THE SAFETY AND MOBILITY OF OLDER DRIVERS: WHAT WE KNOW AND PROMISING RESEARCH ISSUES

Michael Sivak

Kenneth L. Campbell

Lawrence W. Schneider

James K. Sprague

Fredrick M. Streff

Patricia F. Waller

The University of Michigan

Transportation Research Institute

Ann Arbor, Michigan 48109-2150

U.S.A.

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16. Abstract

This report was designed to provide a multidisciplinary overview of issues related to the safety and mobility of older drivers. The areas considered included the following:

Mobility, travel patterns, and well-being,
Vision, perception, and attention,
Human biomechanics, and
Alcohol effects.

For each of these areas, major past findings are highlighted, along with promising research issues.

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  Fredrick M. Streff,
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CONTENTS

INTRODUCTION

Increasing interest in older driver traffic safety issues is driven, in part, by changes in the U.S. population. As the "baby boomers" age, the proportion of elderly drivers is increasing. In addition to the changes in the age distribution of the population, several other age-related factors influence the impact of older drivers on traffic safety. These factors include driver license rates, average annual mileage, accident risk, and injury risk. This section summarizes the literature that describes these factors, and their influence on traffic safety in the coming decades.

Population changes

In a 1988 Transportation Research Board Special Report, *Transportation in an Aging Society* (Transportation Research Board, 1988), the changing age distribution of the U.S. population was described as the "squaring of the population pyramid." The illustration from this TRB report has been updated with projections based on the 1990 Census (U.S. Department of Commerce, 1993), and extended to the year 2050, as shown in Figure 1. The width of the bars are proportional to the population in each age group. The total population is proportional to the area covered by the sum of the age-group bars, and is shown in parenthesis below each year.

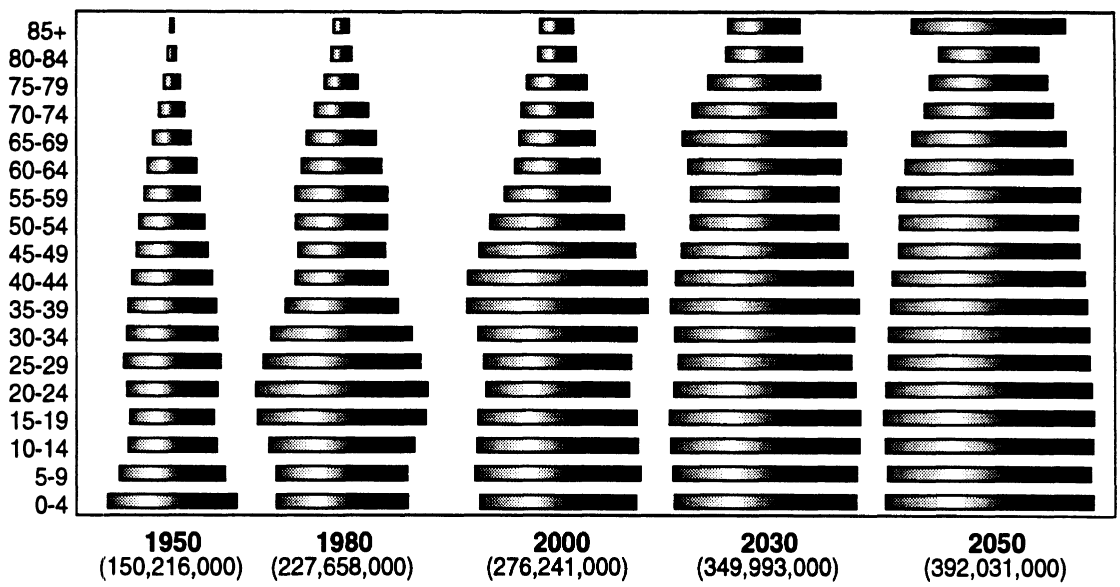

Figure 1. Squaring the population profile.

The "baby boom" generation is evident as a bulge moving up the population distribution as the years pass. It is the aging of the "boomers," and the trends in birth and death rates, that are responsible for the changing age distribution in the U.S. population. These Census Bureau projections (U.S. Department of Commerce, 1993) are based on assumed trends in births, deaths, and immigration. The figures shown assume 2.1 births per woman, an increase in the average life expectancy to 82.1 years by 2050, and an annual net immigration of 880,000 by the turn of the century. Future population changes could be substantially different, depending on the actual trends. As the boomers move through an age group, the corresponding population proportion swells. The age group experiencing the fastest *annual* growth between now and 2050, will be persons 45 to 54 from now until the year 2000.

The trend in the percentage of the population over the age of 65 is shown in Figure 2. In 1950, the proportion of the population over the age of 65 was less than 10%. The period of sharpest increase is projected to be from 2010 to 2030. The long period of gradual increase before 2010 is largely due to increased lifetimes. The sharp increase corresponds to the boomers reaching age 65. After 2030, the percentage of the population over 65 levels off at about 21%, and the population proportions will remain relatively stable until some future disruption in births, deaths, or immigration occurs.

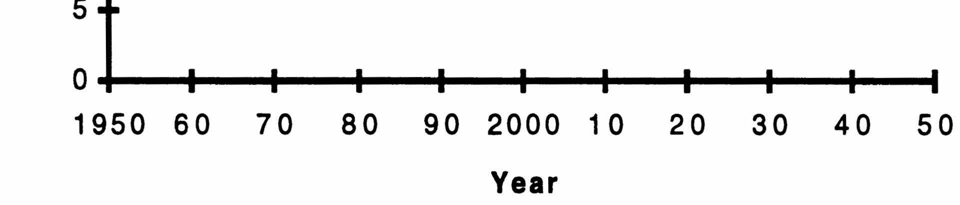

Figure 2. Percentage of the population over 65.

Licensure

The focus of this discussion is on older people as drivers. Before they can drive, they must hold a driver's license. Based on the 1990 National Personal Transportation Survey (NPTS) (Massie and Campbell, 1993), licensure rates drop in the older age groups, particularly for women. However, comparison with the 1983 NPTS shows that the licensure rate in the older age groups is higher in 1990 than in 1983, again particularly for women. One interpretation is that the decrease in licensure rates among older people is partly a reflection of the proportion of the population that never held a driver's license. Since current licensure rates among the younger age groups are well over 90%, one would expect that most of these drivers will continue to renew their license, and that the licensure rate among the older age groups will continue to increase, approaching current rates for the younger age groups.

