Transportation & Vehicle Safety Policy

4-1-1995

The Potential for Advanced Vehicle Systems to Increase the Mobility of Elderly Drivers

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DOI: https://doi.org/10.17077/8ltc-qmv9

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Comments
Prepared by the University of Iowa Public Policy Center for the Midwest Transportation Center. This study was funded by the University Transportation Centers Program of the U.S. Department of Transportation and the Iowa Department of Transportation. The conclusions are the independent products of university research and do not necessarily reflect the views of the funding agencies.

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THE POTENTIAL FOR

ADVANCED

VEHICLE SYSTEMS

TO INCREASE

THE MOBILITY OF

ELDERLY DRIVERS

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The Potential for Advanced Vehicle Systems to Increase the Mobility of Elderly Drivers
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April 1995

Prepared by the
University of Iowa Public Policy Center
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This study was funded by the University Transportation Centers Program of the U.S. Department of Transportation and the Iowa Department of Transportation. The conclusions are the independent products of university research and do not necessarily reflect the views of the funding agencies.
Mobility and self-sufficiency are important aspects of life quality for nearly all people, including those who are elderly. With the dominant role of automobile transportation in the United States, the ability to drive is a key factor in mobility. Issues related to elderly drivers are growing in importance, as the number of them increases. Among the more serious issues are the implications of physical limitations, including eyesight, reaction times, and cognitive processing. A serious need exists to find ways for many elderly people to maintain their ability to drive.

This research was performed to determine how emerging in-vehicle technologies might be used to help elderly drivers. A prototype system was developed to present navigation, collision avoidance, and signing information to elderly drivers via an integrated heads-up display (HUD). Thirty-two subjects drove an interactive driving simulator while using the prototype HUD. Subjects drove under two sets of driving conditions: baseline and experimental. Under baseline conditions, drivers simply drove through the simulation and followed the rules of the road. Then, under navigation and braking driving conditions, subjects were required to travel to a destination and maintain a safe following distance when a lead vehicle decelerated. A variety of driver performance measures were collected and analyzed to determine the effects of the information displays on the driving behavior of elderly drivers. Subjective mental workload and other questionnaire responses also were collected. The results are discussed in terms of their effect on the mobility of elderly drivers.

The research presented in this report was carried out at the University of Iowa collaboratively by the Public Policy Center and the Center for Computer-Aided Design. Funding was provided by the U.S. Department of Transportation, University Transportation Centers Program. The program was created by Congress in 1987 to “contribute to the solution of important regional and national transportation problems.” Following a national competition, the program established university-based centers in each of the ten federal regions. This project was funded by Region 7’s Midwest Transportation Center, a consortium of Iowa State University and the University of Iowa. Matching funds were provided by the Iowa Department of Transportation.
ACKNOWLEDGMENTS

We would first like to thank the U.S. Department of Transportation, University Transportation Centers Program, and the Iowa Department of Transportation, whose support allowed us to conduct this research.

We would also like to thank the members of the project advisory committee whose guidance provided the direction for this project. The members of the advisory committee were Scott Falb, Iowa Department of Transportation; Paul Green, University of Michigan Transportation Research Institute; Helen Gjovak, American Association of Retired Persons; Bill Kelly, American Association of Retired Persons; Truman Mast, Federal Highway Administration; and Joe Peters, Science Applications International Corporation.

Our special thanks go to the elders who participated in the driving simulator experiment. Their patience and courage made the process of conducting the experiment a pleasure.

We received outstanding technical assistance from staff members at the University of Iowa’s Center for Computer Aided Design. Mike Morrison went to great lengths to provide us with flexible programming software that allowed us to create our prototype displays. Loren Stowe provided us with sound engineering advice during the construction of the prototype heads up display (HUD). Without their efforts and ideas, this project would not have been possible.

A special thanks to Research Assistant Cher Carney for her organization and dedication to the project. We recognize the countless number of hours she put forth to help the entire project run smoothly. We would also like to thank Research Assistants Jon Hankey, Tim Brown, Steve Jahns, and Ken Cho for their contributions during the implementation of the experiment.

A special thanks to our colleagues at the Public Policy Center. Anita Makuluni served as editor. Norman Foster formatted the final report, helped to pull the pieces of the report together, and created many of the graphics that appear in the report. David Forkenbrock reviewed the report, making necessary changes to maintain consistency and positive flow.

We would like to extend thanks to all who participated in this project, it has been a pleasure working with them.
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Mobility is an important issue to the elderly population. When elders are able to drive, they are more likely to be self-sufficient. As Waller (1991) states, the issues of independence and self-sufficiency “become increasingly important as the older person is faced with joining the ranks of the ‘elderly’ with all of the stereotypes associated with that term. Although it is obvious that health can affect mobility, it may often be overlooked that mobility can affect health and well-being” (p. 561).

The ranks of elderly drivers will continue to swell as the “baby-boomers” begin to reach retirement age. As a result, one of the most prevalent issues in transportation is driver aging. According to Franzen and Ilhage (1990), the driver population over 65 will soon consist of one out of every seven drivers on the road. Thus, in the near future the importance of maintaining mobility for older drivers will become even more critical in the U.S. generally and certainly in Iowa as a comparatively elderly state. Parviainen, Atkinson, and Young (1991) studied both the aging population and the handicapped with regard to in-vehicle systems development. They concluded that because the number of aging drivers will double by the year 2030, such systems must be designed to accommodate drivers with special needs. Among the more serious issues associated with an aging driver population are discrimination and lack of highway traffic engineering to accommodate older drivers (Waller, 1991).

PHYSIOLOGICAL EFFECTS OF AGING ON DRIVING

An increase in the number of elderly drivers has implications for both mobility and driving safety. Drivers over the age of 65 account for the second highest per capita incidence of vehicular fatalities (Robinson, 1985). Elderly drivers often have poorer eyesight (Kosnik, Sekuler, and Kline, 1990) and slower cognitive processing than younger drivers. This leads to slower reaction times (Olson and Sivak, 1986; Stelmach and Nahom, 1992). Studies have shown that elderly drivers tend to compensate for these decreases in capability by driving more slowly and taking fewer risks. Walker et al. (1990) found that older drivers (55 years and older) drove slower, had larger variability in lateral placement, had longer reaction times to instruments, were more likely to be in another lane after a turn, and were more likely to make navigational errors than middle aged and younger drivers. The effects of diminishing vision and cognitive and processing are discussed in turn.
Vision

It is generally acknowledged that vision plays a large and vital role in proficient driving (Kosnik, Sekuler, and Kline, 1990; Bailey and Sheedy, 1988). The aging process brings about a variety of changes in drivers' visual functions which may gradually affect their interaction with the vehicle environment. Older drivers often report problems with visual processing speed, visual search, light sensitivity, and near visual acuity (Kosnik, Sekuler, and Kline, 1990). Robinson (1985) suggests that environmentally controlled factors such as the condition of road signs, markings, and highways, when combined with reduced visual functioning, may be a significant component of the driving problems of the elderly. These environmental conditions can often be such that the amount of time to make decisions or to gather visual information are less than adequate for all but the most skilled drivers.

