

UMTRI-2012-5

FEBRUARY 2012

# HAS THE TIME COME FOR AN OLDER DRIVER VEHICLE?

---

DAVID W. EBY  
LISA J. MOLNAR



HAS THE TIME COME FOR AN OLDER DRIVER VEHICLE?

David W. Eby  
Lisa J. Molnar

The University of Michigan  
Transportation Research Institute  
Ann Arbor, Michigan 48109-2150  
U.S.A.

Report No. UMTRI-2012-5  
February 2012

1. Report No. UMTRI-2012-5		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Has the Time Come for an Older Driver Vehicle?				5. Report Date February 2012	
				6. Performing Organization Code 383818	
7. Author(s) David W. Eby and Lisa J. Molnar				8. Performing Organization Report No. UMTRI-2012-5	
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.				10. Work Unit no. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address The University of Michigan Sustainable Worldwide Transportation				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplementary Notes The current members of Sustainable Worldwide Transportation include Autoliv Electronics, China FAW Group, General Motors, Honda R&D Americas, Meritor WABCO, Michelin Americas Research, Nissan Technical Center North America, Renault, Saudi Aramco, and Toyota Motor Engineering and Manufacturing North America. Information about Sustainable Worldwide Transportation is available at: <a href="http://www.umich.edu/~umtriswt">http://www.umich.edu/~umtriswt</a>					
16. Abstract The population of the world is growing older. As people grow older they are more likely to experience declines that can make operating a personal automobile more difficult. Once driving abilities begin to decline, older adults are often faced with decreased mobility. Due to the preference for and pervasiveness of the personal automobile for satisfying mobility needs, there is a global necessity to keep older adults driving for as long as they can safely do so. In this report we explore the question: Has the time come for an older driver vehicle? Great gains in safe mobility could be made by designing automobiles that take into account, and help overcome, some of the deficits in abilities common in older people. The report begins by providing a background and rationale for an older driver vehicle, including discussions of relevant trends, age-related declines in functional abilities, and the adverse consequences of decreased mobility. The next section discusses research and issues related to vehicle design and advanced technology with respect to older drivers. The next section explores crashworthiness issues and the unique requirements for older adults. The following section discusses the many issues related to marketing a vehicle that has been designed for older drivers. The report concludes that there is a clear global opportunity to improve the safety, mobility, and quality of life of older adults by designing vehicles and vehicle technologies that help overcome common age-related deficits. The marketing of these vehicles to older consumers, however, will be challenging and will likely require further market research. The development of vehicle design features, new automotive technologies, and crashworthiness systems in the future should be guided by both knowledge of the effects of frailty/fragility of the elderly on crash outcomes, as well as knowledge of common driving-related declines in psychomotor, visual, and cognitive abilities. Design strategies that allow for some degree of customization may be particularly beneficial. It is clear that training and education efforts for using new vehicle features will need to be improved.					
17. Key Words older adults, vehicle design, crashworthiness, marketing				18. Distribution Statement Unlimited	
19. Security Classification (of this report) None		20. Security Classification (of this page) None		21. No. of Pages 72	22. Price

## **Acknowledgments**

This research was supported by Sustainable Worldwide Transportation (<http://www.umich.edu/~umtriswt>). The current members of Sustainable Worldwide Transportation include Autoliv Electronics, China FAW Group, General Motors, Honda R&D Americas, Meritor WABCO, Michelin Americas Research, Nissan Technical Center North America, Renault, Saudi Aramco, and Toyota Motor Engineering and Manufacturing North America.

The authors thank Michael Sivak, Renée St. Louis, Jonathan Rupp, and Robert Sweet from UMTRI for their comments on this report. The authors also thank Jan Aase, John Combest, Jim Keller, Yves Page, Steve Rouhana, Scott Schmidt, Robert Strassburger, and Carl Wellborn for sharing their insights and helping us focus on the issues that were most relevant for this report. However, the authors are responsible for the final content of the report.

# Contents

Acknowledgments.....	ii
Introduction.....	1
Background and Rationale for an Older Driver Vehicle .....	2
The World’s Population is Aging .....	2
Dependence on the Personal Automobile for Mobility .....	3
Licensing Trends.....	3
Driving Trends .....	4
Self-Regulation .....	5
Crashes .....	5
Age-Related Declines in Functional Abilities .....	10
Psychomotor .....	10
Visual.....	11
Cognitive .....	12
Fragility/Frailty.....	12
Consequences of Driving Reduction and Cessation .....	13
The Need for a Vehicle Designed for the Older Driver.....	14
Vehicle Design and Advanced Technology for Older Drivers.....	15
Adaptive Devices .....	15
Vehicle Design.....	16
Ingress/Egress.....	16
Seating .....	17
Visibility .....	17
Cargo Areas .....	17
Dashboard Controls .....	18
Advanced Technology .....	18
ADAS .....	19
IVIS .....	21
A Holistic Approach to Designing Vehicles for Older Drivers .....	22
Crashworthiness for Older Adults .....	24
Crash/Injury Patterns of Older Drivers .....	24

Type of Crash .....	24
Severity of Injury.....	25
Patterns of Injury .....	26
Challenges for Improving Crashworthiness.....	28
Country-Specific Differences with Implications for Crashworthiness .....	30
Advancements in Crashworthiness .....	30
Structural Design .....	31
Seat Belts .....	31
Airbags .....	34
Marketing Vehicles to Older Adults .....	35
Overview of Older Consumer Market .....	35
Older Driver Vehicle Purchasing Decisions .....	39
Vehicle Marketing to Older Consumers .....	41
Marketing of Products Other Than Vehicles .....	42
Discussion and Recommendations .....	45
References.....	47

## **Introduction**

The population of the entire world is growing older. This trend is expected to continue for the next several decades. In many countries, driving a personal automobile will remain the primary (or at least a very important) mode for maintaining mobility. It is also expected that the next cohort of older drivers will more likely be keeping their licenses longer and driving more than the current cohort. As people grow older they are more likely to experience medical conditions and take medications that can make operating a personal automobile more difficult. Even though many older drivers voluntarily self-regulate their driving to the times and places that they feel most comfortable, crash rates (especially fatal crash rates) per licensed driver and per population are higher for older drivers than for any other age group except teenage drivers. Once driving abilities begin to decline, older adults are often faced with a decreased ability to travel to the places that they both want and need to go, due largely to the lack of non-driving options needed for personal mobility. There are a number of documented adverse consequences associated with decreased mobility in older adulthood, including decreased quality of life. Thus, due to the preference for and pervasiveness of the personal automobile for satisfying mobility needs, there is a global necessity to keep older adults driving for as long as they can safely do so.

In this report we explore the question: Has the time come for an older driver vehicle? Although the challenge of keeping older adults safely driving will require a multidisciplinary approach, great gains in safe mobility could be made by designing automobiles that take into account, and help overcome, some of the deficits in abilities common in older people. The paper begins by providing a background and rationale for an older driver vehicle, including discussions of relevant trends, age-related declines in functional abilities, and the adverse consequences of decreased mobility. The next section of the paper discusses research and issues related to vehicle design and advanced technology with respect to older drivers. The next section explores crashworthiness issues and the unique requirements for older adults. The following section discusses the many issues related to marketing a vehicle that has been designed for older drivers. The paper concludes with a discussion and recommendations.

## Background and Rationale for an Older Driver Vehicle

### The World's Population is Aging

Late in 2011 the world's population soared past 7 billion people, despite global decreases in birth rates (United Nations Population Fund, UNFPA, 2011). According to the UNFPA (2011), the dramatic increase in global population over the last several decades has been driven largely by decreases in infant mortality (133 deaths per 1,000 births in 1950s to 46 deaths per 1,000 births during the years 2005 through 2010) and increasing life expectancy (from 48 years in the 1950s to 68 years in 2010). The world's population is older today than at any other time in history. The proportion of older adults is expected to continue to increase faster than any other segment of the global population. Projections from the United Nations (2009) show that the global proportion of people age 60 and older was 8% in 1950, 11% in 2009, and is expected to be 22% in 2050. These proportions are even greater for more developed countries where by 2050 one-third of each country's population is expected to be age 60 or older. Table 1 shows the percentage of population that is age 60 or older for a number of selected countries.

Table 1  
Percent of population that is age 60 or older and world ranking  
by country (United Nations, 2009).

Country	% Country Population Age 60 and Older	World Ranking (Out of 196)
Japan	29.7	1
Sweden	24.7	4
France	22.7	14
Canada	19.5	30
Australia	19.1	33
United States	17.9	43
China	11.9	65
Brazil	9.9	79
India	7.4	105
Qatar	1.9	196

In many countries, such as the U.S., the aging of the population will be also driven by the aging of the post-war baby boomers who began turning age 65 in 2011 (Molnar & Eby, 2009). According to the U.S. Census Bureau (2008), the number of Americans age 65 and older is projected to grow from about 40 million in 2010 to more than 88 million in 2050. In terms of the percentage of the total population, those age 65 and older will account for about 20% of the population in 2050, up from about 13% in 2010. Even larger increases are expected for the oldest-old—those age 85 and older. This age group is expected to grow from about 5.8 million in 2010 (1.9% of the U.S. population) to 19.0 million in 2050, when they will account for 4.3% of the population (U.S. Census Bureau, 2008). Similar increases are expected for many other developed countries.

### **Dependence on the Personal Automobile for Mobility**

As the global population ages, there will be an increased preference for the automobile to meet mobility needs. In the U.S. and in many other countries, the baby boomers consider driving to be vital to their independence and well-being (Molnar & Eby, 2009). Indeed, in many countries, older adult mobility is closely linked to the personal automobile, either as a driver or a passenger. This linkage partly results from the lack of transportation alternatives (Kostyniuk, Shope, & Molnar, 2000) and partly from the “driving culture” within which baby boomers grew up. Furthermore, during the years in which baby boomers were first becoming licensed to drive (about 1961-1981), changes in family composition, the tendency to move out of urban areas, the increased affordability of automobiles, and the development of extensive roadway systems made the personal automobile the preferred mode for personal travel (McGuckin & Srinivasan, 2003).

### **Licensing Trends**

Coincident with the increase in both the number and proportion of older people will be an increase in the number of older people who are holding licenses and driving. Data from the U.S. show that more than 90% of men over age 65 hold a license and more than 80% of women in this age group hold a license (Federal Highway Administration, 2008), with older women showing large increases in licensure over the past decade. In

the U.S., licensure rates for older women are approaching the rate for older men and this trend is expected to continue (Burkhardt & McGavock, 1999).

An increase in the number of older adults who hold a driver license is also occurring globally. A recent report by Sivak and Schoettle (2011) explored changes in the age composition of drivers in 15 countries. The study found that the percentage of older adults who held driver licenses increased in every country studied over the past few decades. In some countries these increases were quite large. For example, the percentage of adults age 70 and older in Sweden with a driver's license increased from about 28% in 1983 to about 72% in 2008 (Sivak & Schoettle, 2011). These trends will likely continue.

Older adult licensing trends are highly influenced by the older adult driver licensing policy in a country. In the U.S., no state has a policy that prohibits a person from getting a license based on age (see Molnar & Eby, 2005). In China, however, older adults are prohibited from obtaining a license after age 70 (Zhang, 2011, personal communication), so in China there are no licensed older drivers.

### **Driving Trends**

Not only will there be a larger proportion of older drivers holding licenses in the future, these drivers will likely be driving more trips and longer distances. According to the National Household Travel Survey (NHTS) in the U.S., the average number of trips per day per older adult increased from 2.4 in 1990 to 3.2 in 2009 (Santos, McGuckin, Nakamoto, Gray, & Liss, 2011). Older adults also seem to be traveling longer distances than in the past, although this trend may be changing. When the 2009 NHTS daily-miles-traveled data are compared with 1990 data, daily miles traveled increased from 18.4 miles to 24.0 miles (Santos, et al. 2011). However, when compared with 2001 numbers, the average daily number of miles traveled has decreased not only for those age 65 and older, but also for all age groups. It is possible that this recent downward trend is related to the increasing cost of fuel or a saturation effect, where increasing income no longer translates into more driving when incomes are high.

Increased driving among older people also seems to be a trend in other countries, although there are few published data available. For example, a study of German driving assessed changes in driving between 1982 and 2002 (Buehler & Nobis, 2010). The study

found that the daily travel distance increased from 10 to 15 km, and the percentage of trips by personal automobile increased from 28% to 47% for people age 65 and older. Although travel data from other countries are limited, the International Transport Forum (ITF) of the Organisation for Economic Co-operation and Development (OECD) predicts that car ownership and travel will increase rapidly in many non-OECD countries such as China, Brazil, and India (ITF, 2011).

### **Self-Regulation**

It is well-known that as people age, many begin to change when, where, and how they drive. The literature shows that older drivers are more likely to report avoiding the following driving scenarios: nighttime, inclement weather, high traffic times, urban areas, and highways (Gallo, Rebok, & Lesikar, 1999; Kostyniuk, Shope, & Molnar, 2000; Stamatiadis, Taylor, & McKelvey, 1991; Chipman, MacGregor, Smiley, & Lee-Gosselin, 1993; Hakamies-Blomqvist & Wahlström, 1998; Ball et al., 1998). Studies also show that older drivers are more likely than younger drivers to report the following changes in how they drive: driving slower, driving more often with a passenger, avoiding unprotected left turns across traffic, needing larger traffic gaps for merging and lane changing, and more frequent use of a seat belt (Ball, et al., 1998; Eby, Molnar, & Olk, 2000; Hakamies-Blomqvist & Wahlström, 1998; Keskin, Ota, & Katila, 1989; Van Wolffelaar, Rothengatter, & Brouwer, 1991). These changes in driving patterns result in part from the lifestyle changes that accompany growing older, such as children moving out of the house, retirement, changes in income status, and home relocation (Hakamies-Blomqvist, 2004). The changes in driving patterns can also be an adaptive response to perceived declines in driving abilities, often expressed in terms of a lack of comfort while driving in certain conditions. These latter driving changes to increase subjective driving safety/comfort have been termed driving self-regulation (Molnar & Eby, 2008). Self-regulation of driving among older adults is an important phenomenon to consider when designing technology and vehicle design features for an older adult.

### **Crashes**

Whether or not older adults are at a high risk of being in a crash, in particular a fatal crash, continues to be a topic of debate in the older driver literature (see e.g.,

Alvarez & Fierro, 2008; Eby, Molnar, & Kartje, 2009; Hakamies-Blomqvist, Raitanen, & O’Neill, D., 2002; Langford, Methorst, & Hakamies-Blomqvist, 2006; Staplin, Gish, & Joyce, 2008). The debate is fueled in part by how crash rates are calculated and the selection of age groups. Figure 1 shows driver fatality rates by age group in the U.S. by miles driven, licensed drivers, and population. When rates are expressed by population, driver fatality rates are highest for young drivers and slightly elevated for drivers over age 75. Older adults, however, are less likely to hold a license and drive less than those in the middle age groups (Eby, Molnar, & Kartje, 2009). In the U.S., young drivers also are less likely to hold a license and drive less than those in the middle age groups. Thus, when fatality rates are calculated by licensed driver and by miles driven, the rates for both the youngest and oldest drivers are significantly elevated when compared with rates for drivers age 30-65 years, suggesting higher crash rates for these age groups. Figure 1 also shows that, at least in the U.S., driver fatality rates do not begin to increase until about age 70 or 75. These increases could be masked if the fatal crash data were combined for all drivers age 65 and older.

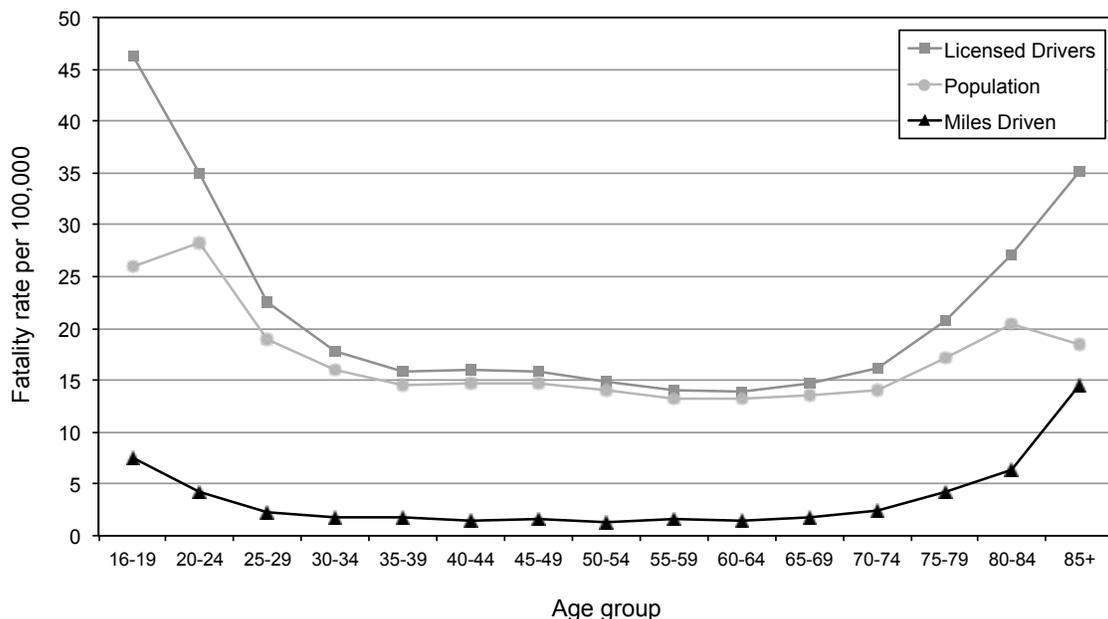


Figure 1: U.S. motor vehicle driver fatality rates by age group, 2008 (Insurance Institute for Highway Safety, 2007; FHWA 2008).