Annual travel

If you don't drive, you won't be involved in a traffic accident, and people who drive more generally have a greater risk of accident involvement. Annual mileage is one measure of exposure to the risk of an accident. The 1990 NPTS data (Massie and Campbell, 1993) show a strong trend of declining travel among the older age groups. Again, comparison with the 1983 NPTS shows increases in annual mileage across all age groups, and greater increases in the older age groups. As drivers that are accustomed to driving higher annual mileage age, one would expect the annual mileage of the older age groups to continue increasing.

Old age is historically associated with a declining population, and with declines in driving. While the general trend will continue, the magnitude of the decline will be much less. The projected increases in the population over 65, combined with increases in the proportion with driver's licenses and annual travel per driver, will increase total annual travel by older drivers. In 1990, drivers over 65 accounted for about 5% of the annual passenger car travel. Based on the population changes alone, this proportion would be expected to nearly double by 2030. Increases in licensure rates and annual mileage per driver could push the proportion of travel by older drivers even higher.

Accident risk

Given the projected increase in miles driven by older drivers, the next factor to consider is the risk of accident involvement. This risk is often expressed as an accident rate: the number of accidents per mile traveled. Several studies over the years (Massie and Campbell, 1993; Williams and Carsten, 1989; Cerrelli, 1989) have found that drivers over age 65 have an increased risk of fatal accident involvement. In general, the relationship of accident rates to driver age follows a "U" shaped curve, with both the younger and older age groups showing substantially elevated rates. Drivers under the age of 25 and drivers over the age of 65 each have about twice the relative risk of fatal accident involvement, in comparison to the overall risk for drivers of all age groups. Cooper (1989) developed a "relative probability of accident responsibility," and showed several fold increases in this probability over the age of 60.

Some studies have identified specific problems associated with older drivers. For example, older drivers are involved in fewer single-vehicle accidents, and more intersection accidents (Viano, Culver, Evans, Frick, and Scott, 1989). Older drivers have more difficulty with merging and gap acceptance, for example, in making left turns (National Highway Traffic Safety Administration, 1993b).

Injury risk

The last factor to be addressed here is the increased risk of injury or fatality when an older driver is involved in an accident. While the previous material has pertained to older drivers, this risk factor applies to older passengers, as well. Physical changes with age cause the body to be more susceptible to injury in an impact. The risk of bone fractures, in particular, is increased. Carsten (1981) calculated fatalities per 100 million *passenger*-miles, and showed a several-fold increase in this rate by age 70. The National Highway Traffic Safety Administration (NHTSA) characterized this increased risk of injury as "fragility," and illustrated the effect by calculating the number of fatalities per 1000 crashes by age group (National Highway Traffic Safety Administration, 1993b). This ratio increased from 2 for the younger age groups to 5 by age 80. Other studies have looked at the risk of less severe injuries (Gimotty, Campbell, Chirachavala, Carsten, and O'Day, 1980) and found similar increases, even in the lower age range of 20 to 60. In general, there is broad evidence of an increasing trend in the risk of injury and fatality with age. (Additional discussion of this issue is presented on pages 21 and 22.)

Safety impact

It is difficult to predict the impact that an increasing older driver population will have on traffic safety. Current data were analyzed to estimate the safety impact of the projected population changes. For this analysis, only the population over the age of 15 was considered, since 16 is minimum age to be a licensed driver. In 1990, persons over the age of 65 were 15% of the population over the age of 15, and this age group was 11% of the passenger car drivers involved in fatal accidents. By 2030, the proportion of the population over the age of 65 will have grown to about 25%, based on Census Bureau projections. The population projections can be used to estimate fatal accident involvement, assuming current licensure rates, annual mileage per driver, and fatal accident rates. This might be thought of as the expected fatality experience if the population projected for 2030 were present in 1990. Under these assumptions, the proportion of drivers over the age of 65 involved in fatal accidents would increase from 11 to 19%. This estimate is sensitive to the accident rate for drivers over 65. Current data are insufficient to provide a precise rate for the older age groups. The accident rate may be lower when today's younger drivers are over 65 in 2030 or 2050. On the other hand, increases in licensure rates and annual travel per driver among older drivers would tend to increase their accident experience. Under the same assumptions, the proportion of drivers under the age of 25 involved in fatal accidents would decrease from 29.6% in 1990 to 26.6% in 2030. Thus, it is likely that the larger portion of the traffic fatality toll will still be among the younger drivers in 2050, as it is today.

MOBILITY, TRAVEL PATTERNS, AND WELL-BEING OF OLDER DRIVERS

> ". . . I discovered the enormous misery that is generated by the loss or threatened loss of independent mobility. Many seniors simply refused to discuss a future without a car. Others told me that they could not conceive of such a future, and some confessed they would rather die than quit driving. . . [those] who were clearly unfit to drive . . . denied their functional status and continued to drive in defiance of their families because independent mobility was central to their definition of self." (Villeneuve, 1994, p. 3)

Considerable focus has been placed on the older driver in recent years (e.g., Transportation Research Board, 1988; Barr and Eberhard, 1991; National Highway Traffic Safety Administration, 1993b). Much of this research has focused on relationships among demographic, physiological, psychological, biomechanical factors and motor vehicle crash involvement, subsequent injury causation, and remediation. While this research is clearly invaluable for determining what challenges must be overcome and helping to find solutions to these challenges, far less research has been focused on issues surrounding the mobility needs and desires of older persons, current and projected travel patterns of this group, and how the use of personal vehicles affects the emotional and physical well being of older persons. These issues impact not only safety, but also the design and marketing of vehicles appropriate for this booming market segment.

