HELPING OLDER DRIVERS BENEFIT FROM IN-VEHICLE TECHNOLOGIES

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ABSTRACT

Age-related changes in cognitive, perceptual, and motor abilities are thought to be responsible for older driver safety problems and reduced mobility. In-vehicle navigation and collision avoidance technologies may help counter some of the performance limitations associated with aging. Whether or not older drivers will purchase and use such technologies to increase their safety and mobility depends on how well system designers understand the special needs and capabilities of this group and incorporate them into device designs. This paper will examine research findings related to older driver safety problems and capabilities that are relevant to the design of advanced technology, in-vehicle systems.

INTRODUCTION

Developers of Intelligent Transportation Systems (ITS) are designing in-vehicle devices and services to improve driver safety and mobility. The products are generally grouped into two categories: collision avoidance systems and traffic information systems. Some of these products are expected to be of particular value to older drivers because of their perceived need for enhanced safety and mobility.

The future older driver market for such products may be huge. By 2000, the Census Bureau estimates that about 12.8 percent of the population will be over 65; by 2010, the percent rises to 13.3; and increases to 16.4 percent by 2020 as the "baby boomers" enter this age group. Currently, the American Automobile Manufacturers Association estimates that drivers 60 and older are the principal purchasers of 23 percent of new passenger cars in the United States. This percent is likely to increase over time along with the changing demographics.

Will these future seniors buy and benefit from such ITS devices? The answer depends on two issues: The extent to which the devices have functions and features that address the specific safety and mobility needs of seniors; and whether they are designed in accordance with human factors practices and principles so that they minimize distraction and are easy to understand and operate. If these issues are not addressed, the technology may not only be a turnoff to older drivers, it may create new problems for them. This paper examines crash statistics, mobility patterns, in-vehicle technologies, and human factors research for insights relevant to these issues.

SAFETY AND MOBILITY

Older drivers' safety problems have been documented extensively in terms of their performance capabilities, actual on-road behaviors, and crash statistics. Mobility problems have been described in terms of when and how much they drive.

Performance - The basic findings of the performance studies are that relative to younger drivers, older drivers experience more glare sensitivity, more restricted head/neck movement, and slower reaction time to events. Research has also shown that some older drivers have a narrowed field-of-view and increased difficulty noticing all the critical objects in their visual field. One measure of this problem is called "useful field of view." Research by Ball and Owsley has shown that older drivers who have a poor "useful field of view" are at increased risk of crashes. For many of these measures, the variability in performance from driver to driver is much greater for older drivers than younger drivers. This variability means that representative older drivers have to be considered when designing and evaluating in-vehicle equipment to minimize the possibility that the equipment is inadvertently designed for a biased segment of users, e.g., senior "super stars." Although some of these age-related changes in performance capabilities are often thought to adversely affect senior driver safety, their actual role depends on the ability of older drivers to adjust their driving behaviors to compensate for these changes as well as the extent to which vehicle and roadway designs are compatible with older driver capabilities.

Crash Characteristics - In terms of the overall number of crashes, younger drivers (under 25) are involved in four times as many reported crashes as drivers older than 69. Adjusting the number of crashes to reflect the rate per licensed driver within each age group shows that involvement rates decrease as age increases. (Figure 1) To more accurately reflect the safety problem of older drivers, Eberhard (1998) has noted that these data need to be adjusted for the number of licensed drivers who actually drive, which tends to be lower for the oldest drivers. An indicator of a driver's exposure to risk of a collision while on the road is computed by dividing the number of crashes by the number of miles traveled. (Figure 2) These data (NHTSA, 1998) indicate that the highest crash rates per mile driven occur for drivers under 24 and for drivers over 75.

One interpretation of these statistics is that older drivers are involved in relatively few crashes because they do not drive many miles, but have a high risk of crashes when they do drive. However, this per mile adjustment assumes that each mile driven is equally hazardous for all age groups. This assumption may not hold because the urban roads most often used by older drivers are more congested and have more hazardous intersections than expressway miles more often traveled by the middle age drivers (Janke, 1991).