Figure 2 shows population-based fatal crash rates by age group for 12 selected countries from the *International Transport Forum IRTAD Road Safety 2010 Annual Report* (OECD/ITF, 2011). (Crash rates by distance driven or by licensed driver were not available for these countries.) Note that there is great variability in these curves, but in most of the countries the fatal crash rates for drivers age 65 and older are higher than for drivers age 25-64, suggesting that older adults have a higher fatal crash risk in many countries across the globe.

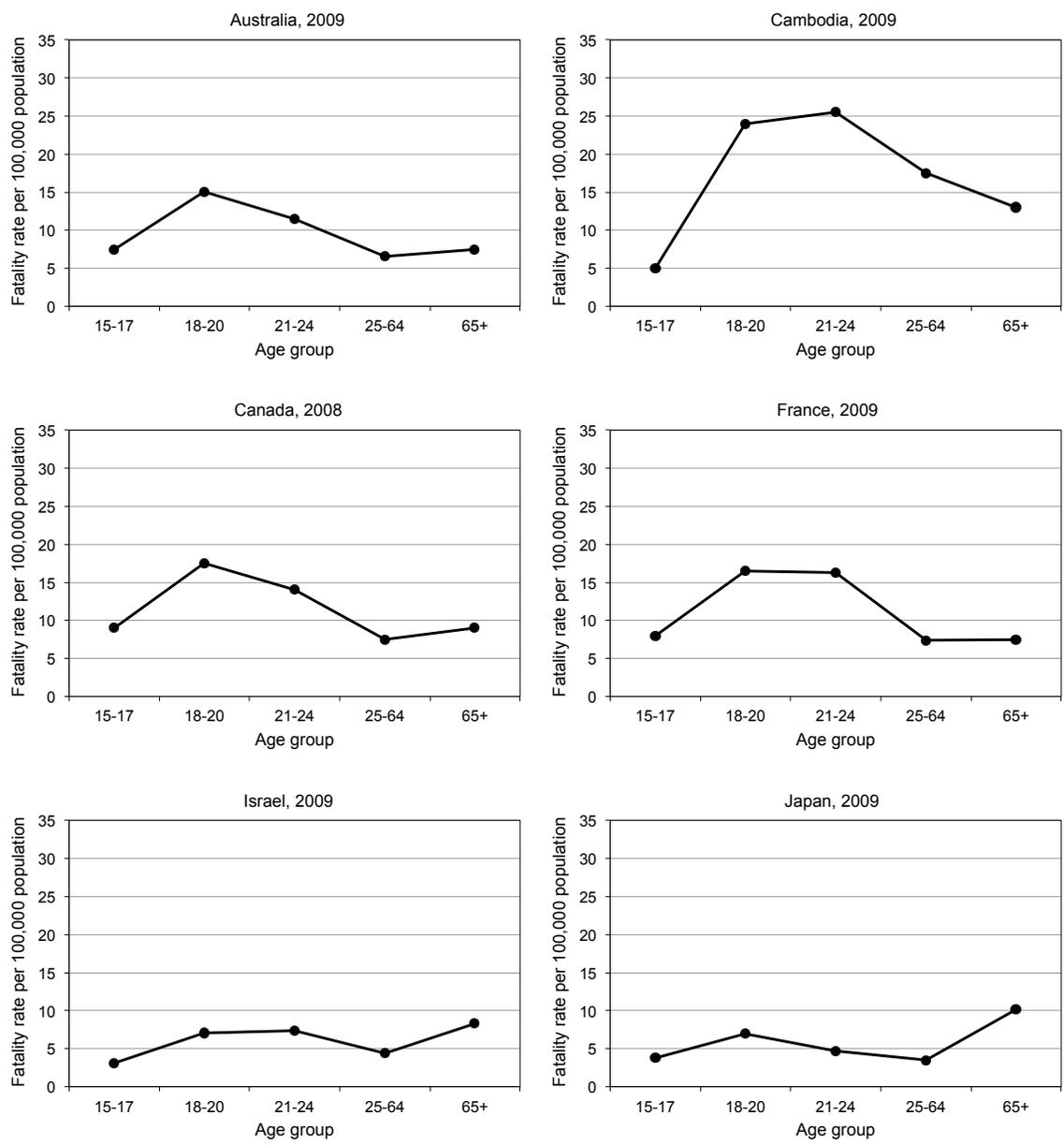


Figure 2. Fatal crash rates for drivers by age group in 12 countries (OECD/ITF, 2011).

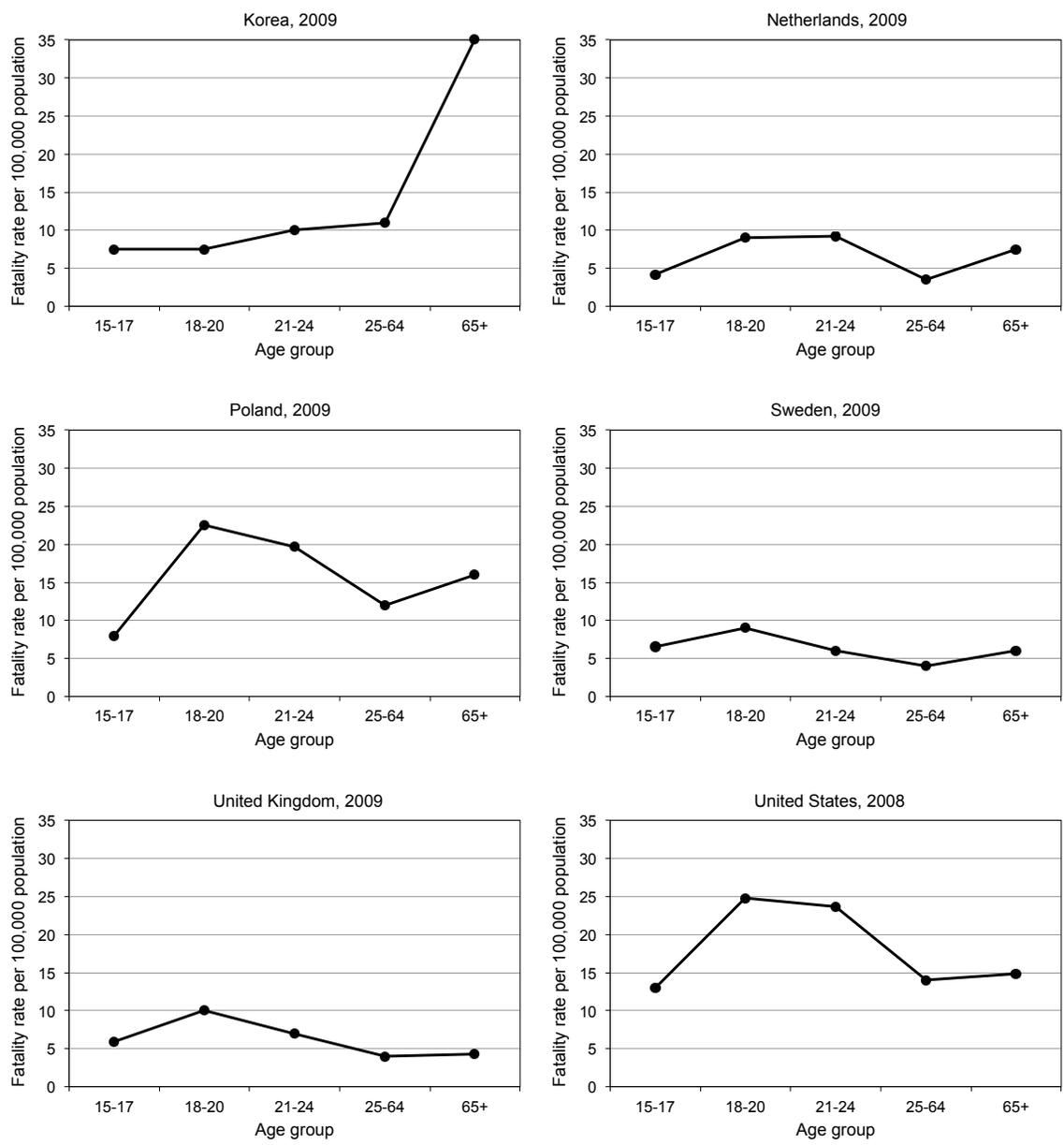


Figure 2 (continued). Fatal crash rates for drivers by age group in 12 countries (OECD/ITF, 2011).

## **Age-Related Declines in Functional Abilities**

The complex task of driving involves several types of functional abilities, broadly categorized as psychomotor, visual, and cognitive. Frailty is also associated with growing older. As people age, they may experience declines in these functional abilities as a result of age-related medical conditions, the medications used to treat these conditions, and/or the normal process of aging. Declines in any of these abilities can make safe driving more difficult.

### *Psychomotor*

Psychomotor functioning is a person's ability to coordinate, control, and orient parts of his or her body (Kelso, 1982). Declines in psychomotor functioning can increase the difficulty of vehicle ingress and egress, using vehicle controls, and taking cargo in and out of the trunk (Herriotts, 2005; Sivak et al. 1995). Several aspects of psychomotor functioning can decline with increasing age. One widely recognized age-related psychomotor change is increased reaction time among older adults (Department of Transport, 2001; Klavara & Heslegrave, 2002). Decreasing reaction time can result from a slowing of cognitive functions, joint stiffness, and muscle weakness. Another ability that can decline with age is flexibility, the range through which a joint or muscle can move. Flexibility declines can result from a variety of conditions, particularly arthritis, lack of exercise, or a decrease in overall activity levels (States, 1985). Loss of flexibility in the limbs may affect a driver's ability to quickly shift his or her right foot from the accelerator to the brake or to safely maneuver the vehicle through turns and around obstacles (Staplin, Lococo, Stewart, & Decina, 1999). Lack of flexibility in the neck can make it difficult for drivers to check mirrors, look over their shoulders before merging or changing lanes, observe blind spots, and back up (Janke, 1994; Malfetti, 1985; Marottoli et al., 1998; Staplin et al., 1999.)

Coordination of movement is also an important psychomotor ability needed for driving (Wheatley, Pellerito, & Redpenning, 2006) and tends to decline with age (Anshel, 1978; Marshall, Elias, & Wright, 1985; Welford, 1959). Declines in coordination can make it difficult for a driver to manipulate vehicle controls and to effectively perform moment-to-moment control of the vehicle, such as lane keeping. Finally, one clear effect

of aging is that muscle strength decreases by up to 25% for older adults (Petrofsky & Lind, 1975; Shepard, 1998). Loss of upper body strength can affect a driver's ability to steer the vehicle (particularly on sharp turns), and loss of strength in the lower body may affect the ability to apply correct pressure for braking and throttling (Staplin et al., 1999). Loss of muscle strength can also make a driver more prone to fatigue while driving, even on short trips.

### *Visual*

Driving is an activity that is highly dependent upon visual information. Declines in visual abilities are common with increasing age both through the normal aging process and the increased prevalence of eye diseases (Anstey, Wood, Lord, & Walker, 2005; Attebo, Mitchell, & Smith, 1996). Collectively, several visual abilities are more likely to decline in older adulthood, including static and dynamic visual acuity (Burg, 1966; Burg & Hurlbert, 1961; Heron & Chown, 1967; Long & Crambert, 1989; Owsley & Sloane, 1990), sensitivity to light (Birren & Shock, 1950; McFarland, Domey, Warren, & Ward, 1960), glare recovery (Wolf, 1960); contrast sensitivity (Derefeldt, Lennerstrand, & Lundh, 1979; Owsley, Sekuler, & Siemsen, 1983; Schieber, Kline, Kline, & Fozard, 1992), and useful field of view (Ball, Beard, Roenker, Miller, & Griggs, 1988; Scialfa, Kline, & Lyman, 1987; Sekuler & Ball, 1986). These declining abilities can lead to a number of problems with safe driving and interacting with a motor vehicle such as reading street signs, traffic control devices, and in-vehicle displays; seeing lane markings and other low contrast information at night; seeing pedestrians and roadside objects; driving safely at night; and seeing traffic in adjacent lanes. Research also shows that older adults may have declines in stereoscopic space perception (Bell, Wolf, & Bernholz, 1972; Hofstetter & Bertsch, 1976; Jani, 1966) and motion sensitivity (Ball & Sekuler, 1986; Schieber, Hiris, White, Williams, & Brannan, 1990), although these studies are not conclusive. These declines can make it difficult for a driver to perceive the position of his or her vehicle in relation to other vehicles and to judge traffic gaps for merging and negotiating intersections.

### *Cognitive*

Good cognitive or thinking abilities are critical for safe driving. Cognitive abilities allow a driver to acquire important information in the driving environment and elsewhere, and to make good operational, strategic, and tactical decisions about driving (Eby, Molnar, & Kartje, 2009). Although there is great variability among older adults, several cognitive abilities are more likely to show declines as one ages. Divided attention, or the ability to focus on two or more information sources simultaneously or to perform two or more tasks simultaneously (Parasuraman, 1991), has been shown to decline with age (Ponds, Brouwer, & van Wolffelaar, 1988; Salthouse, Mitchell, Skovronek, & Babcock, 1989). Selective attention declines can make driving in heavy traffic and negotiating intersections more difficult. The speed with which a person can process information has also been shown to slow with increasing age (French, West, Elander, & Wilding, 1993; West, Crook, & Barron, 1992), leading to greater difficulty responding appropriately to quickly changing traffic information. Spatial cognition, or the ability to think about one's position relative to other objects in the environment (Matlin, 1989), tends to decline with age (Salthouse, 1987). Poor spatial cognition can translate into difficulty navigating and getting lost. Recent research has begun to determine the relationship of executive functioning declines to unsafe driving and crash risk in older adults (see e.g., Anstey et al., 2005; Daigneault, Joly, & Frigon, 2010). Executive function refers to the meta-cognitive ability that enables a person to effectively plan, organize, strategize, reason, and self-regulate (National Center for Learning Disabilities, 2010). Studies show that executive function measured in several ways tends to decline in older adulthood (Mayr, Spieler, & Kliegl, 2001; Zelazo, Craik, & Booth, 2004). Poor executive functioning can impact safe driving in several ways including engaging in unsafe self-regulation of driving.

### *Fragility/Frailty*

Both fragility and frailty are commonly associated with old age. Fragility refers to increasing inability to withstand disease or injury. In terms of motor vehicle crashes, fragility is the likelihood of sustaining a greater level of injury for a given amount of force (Kent, Trowbridge, Lopez-Valdes, Ordoyo, & Segui-Gomez, 2009). Thus, for a

crash of given dimensions, a person who is more fragile will sustain a great level of injury. According to Kent (2010), the biomechanics of fragility involve age-related reductions in bone density, declines in bone area, and changes in bone morphology/geometry that make bone more likely to fail. Frailty, on the other hand, refers to the ability to recover from a disease or injury. Although there is no agreed upon measure for frailty (see e.g., Fillit & Butler, 2009; Heppenstall, Wilkinson, Hanger, & Keeling, 2009; Szanton, Seplaki, Thorpe, Allen, & Fried, 2009; Yunkyung, Gruenewald, Seeman, & Sarkisian, 2010), the syndrome is thought to be distinct from other conditions and involves a systemic decline in functioning. According to Heppenstall et al. (2009) the physical components of frailty are weakness, muscle atrophy (sarcopaenia), weight loss, physical inactivity, and slowed movement. Like other age-related conditions, frailty is more common in old age but not all old people are frail (Rockwood & Mitnitski, 2007). A large-scale study found that the incidence of frailty in Canada was 2% for people younger than age 30, 22% for those age 65 and older, and 44% for those age 85 and older (Rockwood, Song, & Mitnitski, 2011). People who are frail are at a significantly increased risk of death or disability from an injury or disease, when compared with people who are not frail (Campbell & Buchner, 1997). This process has been described as a “domino” effect where the insult results in a cascade of adverse events leading to death or long-term disability (Heppenstall et al., 2009). Frailty and fragility have been implicated as major reasons for the increased risk of death for older adults in traffic crashes (Langford & Koppel, 2006; OECD, 2001; Koppel, Bohensky, Langford, & Taranto, 2011).