Major past findings

- The average number of trips per year taken by persons age 65 and over increased by 6.1% between 1983 and 1990; the average annual number of person miles of travel for this age group increased by 25.8%—almost twice the rate of all ages taken as a whole; and the average trip length increased 19.4%—more than twice the rate of all ages taken together (Hu and Young, 1992).
- Almost half of all U.S. households with no personal vehicles are households maintained by persons age 65 or over (Lave and Crepeau, 1994).
- Persons over 80 years of age make up the fastest growing segment of the "over 65" population (Rosenbloom, 1994).
- The "gender gap" in driver licensing (with a greater proportion of men holding licenses) will likely continue, but it will narrow considerably for persons age 65 and over (Walcoff & Associates, 1994).
- At least 15% of the elderly with licenses do not drive at all, but continue to own cars (Walcoff & Associates, 1994).
- Older drivers tend to live in the suburbs and therefore require some form of motor transportation (Walcoff & Associates, 1994).
- Older persons are living longer, more active lives (Walcoff & Associates, 1994).
- The transition from independent living to institutionalization may be hastened by a lack of mobility (Walcoff & Associates, 1994).
- Driving for pleasure was identified by 32% of persons age 65 and over as their most frequent outdoor recreation (Mc Avoy, 1979).
- Vacation travel by personal automobile is common for older Americans (Gordon, Gaitz, and Scott, 1976), with perhaps 50+% taking at least one long pleasure trip in a car each year (Friedsam and Martin, 1973).
- There is a significant correlation between self-reported life-satisfaction and the ability for personal travel (Cutler, 1972; 1975).

Topics for future research

Cohort effects related to mobility, travel patterns, and well-being

While some may argue that we already know a considerable amount about the older driver's need for mobility, travel patterns, and effects of these factors on well-being, this may well not be the case. Older drivers of tomorrow may have less in common with older drivers of today than they have in common with the younger cohort of persons from which they evolve. Take for example the cohort of older female drivers. Today, many have only begun to experience any significant amount of driving. However, in the future, we can expect that the driving experience, desire to drive, and many other attributes of this older female cohort will be much less like the current cohort and much more like the younger cohort that is accumulating significant driving experience. Indeed, Waller (1991) points out that these cohort differences may result in "unprecedented problems among older drivers" and that we should be cautious about assuming that what is characteristic in the current cohort of older drivers will continue to be characteristic of future cohorts.

There is a general axiom of human behavior that past behavior is the best predictor of future behavior. Therefore, we would be well advised to try to learn much about the aging cohorts in an attempt to project the needs and behaviors of these aging cohorts. That is, while we must continue to study current older drivers, we should reemphasize research on drivers age 45+ with the goal of being able to predict future needs and challenges that are likely to arise as these persons age.

Given the current state of knowledge, what are the research needs that can be foreseen to help the vehicle manufacturers develop and market vehicles for new cohorts of older drivers? The answer to this question has much to do with the perspective one chooses to examine the issue. As stated earlier, much research emphasis has been put on how society can improve the safety of travel for older persons. Much research effort has also been expended examining how alternate transportation systems may be developed and implemented to improve the safe and efficient mobility of older persons. Unfortunately, there has been a conspicuous lack of solid research on motivations, needs, and strategies used by older persons to achieve these needs in the absence of some external intervention. It seems clear from the literature to date that there is considerably more to being able to drive one's own personal vehicle than simply getting to the store to buy groceries. Future cohorts of aging drivers will likely relish the affective components of driving more and hold a greater disdain for losing driving as a means to achieve affective satisfaction to a greater extent than the current cohort.

Hierarchy of needs related to travel

A first step should be to develop a hierarchy of needs for older drivers. This hierarchy would enable future researchers and product developers to concentrate efforts toward helping older persons achieve lower level needs first, moving on to higher and higher order needs as lower order needs are satisfied. What role does a private vehicle serve to older persons? Is its primary role to provide regular mobility to satisfy simple life needs (food, medical attention) or does private mobility serve to achieve affective needs associated with social and recreational activities? To what extent do these needs covary within the older person cohort?

Independence appears to be an important component of private vehicle ownership and use. What is "independence?" Another way of looking at it is, "Independence from what?" How does independence relate to sensation seeking, enjoying one's "golden years" or more loosely defined matters of freedom and life satisfaction?

To what extent does driving or the ability to have personal mobility options relate to feelings of security or insecurity? For example, having a personal vehicle available for use at all times may provide a sense of security in that a person may then use that vehicle to escape an uncomfortable or threatening situation. On the other hand, once a person is traveling in a vehicle, how secure is he or she from intruders (e.g., carjacking) or from crashes or subsequent crash-related injuries? A newer car or a car with a reputation for reliability may indeed provide the necessary feelings of security that older persons may desire more than their younger cohorts.

One cannot overlook the importance of the vehicle as a status symbol in America. This symbol may or may not take on different meanings for older persons than younger persons. Is the status symbol in the appearance, speed, cost, exclusivity of the vehicle, or is status derived from comfortable, independent mobility?

Land use patterns are changing in America, and will continue to change in the future. Increasingly population areas are becoming decentralized, putting a premium on vehicular mobility. New cohorts of older persons will have greater experience with these decentralized land use patterns, but also will probably have greater perceived needs and expectations for continued independent mobility through the use of personal vehicles. The question is, to what extent do current and projected land use patterns affect the perceived needs and travel patterns of older persons?

Given the needs, desires, and opportunities for travel among older persons, what are their travel patterns like? We know that many older persons self-restrict their driving to times of the day and road types with which they are comfortable. Many of these drivers have perceived their declining physical and mental abilities and have chosen to modify their transportation accordingly. However, we also know that this group has considerable free time for recreational travel, and research indicates that a considerable proportion of older persons drive for pleasure as their most frequent outdoor activity. What are the travel patterns of older persons? Where do they go, when, on what road types, for what reasons? Little research exists in this area, and the research evidence that does exist may not tell us much about future cohorts of older persons.

Willingness to pay for transportation-related products and services

It has been stated that new cohorts of older persons will have higher disposable incomes than previous cohorts. The first question is to determine the veracity of this statement and the level of incomes that one may expect. Not only must we examine absolute income and personal wealth, but also wealth relative to other costs the cohort may incur. If they have more money, what are their expenses and how are these expenses distributed? These issues are vital for an understanding of older persons' willingness to pay for transportation-related products and services. The understanding of this willingness to pay may well be closely linked to the hierarchy of needs perceived by the cohort. It is possible that persons are willing to pay more for the satisfaction of basic needs than for the satisfaction of higher order needs.

