active older commercial drivers need not provide an exaggerated risk to traffic safety. Although counterintuitive, both the research and the large truck crash data support this stance. Most important is the evidence showing that loss of function for *any* driver underlies a higher risk of crash causation, regardless of age.

CONCLUSIONS

The synthesis findings suggest that older persons who are currently commercial drivers pose no greater safety risk than their younger and middle-aged counterparts.

Some decline—which varies greatly from individual to individual—in the visual, cognitive, and psychomotor abilities needed to drive safely is inevitable with normal aging, with the diseases that are more common among older people, and with the medications used to treat them. Therefore, as the number of older persons, including professional truck drivers grows larger, it is important that crash data continue to be monitored for any trends that differ from these findings.

The need for minimum qualifications for medical fitness to drive that are evidence-based, and are fairly and consistently applied, is widely recognized. However, the literature review and interviews conducted for this study show no reason that older commercial drivers should be treated differently by CDL testing and licensing jurisdictions.

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Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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