### **Consequences of Driving Reduction and Cessation**

Given the greater likelihood of medical conditions that can compromise safe driving skills and the higher risk of a fatal crash in older adulthood, it might be thought that getting an older driver to reduce or stop driving should be encouraged. Indeed, in cases where a comprehensive evaluation shows that driving abilities have declined to unsafe levels, and options for overcoming or compensating for these declines are not feasible, drivers should stop driving. Given the lack of available and effective alternatives to driving for meeting ones mobility needs, stopping or reducing driving

often means a reduced ability to travel to places where a person wants and needs to go. This reduced mobility can have adverse consequences. As shown in a wide variety of studies, stopping or reducing driving is a stressful experience for many older adults, resulting in a poor psychological outlook and reduced quality of life (e.g., Whelan, Langford, Oxley, Koppel, & Charlton, 2006). Loss of driving has been associated with increased social isolation (Liddle, McKenna, & Broome, 2004; Ragland, Satariano, & MacLeod, 2004), reduced independence, mobility, and freedom (Adler & Rottunda, 2006; Bauer, Rottunda, & Adler, 2003; Cornoni-Huntley, Brock, Ostfeld, Taylor, & Wallace, 1986), self-reported feelings of low self-worth, low self-esteem, and loss of identity (Eisenhandler, 1990), and increased depressive symptoms (e.g., Fonda, Wallace, & Herzog, 2001; Marottoli et al., 1997; Ragland, Satariano, & MacLeod, 2005). This wide range of adverse consequences associated with driving reduction and cessation, and the dependence on the personal automobile for continued mobility, led a recent group of experts in older adult safety and mobility to conclude that it is in society's best interest to keep older adults driving for as long as they can safely do so (Dickerson et al., 2007).

### **The Need for a Vehicle Designed for the Older Driver**

The world's population is aging. Older adults in many countries will likely drive more than previous cohorts. For a variety of reasons, older adults will continue to need and prefer the personal vehicle for meeting mobility needs. Losing access to the personal vehicle, such as losing one's driver license, has many adverse consequences. Based on these facts, there is a clear worldwide opportunity to positively impact global safety and mobility among older adults by designing a vehicle that recognizes and helps to overcome some of the driving abilities that commonly decline in older adulthood. Further, there also seems to be an opportunity to impact not only driving safety but also older adult mobility and driving/riding comfort.

## **Vehicle Design and Advanced Technology for Older Drivers**

Designing motor vehicles and advanced technologies for an older adult population is not a new idea. Indeed, several researchers have suggested that vehicle designs and advanced technology could be adapted to make driving easier, more comfortable, and safer for older adults (Caird, 2004; Coughlin, 2005; Herriotts, 2005; Murray-Leslie, 1991; Petzäll, 1995; Perel, 1998; Pike, 2004; Shaheen & Neimeier, 2001; Zhao, Popovic, Ferreira, & Lu, 2006). Many of these researchers, however, pointed out that research in this area is lacking (see Eby, Molnar, & Kartje, 2009, for a review). In this section we review adaptive devices, vehicle design features, and advanced technologies that could benefit older adults who are experiencing declines in driving abilities. We also discuss a holistic approach to designing a vehicle for older adults.

### **Adaptive Devices**

Vehicle adaptive devices are aftermarket devices that can assist in making driving tasks easier and safer for people experiencing declines in driving abilities (Bouman & Pellerito, 2006; Mollenhauer, Dingus, & Hulse, 1995; Mitchell, 1997). Adaptive devices are available for vehicle ingress and egress (e.g., additional bars and handles; swivel seats, key turners), seating (e.g., seat belt extensions/easy reach handles, custom armrests), steering (e.g., spin knobs, special grips), throttle/braking (e.g., pedal extension, hand throttles), and auxiliary controls (e.g., multifaceted mirrors, adapted dashboard controls) (Bouman & Pellerito, 2006). The current best practice for adaptive devices is to work with an occupational therapist who can determine specific declines in driving abilities, suggest appropriate accommodations, and train the driver on proper use (National Highway Traffic Administration, NHTSA, 2007). Unfortunately, few of these adaptive devices have been formally evaluated for safety or improved mobility. We include here a discussion of adaptive devices because these devices can help inform future vehicle design that can benefit older drivers. For example, a push button ignition was an adaptation suggested for people with limited hand strength. This is now a feature on many new vehicles.

## **Vehicle Design**

Although research on vehicle design for older occupants is sparse, some studies have addressed design categories that might be relevant for people who are experiencing age-related declines. These categories are getting in and out of the vehicle (ingress and egress), seating, visibility of the external driving environment, cargo areas, and dashboard controls.

### *Ingress/Egress*

A nationwide survey of more than 1,000 people in the UK investigated issues older drivers had with using motor vehicles (Herriotts, 2005). About 80% of the sample were age 65 and older. The study found that when compared with younger respondents, older drivers were significantly more likely to report difficulties both entering and exiting the vehicle, with nearly one-third of older adults reporting difficulty with ingress, and about one-quarter reporting difficulty with egress. Respondents who reported ingress/egress problems were asked which design features contributed to this problem. In order of frequency, respondents reported the following: door sill, seat cushion, steering wheel, cant rail (top of door frame), door, seat back, A-pillar, and the dashboard fascia. The specific issue with the features (e.g., door sill being too low or too high) was not reported.

A focus group study of older adults in Canada also found that older people report difficulties with vehicle ingress and egress (Shaw, Polgar, Vrkljan, & Jacobson, 2010). In this study, respondents reported that declines in psychomotor abilities, such as strength and balance, were the main reasons for these difficulties. The respondents reported the following difficulties with vehicle ingress and egress: opening and closing the door, lowering the body or raising it from the seat, and the lack of good interior vehicle lighting at night. The vehicle design features that respondents mentioned as factors that contributed to ingress and egress problems were small door aperture size, low seats, low door frames, raised door sills, heavy door weight, and the location/absence of handles.

### *Seating*

Seating comfort and being able to adjust the seat for safe driving are important vehicle design features. The Herriotts (2005) study found that about 95% of older drivers reported that they could adjust their seat to a comfortable and safe position. However, significantly more older drivers reported using a “bead mat” (6%) or an extra seat cushion (25%) while driving as compared with drivers younger than age 65. Thus, seat comfort is clearly an issue for some older adults.

### *Visibility*

An important vehicle safety feature is the design of windows and mirrors so that a driver has good visibility outside of the vehicle. Studies suggest that older adults have some difficulties using and adjusting vehicle mirrors. A recent study evaluated CarFit, an educational program that teaches older drivers optimal alignment for vehicle features, such as mirrors (Gaines, Burke, Marx, Wagner, & Parrish, 2011). The study found that many older drivers reported difficulty seeing outside objects with the left (26%) and right (32%) mirrors. After proper mirror adjustment by the trained CarFit technician, nearly all drivers reported improved visibility.

Older drivers also report that they have difficulties turning their heads to see out the back and side windows. The nationwide study in the UK (Herriotts, 2005) found that significantly more older drivers (56%) reported difficulties with turning to see out the back window. Of those who reported this problem, 74% reported that the difficulty arose from limited neck mobility and 14% reported that the headrest restricted them.

### *Cargo Areas*

Although not related to driving safety, the cargo areas of a vehicle, such as the trunk or hatch, are important vehicle features that are utilized by older adults. The Herriotts (2005) study found that about 17% of all drivers reported difficulties in putting objects into and taking objects out of the cargo area, with no significant difference by age group. However, of those who reported this difficulty, significantly more older adults reported that the difficulty resulted from having to lift heavy objects into or out of the cargo area. The Canadian focus group study also found that older adults report problems

with heavy objects in cargo areas (Shaw et al., 2010). Older adults reported that they preferred cargo areas that required minimal bending or stooping for use. The study also found that many older adults reported using the back seat as a cargo area rather than the vehicle trunk, so that objects did not have to be lifted as high.

### *Dashboard Controls*

Dashboard controls include the gauges, dials, knobs, and buttons used for controlling the vehicle lights, wipers, climate control, radio, and information systems. A recent focus group study in Alabama assessed older drivers' attitudes about dashboard designs in vehicles (Owsley, McGwin, & Seder, 2011). Through detailed comment analysis, the study identified dashboard design features that were considered by participants to be mostly negative. These features were a lack of uniformity of symbols, difficulty learning how to use the dashboard instruments from the owner's manual, limitations in adjusting dashboard lighting in the daytime, use of lettering that is too small to see, and the complexity of radio/entertainment systems. Features that were most positive were: the number and format of gauges; the presence of a GPS navigation system; and the coloring of dashboard controls. Focus group work in Canada with older adults has found similar results regarding dashboard controls (Shaw et al., 2010). This work also found that some older adults reported not wanting to use dashboard controls while driving because of the distraction those interactions caused, and some reported that they had the passenger make necessary adjustments.

### **Advanced Technology**

New vehicle technologies can increase safety, driving enjoyment, and mobility for older adults (Caird, 2004; Perel, 1998). These systems vary in the types of information they utilize and provide to the drivers as well as the degree to which the technologies assume control of the driving task. Collectively, these systems have been called Intelligent Transportation Systems (ITS). According to Molnar, Eby, St. Louis, and Neumeyer (2007), ITS for older drivers need to be affordable, easy, and safe to use. Few ITS technologies have been developed by taking into account the common age-related declines found with older drivers. One particular concern is that poorly designed ITS

technologies could increase distractions and the driving workload for older users, thereby reducing driving safety. To achieve widespread use of ITS by older drivers, ITS technologies of tomorrow will need to be designed to ensure that safety is enhanced rather than reduced (Henderson & Suen, 1999; Stamatiadis, 2001).

A number of studies have documented that older adults often use ITS technologies differently than younger people (Caird, 2004; Dingus et al., 1997; Eby & Kostyniuk, 1998; Kostyniuk, Streff, & Eby, 1997; Stamatiadis, 1998; Wochinger & Boehm-Davis, 1997). For example, in an evaluation of Global Positioning System (GPS) navigation assistance technology, Kostyniuk, Streff, and Eby (1997) found that older drivers used the GPS more frequently than younger drivers, but they reported that it was their passenger who interacted with the navigation system. Studies also report that older drivers take much longer to learn how to use ITS technology (AAA Foundation for Traffic Safety, AAAFTS, 2008; Caird, 2004; Kostyniuk, Streff, & Eby, 1997).

There are a number of ITS technologies that have the potential to be of benefit to older adults who are experiencing age-related functional declines. Here we classify these technologies into two categories (Simões & Pereira, 2009): advanced driver assistance systems (ADAS) and in-vehicle information systems (IVIS).

### *ADAS*

ADAS are technologies that are involved in the immediate driving task (Meyer, 2011). Some of these technologies provide highly context dependent information, such as notification of a roadside pedestrian, while others may take over partial control of the vehicle, such as a system that initiates braking to avoid a collision. Here we discuss several ADAS applications that seem particularly relevant to older driver safety and mobility.

*Night Vision Enhancement.* Night vision enhancement (NVE) systems use infrared cameras to detect objects and the roadway scene and provide the driver with this information on an in-vehicle display (Rumar, 2002). NVE systems can already be found in some luxury vehicles as an option. Safety and usability studies of NVE systems among drivers of all ages have found that the following: drivers can understand the information; NVE systems can help people see objects while driving that are difficult to

see at nighttime; and the systems produce only a small increase in workload (Druid, 2002; Raytheon Commercial Infrared and EICAN-Teaxs Optical Technology, 2000). Other studies have found that older drivers use NVE systems less than drivers of other ages but report being satisfied with the systems (Gish, Shoulson, & Perel 2002; Ståhl, Oxley, Berntman, & Lind, 1994; Van Wolffelaar & Rothengatter, 1990). The safety impacts of NVE systems are not conclusive. Self-report data suggest that NVE systems do not increase distraction and reduce the need to look at oncoming headlights that produce glare (Druid, 2002; Raytheon Commercial Infrared and EICAN-Teaxs Optical Technology, 2000).

*Forward Collision Warning.* Forward collision warning systems use radar information to determine the changes in distance to forward objects. When this distance decreases to a level where a collision is likely, the system will warn the driver and/or initiate vehicle braking. Studies that have investigated the safety benefits of forward collision warning systems among older adults have found that the following: acceptance was high, provided that there were not many false alarms; older drivers had greater safety benefits than younger drivers; older drivers drove more slowly than younger drivers and maintained longer headways from forward vehicles; and older drivers viewed the system more favorably (Cotté, Meyer, & Coughlin, 2001; Dingus et al., 1997; Ervin et al. 2005; Kramer Cassavaugh, Horrey, & Mayhugh, 2007; Maltz & Shinar, 2004).

*Adaptive Cruise Control.* Adaptive cruise control (ACC) systems not only maintain a driver-set vehicle speed, but also maintain a set distance from forward vehicles without the driver having to use the brake or throttle (Davidse, 2007; Fancher et al., 1998; Hoedemaeker & Brookhuis, 1998). Safety and usability studies of ACC among drivers of all ages have found that driver workload and stress were reduced when using ACC, and drivers trusted the system (Rudin-Brown & Parker, 2004; Stanton & Young, 2005). A study of ACC use among both older and younger drivers under natural driving conditions found that all drivers were overwhelmingly pleased with the system and thought it was trustworthy and safe (Fancher et al., 1998). The authors reported no crashes during the period of ACC use and, based on several analyses, concluded that ACC was safe.

*Lane Departure Warning.* Lane departure warning (LDW) systems help drivers avoid drifting off the road by warning a driver when the vehicle starts to drift out of its travel lane through the use of side cameras and video analysis (LeBlanc et al., 2006). The alert is usually directionally-linked so that a lane departure to the right would produce a warning signal to the right, such as the right side of the driver's seat. Safety and satisfaction studies of LDW systems have found that among young drivers, the system can help prevent crashes related to drowsy driving (Rimini-Doering, Altmueller, Ladstaetter, & Rossmeier, 2005). A study in a natural driving environment among young, middle-age, and older drivers found that drivers of all ages tended to stay closer to the center of the lane, use turn signals more, and have fewer lane excursions when compared with driving without the system (LeBlanc et al., 2006).

### *IVIS*

IVIS technologies provide the driver with information and allow communication from and to the driver (Simões & Pereira, 2009). Generally this information is not critical for the moment-to-moment control of the vehicle but is useful for making strategic driving decisions, such as deciding where to make a turn. Here we discuss two IVIS technologies that seem particularly useful for older adults.

*Navigation Assistance.* Navigation assistance, or route guidance, systems combine GPS vehicle location information with electronic routing algorithms to provide drivers with turn-by-turn navigation assistance as they drive. These systems are commonly found in vehicles and can be added as an easily fitted aftermarket device. The safety and usability of navigation systems among older adults has been well-researched. Collectively, these studies show that older drivers: use the systems frequently; report some distraction from the systems; are more willing to travel to unfamiliar locations when using the system; report increased feelings of safety, confidence, attentiveness, and relaxation when using the system; have great difficulty reading the navigation assistance displays; take longer than young drivers learning to use the system, particularly entering destinations; and more often report using them with a passenger (Dingus et al., 1997; Eby & Kostyniuk, 1998; Kostyniuk, Eby, Christoff, & Hopp, 1997a, 1997b; Oxley, Barham, & Ayala, 1995; Vrkljan & Polgar, 2007). Given the low cost of commercially available

systems, ease of their installation, the positive regard drivers have for them, and the fact that they seem to be safe, route guidance systems are a very promising advanced technology for helping to maintain safe mobility in an aging society.

*Automatic Crash Notification.* Automatic crash notification (ACN) systems automatically contact emergency medical services personnel in the event of a crash and transmit vehicle location information and, in some systems, crash severity (Champion et al., 2003; Williams, 2002). Clearly, ACN systems are not designed to facilitate mobility, but studies show that these systems can improve safety by getting emergency personnel to the crash scene more quickly (Berryman, 2004; Champion et al. 2003; Clark & Cushing, 2002; Kianianthra, Carter, & Preziotti, 2000; Ram, Talmor, & Brasel, 2005). No research has directly considered the safety benefits of ACN systems for older drivers, but it is reasonable that ACN systems would provide greater safety benefits for older adults.