Older drivers' crash patterns can be describe in terms of the percent of their crashes having various characteristics. Many of their crash patterns are similar to those of younger drivers. One exception is crashes at night. Drivers between 65 and 74 have 12.5 percent of their crashes after dark compared to 33 percent for drivers 16-24. The primary reason for this difference is the fewer miles driven by older

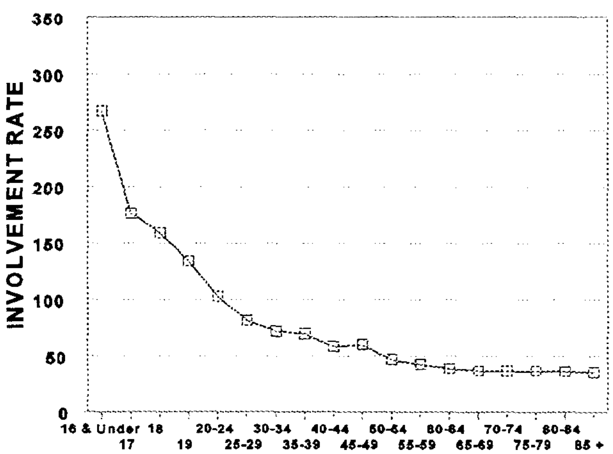

Figure 1. Crash Rate per 1000 Drivers, 1996.

drivers at night. Crashes occur most frequently at intersections for all age groups. However, drivers over 64 have a larger proportion of their crashes at intersections (60 percent) than other age groups (50 percent). At intersections, older drivers have increased problems when turning left. This problem may be related to the research findings that some older drivers have narrow fields-of-view and poor perception of spatially separated sources of information.

Compared to younger drivers, older drivers have only slightly larger percentages of their crashes involving lane changing and backing. Lane changing occurs in about 4.8 percent of crashes for drivers over 64 compared to 2.6 percent for drivers aged 25 - 64, and 2.7 percent for those under 25. Backing is involved in about 4 percent of crashes for drivers over 64 compared to about 2 percent for each of the younger age groups. (Derived from NHTSA 1996 General Estimate System)

However, it is important to keep these relative

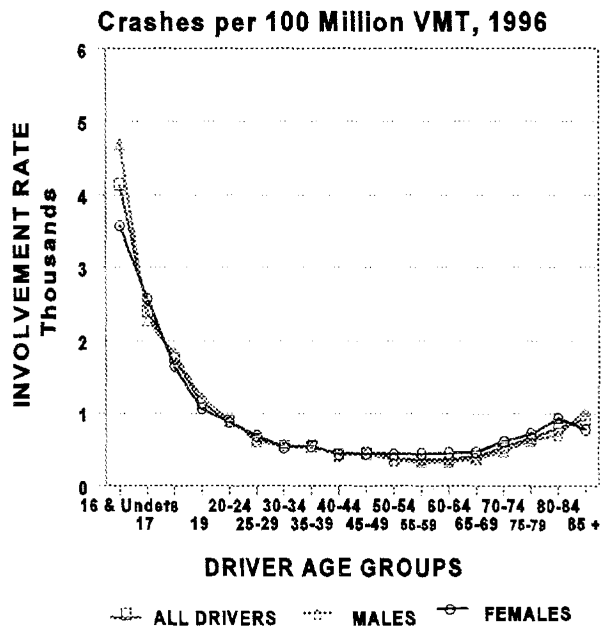

Figure 2. Crash Involvement Rate per Mile Traveled.