VISION, PERCEPTION, AND ATTENTION OF OLDER DRIVERS

Major past findings

Recent research in vision, perception, and attention of older drivers was comprehensively reviewed in an interim report to this study (Schieber, 1994). Tables 1 through 5, based primarily on that review, provide a summary of major findings concerning age-related changes in anatomy, vision, perception, and attention; as well as the relationships of these changes to driving performance and driving accidents.

Table 1
Anatomical changes with age that are relevant to vision, perception, and attention.

Aspect	Typical Age-Related Finding	Sample Reference(s)
Pupil diameter	Decrease	Lowenfield (1979)
Transmissivity of the lens and vitreous body	Decrease	Spector (1982) Spence (1989)
Accommodation	Decrease	Duke-Elder (1963)
Number of cones	No change	Curcio et al. (1993)
Number of rods	Decrease	Curcio et al. (1993)
Number of cells in visual cortex	Probably no decrease	Leuba & Garey (1987)

Table 2
Changes in visual and perceptual performance with age.

Aspect	Typical Age-Related Finding	Sample Reference(s)
Eye movements	Slower and delayed saccades; more saccades to acquire a target	Wacker et al. (1993) Lapidot (1987)
Dark adaptation	Decrease in maximum sensitivity, but no change in the relative rate of adaptation	Eisner et al. (1987)
Visual acuity	Decrease, especially for low contrast targets	Sturr et al. (1990)
Contrast sensitivity	Moderate decline for intermediate spatial frequencies; progressively greater loss for high frequencies	Scialfa et al. (1992)
Glare recovery	Slower	Olson & Sivak (1984)
Peripheral vision	Decrease	Jaffe et al. (1986)
Useful field of view	Decrease	Sekular & Ball (1986)
Distance perception	Impaired at low luminance levels	Bourdy et al. (1991)
Color vision	More color discrimination errors	Knoblauch et al. (1987)
Speed perception	Decrease in sensitivity	Scialfa et al. (1991)
Visual search	Greater loss with more distractors	Scialfa et al. (1987)

Table 3
Attentional changes with age (based on McDowd and Birren, 1990).

Aspect	Typical Age-Related Finding	Sample Reference(s)
Divided attention	Decrease	Salthouse et al. (1984)
Attention switching	No major changes	Hartley et al. (1987)
Sustained attention	Inconsistent results	Surwillo & Quilter (1964) Giambra & Quilter (1985)
Selective attention	Decrease	Hoyer et al. (1979)

Table 4
Relationships of vision, perception, and attention to driving performance.

Aspect	Typical Finding	Sample Reference(s)
Visual acuity	Not related to driving performance	Schreuder (1988)
Contrast sensitivity	Related to self-reported visual problems and to sign legibility	Schieber et al. (1992) Kline et al. (1990)
Peripheral vision	Related to driving performance	Wood & Troutbeck (1992)
Divided attention	Related to driving performance	Ponds et al. (1988)

Table 5
Relationships of vision, perception, and attention to driving accidents.

Aspect	Typical Finding	Sample Reference(s)
Visual acuity	Statistically significant but weak relationship	Henderson & Burg (1974)
Peripheral vision	Statistically significant but weak relationship	Henderson & Burg (1974)
Useful field of view	Inconsistent results	Ball et al. (1993) Brown et al. (1993)

Topics for future research

Automatic vs. controlled processing

A distinction between automatic and controlled processing (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977) is relevant to the understanding of certain age-related changes in human performance. According to Schneider and Shiffrin, automatic processing relies on learned associations between relevant stimuli and appropriate responses. It is initiated by the relevant stimuli and then proceeds automatically (without the person's control). It is generally parallel in nature (and thus it does not tax information-processing capacity), and it does not require explicit attention. Controlled processing, on the other hand, is a temporary activation of a sequence of stimuli and responses, is frequently serial in nature, and requires attention.

Many controlled processes show substantial decrements with advanced age. On the other hand, automatic processes are more resistant to aging (Salthouse, 1991). As we grow older, however, it becomes more and more difficult to acquire *new* automatic processes (Fisk and Rogers, 1991). This finding is relevant not only to the development of new vehicle technologies, but also to the design of highways, signing, and a wide range of vehicle components.

The research challenge is to understand stimulus-response combinations that readily lead to formations of automatic associations by the elderly. Such combinations should then be recommended for use in the driving environment. Conversely, stimulus-response combinations that require controlled processing (or need prolonged use for the emergence of automatic processing) should be avoided.

Divided attention: The role of the demand on motor coordination

Overall performance on two simultaneous tasks that require motor responses usually shows age-related decrements (Ponds, Brouwer, and van Wolffelaar, 1988). However, it is not clear whether this effect is due to diminished "supervisory task control" or to difficulty in coordinating two different motor programs (Ponds et al., 1988). The relevance of both mechanisms is supported by a finding of Brouwer, Ickenroth, Ponds, and van Wolffelaar (1990). This study showed that when one of the two required motor responses was replaced by an oral response, the age effect was reduced substantially (but not eliminated). As pointed out by Schieber (1994), this finding is of potentially great importance for the design of new vehicle technologies, which should be designed to meet the needs of the elderly without overloading their attentional capability.

Divided attention: Usefulness of nonvisual information channels

Schumann performed a series of studies that indirectly relate to a potential solution for the older driver's information-processing overload. His studies (using younger subjects only) dealt with the potential benefits of the haptic channel for providing information to the driver. Schumann (1993) used the steering wheel as a "display" for discrete haptic signals to aid steering behavior. The results indicate that a discrete haptic signal can be effective in interrupting an ongoing open-loop control behavior and transferring it to closed-loop control (e.g., during overtaking). On the other hand, Schumann recommends against the use of such a signal during closed-loop steering (e.g., during curve driving) because of its low information content.

In a follow-up study, Schumann, Lowenau, and Naab (in press) used the steering wheel as a means of displaying continuous haptic information about the driver's lateral control. This was achieved by superimposing artificial torque on the regular steering torque when the actual steering behavior deviated from the calculated optimal steering behavior. The results appear to show that a continuous haptic feedback was useful, because it resulted in a reduction of the driver's workload.