### **A Holistic Approach to Designing Vehicles for Older Drivers**

It might be possible to impact older driver safety, mobility, and quality of life by taking a system-wide or holistic approach to vehicle design, rather than by focusing on developing specific vehicle design features or advanced technologies. Researchers from the Massachusetts Institute of Technology (MIT) AgeLab discuss a concept for a vehicle designed to optimize older adult driving safety and wellness (Coughlin, Reimer, & Mehler, 2009; Reimer, Coughlin, & Mehler, 2009). This concept, called the AwareCar, is based on the idea that crashes can be mitigated by exploiting the interactive and overlapping roles of the vehicle, environment, and driver. The researchers used the public health perspective of “wellness” (the pursuit of optimal personal goals) as a framework for the AwareCar. To that end, they viewed driver performance as dynamic and improvable and the vehicle as a wellness platform that supports optimal driving performance. According to the authors, the framework is based on three wellness inspired components: detection and monitoring of the driver’s state (e.g., fatigue, impairment); providing information to the vehicle, environment, and driver; and producing alerts as needed to meet the needs of the driving situation. A key feature of the AwareCar is its ability to acquire context sensitive information on the driver, environment, and vehicle. Of particular importance is gathering and processing data that

can provide an assessment of driver state. In the AwareCar framework, research is investigating a number of behavioral and physiological measures, such as heart rate and skin conductance, to determine in real time the driver's state (Reimer, Mehler, Coughlin, Godfrey, & Tan, 2009). The three questions guiding the long-term research on the AwareCar are the following (Reimer, Coughlin, & Mehler, 2009): What are the key vehicle, infrastructure, and environmental data points that provide a comprehensive and integrated assessment of individual driver situational awareness and management of driver workload? How, when, and where are these data most effectively presented to the driver? And, if these data are presented to the operator, will the driver alter his or her behavior in real time as well as inform the overall pattern of driving?

## **Crashworthiness for Older Adults**

Crashworthiness refers to the safety performance of a motor vehicle in a crash (Pike, 2004). In its broadest sense, it encompasses a variety of vehicle features intended to provide crash protection to occupants in the vehicle, including structural designs, seat belt systems, and airbags. Older vehicle occupants present a unique set of challenges for improving crashworthiness (Kent, 2010). While there is great heterogeneity among individual older adults, as a group they are more fragile than younger people (i.e., they sustain more severe injuries for a given mechanical load) and more frail (i.e., they experience worse outcomes given a certain injury; Wang, 2010). In addition, they tend to be involved in different types of crashes and different crash severities than younger drivers. These differences in crash exposure or environment, combined with the greater fragility and frailty of older adults, result in changes in the distribution of crash-related injuries as people age (Kent, 2010). Consequently, there is a greater need to improve the crashworthiness of vehicles to provide better protection for older drivers in the event of a crash (Charlton, Fildes, and Andrea, 2002). In this section we discuss crash and injury patterns of older drivers, challenges for improving crashworthiness, and advancements in crashworthiness for older vehicle occupants.

### **Crash/Injury Patterns of Older Drivers**

#### *Type of Crash*

There is considerable evidence that older drivers, as a group, are over-involved in intersection crashes relative to younger drivers (e.g., Abdel-Aty & Radwan, 2000; Cooper, 1990; Hakamies-Blomqvist, 2004; Langford & Koppel, 2006; Larsen & Kines, 2002; Li, Braver, & Chen, 2003; Oxley, Fildes, Corben, & Langford, 2006; Zhang, Fraser, Lindsay, Clarke, & Mao, 1998). For example, Langford & Koppel (2006) examined national fatal crash data for Australia for the period 1996-1999 and compared crashes among three driver age groups: middle (40-55), young-old (65-74), and old (75 years and older). They found that the percentage of fatal crashes at intersections was 50% for the old age group compared with only 21% for the middle age group, while the young-old had 35% of fatal crashes at intersections. Similar work in the U.S. using

national fatality data has found that when compared with middle age drivers, U.S. drivers age 65-69 were 2.3 times more likely to be in an intersection crash, and drivers age 85 and older were 10.6 times more likely to be in an intersection crash (Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998).

Older drivers are also more likely than younger drivers to be involved in multiple-vehicle crashes (e.g., Langford & Koppel, 2006; Cooper, 1990; Hakamies-Blomqvist, 1993). Langford and Koppel (2006) found that 74% of older driver fatal crashes involved multiple vehicles compared with 60% for middle aged drivers. This outcome is not surprising given the high percentage of intersection crashes among older adults and that older drivers are underrepresented in alcohol- and illicit drug-related crashes (Eby, 1995; Langford & Koppel, 2006; Hakamies-Blomqvist, 1993). However, the greater likelihood of multiple-vehicle, intersection crashes results in older adults being over-represented in lateral crashes, which has implications for the severity and type of injuries sustained by older adults (Kent et al., 2009), as discussed below.

### *Severity of Injury*

Age is one of the most important factors affecting an individual's risk of injury in a motor vehicle crash (Liu, Utter, & Chen, 2007). As people age, they become more vulnerable to injury because it takes less energy to cause tissue disruption and damage, and older adults' skeletal structures are more easily damaged through bone loss (Charlton, Fildes, & Andrea, 2002; Kent, Funk, & Crandall, 2003). Numerous studies have documented this increased susceptibility to injury among older drivers (e.g., Austin & Faigin, 2003; Li, Braver, & Chen, 2003. Braver & Trempel, 2003; Lyman, Ferguson, Braver, & Williams, 2002; Morris, Frampton, Fildes, and Charlton, 2002a; Morris, Welsh, Frampton, Charlton, Fildes, 2002b, 2003).

For example, Morris et al. (2003) found that older drivers in the UK were significantly more likely than middle age drivers to be fatally injured in both frontal and side impact crashes when the crashes were of approximately equal severity. Using the same data source, Morris et al. (2002a) examined the severity of crash injuries based on the Abbreviated Injury Scale (with MAIS 1 indicating a minor injury and MAIS 6 indicating an injury certain to result in a fatality). Study findings indicated that 12% of

older drivers had sustained injuries at the MAIS 4 level compared with 2% of younger drivers and 3% of middle age drivers. Similar findings came from a U.S. study of driver injury severity in real-world traffic crashes, based on data from the Crashworthiness Data System (NASS-CDS) which indicated that the older the driver age group, the higher the percentage of drivers to sustain severe injuries (MAIS  $\geq$  4) in crashes (Liu et al., 2007).

Another U.S. study focused on traumatic brain injuries associated with crashes (Richmond et al., 2011). The study examined adult motor vehicle occupants who had sustained a traumatic brain injury in a crash between 1996 and 2009, using data from the Crash Injury Research and Engineering Network (CIREN). Findings indicated that older patients who sustained a traumatic brain injury as a result of a crash had poorer outcomes than their younger counterparts. Specifically, the authors found a higher mortality secondary to head injuries among crash-involved adults older than age 60, with these older adults being more likely to have struck the airbag (generally a first generation airbag), door, and seat. The CIREN database also found an increase in mortality in the older patients despite no difference in mean Injury Severity Score and a lower crash severity.

### *Patterns of Injury*

While it is clear that older drivers are more likely to sustain injuries in a crash, less is known about age-related differences with regard to specific types of injuries (Koppel et al., 2011). The most consistent study finding is that the risk of chest injury increases with age and that fractures to the chest may be the most significant difference between older and younger vehicle occupants (e.g., Augenstein, 2001; Kent, Henry, & Matsuoka, 2005; Koppel et al., 2011; Langford, Bohensky, Koppel, Taranto, 2010; Morris et al., 2003; Liu et al., 2007; Padmanaban, 2001; Yee, Cameron, & Bailey, 2006). The most common chest injuries among older adults are to the chest wall and include rib fractures, flail chest, and sternum fractures (Yee et al., 2006).

Koppel et al. (2011) found that a higher proportion of older drivers in Australia sustained chest injuries compared with middle age drivers (30.6% versus 18.5%, respectively). They noted that their findings were consistent with findings from several analyses of crash injury data from the UK (Morris, Welch, Frampton, Charlton, & Fildes,

2003; Morris, Welch, & Hassan, 2003; Welch, Morris, Hassan, Charlton, & Fildes, 2006) showing that in crashes of approximately equal severity, older vehicle occupants were significantly more likely to sustain serious chest injury than their younger counterparts.

Studies in the U.S. have reached similar conclusions. For example, Kent, Henary, and Matsuoka (2005) examined data from two U.S. databases – the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) and the Fatality Analysis Reporting System (FARS). They found that the fatality rate associated with crashes increased significantly with age. Further, among those killed in crashes, older drivers were significantly more likely than younger drivers to have died from a chest injury (47.3% versus 24.0%, respectively). They concluded that as people age, they become increasingly susceptible to thoracic injury, primarily rib fractures, in a crash, and that the ability to recover from rib fractures lessens as an individual ages. In contrast, young people are better able to tolerate rib fractures and damage to the underlying lung parenchyma due to the following factors: the material and geometric characteristics of their ribs results in a structure that is relatively difficult to damage; they have efficient blood-oxygen exchange; and they have higher pain tolerance.

The main sources of injury to the chest appear to be the seat belt in frontal impact crashes and the vehicle door in side impact crashes (Morris et al., 2003). This is not surprising given that the chest is clearly a vulnerable area and is the major load bearing area for restraint systems, as well as a major point of contact with the vehicle structure during a crash (Charlton et al., 2002). Because fragility increases with age, older adults have less tolerance to shoulder belt loading and therefore a lower level of chest injury tolerance in crashes (Levi, De Leonardis, & Zador, 2008; Zhou, Rouhana, & Melvin, 1996). Despite the association between chest injuries and belt use, it is important to note that seat belt use reduces the total morbidity and mortality in the event of a crash relative to nonuse of belts (Yee et al., 2006). In addition, the predominance of chest injuries among older adults may be attributed at least partly to the role of seat belts and airbags in protecting against head injuries, which until the early 1980s were identified as the leading cause of U.S. crash-related fatalities in this age group (Koppel et al., 2011; Langford et al., 2010).

## **Challenges for Improving Crashworthiness**

Considerable gains have been made in improving crashworthiness for vehicle occupants over the past several decades (Farmer & Lund, 2006). While these efforts continue, some special challenges have been identified with regard to improving crashworthiness for older adults. First, despite evidence that older drivers have distinct crash patterns relative to those of younger drivers, there is still relatively little information regarding injury patterns for specific crash types involving older adults; therefore, more research is needed on the relative protective influences of vehicle size, design, and safety features for older adults (Charlton et al., 2002). This is particularly true for emerging crashworthiness technologies.

For example, Yoganandan, Pintar, Stemer, Gennarelli, and Weigelt (2007) pointed to the case of side airbags, which only appeared in the U.S. vehicle fleet in 1996. They argued that the real-world field data on side airbags are primarily anecdotal and the effectiveness of side airbags is still largely unknown, although a limited number of studies have tried to synthesize data from individual cases. In contrast, research findings on frontal impact airbag-induced injuries, particularly for out-of-position occupants, have led to the development of second generation less aggressive airbags which are now used throughout the automotive fleet (with later models also including an option to deactivate the airbag on the passenger side for a lightweight front seat occupant). Continuing efforts to understand how passive safety devices in side impacts can be optimized for older adults are warranted.

A related challenge is that for the most part, the design and testing of crashworthiness features, including restraint systems, have not been based on older adult anthropometry and performance. For example, Charlton et al. (2002) argued that until recently, vehicle designs were largely based on young adult anthropometry and performance, which meant that the ergonomic specifications of modern vehicles did not necessarily take account of the needs of older people. They pointed to a growing body of literature describing changes in physical and performance characteristics across the adult age span that needs to be taken into account in the design of vehicles. Similarly, Fildes (2008) noted that while the need for a frontal and side airbag (thorax and side curtain) in a crash seems obvious for older occupants, the acceptable injury assessment reference

values used in crash tests involving crash test dummies have assumed a one-size-fits-all standard (e.g., chest injury thresholds for thoracic injury criteria in terms of force, deflection, or compression) without much thought to the frailty brought on by the aging process. He called for a range of injury thresholds across the age distribution of vehicle occupants. The need to develop advanced material and finite element models to better characterize the response of the dummy components and biological tissues used in the study of injury mechanics in crashes has also been recognized (Uduma, 2000).

A third challenge for improving crashworthiness for older adults, according to Brumbelow and Zuby (2009) is that the progress made in improving frontal crashworthiness and the promise of emerging active safety technologies have led to a reduced focus on further passive safety improvements. They pointed to the continuing need for improvements in crashworthiness, given that no combination of active safety technologies will completely prevent all crashes; thus, crash-related deaths and injuries will continue to occur. Based on examination of data from NASS-CDS, the authors identified a need for future test programs promoting structural designs that absorb energy across a wider range of impacts to potentially reduce serious injuries in frontal crashes. In addition, they concluded that further restraint system improvements might require technologies that adapt to occupant and crash circumstances, but noted that it is unclear what types of full-scale crash testing would encourage these improvements.

A fourth challenge has to do with trying to meet the often conflicting demands of safety and vehicle usability. One aspect of usability is comfort for vehicle occupants. As discussed by Udama (2000), decisions on designs of new vehicles are currently driven by the vehicle interior's dual role as both a comfort cabin and a safety cage. At the same time, the requirements for satisfying each of these roles are often quite different and in conflict with one another. While observing a recent trend of increased emphasis on vehicle safety, Udama (2000) pointed to the need for blending together safety and styling to produce a total quality vehicle. Vehicle styling constraints can also have an adverse affect on safety as in the case of hood and trunk geometry that can lead to reduced driver visibility.

A final challenge has been identified by Farmer and Lund (2006) who argued that gains in occupant protection from vehicle design improvements have been partially offset

by an increasingly risky environment in recent years. The authors examined factors contributing to the decline in driver fatality rates over the past 20 years, including changes in the vehicle fleet such as crashworthiness, as well as changes in the roadway and driver behavior. They concluded that several factors that have contributed to the decline in driver fatality rates and argued that further reductions in burden of motor-vehicle crashes will require addressing all aspects of crashes, including the driver, the vehicle, and the environment in which crashes occur.

### **Country-Specific Differences with Implications for Crashworthiness**

Most research on vehicle crashworthiness has been limited to western countries (Yee, Cameron, & Bailey, 2006). Within these countries, however, crash and injury patterns appear to be similar. Langford et al. (2010) for example, reviewed studies in a number of countries and concluded that the pattern of older driver crash epidemiology – that is, that older drivers tend to be involved in multiple versus single vehicle collisions, be legally at fault in these collisions, be over-represented in intersection crashes that involve turning into oncoming traffic and thus being struck on the side of the vehicle – has been repeatedly confirmed in the UK (e.g., Clarke, Forsyth, & Wright, 1998a, 1998b), the U.S. (e.g., Li, Braver, & Chen, 2003; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998), Scandinavia (Hakamies-Blomqvist, 1993; Larsen & Kines, 2002); and Australia (Langford & Koppel, 2006; Ryan, Legge, & Rosman, 1998; Yee et al., 2006).

### **Advancements in Crashworthiness**

Many of the advancements in crashworthiness have been made in areas such as structural designs, seat belts, and airbags, that collectively can help reduce older occupants' susceptibility to injury in frontal, side, and rear impact crashes (Pike, 2004). An overview of recent advancements and opportunities for further improvements is provided here.

### *Structural Design*

One focus of improvements in vehicle structural design is to provide added head impact protection in the event of a frontal crash (beyond what the vehicle's restraint systems may provide). Pike (2004) described the current process of testing the energy-absorbing properties of the vehicle interior which is based on federal regulatory requirements for occupant protection in interior impact (NHTSA, 1999). He noted that the criteria for evaluating head impact with various points inside the vehicle (e.g., pillars, metal framing around the windshield, side glass) have evolved over time, and that in the future it may be possible to adopt tolerance limits of head injury criteria to older drivers and passengers. Improvements in structural design and geometry have also been called for in the area of vehicle aggressivity and fleet compatibility, with the aim of reducing injuries by eliminating incompatibilities between passenger vehicle and their potential collision partners (Uduma, 2000).

### *Seat Belts*

Efforts to make seat belts more effective in reducing injury among older vehicle occupants must also take into account issues of acceptability; that is, if belt systems are not acceptable to users, they may not be worn, resulting in loss of the protective benefits they are intended to offer. As described by Levi et al. (2008), three key aspects of acceptability include ease of use, fit, and comfort. These can be compromised in the following ways for older occupants: the twisting motion involved in reaching for and fastening traditional seat belts can be difficult for older adults with limited range of motion; differences in torso height and weight may cause traditional belts to fit awkwardly across the neck, stomach, and/or chest of some occupants; and belts that do not fit correctly can be uncomfortable and lead to the occupant adjusting the belt in a way that compromises safety. In the Canadian focus group study cited earlier (Shaw et al., 2010), participants expressed concerns about the physical aspects of fastening and unfastening their belts. Among the physical problems that affected their ease of use were reduced grip strength, decreased finger dexterity, decreased range of motion for reach, and decreased ability to exert force.

Efforts continue to develop more protective seat belt designs. One promising area is the development of four-point seat belts, similar to those worn by race car drivers, for passenger vehicles (U.S. Department of Transportation, DOT, 2008). Various types of four-point belt systems are being developed by a number of manufacturers, all with the potential to distribute crash forces across more of the body, thereby minimizing the impact of the seat belt on the body during a crash (Levi et al., 2008). For example, Rouhana et al. (2003) investigated the performance of two types of four-point belt systems and one type of three-point belt system. The four-point belt systems included the “X4,” which consisted of a three-point belt with an extra shoulder belt that "crisscrossed" the chest and the “V4,” a harness style shoulder belt. Findings indicated that the X4 appeared to add constraint to the torso and increased chest deflection and injury risk. In contrast, the V4 loaded the body in a different biomechanical manner than three-point and X4 belts, appearing to shift load to the clavicles and pelvis and to reduce traction of the shoulder belt across the chest, resulting in a reduction in chest deflection by a factor of two.