involvement percentages in perspective. As shown in Figure 3, the most frequent pre-crash maneuver involving older drivers is also the most frequent one found in all age groups: "going straight." The second most frequent maneuver is "stopped in traffic." Third is "turning left." These three categories account for about 75 percent of the vehicle movements prior to impact in the oldest age group. In part, these data reflect the frequency with which drivers make various maneuvers. That is, drivers are going straight much more of the time than they are turning left. Although older drivers have a greater percent of their crashes when turning left compared to younger drivers, the difference is not large. Drivers going straight prior to a collision are often involved in rear-end crashes. Although older drivers are in the striking vehicle in a smaller percentage of such crashes than drivers between 16 and 24 years of age, their percent involvement is about the same as drivers between 25 and 64 years old. Specifically, drivers 65 and over are in the rear-end, striking vehicle in 13.6 percent of their crashes, compared to 17.9 percent for drivers between 16-24, and 13.4 percent for drivers between 25 and 64. (Derived from NHTSA 1996 General Estimate System)

Driver Behaviors - On-road behaviors are demonstrated to some degree by traffic violation characteristics. Studies have shown that compared to younger drivers, older drivers have proportionally more violations for failure to yield, failure to obey signs/signals, and improper turns. Conversely, they are under-involved in speeding and alcohol violations. (NHTSA, 1993)

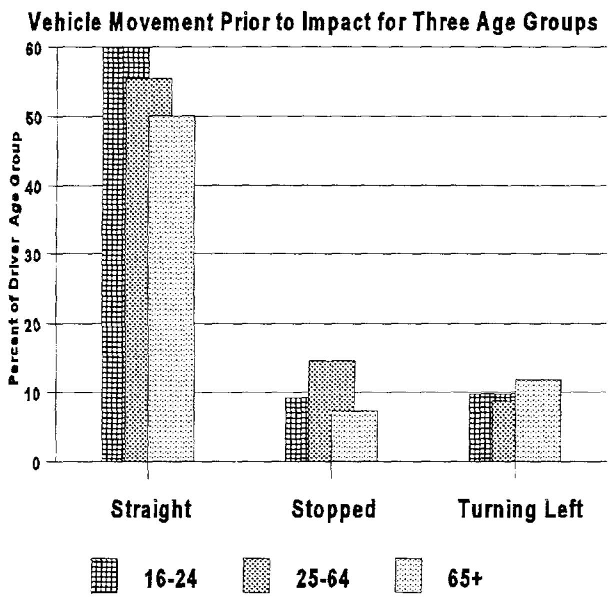

Figure 3. Percent of drivers in different age groups going straight, stopping, or turning left prior to impact.
Source: NHTSA 1996 General Estimate System

Mobility - How can older drivers have reasonably good safety records compared to younger drivers despite all the noted psychological and physiological changes with age? One answer is found in the driving patterns of older drivers. Some older drivers may compensate for their changing capabilities by modifying when, where, and how they drive. They drive less frequently at night. They take an indirect route to avoid making a left turn at an unsignalized intersection. They avoid highway driving. They drive slower. In the extreme, some older drivers cease driving. In other words, they seem to be adjusting their driving to reduce perceived risks. In terms of total miles driven, Figure 4 (NHTSA, 1993) shows the steady decline in mileage as age increases. More research is needed to determine how much of this decrease is due to concern over increased risk (e.g. inability to see well at night) versus other factors (e.g., less need to drive to places at night).

The above data suggest that one of the questions for future research is whether in-vehicle technologies that address older driver safety problems will give drivers more confidence to alter their driving habits and thus enhance their mobility, without jeopardizing their safety. For example, despite increased night vision problems, older drivers have few nighttime crashes. Would technology that helps older drivers see better at night, encourage them to take more night trips without increasing their crash rate per mile driven?

In terms of safety, older drivers may benefit from some of the same collision avoidance technologies as younger drivers, even though their crash patterns are somewhat different. Both groups have a need to prevent rear-end collisions with vehicles ahead, lane change crashes with vehicles to the sides, crashes with intersecting vehicles, and backing crashes.