Vision can be affected in many ways as age increases. As the eye ages, the lens begins to harden, lose transparency, and yellow. Hardening of the lens reduces the ability to accommodate, reducing near-field visual acuity. Most studies, however, show a low correlation between static visual acuity and accident rates. Yet tests of static visual acuity are currently the most common method of testing vision abilities for licensure.

The yellowing and loss of transparency of the lens has the effect of reducing the amount of light that can pass through the lens and cornea before reaching the retina. The reduction in the amount of light that reaches the retina actually begins in the mid-20s and continues to decline steadily. McFarland et al. (1960) estimate that the threshold of the dark adapted eye is reduced to one tenth of its maximum performance. Similarly, Robinson (1985) states that the amount of illumination required to maintain a given level of visual performance must be doubled for every 13 year increase in age. The result of less light reaching the retina is a reduction in visual acuity and reaction times. Loss of transparency of the lens can also cause discomfort and disability when encountering glare from sunlight or oncoming headlights.

Additional visual deficits that occur with increasing age include a reduction in peripheral vision and useful field of view (Robinson, 1985; Schieber et al., 1992). A reduction in the range in which a driver can detect activity has serious implications for their ability to react to a dynamic driving environment. In a survey conducted by Schieber et al., older drivers reported being aware of peripheral vision deficits in responding to items about unexpected appearances of vehicles in the peripheral vision or being surprised by other vehicles while merging. These declines in drivers' "useful field of view" have been found to be related to the incidence of accidents among older drivers (Ball and Owsley, 1991).

Cognitive processing

Information processing has been modeled in the brain as a network of links and nodes that transmit signals throughout the brain (Greene, 1983). As we age, the reduction of information processing speed matches nearly exactly the level of
degeneration of the neural connectivity that is seen in the physical structures of the brain. Information processing latencies that begin to appear around age 55 have been attributed to this gradual deterioration of axonal connections (Cerella, 1990). It is also believed that decreases in the rate of information processing can influence predictors of performance on driving related skills such as perception/reaction time (Spirduso, 1980).

Attention is another cognitive function related to driving abilities. Shinar (1978) estimates that 25 to 50 percent of all motor vehicle crashes are a result of driver inattention. Reduced attentional abilities are also thought to add to the overall problem of driving safety when combined with declining sensory abilities (Transportation Research Board, 1988).

In a discussion of the effects of aging on attention and driving skills and therefore on driver performance, Parasuraman and Nestor (1991) define three different types of attention that are used while driving. Selective attention is the ability to shift and focus attention on different stimulus locations, categories, or features. Divided attention involves two or more tasks that must be performed or monitored simultaneously. Sustained Attention is a vigilance-related task where infrequently appearing stimuli must be detected over longer periods of search time.

Selective attention in driving occurs when monitoring stimuli in the outside environment, selecting vehicle controls and making adjustments, and evaluating the status of the automobile. In order to perform these tasks well, the driver must be able to both select the appropriate stimulus to monitor and focus on the stimulus once it has been selected. Because driving is primarily a visual task, the ability to select the appropriate stimuli to monitor is dependent on perceptual abilities and, in particular, visual perception. The ability to focus on stimuli is related to the ease with which the driver can be distracted from these stimuli. Several sources have correlated poorer selective attention performance to higher accident rates in older drivers but rarely in younger drivers (Ranney and Pulling, 1989; McKenna, Duncan, and Brown, 1986).

The role of divided attention abilities on driving performance is not as obvious as that of selective attention. Even while driving through familiar surroundings and in good conditions several tasks must be performed simultaneously. With driving practice, however, some of the tasks become automatized and can be performed together efficiently. Under conditions of increased driving complexity, the demands that drivers face may exceed their capabilities (Parasuraman and Nestor, 1991). It has been found that performance on divided attention tasks does decline with age (McDowd, 1986; Salthouse, 1985). However, currently there is little evidence to support the hypothesis that decrements in divided attention skills lead to increased accident rates or decreased driving skills.

Sustained attention is important to driving because it involves the detection of infrequently occurring events such as a child darting into the roadway or another vehicle running a stop sign. The results of vigilance studies indicate that sustained attention diminishes as more time is spent performing given tasks. Because attentional abilities reduce with time, it is expected that there would
be an increase in accidents with an increase in the amount of time spent driving. However, evidence to support this hypothesis is weak and there has not been any research to date that has addressed the factor of age on performance decrements.

Women appear to be at risk from age-related changes in cognitive functioning, particularly those over age 75 and those with less driving experience. Men appear to be at risk for both accidents and citations as a result of sensory and psychomotor function degradation. However, there are no significant differences in the rates at which males and females reported either accidents or citations (Bishu, Foster, and McCoy, 1991; Laux, 1991). Still, beyond a certain age (around 75), older drivers are involved in more traffic accidents and receive more traffic citations.

For drivers over age 74, slowing of reaction time has a strong association with overall driving performance and with specific driving measures, especially those related to vehicle control (Ranney, 1989). However, Olson and Sivak (1986) found that older drivers, ages 50 to 84, had relatively the same perception-response time to unexpected roadway hazards as younger drivers, ages 18 to 40. Further research in this area has been reported by Chang (1991), Greatorex (1991), Ranney and Pulling (1990), Reynolds (1991), Stelmach and Nahom (1992), and Vercruyssen, Carlton, and Diggles-Buckles (1989).

Research has shown that elderly drivers are involved in a higher number of collisions related to failure to yield right of way, right angle, and left turn movements. They also tend to have a more difficult time than younger drivers in judging the distance needed to stop, as well as judging gap acceptance. In addition to safety related issues, older drivers often have more difficulty interacting with traffic and navigating to destinations than their younger counterparts. To improve the mobility of older drivers, methods must be developed to compensate for decreasing capability to react in complex driving environments.