Another promising area of research has focused on inflatable seat belts. For example, Kent et al. (2011) investigated the performance of a three-point restraint system called the “Airbelt” that includes an inflatable shoulder belt and a non inflatable lap belt with a pretensioner. The Airbelt was generally found to generate lower head, neck, and thoracic injury outcomes than other non inflatable rear seat restraint concepts. Findings from Sundararajan et al. (2011) also suggested that an inflatable seat belt system will offer additional protective benefits to some vehicle occupants in the rear seat.

In one of the more comprehensive reviews of advancements in crashworthiness, Levi et al. (2008) discussed additional developments in vehicle design that may affect seat belt use among older occupants, some of which are already in place and some of which are still under consideration. Table 2 below summarizes many of these developments.

Table 2  
Additional Developments Affecting Seat Belt Use by Older Occupants.

Development	Description
Belt Force Limiters	Belt force limiters (also referred to as load limiters), are energy management devices intended to reduce the risk of rib fractures due to shoulder belt forces. Load limiters have been shown to benefit a relatively large number of individuals in specific crash scenarios.
Belt Pretensioners	Belt pretensioners retract the seat belt to remove excess slack in the event of a crash. A pretensioner is similar to an air bag in that it needs to be replaced after a crash. Pretensioners have been shown to be effective in reducing Head Injury Criterion scores for front-seat occupants as well as chest acceleration and chest deflection scores for right-front passengers.
Dynamic Optimization	Dynamic optimization systems use sensors to fit the restraint system to the occupant in the event of a crash. In addition, many of these systems can optimally position the occupant and deploy active restraint structures (e.g., deployable doors and front end structures).
Identification Technologies	Identification technologies represent an additional possibility for sensing. They use a type of keyless entry transmitter or fingerprint identification programmed with information about the occupant's age, sex, physical conditions, and size.
Integrated Seat Belt Systems	Integrated seat belt systems incorporate the restraint into the body of the seat so that the seat belt can move with the occupant when the seat is moved, making the belt easier to reach relative to belts attached to the floor or pillar.
Seat Belt Height Adjustors	The seat belt height adjustor is a D-ring mechanism located on the B-pillar on the side of the vehicle allowing the occupant to adjust the shoulder belt to a comfortable height.
Seat Belt Reminder Systems	Seat belt reminder systems are designed to remind drivers (and in some vehicle models, passengers) to put on their seat belts. Systems generally use some combination of a lighted display and audio chime. Reminder systems have been found to be most effective for part-time users.

Adapted from Levi et al. (2008).

### *Airbags*

One advancement in the area of airbags has to do with sensors. As described by Levi et al. (2008), FMVSS 208 led to sensors being installed in new vehicle models as part of the air bag system. The sensors currently are tailored to identify weight and height, and therefore, inflate the air bags in a variable manner for large occupants in high speed crashes or smaller occupants in low speed crashes. Other advancements include side airbags to protect the torso of vehicle occupants in side-impact crashes, external airbags introduced in concept cars to protect pedestrians and occupants of other vehicles during crashes, roll curtain airbags, knee airbags, and airbags for the foot well to mitigate lower-limb injuries (Pike, 2004; U.S. DOT 2008).

## **Marketing Vehicles to Older Adults**

The baby boomers represent a significant and influential segment of the car buying market. Currently making up the single largest market for luxury automobiles and at the peak of their economic power, the baby boomers signal the new wave of older consumers (Coughlin, 2005). Despite this, Coughlin (2005) argued that the automobile industry has failed to keep pace with the aging of the baby boomers and their changing approach to purchasing decisions, with regard to both the vehicles produced and the strategies used to market them. This reflects a broader trend of older consumers having been largely ignored in the general marketplace until fairly recently (Yoon, Cole, & Lee, 2009). The focus on older consumers in the U.S. and elsewhere is now growing, in large part because of the aging of the population in most industrialized countries. In this section, findings from the general marketing literature relative to older consumers are highlighted, as well as findings specific to vehicle marketing and marketing of other products.

### **Overview of Older Consumer Market**

The evolution of marketing efforts directed at older consumers has been characterized as having three distinct stages: 1) total neglect prior to 1980; 2) trial-and-error marketing in the 1980s (often based on stereotypes and anecdotal evidence rather than reliable information); and 3) increasing commitment and caution from the 1990s onward (Moschis, 2003). One important lesson learned from the second stage was that product marketing that stigmatized or labeled people as “old” was ineffective and could actually lead to a backlash by the intended market segment. The sense of caution characterizing the current stage came about in part due to these past marketing errors and in part to the growing recognition that older consumers represent a diverse and complex market.

Although older adults represent arguably the most heterogeneous segment of the population, there are some general patterns among older consumers as a group that have been identified in the literature. One of the most consistent findings is that for most older consumers, self-perceived age is younger than actual chronological age (e.g., Markides &

Boldt, 1983; Myers & Lumbers, 2008; Sudbury & Simcock, 2009). For example, findings from interviews of senior executives in the retail property industry and focus groups with shoppers in the UK suggested that older consumers do not see themselves as old as they are and are often drawn to products aimed at younger consumers (Myers & Lumbers, 2008). Sudbury and Simcock (2009) identified several distinct segments of older consumers, based on their age and various individual characteristics. However, the common theme among each of the groups was that individuals felt about 10 years younger than their actual age.

Moschis (2003) has summarized general findings from the literature with regard to older consumers. In comparison with younger consumers, older consumers have been found to: save/invest more; spend more on luxury products and services; shop during morning hours; prefer “one-stop” shopping; consider shopping to be a social event; be very convenience-oriented; patronize reputable/traditional outlets; seek personal attention and special services such as valet services; choose products based on quality and name brand; be less price conscious and deal prone; use credit as often; be as likely to show non-significant responses to sweepstakes and telemarketing; and complain less when they are not satisfied with something they have bought. Based on these research findings he recommended several marketing strategies. Strategies with particular relevance to the topic of this paper included: segmenting the older consumer market based on life events and circumstances (which influence individual needs and lifestyles), rather than based on age; developing products with an intergenerational or universal appeal (i.e., products that can satisfy the needs of both younger and older consumers but are most beneficial to the older adult); and promoting products in a way that reinforces the “youthful” self-concept many older adults hold rather than emphasizing their old-age status. This last recommendation, in particular, is supported by the earlier finding that older adults tend to perceive themselves as younger than they actually are.

In trying to understand older consumer behavior, it is important to disentangle age-related and cohort-related differences. A cohort or generation can be characterized as a group of people who travel through life together, experiencing similar events at a similar age, sharing a common social, political, historical, and economic environment (Williams & Page, 2010). There have been numerous efforts to discern common patterns

among the baby boom cohort. For example, Reisenwitz and Iyer (2007) in a survey of baby boomers found that, with the exception of self-perceived age, there were no significant differences between younger (age 40-49) and older (age 50-58) baby boomers across a large set of behavioral variables (e.g., entertainment-related activities, volunteer-related activities, culturally-related activities, fashion interest, self-confidence, social involvement, work orientation, innovativeness, loyalty proneness, risk aversion, and nostalgia proneness). The authors cautioned against the widely accepted marketing practice of age segmentation in which the baby boomers are split into young and older boomers. However, one limitation of these findings is that none of the baby boomers in the survey sample had actually reached an age generally considered to be old.

The aging of the baby boomers has led to increased attention to how they differ from previous generations of older adults. Coughlin (2009) argued that perhaps the most striking difference between the baby boomer generation and previous generations is their expectations; that is, the baby boomers throughout their lives have experienced seamless and affordable mobility, new technology, high style, and the constant promise of improvement. Further, they expect to continue an active and mobile lifestyle as they age. The baby boomers have also been characterized as being more educated, more demanding, and having experienced more technology throughout their lives than any previous generation (Coughlin, 2007). Coughlin (2007) argued that the aging baby boomers in developed countries will have mounting expectations for how technological advances can improve their lives that will challenge technology developers and product designers.

At the same time that baby boomers' expectations for technology are increasing, they may face challenges in learning to use new technology systems in their vehicles. There is evidence that older adults use new systems differently than younger adults and may require more training (Eby, Molnar, & Kartje, 2009). Shaw et al. (2010) found that older adults had concerns about how to use some vehicle technologies and misunderstood how they worked to improve safety. Coughlin (2006) has suggested that manufacturers may have to come up with new ways of training drivers of all ages to best use new in-vehicle systems.

More generally, there is a growing body of research on the effects of aging on consumer decision making resources and abilities. As people age, they may experience physiological changes that can affect how they interact with the consumer environment (Yoon & Cole, 2008). Thus, many of the same age-related declines that may pave the way for new or specialized products must also be taken into account in how these products are advertised and marketed. For example, there is evidence that aging consumers who are experiencing changes in abilities and resources may feel an increased need to adapt their decision making processes (Yoon, Cole, & Lee, 2009). These adaptations can take several forms, including greater reliance on selective searching, use of decision aids, delegation of decisions, training, and heuristic processing (i.e., using prior knowledge to develop simple decision rules rather than systematically processing information). The authors pointed out that marketers need to better understand these adaptations not only to optimize their market mix but also to guide the development of intervention strategies.

Yoon, Lee, and Danziger (2007) provided an example of how marketers might use findings with regard to information processing by older adults. They studied the effects of aging, time of day, and available resources on the processing of persuasive messages. Their results support a growing body of research which shows that for many older adults, performance on cognitively demanding tasks peaks in the morning, and declines in the afternoon and evening. Older adults were less able to engage in effort-intensive and systematic processing later in the day. According to the authors, messages should be timed according to their complexity, with more complex messages (those requiring thoughtful or detailed processing) delivered in the morning, and more simple messages delivered in the evening. The authors cautioned, however, that detailed information processing requires more than just matching messages to the optimal time of day; the audience must also be motivated to process the message.

Because aging is often accompanied by functional declines in vision, cognition, and psychomotor skills, older consumers have often been considered part of the same market as disabled consumers, with regard to product development, sales, and distribution. However, concerns have been expressed about this approach, given that similarities in physical requirements between older and disabled consumers do not

necessarily translate into shared self-perceptions and aspirations (e.g., Coughlin, 2007). Coughlin (2005) specifically addressed the issue of the extent to which the vehicle design and marketing process should be planned to appeal to older adults, while at the same time meeting the needs of people with disabilities. Noting that the automobile industry has achieved significant success in introducing design innovations to meet the needs of older drivers, he cautions against focusing only on “needs” as the baby boomers age. He argued that older adults may have similarities in functional requirements but do not see themselves as disabled or equate their age-related functional declines as disabilities. Thus, it will be increasingly important to go beyond an understanding of older adults’ functional needs as drivers to understand how their current and future lifestyles can be best accommodated.

Baby boomers not only constitute the emerging wave of older adults, they also represent the largest generation of women drivers and consumers (Coughlin, 2006). This poses challenges as well as opportunities for the automobile industry. In terms of marketing, it will be increasingly important to understand and respond to women’s preferences and needs in vehicle design in terms of comfort, convenience, and other ergonomic elements.

### **Older Driver Vehicle Purchasing Decisions**

Just as the older adult population is quite heterogeneous, so too are their perceptions about what constitutes a “safe vehicle.” For example, in the Shaw et al. (2010) study, some participants considered smaller vehicles to be safer because they were easier to maneuver, while others considered large vehicles to be safer because they offer occupants greater protection. That being said, it appears that safety, however conceptualized, does appear to play a role in car buying decisions of older adults. At the same time, research findings are mixed with regard to how important that role is.

In a recent review of the literature, Koppel et al. (2005) found that safety is generally not the primary consideration in new car purchasing decisions and is often outranked by factors such as price, appearance, and dependability/reliability. Earlier work by some of these same investigators was consistent with these conclusions (Charlton, Andrea, et al., 2002). The authors conducted focus groups with adults age 55

and older in Victoria, Australia. Overall, participants generally preferred features that improved comfort or the ease of driving. Few participants identified specific safety features such as air bags or ABS brakes. When given a list of five factors and asked to select the most important for buying a vehicle, *handling of the vehicle* was selected by 40%, *vehicle safety* by 30%, *fuel economy* by 20%, and *vehicle appearance* and *make or model* less than 10% each. The commonly identified top five safety features were drivers' visibility, handling of the vehicle, ABS brakes, air bags, seat belt pretensioners, and power steering. However, safety features that protect occupants in a crash were poorly understood by participants and misconceptions about features such as air bags were common.

Similarly, in another focus group study of older drivers age 70-90 in Canada conducted by Zhan and Vrkljan (2011), participants highlighted the importance of a few standard safety features (i.e., seat belts, airbags, power steering, and reliable brakes) but downplayed the role of safety in their car buying decisions. Participants' perceptions of more advanced safety systems, such as adaptive cruise control, were mixed in terms of their contributions to safety, with many arguing that vehicle technologies were less important than drivers' own driving skills and habits. The most important factors influencing buying decisions were price and fuel economy, although it was noted that visibility around the vehicle has become increasingly important.

However, other studies, conducted by some of the same investigators, have produced very different results. For example, Vrkljan and Anaby (2011) surveyed drivers in Canada to explore the importance of certain features (e.g., storage, mileage, safety, price, comfort, performance, design, and reliability) in decisions to purchase a vehicle. They found that safety and vehicle reliability were the highest rated features among all participants. Women rated safety as significantly more important than did men across all age groups, with women's ratings tending to be stable across the lifespan and men's ratings increasing with age in general.

Similarly, in surveys of private vehicle buyers in Spain and Sweden conducted by Koppel, Charlton, Fildes, and Fitzharris (2008), vehicle safety was considered a high priority in the new car purchase process. Overall, survey findings indicated that older participants were more likely to list safety as their most important consideration in the

new car purchase relative to middle age or younger participants, and women were more likely than men to list safety as their most important consideration. Age differences were also found with regard to where they obtained information for their purchasing decisions. Older participants were more likely to consider motoring magazines as their most important information source, as opposed to young and middle age participants who were most likely to cite the vehicle dealership. In addition, participants were most likely to select a safety-related factor (e.g., EuroNCAP rating, see European New Car Assessment Programme, 2005) and a safety-related feature (e.g., ABS brakes) as their highest priorities in the new car purchase decision. Consistent with previous research, most participants equated vehicle safety with the presence of specific vehicle safety features or technologies rather than the vehicles' crash safety/test results or crashworthiness.

Collectively, findings from studies on vehicle purchasing decisions suggest that while safety is clearly important to vehicle buyers, other considerations come into play and often take precedence. In addition, there is some evidence suggesting that older adults may lack knowledge about how some safety features work and may misunderstand their effectiveness in protecting vehicle occupants.

### **Vehicle Marketing to Older Consumers**

The aging of the baby boomers and the increasing share of the consumer market they command have led to increased efforts by vehicle manufacturers to market to older consumers. As a first step in this process, many manufacturers have tried to develop a better understanding of changes that older adults experience as they age and what the implications of these changes are for vehicle design and marketing. To this end, Pak and Kambil (2006) emphasized the need for manufacturers to understand the various biological, physical, economic, and social changes associated with aging so as to effectively realign their offerings and adapt their communications strategies to the older adult market. They cited the example of the "Third Age Suit" as an approach to sensitize engineers and designers to the physical limitations associated with aging. The suit adds bulk and restricts movement in the knees, elbows, stomach, back, and other key areas of the body. Engineers can wear the suit to experience what limitations in mobility, strength, and visions of someone 30 years older might be like.

At the same time, the general pattern among manufacturers has been to focus on safe and comfortable vehicles that may be specifically packaged and marketed to the general population rather than one segment such as older adults (Levi et al., 2008; Levi & De Leonardis, 2008). Such an approach, often termed *universal design*, has been used by human factors engineers to design vehicles for people who are older as well as for the general population (e.g., vehicles that include larger knobs and instrument panels). The idea behind universal design is that it can improve vehicle use for older adults while at the same time benefiting other age groups (Steinfeld & Steinfeld, 2001). This approach is considered especially promising, given the widespread view that baby boomers will not buy vehicles marketed specifically as user-friendly for older adults (Levi & De Leonardis, 2008). Some of the distinct vehicle features that have resulted from a universal design approach include raised seating for easier ingress and egress, extra-wide doors, large controls, nonreflective interior surfaces to reduce glare, power-swivel driver and passenger seats, hand controls with simultaneous one-hand control of both throttle and brake, and all-wheel drive (Levi & De Leonardis, 2008).