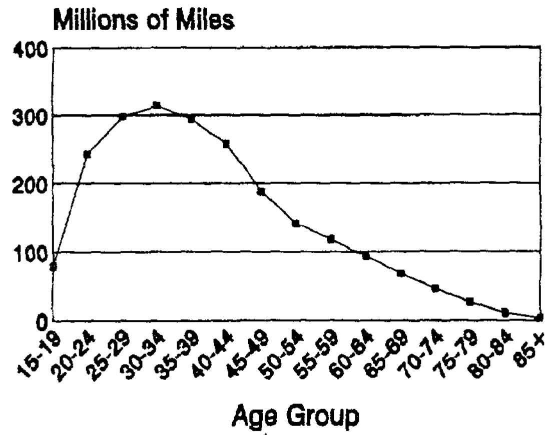

Figure 4. Total Miles Traveled.

IN-VEHICLE TECHNOLOGIES

From the user's point of view, several problems can affect the degree to which in-vehicle technologies will achieve their potential to enhance safety and mobility. These problems are associated with equipment design and operation which does not consider the human factors requirements of the driver. If the drivers' capabilities to understand and operate the devices are not compatible with device design, overall system effectiveness will be diminished. In addition to reducing effectiveness, lack of consideration of driver capabilities may reduce safety. This problem may arise if these technologies are too complicated and distracting. For older drivers, such problems could make the technologies "bitter pills" which provide some benefits but also some adverse side effects. What is the right prescription for these technologies to enhance their benefits and minimize their side effects?.

Head Up Displays - Head Up Displays (HUD) epitomize this "bitter pill" dilemma for older drivers. This technology may be a component of various in-vehicle products for displaying information such as route directions, collision warnings, traffic signs, enhanced forward vision, and vehicle status. By displaying information superimposed on the forward road scene, HUD may help reduce the driver's eyes-off-road time--a potential benefit to older drivers with limited field-of-view and difficulty attending to spatially separated sources of information. Also, because the HUD image is focused at a far enough distance that refocusing and reaccommodating to read the display is minimized, older drivers would not need to look through the near correction in their eyeglasses. On the other hand, researchers are concerned that HUD may have characteristics detrimental to older drivers. For example, if the display contains too much information, it could be distracting. If the display is too bright, too large, or located close to the line of sight, it could mask the presence of critical roadway objects.

The National Highway Traffic Safety Administration (NHTSA) is currently sponsoring research at The Scientex Corporation to investigate older driver reaction and performance using HUD compared to auditory displays and displays on the instrument panel. Three types of information were presented on each display type: collision warning, navigation, and vehicle speed information. The study approach used a fixed-based driving simulator to present filmed scenes containing critical roadway objects. Subjects were measured in terms of how accurately and quickly they responded to display information as well as roadway events in the filmed driving scene. Preliminary findings are suggesting that older drivers prefer vehicle gauge information to be displayed on a HUD. Auditory displays were preferred for most other information types by all age drivers. Surprisingly, younger drivers found the HUD more distracting than older drivers. One possible explanation is that the relatively poorer peripheral vision of older drivers allowed them to ignore the HUD display which was located below their direct line of sight. Further analyses will assess the extent to which their peripheral vision problems affect their ability to utilize the information displayed on the HUD. The study will also determine whether older drivers can devote more attention to the roadway if they can hear some navigation and warning information. The results will help assess the value of HUD to older drivers and define some of the design parameters that may help them to use HUD more effectively.

To obtain further insight into potential HUD benefits and drawbacks, future research needs to focus on collecting real world, on-road baseline data describing the extent to which older drivers become distracted and divert their attention from the road scene. Such data would quantify how and when older drivers are distracted by current vehicle instrumentation and form the basis for comparison with behaviors when using HUD.

Collision Avoidance Systems - Collision avoidance systems detect potential collisions and use auditory, visual, or haptic (e.g., brake pulse) signals to warn drivers of the need to take avoidance maneuvers. These electronic systems may provide direct safety benefits from reduced crashes as well as indirect benefits because they may give older drivers the confidence to use safer, limited-access highways instead of secondary roads with intersections.