Deficits in cognitive processing may also have an effect on secondary driving tasks such as navigation. Standard methods of navigation require the use of maps or direction lists while driving. In a study to assess age differences in interpreting “You-Are-Here” maps in different orientations, Aubrey, Li, and Dobbs (1994) found that older subjects had more difficulty re-orienting contra-aligned maps than younger subjects. The older subjects required more time to complete the re-orientation and were also less likely to respond correctly. The implication of this result is that older drivers will have more difficulty with the cognitive process of extracting information from a road map if the orientation of the map does not match the outside world. This would imply that older drivers would have more difficulty navigating to unknown destinations when using conventional navigation materials.

Early research performed on in-vehicle navigation systems has shown that older drivers spend significantly more time looking at navigation displays than younger drivers (Pauzie, Martin-Lamellet, and Trauchessec, 1991; Dingus, Antin, and Hulse, 1989). Experiments were conducted comparing the visual glance
frequencies of both elderly and young drivers directed toward a CRT screen with navigation information. It was found that on average younger drivers spend 3.5 percent of the driving time looking at the display, while elderly drivers spent on average 6.3 percent. Consequently, when navigation systems are involved, this group devotes less time directed toward the roadway. This dictates that special consideration must be given to this segment of the population, and that minimization of glance time in design of a navigation information display is critically important.

PERCEPTUAL EFFECTS OF AGING ON DRIVING

Elderly driver mobility is affected by a number of perceptual aspects in addition to the physiological effects of aging. For example, Winter (1988) found that elderly drivers perceive greater risks associated with driving. Winter suggests that more older drivers are "running scared," frightened away from traffic situations they can probably handle as well as from those they cannot. Psychologically, some elderly experience fear and anxiety about their vulnerability in a fast, complex traffic world, and in relation to citations, insurance, and licensing examinations. According to Winter, older drivers may develop compensatory attitudes and behaviors, some of which are positive and contribute to safety and some of which are negative and promote unsafe practices. On the positive side, they become more responsible and law-abiding. However, older drivers may deny that their skills are decreasing and continue to drive under conditions highly unsafe for them. Winter reasons that a prime factor in the immoderate attitudes of the elderly toward driving is the fear of an accident or a violation that would lead to reexamination for licensure and end in a possible loss of both the license and of the independence it affords. Another threat is the cancellation of insurance or the rise in premiums that would make driving too costly.

In a study to determine the reasons elderly drivers finally make the decision to stop driving, Persson (1993) participated in discussions and gave questionnaires to members of ten focus groups of elderly ex-drivers. When queried about the reasons for deciding to stop driving, most individuals (80 percent) stated that after gradually accumulating more and more compensatory driving behaviors (e.g., avoiding night driving or heavy traffic), and driving fewer and fewer miles, they eventually determined on their own that it was time to stop. Sometimes, family members or physicians also may have offered advice about the decision to stop. However, physicians in general appear to be reluctant to assess an individual's competence to drive.

The decision to stop driving has a large impact on persons living in rural areas where alternative transportation is not available. Even when public transportation is available in urban areas, fear for personal safety (often justifiable) can deter the elderly from making use of available services (Levine and Wachs, 1986). Isolation from family and friends and loss of independence can be devastating to the quality of life that older persons experience. Often, the
loss of personal mobility comes at a time when the need to make trips of greater importance, such as to receive medical care, is increasing.

TECHNOLOGICAL COUNTERMEASURES

Most drivers are aware of the cognitive and perceptual deficits that they experience as they grow older. As a result, most drivers tend to impose self-limitations over the conditions under which they are willing to drive (Robinson, 1985; Transportation Research Board, 1988). These limitations include a reduced willingness to drive at night, in heavy traffic, or in unfamiliar locations. Elderly drivers also tend to adopt what they consider to be safer driving strategies such as increased following distances and slower driving speeds.

Research has shown that the effect of some visual performance deficits may be minimized through the use of specific display characteristics. Babbitt-Kline, Ghali, and Kline (1990) report that the use of icons over textual displays will improve user visibility in less than optimal lighting conditions (e.g., daylight versus dusk) and viewing distances. If textual displays must be used, Hayes, Kurokowa, and Wierwille (1989) suggest that many performance problems can be eliminated by increasing the character size of textual labels. Yanik (1989) observes that for color displays, drivers had better visual responses to yellows, oranges, yellow-greens, and whites on contrasting backgrounds. Other studies involving older drivers' visual abilities include Mortimer (1989); Ranney and Simmons (1992); and Staplin and Lyles (1991).

Studies have been conducted addressing the issue of “safer driving” for the elderly. A previous Midwest Transportation Center project conducted by McCoy et al. (1992) used engineering and other countermeasures to try to decrease intersection collisions. Their countermeasures involved the use of signs, pavement markings, and traffic signal displays. While some of these items appear promising, additional countermeasures are needed to help mitigate accidents and thereby maintain mobility for older drivers.

Due to the high cost of transportation alternatives, it is also very important for the elderly to maintain independent mobility throughout their later years in life. The goals of providing both independent mobility and transportation safety can often be in conflict. Therefore, it is important that technological developments advance and research on how to apply them be performed to compensate for age-related driving performance deficiencies.

One method of compensating for degradation in driving performance is to employ advanced technology in the vehicle which can serve to aid the elderly in driving and thereby potentially increase their safety, efficiency, and level of comfort. The policy of employing advanced technologies to aid drivers and reduce accidents has been proposed for the driving population at large, and the National Highway Traffic Safety Administration (NHTSA) is sponsoring research investigating advanced collision warning devices. The Federal Highway Administration (FHWA) is conducting research on in-vehicle routing and navigation systems (IRANS), in-vehicle sign information systems (ISIS), in-
vehicle safety advisory warning systems (IVSAWS), and automatic vehicle control systems (AVCS) (Perez and Mast, 1992).

Each of these systems utilizes advanced technology to provide information and/or selective automatic control over vehicles to aid the driver. A critical constraint in the development of these systems is the ability of the driver to appropriately use the information or selective control provided. The subject population that will dictate the design of such systems is primarily comprised of elderly drivers, whose needs are greater due to decreased vision and hearing capabilities, and increased decision making and reaction time requirements. Technological devices may prove particularly helpful to them by providing additional time to react in critical situations, or by providing salient information in a timely manner.

The ability to market new systems to the elderly will depend on several factors. According to Brickfield (1984), the elderly are very accepting of new technologies that will enhance their capabilities for independent living. In particular, the elderly are interested in technologies that will increase their opportunities to socialize, and reduce the possibility of isolation. Any product that increases their sense of emotional well-being through improving mobility will have a reasonable chance of success. It is important, however, not to single out the elderly as the sole consumer of advanced technologies to aid drivers. There is considerable resistance toward applications that label the purchaser as elderly or in need of any special assistance the product might offer.