Schumann's results open the possibility that additional information that is vital for certain aspects of driving performance (e.g., steering performance) can be presented through a nonvisual information channel, thereby reducing visual information overload. Extending Schumann's studies to older drivers would be desirable, especially in view of the fact that older persons are more likely to reach the limits of their information processing capability during the course of driving.

Selective attention: Ignoring irrelevant information

Older adults have more difficulty ignoring irrelevant information (Rabbit, 1965). This deficit is evident, for example, in tasks involving memory (Kausler and Kleim, 1978), problem-solving (Hoyer, Rebok, and Sved, 1979), or visual-search (Salthouse, 1991). The problem of ignoring irrelevant information in visual-search tasks is of direct relevance to driving. In their review of selective attention, McDowd and Birren (1990) pointed out two important aspects of the role of age-related distractibility in visual tasks. First, the effect of irrelevant information is present only if the search task is rather demanding (Madden, 1986). Second, older persons have more difficulty in *discriminating* relevant from irrelevant information (Nebbes and Madden, 1983). These findings suggest, for example, that in-vehicle displays (1) should not create demanding visual-search tasks, and (2) should clearly differentiate relevant from irrelevant information (or even remove irrelevant information).

Better understanding of the special problems the elderly have with ignoring irrelevant information would be desirable. Such knowledge should then be applied to the design not only of in-vehicle displays, but of the entire driving environment as well.

Useful field of view

Ball and Owsley (e.g., Ball and Owsley, 1992) have developed a measure of visual functioning that they call "useful field of view" (UFOV). This measure is based on performance on a device called the *Visual Attention Analyzer* (Visual Resources, Inc.), and is derived from scores on three subtasks that evaluate information processing speed, divided attention, and selective attention. Because the latter two subtasks involve peripheral information processing, the useful field of view is conceptualized as "the spatial area within which an individual can be rapidly alerted to visual stimuli" (Owsley and Ball, 1993, p. 395). In one of their studies, older drivers with substantial shrinkage in the useful field of view experienced 4.2 times more crashes during the previous five years than older drivers with large useful fields of view (Owsley, Ball, Sloane, Roenker, and Bruni, 1991). In a confirmatory study, Ball, Owsley, Sloane, Roneker, and Bruni (1993) found that if a subject was involved in at least one crash, the probability of failing the UFOV test was 0.89. On the other hand, Brown, Greaney, Mitchel, and Lee (1993) found only a weak correlation ($r = 0.05$) between UFOV and crashes.

The utility of UFOV for predicting crash involvement that was observed in studies by Ball and Owsley deserves further research, especially because older persons tend to have smaller UFOVs than do younger persons (e.g., Sekuler and Ball, 1986). First, a resolution of the discrepancy between the results of Brown et al. (1993) and Ball and Owsley is needed to ascertain whether UFOV is indeed the best visual/attentional predictor of accident involvement for the elderly (as suggested by the findings of Ball and Owsley). Second, should Ball and Owsley's findings be confirmed, better understanding is needed of the mechanisms that contribute to the UFOV measure. Because it is a composite of three subtests, further research on the predictive power of each individual subtest would be desirable to clarify the relative involvement of information processing speed, divided attention, and selective attention. Third, the potential effect of therapeutically enlarged UFOV on crash involvement is of interest, especially because there is some evidence that training has positive effects on the size of UFOV (Ball, Beard, Roenker, Miller, and Griggs, 1988).

HUMAN BIOMECHANICS AND AGING IN THE AUTOMOTIVE ENVIRONMENT

Major past findings

This section provides a brief overview of current knowledge of biomechanical changes in the human body with age that may affect the ability of elderly persons to access and/or safely operate motor vehicles, and that may increase their susceptibility to, and recovery from, injuries in a crash. Biomechanical factors discussed include muscular strength, reflex and reaction times, manual dexterity, joint range of motion, and mechanical tissue properties.

Muscular strength

Larsson et al. (1979) measured knee joint torque of males of different ages, and observed a general trend found by other researchers that muscle strength tends to peak at about age 20, plateaus throughout middle age, and then declines at an increasing rate beyond age 50. Beyond adolescence, this same trend is found even when strength data are normalized by body weight. Various authors have reported strength declines in the elderly, ranging from 0 to 30% per decade, depending on the age groups and muscles studied, with the effect becoming more pronounced with advancing age beyond about 65 years (Shephard et al., 1991; Bassey and Harries, 1993).

It is also well documented that there are relatively large gender differences in strength. While most studies do not show increasing strength differences between males and females with age, a four-year longitudinal study of strength by Bassey and Harries (1993) found that grip strength declined more in women than in men (19% versus 12%).

Reflex and reaction times

For purposes of this discussion, reflex time is considered to be the time required for a muscle to respond automatically (i.e., at a subconscious level) to an external load, such as an inertially generated force. The response is set up by stretch receptors in the muscle fibers and/or tendons, and includes the time up to initiation of muscle contraction, but not the time to actually contract the muscle. In contrast, reaction time involves a conscious process during which an individual initiates and completes the muscle action and body movement necessary to accomplish a task in response to an external stimulus.

Snyder et al. (1975b) have shown an increase in neck muscle reflex time with age for adult males and females subjected to sudden lateral load applied to the head. Reflex times for females were 18% longer at age 68 than at age 21, while reflex times were 9% longer in elderly males compared to young males.

Baron and Journey (1989) have shown that manual reaction time (i.e., pointing with a joystick in response to a CRT cursor) for young and elderly subjects increases significantly with age and increases for all ages as the number of choice alternatives increases (i.e., as the cognitive load increases). There is considerable literature suggesting that older people exhibit significantly different performance than the young in motor tasks that have more substantial cognitive loads (Stelmach et al., 1987; Salthouse and Somberg, 1982). Also, data from Stelmach et al. (1987) show that reaction time for arm movement increases with decreased knowledge of impending movement requests (more uncertainty), and that this effect is accentuated by age.

Manual dexterity

In the automotive environment, dexterity is needed to quickly locate and manipulate accessories and secondary controls, such as climate controls and radio knobs. Reaching and manipulating these controls can involve a combination of visual, kinesthetic, proprioceptive, somatosensory, and tactile sensory cues, and muscle control.