In order for such systems to be most effective, the design of the driver interface (i.e., the controls and displays) and operating characteristics need to be compatible with driver capabilities to process the warning information. Driver failures to comprehend the information, select an appropriate response, or perform the response can lead to an ineffective system. For example, a warning signal that cannot be heard or seen will not attract driver attention; several similar warning signals in a vehicle or non-standardized warnings in different vehicles can confuse drivers; if the false alarm rate of the warning is too high, drivers may not take appropriate action; if the urgency of the warning is not conveyed, drivers may not respond fast enough. Thus, effective warning system design requires knowledge about driver information processing capabilities and limitations.

In recognition of the importance of designing the interface of crash avoidance systems to be compatible with drivers' abilities and needs, NHTSA published preliminary human factors guidelines that recommend features and functional requirements to help assure that drivers understand and can respond quickly and appropriately to warning information. (Lerner, et. al. 1996) The guidelines included the following recommendations:

1) Use multiple levels of warning for any particular device. The "imminent crash warning" would use an intrusive signal; the "cautionary warning" would provide the driver with greater advanced warning without being disturbing.
2) Use warning signals that are standardized for uniqueness for "imminent crash warnings"
3) Because no warning modality will be completely effective under all conditions, "imminent crash warnings" should be presented in two modes (e.g., visual and auditory)

These guidelines were developed in part to help identify gaps in research where more data would be needed to refine the recommendations. Such research is needed to determine auditory warning characteristics (e.g., loudness, uniqueness, time duration); visual display characteristics (e.g., location, brightness, symbology); and operational characteristics (e.g., false or nuisance alarms, response time, detection zone).

In the case of forward collision warning systems, there are numerous questions about the most effective display parameters for alerting the driver without making the system so annoying that drivers shut the system off. For example, what modality (visual, auditory, haptic) should the display use, what symbology best informs drivers, what threat detection criteria represent the best tradeoff between too many nuisance alarms and needed collision warnings?

One of the important characteristics that can affect the benefits of a forward collision warning system is driver response time to the warning. A system that does not provide its warning in time for drivers to perceive and respond will not be effective. While many studies have been conducted to measure perception/reaction times, they are not directly relevant to the design of in-vehicle warning systems. One relevant study of the response of drivers to emergency warnings in a vehicle was conducted by Vernet and Fraigneau. Drivers in a simulator had to brake in response to an auditory warning at unexpected times. The experimenters measured the time between the alarm and the time it took the subjects (N=114) to step on the brake pedal. The data indicated that 99 percent of the response times were under 1.36 seconds. The findings also indicated that when performing more complex tasks (e.g., conversing with a passenger while driving) older drivers had longer response times. Also, the variability of the response time increased with age. Thus, warning systems based on average times of younger drivers may not give older drivers enough time to respond to the signal and avoid the crash. However, to the extent that older drivers follow at longer distances and slower speeds than younger drivers, they may be able to compensate for their slower response times.

Another simulator study of braking response time as influenced by collision warnings was conducted by Vercruyssen, et. al. Subjects performed four tasks of varying complexity in a driving simulator. They were asked to brake as quickly as possible in response to a lead car braking and to auditory and visual collision warning systems. The task complexity was varied by having subjects respond when their car was stationary, when driving on an empty road, when following a car at a comfortable distance, and when following very closely. Without the warning signals, as task complexity increased, the older driver response time increased compared to that for younger drivers. However, with a warning, age differences were not significantly different. These findings suggest that forward collision warning systems may have the potential to help some older drivers compensate for their age-related slowing of response time. However, it is important to find out the extent to which older drivers choose headways that correspond to the more difficult levels of task complexity found in this study. If they do not follow cars at distances as close as younger drivers, then warning system design parameters can be chosen accordingly.