Note that the systems described above are proposed for development as part of the intelligent transportation systems (ITS) initiative in the U.S. Preliminary development work, including sensor and vehicle position technology, has already been completed, and results indicate that such devices will be feasible and affordable in the near future. However, at the time this research was conducted, no research had explored the application of this technology to aid older drivers, nor had research conceived of user interfaces specifically designed to aid the elderly.

RESEARCH HYPOTHESES

This study is designed to assess the feasibility of using advanced in-vehicle technologies to help compensate for age-related degradation in driving performance. If these technologies are feasible for elderly drivers, they could potentially increase mobility by maximizing elders' safety, efficiency, level of comfort, and willingness to drive. We selected three emerging in-vehicle technologies to include in this experiment. These technologies include In-vehicle Signing Information Systems (ISIS), In-vehicle Routing and Navigation Systems (IRANS), and Collision Avoidance Systems (CAS). Portions of information from each of these systems were integrated into a prototype heads-up display and tested by elderly drivers under a variety of driving conditions.
There are several hypotheses associated with how effectively elderly drivers will be able to use the features of the prototype system and how it will impact their driving performance. These hypotheses are as follows:

- Elderly drivers will experience no degradation in driving performance and might experience an increase in driving performance while using an integrated heads-up information display under various driving conditions.
- Driving performance will be worse under conditions of increased complexity (such as while navigating or during heavy braking) than under baseline driving conditions, regardless of the type of display used.
- Elderly drivers will perform better under complex driving conditions (such as navigation or avoiding potential collision situations) with the integrated heads-up information display.
- Elderly drivers will be more aware of road sign information when using the integrated heads-up information display.
- Elderly drivers will experience a reduced level of mental workload when driving with the integrated heads-up information display.
CHAPTER 2

DESCRIPTION OF PROTOTYPE SYSTEM

The IRANS, ISIS, and CAS systems described in the previous chapter have the potential to provide a wide variety of information that could be used at different times while driving. Usually when these systems are discussed, they are addressed as stand-alone systems rather than components of a fully integrated system. Presumably, the information being presented by multiple subsystems would have to be combined into an integrated display system. If not, drivers may be inundated by too much information presented by too many sources. For example, systems providing safety and warning information and road sign information might both signal the presence of an upcoming construction zone. If they were not integrated together they could provide redundant or incompatible displays, causing unnecessary workload or confusion for the driver.

For the proposed advanced traveler information system (ATIS) components to work in concert with one another, they must have some method of determining which system has responsibility for providing which messages, a hierarchy of message priorities, and an integrated method of displaying information. By integrating displays of information from multiple subsystems, designers can help assure consistent message formats, display locations, inexperienced user comprehension, and conformance with the user’s expectations about how the system should work. Integration of displays theoretically results in fewer errors, reduced workload, greater efficiency, and increased safety while using the system.

HEADS-UP DISPLAY FORMAT

The goal of the prototype system developed as part of this research was to present a fully integrated display of navigation, collision avoidance, road sign, and standard dash information. To further aid the driver in reading the display, the visual elements were to be positioned so that information could be retrieved as quickly and easily as possible. We hypothesized that if drivers could be presented with information in a manner that minimized the frequency and duration of glances away from the roadway, safety and overall awareness of the driving environment might be increased, especially for older drivers. Rackoff (1975) concludes that older drivers need to view the road a greater percentage of time than younger drivers to maintain vehicular control. For this reason, a heads-up display (HUD) was tested for presenting the visual elements of the display.

The HUD format provides the ability to display visual information directly within or very near the driver’s natural line of sight. It is possible that the use of a HUD could reduce the number of driver eye movements, shorten reaction
time, reduce the visual workload, and improve visibility, perhaps reducing the likelihood of accidents and improving overall driving performance (Huckins, 1988).

Displays in the vehicle dash or instrument panel would require more time than heads-up displays for the driver to change eye position and locate the desired information. Typical driver visual monitoring behavior involves switching back and forth between the roadway and the display in question. Dingus et al. (1990) found that while performing most automotive tasks, switching occurs every 1.0 to 1.5 seconds. If the display is farther away from the roadway, switching takes longer, and less time can be devoted to the roadway or the display (Weintraub, Haines and Randle, 1985). Therefore, with the HUD, the amount of time required for the driver to switch his or her glance from the forward roadway to the display will be minimized. There is still some switching time required due to accommodation, but a similar amount of time would also be necessary for simple accommodation when using an in-dash display.

There has been a considerable amount of research on the use of HUDs in aircraft. However, fundamental differences exist between the use of a HUD in an aircraft and in an automobile. The background that lies behind the view of an aircraft windshield is usually sky or clouds, making it solid, uncluttered and of consistent coloration. The same cannot be said for automobiles, where the background consists of marked roadways, dynamically changing scenery, and other vehicles that are in much closer proximity to the vehicle. Differences in backgrounds could make the HUD much more difficult to read in an automobile than in an aircraft.

The user populations that would be using the equipment are also quite different. Pilots are typically well trained, younger to middle age persons with good visual acuity. The driving population consists of persons of all ages, education levels, and visual abilities. Because the conditions for use and the user populations are so different, care must be taken when applying the findings of aircraft HUD research to automobile HUDs.

Despite all of the apparent advantages of using HUDs for displaying information in automobiles, a number of concerns have been raised by Dingus and Hulse (1993) about the use of HUDs:

- Luminance may be a severely limiting factor in the automobile due to the presence of glare. Certainly, a heads-up display that was too dim and hard to read could be much worse than an in-dash display.

- Issues regarding display information density and distraction must also be carefully addressed for heads-up displays because they could create their own set of problems.

- Division of cognitive attention is an issue with heads-up displays. The fact that a driver is looking forward does not mean that roadway/traffic information is being processed. The importance of this division of attention to driving task performance has yet to be determined.
On the positive side, a well designed HUD has the potential to make the driving task safer and easier if some of the visibility and placement issues can be resolved.

Figure 1 shows the position of the prototype HUD from the driver's perspective. The display was located just over the steering wheel, directly in or just below the driver's line of sight. The main group of information elements was positioned directly in the center of the lane when the driver was looking straight ahead.

![Figure 1. Driver's perspective of prototype HUD](image)

**DISPLAY ATTRIBUTES**

When designing the prototype HUD, several key attributes required particular attention. Among them were the use of color and presentation of standard instrument readings.