### **Marketing of Products Other Than Vehicles**

Findings from selected studies of consumer behavior relative to products other than motor vehicles reinforce some of the findings on vehicle marketing and point to differences between older and younger consumers, as well as between baby boomers and other groups. Several studies have focused on consumer behavior with regard to technology or technology related products and may provide insights into marketing vehicles with “senior friendly” features. Yang and Jolly (2008) examined several factors that might account for the lower level of adoption of mobile data services by baby boomers than gen Xers (born between the mid 1960s and early 1980s), including perceived usefulness, perceived ease of use, and perceived fun associated with the services. They found that the perception among baby boomers that the technology was not easy to use appeared to hinder its adoption. Interestingly, baby boomers were actually more likely to perceive such services to be of value. Kumar and Lim (2008) also examined differences in mobile service, focusing on perceptions of service quality and its impact on perceived value, satisfaction, and loyalty, among baby boomers and

Generation Y (born between 1980 and 1994). Among the key findings were that emotional value had a greater effect on satisfaction for Generation Y, while economic value had a greater effect on satisfaction for baby boomers.

Research on assistance technologies targeted to older adults (e.g., mobility aids, vision aids, hearing aids, furniture or daily living aids, gadgets or small aids) may also be useful for thinking about vehicle marketing. For example, McCreadie and Tinker (2005) studied the acceptability of various types of assistive technology and found that acceptability depended on the interactions between a “felt need” for assistance, the recognition of “product quality” (the efficiency, reliability, simplicity, and safety of the technology or device), and its availability and cost. In work on one type of assistive technology, Resnik, Allen, Isenstadt, Wasserman, and Iezzoni (2009) examined attitudes about mobility aids by race and ethnicity through focus groups with White, Black, and Hispanic older adults. A key theme that emerged was that participants felt mobility aid use to be stigmatizing because of a strong association with aging and physical decline. There were few differences between minority and nonminority groups, although Hispanic participants expressed a more fatalistic view of age-related functional decline, and heightened concerns about mobility aid users being subject to negative biases.

In general, the field of marketing has tended to focus on younger consumers, resulting in a lack of experience in marketing to older consumers in ways that are compatible with their unique characteristics (Antony & Purwar, 2007). At the same time, Dann (2007) emphasized the difficulty of directly targeting the baby boomer cohort, especially given the importance that baby boomers place on the value of individualism. One example of a success in marketing specifically to older consumers is the product OXO Good Grips. The product was originally conceived of as an assistive device for older adults with arthritis. However, by ensuring that the product was also stylish and functional, Dann (2007) argued that the company was able to create a product that not only appealed to consumers but also stayed true to its core brand values. She contrasted this with marketing efforts by financial institutions and banks that promote easy access to finance as a way for baby boomers to enjoy themselves, “spend the kids” inheritance, or “payback” their children by making them worry about their parents’ whereabouts. She concluded that although these messages are meant to be humorous, they essentially

promote financial and personal irresponsibility, values that are clearly at odds with the traditional brand values associated with financial institutions.

## Discussion and Recommendations

Has the time come for an older driver vehicle? We answer this question with a qualified “yes.” Based on the information reviewed here, there is a clear global opportunity to improve the safety, mobility, and quality of life of older adults by designing vehicles and vehicle technologies that help overcome common age-related deficits. Given the global aging and driving trends, it is reasonable to assume that there will be a large market of older consumers who may be interested in purchasing vehicles that help them to continue driving for as long as they can safely do so. The marketing of these vehicles to older consumers, however, will be challenging and will likely require further market research.

The development of vehicle design features, new automotive technologies, and crashworthiness systems in the future should be guided by both knowledge of frailty/fragility and its effect on crash outcomes, as well as knowledge of common driving-related declines in psychomotor, visual, and cognitive abilities. Utilizing principals of universal design is recommended. In most cases, vehicle design changes and technology developments that make driving safer and easier for older adults will also help drivers of any age. However, because of age-related frailty and fragility, universal design principals may not always be ideal for improving crashworthiness.

At the same time, developers need to recognize that older adults are a highly heterogeneous group. Design strategies that allow for some degree of customization may be particularly beneficial. Offering certain design features and/or technologies as an optional package may be one method to allow a small level of customization for older adults. How such an optional package is marketed will require careful thought, but it is clear that it should not be marketed as being specifically for older adults or people with disabilities. Another way to allow a degree of customization is to have programmable features that adjust themselves based on the driver characteristics—similar to some current vehicles that can sense who the driver is based on a key fob and which adjust seats, mirrors, and other features to fit that driver’s preferences. Although not possible at present, another method for customizing vehicle features and technologies is to have a vehicle capable of sensing the driver’s characteristics in real time (including

psychomotor, visual, and cognitive abilities) and adjust features and interfaces to optimize usefulness given the driver's current status, as was suggested by the AwareCar concept discussed previously.

Independent of the specific design features and technologies for future older drivers, it is clear that training and education efforts will need to be improved. Without adequate knowledge about vehicle features and technologies, the benefits of these new designs may not be achieved and, in the worst case, may compromise safety. Older adults report difficulties learning about current technologies and vehicle features, and lack knowledge about how crash protection systems operate. It is highly likely that this situation will continue into the future unless new ways to train and educate older adults are devised. Whether or not this training can take place at a vehicle dealership is unknown and should be explored in future research. Another method for training could involve a third party who provides the training on behalf of either the manufacturer or the consumer. It may also be possible to work with groups like those who organize CarFit events, where trained volunteers provide expert feedback about adjusting vehicles to better fit with an individual driver's characteristics.

Finally, even though we argue that the time is ripe for an older driver vehicle, we qualify that statement by cautioning that the marketing of such a vehicle will be complicated and will likely need to be based on more research. In particular, more research is needed on how older adults process marketing information. Studies are clear that older adults do not resonate to products that are linked to "old age" or being "disabled." On the other hand, if vehicle designs, automotive technologies, and crashworthiness systems are optimized for overcoming many common age-related declines making the operation of a vehicle safer and easier, there is an excellent opportunity to capitalize on these benefits in a marketing strategy for selling cars to older consumers.

## References

- AAA Foundation for Traffic Safety (2008). *Use of Advanced In-Vehicle Technology by Younger and Older Early Adopters*. Washington, D.C.: AAAFTS.
- Abdel-Aty, M.A. & Radwan, A.E. (2000). Modeling traffic accident occurrence and involvement. *Accident Analysis & Prevention*, 32, 633-642.
- Adler, G. & Rottunda, S. (2006). Older adults' perspectives on driving cessation. *Journal of Aging Studies*, 20, 227,-235.
- Alvarez, F.J. & Fierro, I. (2008). Older drivers, medical conditions, medical impairment and crash risk. *Accident Analysis & Prevention*, 40, 55-60.
- Anshel, M.H. (1978). Effect of aging on acquisition and short-term retention of a motor skill. *Perceptual Motor Skills*, 47, 993-994.
- Anstey, K.J., Wood, J., Lord, S., & Walker, J.G. (2005). Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review*, 25, 45-65.
- Antony, S.P. & Purwar, P.C. (2007). Do we know enough to market to the older consumer? The case of marketing correctness. Paper presented at *International Marketing Conference on Marketing & Society*, April 8-10, IIMK, pp. 477-484.
- Attebo, K., Mitchell, P., & Smith, W. (1996). Visual acuity and the causes of visual loss in Australia: The Blue Mountain Eye Study. *Ophthalmology*, 103, 357-364.
- Augenstein, J. (2001). Differences in clinical response between the young and the elderly. Paper presented at the *Aging and Driving Symposium*, February 19-20, Des Plaines, Illinois.
- Austin, R.A., & Faigin, B.M. (2003). Effect of vehicle and crash factors on older occupant injury. *Journal of Safety Research*, 34, 441.
- Ball, K., Owsley, C., Stalvey, B., Roenker, D.L., Sloane, M.E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis & Prevention*, 30, 313-322.

- Ball, K.K., Beard, B.L., Roenker, D.L., Miller, R.L., & Griggs, D.S. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America*, 5, 2210-2219.
- Ball, K. & Sekuler, R. (1986). Improving visual perception in older observers. *Journal of Gerontology*, 41, 176-182.
- Bauer, M.J., Rottunda, S., & Adler, G. (2003). Older women and driving cessation. *Qualitative Social Work*, 2, 309-325.
- Bell, M.D., Wolf, E., & Bernholz, C.D. (1972). Depth perception as a function of age. *Aging & Human Development*, 3, 77-81.
- Berryman, M.E. (2004). Automatic crash notification and 9-1-1: A success story. In *Proceedings 2004 ESRI Users Conference*. Redlands, CA: ESRI International.
- Birren, J.E. & Shock, N.W. (1950). Age changes in rate and level of dark adaptation. *Journal of Applied Psychology*, 26, 407-411.
- Bouman, J. & Pellerito, J.M. (2006). Preparing for the on-road evaluation. In J.M. Pellerito (Ed.) *Driver Rehabilitation and Community Mobility*. St. Louis, MO: Elsevier Mosby.
- Braver, E.R., & Trempe, R.E. (2003). *Are Older Drivers at Higher Risks of Involvement in Collisions Resulting in Death or Nonfatal Injuries among Their Passengers and Other Road Users?* Arlington, VA: Insurance Institute for Highway Safety.
- Brumbelow, M.L. & Zuby, D.S. (2009). Impact and injury patterns in frontal crashes of vehicles with good ratings for frontal crash protection. Presented at the *21st International Technical Conference on the Enhanced Safety of Vehicles*, Stuttgart, Germany.
- Buehler, R., & Nobis, C. (2010). Travel behavior in aging societies: Comparison of Germany and the United States. *Transportation Research Record*, 2182, 62-70.
- Burg, A. & Hurlbert, S. (1961). Dynamic visual acuity as related to age, sex, and static acuity. *Journal of Applied Psychology*, 45, 111-116.

- Burg, A. (1966). Visual acuity as measured by dynamic and static tests. *Journal of Applied Psychology, 50*, 460-466.
- Burkhardt, J.E., & McGavock, A.T. (1999). Tomorrow's older drivers: Who? How many? What impacts? *Transportation Research Record, 1693*, 62-70.
- Caird, J.K. (2004). In-vehicle intelligent transportation systems: Safety and mobility of older drivers. In *Transportation in an Aging Society: A Decade of Experience*. Washington, D.C.: Transportation Research Board.
- Campbell, A.J. & Buchner, D.M. (1997). Unstable disability and the fluctuations of frailty. *Age and Ageing, 26*, 315-318.
- Champion, H.R., Augenstein, J.S., Blatt, A.J., Cushing, B. Digges, K.H., Hunt, R.C., Lombardo, L.V., & Siegel, J.H. (2003). Reducing highway deaths and disabilities with automatic wireless transmission of serious injury probability ratings from vehicles in crashes to EMS. In *Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles*. Washington, D.C.: U.S. Department of Transportation.
- Charlton, J., Andrea, D., Fildes, B., Oxley, J., Morris, A., Langford, J., & Johnson, L. (2002b). Safer Vehicle Choices for Older Adults. Report No. 02/01. Melbourne, AU: Monash University Accident Research Centre.
- Charlton, J., Fildes, B., & Andrea, D. (2002). Vehicle safety and older occupants. *Gerontechnology, 1(4)*, 274-286.
- Chipman, M.L., MacGregor, C.G., Smiley, A.M., & Lee-Gosselin, M. (1993). The role of exposure in comparisons of crash risk among different drivers and driving environments. *Accident Analysis & Prevention, 25*, 207-211.
- Clark, D.D., Forsyth, R., & Wright, R. (1998a). Behavioural factors in accidents at road junctions: The use of a generic algorithm to extract descriptive rules from police case files. *Accident Analysis & Prevention, 30*, 223-234..
- Clark, D.D., Forsyth, R., & Wright, R. (1998b). Junction road accidents during cross-flow turns: A sequence analysis of police case files. *Accident Analysis & Prevention, 31*, 31-43.

- Clark, D.E. & Cushing, B.M. (2002). Predicted effect of automatic crash notification on traffic mortality. *Accident Analysis & Prevention*, 34, 507-513.
- Cooper, P. (1990). Differences in accident characteristics among elderly drivers and between elderly and middle-aged drivers. *Accident Analysis & Prevention*, 5, 499-508.
- Cornoni-Huntley, J., Brock, D.B., Ostfeld, A.M., Taylor, J.O., & Wallace, R.B. (1986). *Established Populations for Epidemiological Study of the Elderly: Resource Data Book* (NIH Publication No. 86-2443). Bethesda, MD: National Institute on Aging.
- Cotté, N., Meyer, J., & Coughlin, J.F. (2001). Older and younger drivers' reliance on collision warning systems. In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society.
- Coughlin, J.F. (2005). Not your father's auto industry? Aging, the automobile, and the drive for product innovation. *Generations*, 28(4), 38-44.
- Coughlin, J. (2006). Invention vs. Innovation: Technology and the Future of Aging. *Aging Today*, 27(2), 3-4.
- Coughlin, J. (2007). *Speaking Silver: Lessons for Product Innovation & Development in an Aging Marketplace* (MIT AgeLab I2 Report, Working Paper 2007-02). Cambridge, MA: MIT AgeLab.
- Coughlin, J.F. (2009). Longevity, lifestyle, and anticipating the new demands of aging on the transportation system. *Public Works Management & Policy*, 13(4), 301-311.
- Coughlin, J.F., Reimer, B., & Mehler, B. (2009). *Driver Wellness, Safety & the Development of an AwareCar*. Cambridge, MA: MIT AgeLab.
- Daigneault, G., Joly, P., & Frigon, J-Y. (2002). Executive functions in the evaluation of accident risk of older drivers. *Journal of Clinical and Experimental Neuropsychology*, 24(2), 221-238.

- Dann, S. (2007). Branded generations: Baby boomers moving into the seniors market. *Journal of Product & Brand Management*, 16(6), 429-431.
- Davidse, R. (2007). *Assisting the Older Driver: Intersection Design and In-Vehicle Devices to Improve the Safety of the Older Driver*. Groningen, the Netherlands: SWOV.
- Department of Transport. (2001). *Older Drivers: A Literature Review*. London: Department of Transport.
- Derefeldt, G., Lennerstrand, G., & Lundh, B. (1979). Age variation in normal human contrast sensitivity. *Acta Ophthalmology*, 57, 679-690.
- Dickerson, A.E., Molnar, L.J., Eby, D.W., Adler, G., Bédard, M., Berg-Weger, M., Classen, S., Foley, D., Horowitz, A., Kerschner, H., Page, O., Silverstein, N.M., Staplin, L., & Trujillo, L. (2007). Transportation and aging: A research agenda for advancing safe mobility. *The Gerontologist*, 47, 578 - 590.
- Dingus, T., Hulse, M.C., Mollenhauer, M.A., Fleischman, R.N., McGehee, D.V., & Manakkal, N. (1997). Effects of age, system experience, and navigation technique on driving with an advanced traveler information system. *Human Factors*, 39, 177-179.
- Druid, A. (2002). *Vision Enhance System-Does Display Position Matter?* Master's Thesis. Vargarda, Sweden: Linkoping University.
- Eby, D.W. & Kostyniuk, L.P. (1998). Maintaining older driver mobility and well-being with traveler information systems. *Transportation Quarterly*, 52, 45-53.
- Eby, D.W., Molnar, L.J., & Kartje, P.S. (2009). *Maintaining Safe Mobility in an Aging Society*. New York, NY: CRC Press.
- Eby, D.W., Molnar, L.J., & Olk, M.L. (2000). Trends in driver and front-right passenger safety belt use in Michigan: 1984 to 1998. *Accident Analysis & Prevention*, 32, 837-843.
- Eisenhandler, S.A. (1990). The asphalt identikit: Old age and the driver's license. *International Journal of Aging and Human Development*, 30, 1-14.

- Ervin, R.D., Sayer, J., LeBlanc, D., Bogard, S., Mefford, M., Hagan, M., Bareket, Z., & Winkler, C. (2005). *Automotive Collision Avoidance System Field Operational Test Report: Methodology and Results* (Report No. DOT HS 809 900). Washington, D.C.: U.S. Department of Transportation.
- European New Car Assessment Programme. (2005). Creating a Market for Safety. URL: [http://www.fiafoundation.org/Documents/Road%20Safety/brochure\\_10th\\_anniversary.pdf](http://www.fiafoundation.org/Documents/Road%20Safety/brochure_10th_anniversary.pdf). Accessed December 29, 2011.
- Fildes, B.N. (2008). Future directions for older driver research. *Traffic Injury Prevention, 9*, 387-393.
- Fancher, P., Ervin, R., Sayer, J., Hagan, M., Bogard, S., Bareket, Z., Mefford, M., & Haugen, J. (1998). *Intelligent Cruise Control Field Operational Test* (Report No. UMTRI-98-17). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Farmer, C.M. & Lund, A. K. (2006). Trends over time in the risk of driver death: What if vehicle designs had not improved? *Traffic Injury Prevention, 7*, 335-342.
- Federal Highway Administration. (2008). Highway Statistics Publications. URL: <http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm>. Washington, D.C.: FHWA, Office of Highway Policy Information.
- Fillit, H. & Butler, R.N. (2009). The frailty identity crisis. *Journal of the American Geriatrics Society, 57*, 348-352.
- Fonda, S.J., Wallace, R.B., & Herzog, A.R. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *Journal of Gerontology Series B: Psychological Sciences and Social Sciences, 56*, S343-S351.
- French, D.J., West, R.J., Elander, J., & Wilding, J.M. (1993). Decision-making style, driving style, and self-reported involvement in road traffic accidents. *Ergonomics, 36*, 627-644.
- Gaines, J.M., Burke, K.L., Marx, K.A., Wagner, M., & Parrish, J. (2011). Enhancing older driver safety: A driving survey and evaluation of the CarFit program. *Journal of Safety Research, 42*(5), 351-358.