Thornberry and Mistretta (1981) have demonstrated evidence of significantly increased tactile thresholds with age. Similar results have been reported by Bruce (1980) and Kenshalo (1986). The cause may be peripheral neuropathy—the degeneration of the distal nerves (Schmidt et al., 1990). A general study of adult hand function (Shiffman, 1992) found that task performance time tended to remain stable until age 65 years, after which it diminished slowly. After age 75, differences in performance became more apparent. In addition to the likely decline in manual dexterity in the elderly, Goggin and Meeuwsen (1992) showed evidence that the elderly may perform manual tasks with increased caution and conservatism, in that they have a tendency to emphasize accuracy at the expense of speed.

Joint range of motion/flexibility

Joint flexibility or range of motion (ROM) has been shown to decrease with age (Adrian, 1981), but the degree of decrement appears to be highly dependent on the region of the body. Furthermore, joint range of motion can be greatly influenced by degenerative diseases such as arthritis, which is experienced to some degree by approximately half the population over age 75 (Adams and Collins, 1987). Smith and Sethi (1975) have estimated approximately 25% degradation of joint range of motion in the older adult. Vandervoort et al. (1992) found a significant decrease in ankle dorsiflexion ROM with age. Mean values decreased from 20 to 13.5 degrees in males, and from 21 to 10.1 degrees in females between middle aged and elderly persons. Cervical or neck motion has been shown to be fairly severely influenced by age. In a study by Kuhlman (1993), the elderly group had approximately 12% less cervical flexion, 32% less neck extension, 22% less lateral flexion, and 25% less rotation than the younger control group. These results are in excellent agreement with the findings of Snyder et al. (1975a), which show significant age-related declines in total cervical flexion, extension, and rotational motion.

Mechanical properties of body tissues

Changes in the mechanical properties of body tissues are also known to change with age, with the general trend being toward reduced elasticity and increased fragility. For example, cortical bone area (Sparrow et al., 1982) and bone mineral content (Trouerbach et al., 1988) have been shown to decrease with age, resulting in a net loss of bone with age. The rate at which this loss occurs is highly dependent upon age, gender, and lifestyle (Raab et al., 1990), with the effect tending to be accelerated in women in their mid-fifties and in men after age 68. The greatest rate of bone mineral loss of about 2 to 3.5% per year generally appears in early post-menopausal women.

Using specimens machined from human tibiae bone, Burstein et al. (1976) and Evans (1976) have shown that these changes in bone content result in decreased ultimate strength, stiffness, ultimate strain, and other properties, with age. Burstein et al. have also demonstrated a dramatic decrease with age in the energy required to fracture cortical bone specimens machined from the diaphysis of human femurs. Similarly, Schmidt (1974) examined the incidence of rib fractures in unembalmed cadavers of different ages restrained by seat belts in sled tests, and demonstrated that increasing age dramatically increases the likelihood of fracture injury, thereby increasing likelihood of flail chest.

Martin et al. (1977) have shown that human tissue from the alveolar wall in the lung exhibits a progressive decrease in maximal extensibility with approximately 30% decline in elasticity over 50 years. However, a study of mechanical properties of tendons by Hubbard and Soutas-Little (1984) found no effect of subject age on tendon elasticity and a very small effect on hysteresis and relaxation. On the other hand, Neumann et al. (1994) found substantial age-related changes in the elastic modulus of different regions of the anterior longitudinal ligament, and found the overall strength of the lumbar vertebral ligament complex to decrease two fold between the ages of 21 and 79. Agache et al. (1980) report diminished elasticity and stretchability of human skin after age 30, including a two fold increase of Young's modulus. Escoffier et al. (1989) describe the skin as maintaining its thickness and extensibility up to age 70, but with gradually reduced elasticity and recovery capacities from an early age on.

Implications for the automotive context

There are significant changes in the biomechanical properties of the human body with age, and these changes tend to become accelerated with increasing age, such that the elderly tend to have reduced muscle and bone strength, reduced manual dexterity, decreased joint range of motion and body mobility, reduced elasticity and increased frailty of soft tissues, and increased reflex and reaction times. In terms of the automotive environment, these changes can be interpreted in the following three general areas or categories: ingress/egress, operating a vehicle, and injury and recovery.

Ingress/egress. For the automotive manufacturer interested in improving vehicle design to meet the needs of elderly occupants, getting in and out of the vehicle is an important area of focus since it applies to all elderly occupants, not just to those who drive, or to only front-seat occupants. Also, changes in biomechanical factors with age would be expected to have a greater impact on ingress/egress than changes in visual or cognitive factors. In particular, it can be expected that decrements in muscular strength and joint range of motion will have the most significant effect on getting in and out of a vehicle, especially decreases in leg, torso, hip, hand, and arm strength, balance, and mobility.

Operating a vehicle. From the standpoint of mobility independence and driver licensing, the primary concern is the ability to operate a vehicle in a safe and effective manner. In addition to declining visual and cognitive abilities, changes in biomechanical factors may play an important role in vehicle operation. For example, while reduction in absolute strength may not be an issue in steering and braking of vehicles with power-assisted controls, it could have important consequences in applying the parking brake, or in emergency braking. Reductions in hand and/or finger strength, as well as reduction in upper extremity range of motion, may become factors in driving tasks, such as turning the ignition switch, attaching and releasing seat belt buckles (particularly for large or heavy set persons), adjusting seat position, opening a door, or moving a shift lever.

In the operation of secondary and accessory controls, the impact of divided attention and cognitively challenging tasks on the elderly is of great importance. In addition, the tendency to emphasize accuracy at the expense of speed in manual tasks, such as adjusting the heater control, combined with additional difficulty in finding and operating control buttons because of reduced manual dexterity and motor control, could result in significantly increased distraction times from the primary task of driving. This may increase the probability of an accident.

The degradation in neck rotational range of motion may be particularly important as the visual field narrows with age. Data from Burg (1968) show that the lateral peripheral vision field decreases about 17 total degrees between age 22 and 67 when the head is fixed. The amount of total neck rotational range of motion reduction for the same age range is 32 degrees (Snyder et al., 1975b). Further, limitations of neck range of motion would reduce the lateral field of fovea vision and may be a factor, along with a decreased frequency of head turning to look for oncoming traffic, in the increased incidence of the elderly being involved in intersection collisions. Reductions in torso and shoulder mobility in the elderly, especially with regard to twisting, may also play an important role in safely executing backing-up maneuvers.