**Color**

Brown (1991) found that highlighting techniques using color resulted in quicker and more accurate recognition of targets on a visual display. Although instrument panel color has been shown to have no significant effect on reading and driving performance (Imbeau et al., 1989), Brockman (1991) found that color on a computer display screen can be distracting if used improperly. Brockman recommends several guidelines to avoid confusion when using color to code information. First, color codes should be used consistently. Colors from extreme ends of the color spectrum (i.e., red and blue) should not be put next to each other since doing so makes it difficult for the reader's eye to perceive a straight line. Second, familiar color coding, such as red for danger should be used. Third, color alone should not be relied on to discriminate between items. Brockman recommends designing applications first in black and white, then adding color to provide additional information.
In developing an integrated prototype display of driving information, a large number of information items needed to be displayed. The items were redundantly color coded by which functional grouping that they belonged to (i.e., navigation information was generally displayed in cyan and collision avoidance displays were color-coded based on the severity of the message). While the use of many different colors on a HUD is beyond the capabilities of current low-cost technology, they were included on the prototype system as a redundant cue in anticipation of advances in HUD technology.

**Standard dash instruments**

The standard dash instruments that we included in the integrated display include the speedometer, fuel gauge, and temperature gauge. The standard dash instruments and their positions on the integrated display are shown in Figure 2. We chose these three instruments because they are the most common instruments and may be found on virtually every vehicle being produced today. These instruments are generally always presented regardless of the interior configuration, instrumentation package, or transmission style of the vehicle.

![Figure 2. Standard dash instruments](image)

Maintaining proper speed is a continuous task that requires drivers to glance at the speedometer and compare it to the current speed limit. Occasionally, drivers become absorbed in the driving task and cannot glance at the speedometer as often. In these instances, the driver is forced to estimate the vehicle operating speed without the aid of the speedometer. Evans (1988) found that people can
give a rough estimate of their speed without referring to the speedometer, but they often underestimate how fast they are going.

Briziarelli and Allan (1989) tested the effect of a heads-up display (HUD) speedometer on speeding behavior. Although no significant difference was found between a conventional speedometer and the HUD speedometer, most subjects (70 percent) felt that the HUD speedometer was easier to use and was more comfortable to read than a conventional speedometer. Subjects also reported being more aware of their speed when using the HUD speedometer.

Because drivers need to check a speedometer often, we included it on the heads-up display. The speedometer portion of the display was a two-digit, alphanumeric display located in the center of the display closest to the driver’s line of sight.

We included fuel and temperature gauges in the display to maintain a consistent location for all standard dash instruments. The premise behind placing instruments on the heads-up display was to put information that the driver normally would find on the dashboard in a position where it could be read easily. Because the fuel gauge and temperature gauge are sampled less frequently, they could have been left as dash instruments rather than being included as part of the heads-up display. However, a desirable feature of the fully integrated heads-up display is that it contains all necessary information the driver might need and eliminates any uncertainty about where it is located. The design decision to include all standard dash instruments on the display increased the total amount of information being presented, but it eliminated any uncertainty about where routine information is to be found.

ADVANCED INFORMATION PRESENTATION

In addition to new methods for providing the driver with routine instrument readings, the prototype HUD displays navigational, signing, and collision avoidance information. Each is discussed in turn.

Navigation information

Recently, there has been significant research performed to determine the best methods for presenting navigation information. A goal of a navigation system is to give the driver instructions about how to get to a destination. There are many different individual information items that could be used to assist drivers in navigating to a destination. A comprehensively, real-world navigation system would also include information about trip planning and the status of the navigation system. For purposes of this experiment, we decided that the majority of trip planning and route selection information items would not be included as part of the HUD because they are not needed while the vehicle is in motion (Hulse et al., 1993).

Research performed to date on issues surrounding navigation systems has consisted mainly of analyzing different display formats. One question that has
been addressed is whether route-following information should be provided to the
driver as turn-by-turn instructions or as a full map display. Another is the format
of turn-by-turn instructions. A discussion of these and several other questions
follows.

A study conducted by Wetherell (1979) found that after subjects studied a driving
route either using a map or a linear list of turns, those using a map made more
errors when actually driving the route. Wetherell concludes that these findings
could have been caused by two factors: (1) the spatial processing demands of
driving, seeing, and orienting interfere with maintaining a mental map in
working memory and (2) subjects had a harder time maintaining a mental model
of a map learned in a north-up orientation when approaching an intersection
going east, west or south. In a study conducted by Streeter, Vitello, and
Wonsiewicz (1985), subjects who drove a route through neighborhoods using a
route list (series of verbal directions) were faster and more accurate than those
who drove using a customized map with the route highlighted. Popp and Farber
(1991) found that symbolic presentation of route guidance information was
superior to other visual presentation modes such as text or maps. Symbolic
presentation had the lowest driver workload rating and best traffic safety
behavior.

Green and Williams (1992) compared the viewing perspective of different
navigation displays, using either a map-like “plan view,” a forward “perspective
view,” or a combination of the two in an “aerial view.” The authors found that
drivers performed best when recognizing the presented display as matching the
environment outside of the car when an “aerial view” was used. They concluded
that the “aerial view” was especially good when the display was located in a
heads-up position or closer to the driver’s forward line of sight.

The studies above indicate that either symbolic guidance displays or textual lists
are easier to use than maps while navigating to unknown destinations. Note,
however, that maps provide additional information (e.g., orientation information
such as cross-streets) that textual lists do not. One approach to in-vehicle
information display is to visually provide the information to the driver either in a
graphical or textual format, depending on preference (Lunenfeld, 1989).

Dudek (1979) reports that information display format and style can affect drivers’
processing time and perception of the information. Familiarity of messages,
messages arranged proportionally within the horizontal and vertical dimensions,
and optimal message lengths (less than eight words for high speeds) have been
shown to permit appropriate processing times for drivers. When dealing with
local drivers, particularly commuters, studies show that drivers wish to know the
location of incidents in terms of cross streets or landmarks; while nonlocal
drivers prefer distances (Dudek, 1979).

Regardless of format type, an information display must be designed such that all
in-vehicle information can be received in short glances, and displays must not
distract the driver (Lunenfeld, 1989). It is clear that less attention will generally
be required in a well-designed turn-by-turn format than a full route format. Very
little information is required for a graphic turn-by-turn screen, including only
direction of turn, distance to turn, and turn street name. Such information can be easily displayed in a legible, low attention demanding format.

We restricted the information for display on the prototype HUD to only those items that are required by the driver while the vehicle is in motion. These items include: name of the next street to turn on, distance to next turn, direction of the next turn, name of the street the vehicle is currently on, current compass heading of the vehicle, and a representation of the intersection where the next turn is to be made. Information included in this list follows the information system design guidelines suggested by Green et al. (1993). The visual portion of the prototype navigation display is depicted in Figure 3.