Future studies to determine effective design parameters of the driver/vehicle interface for forward collision warning systems need to take into account other characteristics of older drivers. For example, should forward collision warning information be displayed on HUD? An argument against this HUD application is that a distracted driver might not notice the warning information quickly enough to respond to the threat. Given the relatively weaker peripheral vision of older drivers, designing an effective display may be particularly problematical. However, a bright, pulsating, and properly located display may be effective in attracting a driver's attention without being as annoying as an auditory display.

Human factors design issues for rear object detection systems are being evaluated in NHTSA-sponsored research.(Harpster, et. al.) This study is an example of how quantifying driver on-road behaviors, in this case when backing the vehicle, can be used for recommending the driver interface and operation of a warning system. Initial findings are indicating, for example, that older drivers are far more likely to use their mirrors than younger drivers when backing. The research also found that, surprisingly, older drivers, even with their slower reaction times, did not take significantly longer than younger drivers to stop in response to a warning alarm. The reason was that older drivers appeared to compensate by driving slower and keeping their foot on the brake while backing. These findings have implications for the timing of warnings and the location of visual displays.

Navigation Systems: Navigation system displays that are complicated and require visual attention while driving may increase safety problems for older drivers. Interestingly, it has even been shown that older drivers have a tendency to look at an information screen, whether or not information was actually displayed. (Pauzie, 1994). As noted above, displays that require close focusing will be more difficult for older drivers with presbyopia to see clearly. These problems suggest that navigation systems with auditory displays and carefully designed HUD or displays located at the top of the dashboard may be safer for older drivers. If visual information needs to be displayed, the size of the information can make a significant difference to older driver performance. For example, making the symbols or letters large enough can allow older drivers to process the information as efficiently as younger drivers. (Pauzie, 1994)

A properly human engineered navigation display can help minimize adverse safety effects for older drivers. Can the functions provided by such a system increase safety while enhancing mobility? Safety can be indirectly enhanced if the navigation information reduces the workload needed for searching for unfamiliar roads and gives the driver needed time to be in the proper lane for turning. More research is needed to determine the extent of such benefits. Whether mobility will be enhanced to the extent that drivers will venture to new and unfamiliar places has been addressed in a study by Oxley et.al. 1994. They observed and questioned a sample of older drivers who were given navigation systems to use. About 40 percent of the older drivers said that they would drive to new and unfamiliar places if they had a route guidance system in their own vehicles.

Vision Enhancement Systems - One of the common complaints of older drivers is the difficulty of driving at night, due to headlight glare and the difficulty seeing very far with conventional headlighting systems. Two types of vision enhancement systems (VES) are being developed which may extend the driver's visibility range: a near-infrared system which uses an active IR light source to sense and display the scene ahead on a Head-Up Display superimposed along the driver's line of sight; and a far-infrared system which passively detects IR radiation from roadway objects and displays them at an angle below the line of sight. One of the key questions is whether older drivers will take advantage of VES capabilities to drive more at night. Current research is concentrating on the basic question of the extent to which VES improve seeing distance to critical objects and how VES design parameters influence this distance.

One study that evaluated how much a prototype near-infrared system could improve older driver visibility was reported by Ståhl, et.al. Several tests were conducted on a test track using 15 subjects aged 65-80 who had to drive while calling out when they saw a particular visibility object (either a pedestrian dummy, cone, or sign). The results showed that all but two subjects saw the dummies further with the vision enhancement system than with conventional low beams. The increase ranged from 12.5m to 112.5m. The results for detecting road signs were mixed. Half the subjects saw the large road sign sooner with the vision enhancement systems and half saw it later. Another test measured visibility to an actual pedestrian moving towards a stationary car. Subjects had a large improvement in detecting the actual pedestrian. Most of the subjects regarded the system as beneficial and reported that they would use it to drive more at night.