- Gallo, J.J., Rebok, G.W., & Lesikar, S.E. (1999). The driving habits of adults aged 60 years and older. *Journal of the American Geriatrics Society*, 47, 335-341.
- Gish, K.W., Shoulson, M., & Perel, M. (2002). Driver behavior and performance using an infrared night vision enhancement system. Paper presented at the *81st Annual Meeting of the Transportation Research Board*. Washington, D.C.: Transportation Research Board.
- Hakamies-Blomqvist, L. (1993). Fatal accidents of older drivers. Why do older drivers give up driving? *Accident Analysis & Prevention*, 25, 19-27.
- Hakamies-Blomqvist, L. & Wahlström, B. (1998). Why do older drivers give up driving? *Accident Analysis & Prevention*, 30, 305-312.
- Hakamies-Blomqvist, L. (2004). Safety of older persons in traffic. In *Transportation in an Aging Society: A Decade of Experience*. Washington, D.C.: Transportation Research Board.
- Hakamies-Blomqvist, L. Raitanen, T., & O'Neill, D. (2002). Driver ageing does not cause higher accident rates per km. *Transportation Research Part F*, 5, 271-274.
- Henderson, S. & Suen, S.L. (1999). Intelligent transportation systems: A two-edged sword for older drivers? *Transportation Research Record*, 1679, 58-63.
- Heppenstall, C.P., Wilkinson, T.J., Hanger, H.C., & Keeling, S. (2009). Frailty: Dominos or deliberation? *The New Zealand Medical Journal*, 122(1299), 42-52.
- Heron, A. & Chown, S.M. (1967). *Age and Function*. London, UK: Churchill.
- Herriotts, P. (2005). Identification of vehicle design requirement for older drivers. *Applied Ergonomics*, 36, 255-262.
- Hoedemaeker, M & Brookhuis, K.A. (1998). Behavioural adaptation to driving with an adaptive cruise control (ACC). *Transportation Research Part F*, 1, 95-106.
- Hofstetter, H.W. & Bertsch, J.D. (1976). Does stereopsis change with age? *American Journal of Ophthalmology & Physiological Optics*, 53, 664-667.
- Insurance Institute for Highway Safety. (2007). *Fatality Facts: Older People*. URL: [http://www.iihs.org/research/qanda/older\\_people.html](http://www.iihs.org/research/qanda/older_people.html).

- International Transport Forum, ITF. (2011). *Transport Outlook: Meeting the Needs of 9 Billion People*. Paris: International Transport Forum/Organisation for Economic Co-operation and Development.
- Jani, S.N. (1966). The age factor in stereopsis screening. *American Journal of Ophthalmology*, 43, 653-657.
- Janke, M.K. (1994). *Age-Related Disabilities that May Impair Driving and their Assessment: Literature Review* (Report No. RSS-94-156). Sacramento, CA: California Department of Motor Vehicles.
- Kanianthra, J., Carter, A., & Preziotti, G. (2000). *Field Operational Test Results of an Automated Collision Notification System* (Report No. 2000-01-C041). Warrendale, PA: SAE International.
- Kelso, J.A.S. (1982). *Human Motor Behavior: An Introduction*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Kent, R. (2010). The biomechanics of aging. *NTSB Forum on Safety, Mobility, and Aging Drivers*. Washington, D.C.: Transportation Research Board.
- Kent, R., Funk, J., & Crandall, J. (2003). How future trends in societal aging, air bag availability, seat belt use, and fleet composition will affect serious injury risk and occurrence in the United States. *Traffic Injury Prevention*, 4, 24-32.
- Kent, R., Henary, B., & Matsuoka, F. (2005). On the fatal crash experience of older drivers. *Annual Proceedings of the Association of Advanced Automotive Medicine*, 49, 371-391.
- Kent, R., Lopez-Valdes, F.J., Dennis, N.J., Lessley, D., Forman, J., Higuchi, K., et al. (2011). Assessment of a three-point restraint system with a pre-tensioned lap belt and an inflatable, force-limited shoulder belt. *Stapp Car Crash Journal*, 55, 141-159.
- Kent, R., Trowbridge, M., Lopez-Valdes, F.J., Ordoyo, R.H., & Segui-Gomez, M. (2009). How many people are injured and killed as a result of aging? Frailty, fragility, and the elderly risk-exposure tradeoff assessed via a risk saturation model. *Annals of Advances in Automotive Medicine*, 53, 41-50.

- Keskin, E., Ota, H., & Katila, A. (1989). Older drivers fail in intersections: Speed discrepancies between older and younger male drivers. *Accident Analysis & Prevention, 30*, 323-330.
- Klavora, P. & Heslegrave, R.J. (2002). Senior drivers: An overview of problems and intervention strategies. *Journal of Aging and Physical Activity, 10*, 322-335.
- Koppel, S., Bohensky, M., Langford, J., & Taranto, D. (2011). Older drivers, crashes and injuries. *Traffic Injury Prevention, 12*(5), 459-467.
- Koppel, S., Charlton, J.L., Fildes, B.N., & Fitzharris. (2008). How important is vehicle safety in the new vehicle purchase process? *Accident Analysis and Prevention, 40*, 994-1004.
- Koppel, S., Charlton, J.L., Fildes, B.N., Fitzharris, M., Clark, M., Kullgren, A., Solano, O., Makitupa, S., & Ernvall, T. (2005). *How important is 'vehicle safety' in the new vehicle purchase process? (Report of Sub-Task 4.1). Quality Criteria for the Safety Assessment of cars Based on Real-World Crashes.* Melbourne, AU: Monash University Accident Research Centre.
- Kostyniuk, L.P., Eby, D.W., Christoff, C., & Hopp, M.L. (1997a). *An Evaluation of Driver Response to the TetraStar Navigation Assistance System by Age and Sex* (Report No. UMTRI-97-33). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Kostyniuk, L.P., Eby, D.W., Christoff, C., & Hopp, M.L. (1997b). *The FAST-TRAC Natural Use Leased-Car Study: An Evaluation of User Perceptions and Behaviors of Ali-Scout by Age and Gender* (Report No. UMTRI-97-09). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Kostyniuk, L.P., Shope, J.T., & Molnar, L.J. (2000). *Reduction and Cessation of Driving Among Older Drivers in Michigan: Final Report* (Report No. UMTRI-2000-06). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Kostyniuk, L.P., Streff, F.M., & Eby, D.W. (1997). *The Older Driver and Navigation Assistance Technologies* (Report No. UMTRI-97-47). Ann Arbor, MI: University of Michigan Transportation Research Institute.

- Kramer, A.F., Cassavaugh, N., Horrey, W.J., & Mayhugh, J.L. (2007). Influence of age and proximity warning devices on collision avoidance in simulated driving. *Human Factors, 49*, 935-949.
- Kumar, A. & Lim, H. (2008). Age differences in mobile service perceptions: Comparison of generation Y and baby boomers. *Journal of Service Marketing, 22*(7), 568-577.
- Langford, J. & Koppel, S. (2006). Epidemiology of older driver crashes—Identifying older driver risk factors and exposure patterns. *Transportation Research Part F, 9*, 309-321.
- Langford, J., Bohensky, M., Koppel, S., & Taranto, D. (2010). Older drivers in crashes – identifying the safest vehicles and occupant protection technologies. In *Proceedings of the 20th Canadian Multidisciplinary Road Safety Conference*, Niagara Falls, Ontario, June 6-9, 2010.
- Langford, J., Methorst, R., & Hakamies-Blomqvist, L. (2006). Older drivers do not have a high crash risk—A replication of low mileage bias. *Accident Analysis & Prevention, 38*, 574-578.
- Larsen, L. & Kines, P. (2002). Multi-disciplinary in-depth investigations of head on and left turn road collisions. *Accident Analysis & Prevention, 34*, 367-380.
- Lawrence, C., Marr, N.E., & Prendergast, G.P. (1992). County-of-origin stereotyping: A case study in the New Zealand motor vehicle industry. *European Journal of Marketing, 26*, 37-51.
- LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, J., Mefford, M., Hagan, M., Bareket, Z., Goodsell, R., & Gordon, T. (2006). *Road Departure Crash Warning System Field Operational Test: Methodology and Results* (Report No. UMTRI-2006-9-1). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Levi, S. & De Leonardis, D. (2008). *Occupant Protection Issues Among Older Drivers and Passengers: Volume 1 Final Report* (Report No. DOT HS 810 938). Washington, D.C.: National Highway Traffic Safety Administration.

- Levi, S., De Leonardis, D., & Zador, P. (2008). *Occupant Protection Issues Among Older Drivers and Passengers: Volume II Appendices* (Report No. DOT HS 810 939). Washington, D.C.: National Highway Traffic Safety Administration.
- Li, G., Braver, E., & Chen, L. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analyses & Prevention, 35*, 227-235.
- Liddle, J., McKenna, K., & Broome, K. (2004). *Older Road Users: From Driving Cessation to Safe Transportation*. Brisbane, Australia: University of Queensland.
- Liu, C., Utter, D., & Chen, C. (2007). *Characteristics of Crash Injuries among Young, Middle-Aged, and Older Drivers* (Report No. DOT HS 810 857). Washington, D.C.: National Highway Traffic Safety Administration.
- Long, G.M. & Crambert, R.F. (1989). The nature and basis of age-related changes in dynamic visual acuity. *Psychology of Aging, 5*, 138-143.
- Lyman, S., Ferguson, S.A., Braver, E.R., & Williams, A.F. (2002). Older driver involvements in police reported crashes and fatal crashes: Trends and projections. *Injury Prevention, 8*, 116.
- Malfetti, J.W. (1985). *Needs and Problems of Older Drivers: Survey Results and Recommendations*. Falls Church, VA: AAA Foundation for Traffic Safety.
- Maltz, M. & Shinar, D. (2004). Imperfect in-vehicle collision avoidance warning systems can aid drivers. *Human Factors, 46*, 357-366.
- Markides, K.S. & Boldt, J.S. (1983). Changes in subjective age among the elderly: A longitudinal analysis. *The Gerontologist, 23*, 422-427.
- Marotolli, R. A., Richardson, E. D., Stowe, M. H., Miller, E. G., Brass, L. M., Cooney, L. M., Jr., & Tinetti, M. E. (1998). Development of a test battery to identify older drivers at risk for self-reported adverse driving events. *Journal of the American Geriatrics Society, 46*, 562-568.

- Marottoli, R.A., Mendes de Leon, C.F., Glass, T.A., Williams, C.S., Cooney, L.M. Jr., Berkman, L.F., & Tinetti, M.E. (1997). Driving cessation and increased depressive symptoms: Prospective evidence from the New Haven EPESE. Established populations for epidemiologic studies of the elderly. *Journal of the American Geriatrics Society*, *45*, 202-206.
- Marshall, P.H., Elias, J.W., & Wright, J. (1985). Age related factors in motor error detection and correction. *Experimental Aging Research*, *11*, 201-206.
- Matlin, M.W. (1989). *Cognition, 2nd Edition*. Fort Worth, TX: Holt, Reinhart and Winston, Inc.
- Mayr, U., Spieler, D.H., & Kliegl, R. (2001). Aging and executive control: Introduction to this Special Issue. *European Journal of Cognitive Psychology*, *13*, 104.
- McCreadie, C. & Tinker, A. (2005). The acceptability of assistive technology to older people. *Ageing & Society*, *25*, 91-110.
- McFarland, R.A., Domey, R.G., Warren A.B., & Ward, D.C. (1960). Dark adaptation as a function of age: A statistical analysis. *Journal of Gerontology*, *15*, 149-154.
- McGuckin, N.A. & Srinivasan, N. (2003). *Journey to Work in the United States: 1960 – 2000* (Report No. FHWA-EP-03-058). Washington, D.C.: Federal Highway Administration.
- Meyer, J. (2011). In-vehicle telematics and the older driver. In F. Kohlbacher & C. Herstatt (Eds.) *The Silver Market Phenomenon*. Berlin: Springer-Verlag.
- Mitchell, C.G.B. (1997). *The Potential of Intelligent Transportation Systems to Increase Accessibility to Transport for Elderly and Disabled People* (Report No. TP 12926E). Montreal, Quebec: Transportation Development Centre.
- Mollenhauer, M.A., Dingus, T.A., & Hulse, M.C. (1995). *The Potential for Advanced Vehicle Systems to Increase the Mobility of Elderly Drivers*. Iowa City, IA: University of Iowa.
- Molnar, L.J. & Eby, D.W. (2005). A brief look at driver license renewal policies in the United States. *Public Policy & Aging Report*, *15*(2), 12-17.

- Molnar, L.J. & Eby, D.W. (2008). *Consensus-Based Recommendations from the North American License Policies Workshop*. Washington, D.C.: AAA Foundation for Traffic Safety.
- Molnar, L.J. & Eby, D.W. (2009). *Getting around: Meeting the boomers' mobility needs. In Boomer Bust? Economic and Political Issues of the Graying Society*. R. Houston (Ed). Praeger Publishing.
- Molnar, L.J., Eby, D.W., St. Louis, R.M., & Neumeyer, A.L. (2007). Promising Approaches for Promoting Lifelong Community Mobility. Washington, D.C.: AARP.
- Morris, A., Frampton, R., Fildes, B., Charlton, J. (2002a). Requirements for crash protection of older drivers. Paper submitted to *Proceedings of the Conference of the Association for the Advancement of Automotive Medicine*, 2002, Sept 30-Oct 2, Des Plaines, IL.
- Morris, A., Welsh, R., Frampton, R., Charlton, J. & Fildes, B. (2002b). An Overview of Requirements for the Crash Protection of Older Drivers. *Annual Proceeding of the Association for the Advancement of Automotive Medicine*, 46, 141.
- Morris, A., Welsh, R., Frampton, R., Charlton, J., & Fildes, B. (2003). Vehicle crashworthiness and the older motorist. *Ageing & Society*, 23, 395-409.
- Morris, A., Welsh, R., & Hassan, A. (2003). Requirements for crash protection of older drivers. Paper presented at the *Association for the Advancement of Automotive Medicine Conference*, September 22-24, Lisbon, Portugal.
- Moschis, G.P. (2003). Marketing to older adults: An updated overview of present knowledge and practice. *Journal of Consumer Marketing*, 20, 516-525.
- Murray-Leslie, C. (1991). Driving for the person disabled by arthritis. *Journal of Rheumatology*, 30, 54-55.
- Myers, H. & Lumbers, M. (2008). Understanding older shoppers: A phenomenological investigation. *Journal of Consumer Marketing*, 25(5), 294-301.

- National Center for Learning Disabilities (2010). What is Executive Function? URL: <http://www.nclld.org/ld-basics/ld-aamp-executive-functioning/basic-ef-facts/what-is-executive-function>. Accessed January, 2012.
- National Highway Traffic Safety Administration. (1999). *Federal Motor Vehicle Safety Standards and Regulations: U.S. Department of Transportation*. URL: <http://www.nhtsa.gov/cars/rules/import/fmvss/index.html#SN201>.
- National Highway Traffic Safety Administration. (2007). *Adapting Motor Vehicles for Older Drivers* (Report No. DOT HS 810 732). Washington, D.C.: U.S. Department of Transportation.
- Organisation for Economic Co-operation and Development (2001). *Ageing and Transport. Mobility Needs and Safety Issues*. Paris: OECD Publications.
- Organisation for Economic Co-operation and Development/International Transport Forum. (2011). *IRTAD Road Safety 2010 Annual Report*. Paris: OECD/IRTAD.
- Owsley, C., & Sloane, M.E. (1990). Vision and aging. In F. Bolter, & J. Grafman (Eds.), *Handbook of Neuropsychology: Volume 4*. Amsterdam: Elsevier.
- Owsley, C., McGwin, G. Jr., & Seder, T. (2011). Older drivers' attitudes about instrument cluster designs in vehicles. *Accident Analysis & Prevention*, 43, 2024-2029.
- Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. *Vision Research*, 23, 689-699.
- Oxley, J., Fildes, B., Corben, B., & Langford, J. (2006). Intersection design for older drivers. *Transportation Research Part F*, 9, 335-346.
- Oxley, P.R., Barham, P.A., & Ayala, B.E. (1995). The use of route guidance systems by elderly drivers. In *Proceedings of the 1994 World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*. Boston, MA: Artech House.
- Padmanaban, J. (2001). Crash injury experience of elder drivers. Paper presented at the *Aging and Driving Symposium*, February 19-20, Des Plaines, Illinois.