![Figure 3. Navigation information](image)

Additionally, we included auditory messages as part of the navigation display. An auditory cue was provided to the driver just before the next turn on the route. The message consisted of “turn next left” or “turn next right.” This message was redundant with the information that was provided by the visual display. We kept the message as simple as possible to follow the recommendations of Labiale (1990). Labiale recommends that when considering aurally presented messages, the amount of information presented be restricted (seven to nine bits), or the aural cue be used as a prompt for a very simple visual guidance presentation.

Although voice presentation can alleviate visual attentional demand problems associated with navigation information, it is not a problem-free solution. Dingus and Hulse (1993) recommend that the auditory modality be utilized to (1) provide an auditory prompt to look at a visual display for changing or upcoming information (thus lessening the need for the driver to constantly scan the visual
display in preparation for an upcoming event) or (2) have some type of simple visual information presentation to supplement the auditory message (so that a message that is not fully understood or remembered can be checked, or later referred to, via the visual display).

**Signing information**

To date, there has been little empirical research performed to provide guidance for developing in-vehicle signing and information systems. Mollenhauer et al. (1994) performed one of the few studies to evaluate the effects of varying the sensory mode (auditory or visual) of sign presentation for in-vehicle signing systems. They found that driving performance was better with visual displays of information, but more sign information could be recalled with the auditory displays. Any design decisions beyond the proper sensory mode to be used will require extrapolation from other types of in-vehicle systems research.

The signing display used on the prototype HUD is depicted in Figure 4. Visual icons were used to represent road signs and were presented in the lower right hand portion of the display area. The positioning in the lower right hand portion of the display was chosen to match the direction that drivers currently look most often to obtain road sign information. To maximize comprehension by inexperienced subjects, we patterned the icons after real road signs, making sure to match the same dimensions, coloration, and content for each sign that was developed.

![Figure 4. Signing information](image_url)
The speed limit sign was displayed any time there was no other sign to be presented. When there was another sign such as a “no passing zone” or “pedestrian crossing,” the appropriate sign icon would replace the speed limit icon until the advisory or warning zone had been passed.

**Collision avoidance information**

The National Safety Council (1992) reported approximately 11.3 million motor vehicle crashes in 1991, of which 2.7 million were rear-end crashes (about 23.8 percent of the total). These crashes accounted for 33 percent of all collisions involving two or more vehicles. Because the rear-end collisions are a large problem for the driving population in general, it is a good starting place for the application of advanced technologies toward driving safety. Advanced technologies such as lasers and radar that have been developed for military use can be applied to automobiles to give collision avoidance systems information about what is happening in the roadway ahead. Once analyzed by the system, the information can be presented to the driver to help overcome problems such as driver inattention and perceptual deficiencies.

Driver inattention is the causal factor that most often accounts for rear-end crashes. Although it is possible for a driver to “look, but not see,” attention in driving is generally directly related to where a driver is looking at any given time. The driver is constantly scanning the environment: looking out the forward windshield, side windows, scanning mirrors, and attending to stimuli in the vehicle. Since human visual attention operates for all practical purposes as a single channel processor, drivers experience periods of time when no information is being processed from the forward roadway. Operating in-vehicle controls, navigating to a destination, and carrying on conversations all require drivers to take their eyes off of the roadway and “attend” to other stimuli. Repeatedly drivers will switch their point of gaze “head down” or off the forward roadway. It is these repeated non-forward glances that create the potential for a rear-end crash.

Most glances in-vehicle require more than 1.2 seconds (Bhise, Forbes, and Farber, 1986; Dingus, Antin, and Hulse, 1989). This relatively long glance duration time is one of the key factors contributing to driver loss of situation awareness of the forward vehicle. Scanning behavior, resulting in the “head-down” factor in normal driving, leads to reduced out-the-window glance times. Wierwille et al. (1988) calculated the probabilities of a driver’s eyes being on the forward roadway under varying degrees of attentional demand. They found that as the driver’s subjective rating of attention demand increases, so does the probability that the driver’s eyes will be on the forward view. The authors surmise that drivers undergoing increased visual loading due to the primary task of driving adapt their visual sampling strategy. They are under greater pressure to return their glance to the forward view sooner and maintain it a greater proportion of the total time. Wierwille and his colleagues also found that as the traffic density increases, so does the glance length of the forward view.
Driver age also has a bearing on glance duration. Hayes, Kurokowa, and Wierwille (1989) found that middle-age and older drivers had significantly longer in-vehicle glance times than those of younger drivers. These age effects are generally due to deterioration of vision and slowing of cognitive processes. This effect is critically important to consider when designing in-vehicle controls and displays.

McGehee, Dingus, and Horowitz (1992) investigated the potential value of front-to-rear-end collision warning systems. They report that drivers often follow at distances that are closer than necessary to provide adequate brake-reaction time to avoid an accident. This close driving behavior may be the result of previous experiences which rarely resulted in consequences. A front-to-rear-end collision warning system (whether visual, aural, or a combination of both) has the potential to provide added driver safety and situation awareness and has been generally accepted as a worthwhile device by subjects tested. Displays should be developed that will augment the natural perceptual cues that are used to determine safe following distances wherever possible. Preference for text and voice warning message systems was demonstrated in a study on safety advisory and warning system design by Erlichman (1992).

The collision avoidance display is represented in Figure 5. This collision avoidance system was designed to help the driver maintain a safe following distance and will also warn the driver of high rates of closure toward a lead vehicle. The display consists of several bars that will illuminate in different colors to indicate different levels of warning. Use of red for danger, yellow for caution, and green for safe is intended to match the driver’s cultural stereotypes for color meaning. We laid out the bars as a trapezoid to match the view of the roadway from the driver’s perspective, in an effort to help drivers understand the meaning of the different levels of warning.

![Figure 5. Collision avoidance information](image-url)
For a first level warning, the bar positioned furthest away from the driver on the perspective display was illuminated in green. The first level of warning would activate when the time to collision with the lead vehicle was between 2.6 and 1.6 seconds. This level indicated to the driver that they were at a safe following distance but should pay attention to the vehicle ahead.

For a second level warning, the two bars that were furthest away from the driver were illuminated in yellow. We also accompanied the visual display with an auditory message that said “look ahead.” The auditory message was meant to direct the driver’s attention to the lead vehicle because the following distance was too close. This display was presented when the time to collision with the lead vehicle was between 1.6 and 0.9 seconds.