While these findings are encouraging, it should be noted that subjects were tested under somewhat benign, controlled conditions. The critical test is whether drivers will benefit from the increased visibility under more complex, realistic situations without experiencing disbenefits. Future research is needed to determine the circumstances under which older drivers would use a VES and whether such use provides visibility benefits that allow increased mobility and safety. For example, will a narrow field-of-view further exacerbate the limited focus of attention that some older drivers experience; also, to what extent does the increased visibility provided by VES overcome the problems that drivers have with oncoming headlight glare.

Various system design parameters may affect the net benefits. For example, the system's field-of-view will affect driver workload, comfort, and what objects will be detected. It should be noted that the older subjects in the study cited above expressed a strong desire for a wider field-of-view. Image resolution will affect the detectability of small objects. Display brightness will influence the detectability of roadway objects outside the field-of-view because the driver's eyes will not be adapted to the lower luminance of the roadway. Another display consideration, especially for far-infrared system, is that thermal imagery does not always look the same as objects viewed directly. This may affect the driver's ability to readily recognize objects and determine their distance. NHTSA is planning research to help better understand the influence of these and other parameters on driver performance with vision enhancement systems.

System Integration - As the state of development of ITS technologies advances and multiple systems are introduced in vehicles, the need to consider the integration of systems with each other becomes more critical. For example, if a driver is changing lanes and more than one warning activates, the driver needs to know quickly whether the primary threat is from the side or front. Older drivers may be particularly prone to confusion and distraction caused by the need to attend to multiple sources of information. Message priority schemes and standardized auditory warnings are examples of the requirements needed to help older drivers sort out the proper information in a timely manner.

Driver Acceptance - Research is also starting to address whether or not drivers will appreciate the benefits of in-vehicle ITS and find the systems user-friendly. Some preliminary insights are being obtained from the results of focus group discussions conducted for the U.S. Department of Transportation to explore the reactions of a small sample of the driving population, including a group of active seniors, to various crash avoidance technologies (Charles River Associates Inc., 1998). There was generally a favorable reaction to crash avoidance systems. Interestingly, the older drivers were significantly more favorable towards the concepts than the younger drivers. This was attributed to the perceived benefits of the concepts as well as the tendency to buy cars that were fully equipped with comfort and safety features. The older drivers were particularly interested in rear object detection to help them in parking lots, which is consistent with the crash statistics and increased head turning difficulty for this group.

Despite interest in the concepts, all drivers expressed some concerns about how well the technologies would work. The concerns focused on the potential for warnings to be distracting, whether there would be too many false alarms, whether the driver would be able to react in time, and whether the sound might startle the driver. They also specifically raised the concern that over reliance on these systems might lead to drivers paying less attention to the road or compensating for the perceived safety enhancement with riskier driving (e.g., more lane changing or faster speeds). This problem is known as 'behavioral adaptation' and may be a real concern affecting the potential safety benefits of in-vehicle technologies.

CONCLUSIONS

To some extent, the types of safety problems experienced by older drives are similar to those of younger drivers. Thus, all driver age groups may benefit from the potential safety benefits of in-vehicle collision avoidance systems. The small number of older drivers sampled in studies to date are generally favorable to such systems but are concerned that the devices may have undesirable side effects. These side effects can be minimized and device effectiveness can be enhanced if the systems are designed to be compatible with older driver capabilities for attending to and responding to warning signals and information displays. Many studies have investigated how the physical, psychological, and physiological capabilities of older drivers affect their performance. However, the design of in-vehicle technologies would also benefit from a better understanding of when and how they drive in the real world to accommodate to their limitations. Such data can be obtained from surveys as well as *in situ* measurements of older driver behaviors during car following, lane changing, turning and other driving tasks. This paper emphasized in-vehicle safety and information systems, but other vehicle technologies may also help improve the mobility of older drivers. Such technologies include personal security systems, Mayday crash alert systems, better seating adjustment, easier ingress/egress, and systems to locate vehicles in parking lots.

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