- Pak, C. & Kambil, A. (2006). Over 50 and ready to shop: Serving the aging consumer. *Journal of Business Strategy*, 27(6), 18-28.
- Parasuraman, R. (1991). Attention and driving performance in Alzheimer's dementia. *Proceedings of the Conference: Strategic Highway Research Program and Traffic Safety on Two Continents*. Gothenburg, Sweden.
- Perel, M. (1998). Helping older drivers benefit from in-vehicle technologies. In *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles*. Washington, D.C.: U.S. Department of Transportation.
- Petrofsky, J.S. & Lind, A.R. (1975). Aging, isometric strength and endurance, and cardiovascular responses to static effort. *Journal of Applied Psychology*, 1, 91-95.
- Petzäll, J. (1995). The design of entrances of taxis for elderly and disabled passengers. *Applied Ergonomics*, 26, 343-352.
- Pike, J. (2004). Reducing injuries and fatalities to older drivers: Vehicle concepts. In *Transportation in an Aging Society: A Decade of Experience*. Washington, D.C.: Transportation Research Board.
- Ponds, R.W.H.M., Brouwer, W.H., & van Wolffelaar, P.C. (1988). Age differences in divided attention in a simulated driving task. *Journal of Gerontology*, 43, 151-156.
- Preusser, D.F., Williams, A.F., Ferguson, S.A., Ulmer, R.G., & Weinstein, H.B. (1998). Fatal crash risk for older drivers at intersections. *Accident Analysis & Prevention*, 30, 151-159.
- Ragland, D., Satariano, W.A., & MacLeod, K. E. (2004). Reasons given by older people for limitation or avoidance of driving. *The Gerontologist*, 44, 237-244.
- Ragland, D.R., Satariano, W.A., & MacLeod, K.E. (2005). Driving cessation and depressive symptoms. *Journal of Gerontology: Medical Sciences*, 60A, 399-403.
- Ram, N., Talmor, D., & Brasel, K. (2005). Predicting significant torso trauma. *The Journal of Trauma*, 59, 132-135.

- Raytheon Commercial Infrared and EICAN-Teaxs Optical Technology. (2000). *NightDriver™ Thermal Imaging Camera and HUD Development Program for Collision Avoidance Applications* (Report DOT-HS-809-163). Washington, D.C.: U.S. Department of Transportation.
- Reimer, B., Coughlin, J.E., & Mehler, B. (2009). *Development of a Driver Aware Vehicle for Monitoring, Managing & Motivating Older Operator Behavior*. Washington, D.C.: ITS America.
- Reimer, B., Mehler, B., Coughlin, J.F., Godfrey, K.M., & Tan, C. (2009). An on-road assessment of the impact of cognitive workload on physiological arousal in young adult drivers. *Proceedings of the First International Conference on Automotive user interfaces and Interactive Vehicular Applications*. Essen, Germany.
- Reisenwitz, T. & Iyer, R. (2007). A comparison of younger and older baby boomers: Investigating the viability of cohort segmentation. *Journal of Consumer Marketing*, 24(4), 202-213.
- Resnik, L., Allen, S., Isenstadt, D., Wasserman, M., & Iezzoni, L. (2009). Perspectives on use of mobility aids in a diverse population of seniors: Implications for intervention. *Disability and Health Journal*, 2, 77-85.
- Richmond, R., Aldaghlis, T.A., Burke, C., Rizzo, A.G., Griffen, M., & Pullarkat, R. (2011). Age: Is it all in the head? Factors influencing mortality in elderly patients with head injuries. *Journal of Trauma*, 71, E8-E11.
- Rimini-Doering, M., Altmueller, T., Ladstaetter, U., & Rossmeier, M. (2005). Effects of lane departure warning on drowsy drivers' performance and state in a simulator. In *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. Ames, IA: The University of Iowa.
- Rockwood, K. & Mitnitski, A. (2007). Frailty in relation to the accumulation of deficits. *Journal of Gerontology: Biological Sciences*, 62A, 722-727.

- Rockwood, K., Song, X., & Mitnitski, A. (2011). Changes in relative fitness and frailty across the adult lifespan: Evidence from the Canadian National Population Health Survey. *Canadian Medical Association Journal*, *183*(8), E487-E494.
- Rouhana, S.W., Bedewi, P.G., Kankanala, S.V., Prasad, P., Zwolinski, J.J., Medovsky, A.G., Rupp, J.D., Jeffreys, T.A., & Schneider, L.W. (2003). Biomechanics of 4-point seat belt systems in frontal impacts. *Stapp Car Crash Journal*, *47*,367-99.
- Rudin-Brown, C. & Parker, H.A. (2004). Behavioural adaptation to adaptive cruise control (ACC): Implications for preventive strategies. *Transportation Research Part F*, *7*, 59-76.
- Rumar, K. (2002). Night Vision Enhancement Systems: What Should They Do and What More Do We Need to Know? (Report No. UMTRI-2002-12). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Ryan, G.A., Legge, M., & Rosman, D. (1998). Age related changes in drivers' crash risk and crash type. *Accident Analysis and Prevention*, *30*, 379-387.
- Salthouse, T.A.(1987). Adult age differences in integrative spatial ability. *Psychology & Aging*, *2*, 254-260.
- Salthouse, T.A., Mitchell, D.R., Skovronek, E., & Babcock, R.L. (1989). Effects of adult age and working memory on reasoning and spatial ability. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *15*, 507-516.
- Santos, A., McGuckin, N., Nakamoto, H.Y., Gray, D., & Liss, S. (2011). *Summary of Travel Trends: 2009 National Household Travel Survey* (Report No. FHWA-PL-11-022). Washington, D.C.: Federal Highway Administration.
- Schieber, F., Hiris, E., White, J., Williams, M., & Brannan, J. (1990). Assessing age-differences in motion perception using simple oscillatory displacement versus random dot cinematography. *Investigative Ophthalmology & Visual Science*, *S31*, 355.
- Schieber, F., Kline, D.W., Kline, T.J.B., & Fozard, J.L. (1992). *The Relationship Between Contrast Sensitivity and the Visual Problems of Older Drivers* (SAE Technical Paper No. 920613). Warrendale, PA: Society of Automotive Engineers.

- Scialfa, C.T., Kline, D.W., & Lyman, B.J. (1987). Age differences in target identification as a function of retinal location and noise level: Examination of the useful field of view. *Psychology & Aging, 2*, 14-19.
- Sekuler, R. & Ball, K. (1986). Visual localization: Age and practice. *Journal of the Optical Society of America, 3*, 864-867.
- Shaheen, S.A. & Neimeier, D.A. (2001). Integrating vehicle design and human factors: Minimizing elderly driving constraints. *Transportation Research Part C, 9*, 155-174.
- Shaw, L., Polgar, J.M., Vrkljan, B., & Jacobson, J. (2010). Seniors' perceptions of vehicle safety risks and needs. *The American Journal of Occupational Therapy, 64(2)*, 215-224.
- Shepard, R.J. (1998). Aging and exercise. In T.D. Fahey (Ed.), *Encyclopedia of Sport Medicine and Science*.
- Simões, A. & Pereira, M. (2009). Older drivers and new in-vehicle technologies: Adaptation and long-term effects. In M. Kurosu (Ed.) *Human Centered Design*. Berlin: Springer-Verlag.
- Sivak, M. & Schoettle, B. (2011). *Recent Changes in the Age Composition of Drivers in 15 Countries*. (Report No. UMTRI-2011-43). Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Sivak, M., Campbell, K.L., Schneider, L.W., Sprague, J.K., Streff, F.M., & Waller, P.F. (1995). The safety and mobility of older drivers: What we know and promising research issues. *UMTRI Research Review, 26(1)*, 1-21.
- Ståhl, A., Oxley, P., Berntman, M., & Lind, L. (1994). The use of vision enhancements to assist elderly drivers. In *Towards an Intelligent Transport System: Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-highway Systems*. London, England: Artech House.
- Stamatiadis, N. (1998). ITS and human factors and the older driver: The U.S. experience. *Transportation Quarterly, 52*, 91-101.

- Stamatiadis, N. (2001). Is ITS ready for the older driver? In *2001 IEEE Intelligent Transportation Systems Conference Proceedings*. New Brunswick, NJ: IEEE.
- Stamatiadis, N., Taylor, W., & McKelvey, F. (1991). Elderly drivers and intersection accidents. *Transportation Quarterly*, *45*, 377-390.
- Stanton, N.A. & Young, M.S. (2005). Driver behaviour with adaptive cruise control. *Ergonomics*, *48*, 1294-131.
- Staplin, L., Gish, K.W., & Joyce, J. (2008). “Low mileage bias” and related policy implications—A cautionary note. *Accident Analysis & Prevention*, *40*, 1249-1252.
- Staplin, L., Lococo, K.H., Stewart, J., & Decina, L. (1999). *Safe Mobility for Older People: Notebook* (Report No. DOT HS 808 853). Washington, D.C.: National Highway Traffic Safety Administration.
- States, J.D. (1985). Musculo-skeletal system impairment related to safety and comfort of drivers 55+. In J.W. Malfetti (Ed.), *Proceedings of the Older Driver Colloquium*. Falls Church, VA: AAA Foundation for Traffic Safety.
- Steinfeld, A. & Steinfeld, E. (2001). Universal design in automobile design. In W.F.E. Preiser & E. Ostroff (eds), *Universal Design Handbook*. New York, New York: McGraw-Hill.
- Sudbury, L. & Simcock, P. (2009). A multivariate segmentation model of senior consumers. *Journal of Consumer Marketing*, *26*(4), 251-262.
- Sundararajan, S., Rouhana, S.W., Board, D., DeSmet, E., Prasad, P., Rupp, J.D., et al. (2011). Biomechanical assessment of a rear-seat inflatable seatbelt in frontal impacts. *Stapp Car Crash Journal*, *55*, 161-197.
- Szanton, S.L., Seplaki, C.L., Thorpe, R.J., Allen, J.K., & Fried, L.P. (2010). Socioeconomic status is associated with frailty: The Women’s Health and Aging Studies. *Journal of Epidemiology and Community Health*, *64*, 63-67.
- Uduma, K. (2000). Innovations in auto safety design, a key to quality improvement. *Technological Forecasting and Social Change*, *64*, 197-208.

- United Nations (2009). *World Population Aging 2009*. New York, NY: United Nations.
- United Nations Population Fund, UNFPA (2011). *UNFPA State of World Population 2011*. New York, NY: UNFPA.
- U.S. Census Bureau. (2008). *Births, Deaths, Marriages, and Divorce: Life Expectancy*  
URL: [http://www.census.gov/compendia/statab/cats/births\\_deaths\\_marriages\\_divorces/life\\_expectancy.html](http://www.census.gov/compendia/statab/cats/births_deaths_marriages_divorces/life_expectancy.html). Released March 17, 2008.
- U.S. Department of Transportation, Volpe National Transportation Systems Center, Research and Innovative Technology Administration. (2008). *Technology Applications for Traffic Safety Programs: A Primer* (Report No. DOT HS 811 040). Washington, D.C.: National Highway Traffic Safety Administration.
- Van Wolffelaar, P. & Rothengatter, T. (1990). *Divided attention in RTI-tasks for elderly drivers. EC DRIVE Programme, Project V1006: DRIVAGE*. Groningen, the Netherlands: Traffic Research Center, University of Groningen.
- Van Wolffelaar, P.C., Rothengatter, T., & Brouwer, W. (1991). Elderly drivers' traffic merging decisions. In A.G. Gale et al., (Eds) *Vision in Vehicles III*. Amsterdam: Elsevier.
- Vrkljan, B.H. & Anaby, D. (2011). What vehicle features are considered important when buying an automobile? An examination of driver preferences by age and gender. *Journal of Safety Research*, 42, 61-65.
- Vrkljan, B.H. & Polgar, J.M. (2007). Driving, navigation, and vehicular technology: Experiences of older drivers and their co-pilots. *Traffic Injury Prevention*, 8, 403-410.
- Wang, S.C. (2010). Untitled presentation. *NTSB Forum on Safety, Mobility, and Aging Drivers*. Washington, D.C.: National Transportation Research Board. November 9, 2010.
- Welch, R., Morris, A., Hassan, A., Charlton, J., & Fildes, B. (2006). Requirements for crash protection of older drivers. *Transportation Research Part F: Traffic Psychology*, 89, 322-334.

- Welford, A.T. (1959). Psychomotor performance. *Annual Review of Gerontology & Geriatrics*, 4, 237.
- West, R.L., Crook, T.H., & Barron, K.L. (1992). Everyday memory performance across the life-span: effects of age and noncognitive individual differences. *Psychology & Aging*, 7, 72-82.
- Wheatley, C.J., Pellerito, J.M.Jr., & Redpenning, S. (2006). The clinical evaluation. In J.M. Pellerito (Ed.), *Driver Rehabilitation and Community Mobility: Principles and Practice*. St. Louis, MO: Elsevier Mosby.
- Whelan, M., Langford, J., Oxley, J., Koppel, S. & Charlton, J. (2006). *The Elderly and Mobility: A Review of the Literature* (Report No. 255). Victoria, Australia: Monash University Accident Research Centre.
- Williams, K.C. & Page, R.A. (2010). Marketing to the generations. *Journal of Behavioral Studies in Business*, 8-10.
- Williams, L.E. (2002). *Emergency Vehicle Automatic Crash Notification & Event Reporting Technology*. Aliso Viejo, CA: Roadside Telematics Corporation.
- Wochinger, K. & Boehm-Davis, D. (1995). *The Effects of Age, Spatial Ability, and Navigation Information on Navigational Performance* (Report No. FHWA-RD-95-166). Washington, D.C.: Federal Highway Administration.
- Wolf, E. (1960). Glare and age. *Archives of Ophthalmology*, 64, 502-514.
- Yang, K. & Jolly, L.D. (2008). Age cohort analysis in adoption of mobile data services: Gen Xers versus baby boomers. *Journal of Consumer Marketing*, 25(5), 272-280.
- Yee, W.Y., Cameron, P.A., & Bailey, M.J. (2006). Road traffic injuries in the elderly. *Emergency Medicine Journal*, 23, 42-46.
- Yoganandan, N., Pintar, F.A., Stemer, B.D., Gennarelli, T.A., & Weigelt, B.D. (2007). Biomechanics of side impact: Injury criteria, aging occupants, and airbag technology. *Journal of Biomechanics*, 40, 227-243.

- Yoon, C. & Cole, C.A. (2008). Aging and consumer behavior. In *Handbook of Consumer Psychology* (eds. C.P. Hangtvedt, P.M. Herr, F.R. Kardes). New York: Lawrence Erlbaum Associates.
- Yoon, C., Laurent, G., Fung, H.H., Gonzalez, R., Gutchess, A.H., Hedden, T., et al. (2005). Cognition, persuasion and decision making in older consumers. *Marketing Letters*, *16*, 429-441.
- Yoon, C., Cole, C.A., & Lee, M.P. (2009). Consumer decision making and aging: Current knowledge and future directions. *Journal of Consumer Psychology*, *19*, 2-16.
- Yoon, C., Lee, M.P., & Danziger, S. (2007). The effects of optimal time of day on persuasion processes in older adults. *Psychology & Marketing*, *24*(5), 475-495.
- Yunkyung, J., Gruenewald, T.L., Seeman, T.E., & Sarkisian, C.A. (2010). Productive activities and development of frailty in older adults. *Journal of Gerontology: Biological Sciences and Social Sciences*, *65B*(2), 256-261.
- Zelazo, P.D., Craik, F.I.M., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica*, *115*, 167-183.
- Zhan, J. & Vrkljan, B. (2011). Exploring factors that influence vehicle purchase decisions of older drivers: Where does safety fit? In *Proceedings of the Sixth International Driving Symposium on Human Factors in Driving Assessment, Training and Vehicle Design*. Lake Tahoe, CA. June 27-30.
- Zhang, J., Fraser, S., Lindsay, J. Clarke, K., & Mao, Y. (1998). Age-specific patterns of factors related to fatal motor vehicle traffic crashes: Focus on young and elderly drivers. *Public Health*, *112*, 289-295.
- Zhao, C., Popovic, V., Ferreira, L., & Lu, X. (2006). Vehicle design research for Chinese elderly drivers. *Proceedings Computer-Aided Industrial Design and Conceptual Design, 2006*. New Brunswick, NJ: IEEE.
- Zhou, Q., Rouhana, S.W., & Melvin, J.W. (1996). Age effects on thoracic injury tolerance. In *Proceedings of the 40th STAPP Car Crash Conference*. Warrendale, PA: Society of Automotive Engineers.