For a third level warning, all bars illuminated in red and the words “BRAKE, BRAKE, BRAKE” appeared at the top of the display, just above the speedometer. The visual warning was also accompanied by an auditory message that said “brake, brake, brake.” This level was meant to signal the driver that a collision was imminent and that maximum braking should be applied. The third level warning would be displayed when the time to collision with the lead vehicle was less than 0.9 seconds.

Figure 6 shows the complete integrated prototype heads-up display including standard dash, navigation, signing, and collision avoidance information.
A total of 32 subjects participated in the experiment. Subjects were equally distributed by gender, and half of the subjects in each gender group were between 65 and 69 years of age and the other half were 70 years of age or older. Subjects were recruited by posting flyers, placing newspaper ads, and through referrals from the local chapter of the American Association of Retired Persons (AARP). All subjects were paid at a rate of $10.00 per hour for participating.

Participants were eligible for the experiment if they held a current driver's license and drove a total of more than 3,000 miles per year. A simple visual acuity test was administered and all subjects had corrected vision of 20/40 or better. Subjects were instructed to bring the corrective lenses that they would normally wear while driving (if any). Those who had participated in previous studies involving the Systems Technologies Incorporated (STI) driving simulator at the University of Iowa were not eligible for this experiment.

DRIVING SIMULATOR USED IN THE EXPERIMENT

The equipment used in this experiment included the STI simulator at the University of Iowa, a custom built driver cockpit with HUD capability, and custom software written to drive the HUD display while interfacing with the STI simulator's main program. The STI simulator is a fixed base, interactive driving simulator that employs computer-generated imagery for production of roadway scenes. The simulator has the capability to collect a variety of driving performance measures as the subject operates the simulated vehicle through the driving scenario. Mechanical force systems were connected to the vehicle controls to provide realistic control feedback while driving.

The STI device utilizes an IBM 486 PC with a high speed graphics board producing one forward channel of nontextured graphics. The graphics are projected onto a dome environment to produce a 50x40 degree field of view. The STI system has its own scenario scripting language which allows for development of a variety of specialized driving environments.

A sketch of the custom built driver cockpit that was used by subjects driving the simulator appears in Figure 7. The cockpit consisted of a seat, steering column, and foot pedals from a Chevrolet Chevette mounted on a plywood dash and platform. The steering wheel tilt is adjustable to maximize each subject's comfort and visibility, and the dash was designed to use a PC monitor, mirror, and a thin film of transparent plastic to simulate a HUD in the driver's forward field of view.
The steering, throttle, and brake inputs were connected to the IBM 486 PC that controlled the STI simulation software. Two speakers to provide engine noise and navigation instructions were also housed in the front of the simulator cockpit and controlled by a SoundBlaster PC sound board in the STI's IBM 486 PC.

The 27" color PC monitor was positioned in the front of the dash ahead of the driver's foot pedals and faced backwards toward the driver. A piece of transparent plastic film resembling a windshield (3 feet tall by 4 feet wide) was mounted on top of the dash and sloped back at a 45 degree angle toward the driver. The image on the monitor was reflected from a mirror onto the plastic film located in front of the driver. A piece of one-way front reflective mirror was used to eliminate double images created by conventional mirroring materials. The reflected image from the monitor appeared to float in the driver's line of sight, five to six feet ahead of the driver properly oriented as if the driver was looking directly at the monitor screen.

The HUD image presented on the 27" color PC monitor was controlled by a second IBM 486 PC. The STI's PC was connected to the HUD image PC via an RS232 serial port interface; the PC sent data in real time as the subject drove the simulator through the experiment. Custom code was written on the HUD image PC that read the data being received by the STI's PC and would modify the image being displayed according to a predetermined simulation scenario and display algorithm. A set of speakers were also connected to a second SoundBlaster sound board in the HUD image PC and were used to present navigation and collision avoidance commands during the simulation.
SIMULATION SCENARIOS

Simulation scenarios were developed using the STI simulator's own scenario scripting language. The driving environment used in this experiment consisted of straight, two-lane roadways with cross streets occurring at intervals that might be seen in an urban or suburban area. Each intersection was controlled by a traffic light or a standard octagonal stop sign. All cross streets were labeled with street name signs that consisted of white letters on a green background. The street-name signs were mounted on posts on either the left or right hand side of the road or on the structure of the traffic lights. Speed limit signs were also located along the side of the road to indicate speed changes.

A number of types of buildings were created as objects so they could be placed throughout the simulation scenario. While this made all buildings and visual features look very similar, it did allow the simulation developer to incorporate many buildings and visual features into the scenarios with a minimal amount of development time. The density of buildings and visual features was designed to look similar to that which might be found in a typical suburban area.

One of the tasks the subject performed was to navigate from one place to another using either a paper map or a heads-up navigation display. However, a limitation of the STI simulator is that it does not allow the driver to actually turn onto a different roadway from the one they are currently driving on. To get around this limitation, we told subjects to find the correct location of the next turn on their route and prepare to make the turn without actually making it. At this point, subjects verbally indicated the location and direction of the turn that they would take to follow their route. We then told subjects to continue driving straight and imagine they had made the turn onto the correct street. They were asked to continue driving and looking for the next turn as if they had made the turn. The street name signs and navigation display also indicated that the correct turn had been made.

Four different simulation scenarios, each approximately three miles in length, were developed to test the four different combinations of event and display conditions. For the paper map condition, the layout of streets and street names was constructed to be identical to a small town in the Northwest (Moscow, Idaho). This helped assure that subjects would not be familiar with any routes that they were asked to drive and that a paper map already existed and would not have to be created. In subsequent experimental conditions, the names of the streets were changed to different names of the same length, chosen at random from a phone book.

A practice session was conducted to allow subjects to become familiar with how to control the simulator. The practice session allowed drivers to experience an environment similar to what subject would see during the experimental drives. The ten-minute driving session consisted of straight and curved roadway, intersections, and two-car following events. The full display of information was available on the heads-up display prototype. Events were included to test subjects on their ability to maintain target speeds and their ability to control the vehicle while passing a lead vehicle. The practice session was designed to give
the subjects' exposure to the simulator and the HUD, and to help determine whether they could control the vehicle reasonably well.

INDEPENDENT VARIABLES

Event types

**Baseline.** We asked subjects to perform two levels of tasks while driving the simulator. The baseline activity consisted of the subject looking for and identifying a particular cross street and following two separate simulated vehicles while driving through the simulation scenario. Street names for all cross streets encountered during the drive were posted on a residential-type sign with white letters on a green background. The street name signs were on either the right or left hand side of the road on 8' tall signposts or mounted over the center of the road on a traffic light structure. Subjects reported out loud when they came to the cross street that they were looking for and were immediately given the name of the next cross street to look for. If subjects missed a turn, they were informed that they had passed the street and were immediately given the name of the next cross street to find. Subjects were asked to find four different cross streets during each experimental condition that consisted of baseline driving activities.