Injury and recovery. Reductions in bone strength are a major concern regarding the protection of the elderly in auto accidents. A crash of a given severity is far more likely to result in a bone fracture if the vehicle occupant has decreased bone strength. Reduced elasticity and extensibility in soft tissue, skin, and tendon may significantly increase the probability of a rupture or tear in body tissues and organs in an impact of a given magnitude, but may have a beneficial effect in a reduced likelihood of skin abrasions, particularly those due to impact from deploying airbags.

Muscle strength may also play an important role in reducing injuries during low-severity impacts. Snyder et al. (1975a; 1975b) hypothesized that a preponderance of whiplash symptoms among females might be due to insufficient neck muscle strength to arrest head motion before normal cervical range of motion was exceeded. Also, greater muscle strength is associated with greater muscle mass (Frontera et al., 1991), which may protect the skeleton and internal organs better in the event of a crash.

An analysis of NASS 1984-1987 accident file data (Campbell, 1990) indicates that the elderly experience somewhat different injury patterns than the young, which correspond to these biomechanical changes. In particular, older occupants tend to experience a greater percentage of chest injuries and a corresponding lower percentage of head and face injuries. It addition, and as might be expected from the biomechanical changes discussed above, the elderly tend to experience a greater percentage of skeletal fractures and fewer lacerations.

In addition to concerns about increased probability and severity of injuries, increasing age results in increased recovery times and reduced likelihood of surviving trauma. In a study by Oreskovich et al. (1984), it was found that 92% of elderly over 70 years of age with severe trauma injuries (mean Injury Severity Score [ISS] of 19) never return to their previous level of independence. Also, according to Smith et al. (1990), the Injury Severity Score (ISS) at which persons 65 years of age or younger had a 10%

probability of death was 24.9, while the score for trauma victims over 65 years of age was 17.3. Other data from Bull (1975) and Greenspan et al. (1985) compiled by Pike (1989) show the ISS score for a 50% probability of death to be 40 for the 15 to 44 age group, 29 for the 45 to 64 age group, and 20 for the 65 and over age group.

On the positive side, a preliminary analysis of the 1988-1992 NASS files to examine vehicle mass versus injured occupant age for vehicles involved in frontal collisions, suggests that older drivers may tend to compensate for their increased risk of injury by an increased use of larger vehicles (unpublished).

Topics for future research

From the perspective of the automotive manufacturer, the three areas discussed above can be expressed in the form of three questions that relate to vehicle design for an aging population of drivers and passengers:

1. How can vehicles be designed to improve and facilitate access by the elderly?
2. What can be done to allow elderly people to continue to safely operate a motor vehicle as they age?
3. What should be done with regard to occupant protection systems to offer improved crash protection to elderly occupants who have reduced tolerance to injury and decreased likelihood of full recovery?

While it is clear from this brief overview that there are significant human biomechanical changes with age that may impact on all three of these areas of automotive application, a quantitative understanding of the impact of biomechanical changes on these automotive applications remains poorly defined. There is therefore a need for further research that quantifies the effects of biomechanical changes on ingress/egress, vehicle operation, and occupant protection so that appropriate and practical countermeasures can be implemented in future vehicle designs. The following are suggested research topics involving biomechanics of the elderly:

Vehicle ingress/egress. Conduct experimental research to establish criteria for vehicle entryway and seat design that may present dangerous and/or stressful conditions for elderly occupants. Important biomechanical factors include muscular strength, balance, and joint range of motion.

Vehicle operation. Conduct research that will clarify the role of reduced cervical range of motion in gathering visual information during the driving task, and that will quantify the relationship between reduced muscular strength, range of motion, and manual dexterity with age and the performance of specific driving tasks such as emergency braking, operation of secondary controls, and use of restraint systems.

Occupant protection. Investigate the potential for alternate restraint systems to reduce skeletal injuries to elderly occupants.

ALCOHOL, AGING, AND DRIVING PERFORMANCE

Major past findings

Cohort effects

The elderly in the U.S. today were growing up under Prohibition and its aftermath, the Great Depression. Per capita alcohol consumption was much lower under Prohibition than it is today, and alcohol-related health problems were reduced. If only the direct consequences of alcohol use are considered, Prohibition was a success. The Great Depression was characterized by scarce monetary resources, and alcohol purchase is positively associated with income. Consequently, today's elderly drivers grew up at a time when alcohol use was not high compared to current consumption. Elderly drivers today are less likely to have been drinking than is true for younger drivers.

The baby boomer generation, rapidly approaching their sixth decade, brings a set of attitudes toward many behaviors that is somewhat different from that of their predecessors. Alcohol use by women has increased disproportionately. Traditionally women tended to drink very little, but their alcohol consumption increased as gender roles changed and women became more economically and socially independent. While alcohol is not presently a major problem among the elderly, it may become more so in the future, especially for older women.

Against this scenario is the marked drop in alcohol use, and particularly alcohol use in combination with driving, over the past decade. Both alcohol-related crashes and fatalities have dropped, while overall crashes have increased in numbers. These decreases have been seen for both men and women, with the decrease in the rate of alcohol-related fatalities somewhat greater for women than for men (National Highway Traffic Safety Administration, 1993). However, in part because women are accounting for so much more of the total driving, their proportion of all alcohol-related crashes has greatly increased. These increases in proportion of alcohol-related crashes are especially notable for women in the age range of 20 to 40 (see Table 6), and are particularly alarming when compared to their corresponding changes in proportion of total exposure (see Table 7). If these trends continue over the next decades, older women drivers will become an increasing problem.

Table 6
Changes in proportion of Had Been Drinking Michigan drivers, by age and sex, 1980-1990. (Based on Michigan crash data, 1980 - 1990, drivers of passenger cars, light trucks, or motorcycles.)

Age	Relative change	
	Males	Females
16-20	-29.6	-30.0
21-29	-7.3	+21.4
30-39	+33.9	+73.0
40-54	+5.2	+9.5
55-64	-27.3	-28.5
65-74	+14.3	0
75+	0	0

Table 7
Changes in proportion of total exposure over time for Michigan drivers, by age and sex, 1980-1990. (Based on induced exposure measures calculated from Michigan crash data, 1980 - 1990, drivers of passenger cars, light trucks, or motorcycles.)

Age	Relative change	
	Males	Females
16-20	-29.4	-8.8
21-29	-22.7	-0.9
30-39	+2.3	+33.7
40-54	+8.8	+41.8
55-64	-14.0	+3.4
65-74	+24.0	+55.0
75+	+37.5	+133.3

Differential effects of alcohol

Adding to the complexity of anticipating future cohorts of elderly is the fact that alcohol differentially affects the elderly, women, and persons consuming certain medications. Because of the cohort changes occurring in these groups, these differences could have important implications for future elderly drivers.

The elderly. The same amount of alcohol per body weight will usually result in a higher BAC for older people, presumably because of the increased fat-to-muscle ratio that usually occurs with increasing age. However, alcohol may also result in greater impairment of performance in elderly persons. While most alcohol research is conducted with subjects below the age of 60, and usually much younger, the Grand Rapids Study showed a very marked increase in crash risk for older persons with BACs at or above 0.10% (National Highway Traffic Safety Administration, 1985).

Women. There is limited, but growing, evidence that women are differentially affected by alcohol. It is clearly established that women, on the whole, achieve higher BACs for a given amount of alcohol per body weight (Burns and Moskowitz, 1980). Again, the fat-to-muscle ratio accounts for at least some of this difference. More recently questions have been raised about whether women actually metabolize alcohol differently, achieving a more rapid assimilation and hence a higher peak BAC than men (Frezza et al., 1990). It is established that women develop alcohol addiction and biomedical damage as a result of consuming less alcohol over a shorter period of time than is true for men (U.S. Department of Health and Human Services, 1993).

There is also some evidence that, at a given BAC, the performance of women is more impaired. This finding was reported in the Grand Rapids study (Borkenstein et al., 1964), but was attributed to the fact that women were less experienced drivers. It was again reported by Carlson (1972), and more recently by Jones, Holmgren, and Andersson (1989) and Zador (1991). While women still drive fewer miles than men, they acquire their licenses almost as early as men (a marked change from 20 years ago), and they have increased their driving considerably. They are also driving more at the times and places that are higher risk—again, a change from 20 years ago. Women also account for about half of the purchasers of new cars today. Since it is the earlier part of the learning curve that is the steepest, the differential experience is a less plausible interpretation of the differences in alcohol-related crash experience.

There are a few laboratory studies that suggest that in controlled tasks, not necessarily related to driving, the performance of women shows greater impairment from alcohol administration (Erwin, Wiener, Linnoila, and Truscott, 1978; Haut, Beckwith, Petroa, and Russell, 1989; Moskowitz and Burns, 1990; Niaura et al., 1987; Price, Radwan, and Tergou, 1986). One study has reported that alcohol differentially affects the vision of women, impairing it more than the vision of men (Avant, 1990).

This phenomenon has not been carefully investigated, but because women live longer than men and are a growing presence on the road, and because of their increasing use of alcohol, it is important that research be conducted in this area.

Persons on medication. The elderly, as a group, use a disproportionate number of prescriptions. Little is known about how these medications affect driving performance, and even less is known about how the medications interact with alcohol to further impair driving. Studies have shown effects of drugs on performance under laboratory conditions, with studies often focusing on secobarbitals and diazepam. However, these drugs have not been notable in real world crash experience. Alcohol remains the major drug of abuse so far as traffic safety is concerned. However, if future cohorts of elderly drivers use alcohol more extensively than current older drivers, the synergistic effects of alcohol and medications may take on more importance.

Alcohol and injury

There is the growing evidence that alcohol potentiates injury, that is, in an impact of specified dimensions the drinking driver is more likely to be seriously injured or killed than the driver who has not consumed alcohol. While it has been known since the beginning of recorded history that alcohol is associated with injury, the interpretation has been that alcohol impairs judgment (which it does) and psychomotor performance (which it does) (Carpenter, 1962; Wallgren and Barry, 1971.) However, it is increasingly clear that alcohol also renders an organism more vulnerable to injury in the event of traumatic impact (Waller et al., 1986a; 1986b). Thus, significant changes in drinking behavior (whether increases or decreases) will have implications for the injury experience in motor vehicle crashes.

Emerging technologies

Added to cohort changes is the emerging technology that is designed to facilitate the driving task, but may pose special challenges to the older user, particularly the older user using alcohol and/or other drugs. How will the new intelligent technologies affect older drivers? How can technology counter some of the impairing effects of alcohol and other drugs among the elderly? These are issues that have not been carefully investigated, but that are relevant topics for research.

Topics for future research

Elderly drivers today are increasing in numbers, in their proportion of licensed drivers, and in the miles they drive. While alcohol involvement is not a characteristic of older drivers at the present time, cohort differences in future generations of older drivers may increase motor vehicle injury in this group. Because older occupants, women occupants, and drinking occupants are all more vulnerable to injury in a given crash, the anticipated changes over time pose special challenges to the highway safety community. Possible areas of research include:

1. Investigation of the factors associated with drinking and driving, particularly for the cohort of women currently age 20 to 40, and design of appropriate interventions to reduce the probability of drinking and driving behavior persisting into later years.

2. Investigation of gender differences in driving-related performance as a function of alcohol.

CONCLUSIONS

This report was designed to provide a multidisciplinary overview of issues related to the safety and mobility of older drivers. The areas considered included the following: Mobility, Travel Patterns, and Well-Being; Vision, Perception, and Attention; Human Biomechanics; and Alcohol Effects.

For each of these areas, major past findings were highlighted, along with promising research issues. These issues are summarized in Table 8.

Table 8
Promising future research issues related to the safety and mobility of older drivers.

Area	Future research issues
Mobility, travel patterns, & well-being	Cohort effects related to mobility, travel patterns, & well-being Hierarchy of needs related to travel Willingness to pay for transportation-related products and services
Vision, perception, and attention	Automatic vs. controlled processing The role of the demand on motor coordination The usefulness of the nonvisual information channels Ignoring irrelevant information Useful field of view
Biomechanics	Ingress/egress Operating a vehicle Injury and recovery
Alcohol effects	Factors associated with drinking and driving, particularly for women Gender differences in effects of alcohol on driving performance

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