Baseline driving activities also included two separate car following events. Simulated vehicles would appear in front of the subject on the roadway and maintain a speed that was ten miles per hour slower than the speed limit. Subjects were instructed to follow the slower lead vehicle until they were told to pass. Once told to pass, subjects would maneuver the simulator around the slower lead vehicle and continue looking for the next cross street name. The car following events were timed so that they would not coincide with the cross street recognition task.

While driving under baseline event conditions, subjects used both the standard dash display and the full heads-up display. These types of information display are explained in more detail below.

**Navigation and braking.** The second level of event type, navigation and braking, included a navigation task and braking events. The navigation task consisted of driving to a destination on a predetermined route. We asked subjects to identify and prepare for turns as they approached; however, due to the limitations of the STI simulator described in previous sections, the turn was not actually completed. Navigation was accomplished by comparing street sign information with the information on either a paper map and directions, or a full heads-up navigation display. A more detailed explanation of display conditions below. Seven turns (four left hand and three right hand) were required to successfully reach the destination on the predetermined route.

In addition to the navigation task, there were four car following events. Two of the following events were identical to those found in the baseline event type. The other two following events had the potential to become hard braking events.
If the subject closed to within a six second headway behind the simulated lead vehicle, the vehicle activated its brake lights and began to decelerate at 20 feet per second. If a six second headway was never reached, the simulated lead vehicle never decelerated and the subject was instructed to pass.

**Display types**

*Standard display.* The two levels of displays include the standard display and the full heads-up display. The standard display consisted of only the speedometer, fuel gauge, and temperature gauge portions of the heads-up display. These instruments were chosen for the standard information display because they are the standard gauges that are most commonly seen across all makes and types of automobiles.

The three instruments were displayed on the HUD in the same position and size as they were in the full heads-up display. While these instruments are not typically displayed on HUDs in current passenger automobiles, we decided to present these instruments on the HUD rather than with conventional dash displays. The focus of this experiment is to determine whether any changes in performance are due to differences in the content of the information displays rather than differences in location or method of display. If any differences had been shown between a prototype system that displayed all information on the HUD and a standard information display that used standard dash instruments, it would not be possible to determine whether the differences shown were due to the information content of the display or to the display location and presentation method.

*Full heads-up display.* The full heads-up display consisted of all possible components of information available on the prototype system. The components included the navigation, collision avoidance, and road sign portions of the display integrated with the standard dash instruments that were described above. The additional components included in the full heads-up display added to the complexity of the system. The subject had to monitor multiple pieces of information located in different places on the HUD to arrive successfully and safely to their destination. A goal of the full heads-up display was to allow more information to be integrated into a single display so that negative impacts to driver performance would be minimized. A complete description of the components of the prototype system was provided in Chapter 2.

Subjects drove the simulator using the standard display and the full heads-up display, while experiencing both baseline events and navigation/braking events. When using the standard display and performing the navigation and braking events, there was no navigation information available on the display.

To perform a fair test of the differences in navigation performance with and without the use of the display, the subject used a paper map and/or direction list (as desired) with the standard display and used the HUD navigation information when using the full heads-up display. In the standard dash display condition where subjects had to navigate, we showed the subject the route to follow on a paper map while the subject developed a list of notes to use while driving.
Later, as the subject drove to the destination, they could use either the paper map, the directions they had created, or both to help identify the correct turns en route. An adjustable map reading light was made available to assure adequate lighting while reading the paper map or notes.

**Subject attributes**

*Age.* Age was also an independent variable in this experiment. Subjects were recruited for a younger age group (65 to 69 years of age) and an older age group (70 years of age and up). The original intent was to recruit subjects for age groups of 65-74 and 75+ years of age. However, after attempts to recruit subjects over the age of 75 failed to produce any results, the age groups were modified to their current ranges. Each group was comprised of 16 subjects.

*Gender.* Previous driving-related research indicates there are few differences between males and females when analyzing driving performance measures. However, for this experiment, it was desirable to determine whether there were any differences between the driving performance of men versus women while driving with prototype in-vehicle technologies. Each of the age groups (younger and older) contained equal numbers of male and female subjects so that gender differences could be detected.

**DESIGN**

This experiment used a 2x2x2x2 mixed factor experimental design comparing event type, display type, age group, and gender. Each subject drove the simulator for four experimental drives including all pairwise combinations of both levels of event type and display type. The four experimental drives consisted of baseline events with standard display, baseline events with full heads-up display, navigation and braking events with standard display, and navigation and braking events with full heads-up display. We counterbalanced the order of presentation of the experimental condition to minimize any order effects that might have occurred as subjects gained experience with the simulator and the system.

**DEPENDENT VARIABLES**

We analyzed the impact of using the fully integrated HUD on the mobility of elderly drivers using a number of measures. The first set of measures, driving performance measures, are related to mobility in that they provide some indication of the level of difficulty the driver is experiencing. If information can be presented to elderly drivers on an integrated HUD with no decrease (and a possible increase) in driver performance, then more information will be readily available to elderly drivers and fewer demands will be placed on them while driving. If elderly drivers, as a result, are able to drive with less difficulty, they may be more willing to drive. Driving performance measures are closely related to workload assessments. Increased subjective workload is indicative of driver comfort when driving. If drivers feel they are experiencing less workload, they
may be more comfortable with their driving and will therefore be more willing to drive.

The ability to navigate has a direct impact on elderly driver mobility. Elderly drivers often limit their trips to known destinations because they are uncomfortable navigating to unfamiliar destinations. The ability to navigate effectively would allow elderly drivers to travel to new destinations with confidence. There is also a safety element to effective navigation. The fewer mistakes an individual makes while navigating to a destination, the less the chance of getting lost or of being involved in an accident trying to make a corrective maneuver.

Effective use of the signing portion of the HUD also has the potential to increase mobility. An effective presentation of road sign information to the elderly driver would help eliminate self-reported difficulties in reading road signs. The idea is that if you can use an in-vehicle system to reduce or eliminate perceptual deficiencies, elderly drivers would be more confident that they are receiving the information that is necessary to drive safely. The measures associated with collision avoidance performance can also be used to assess differences in driver safety as a result of using the system. Here again, if elderly drivers are provided with the information that will allow them to drive more safely, they may be more able to avoid accidents of serious injury or accidents that would cause them to consider not driving at all.

**Driving performance measures**

**Variance in steering wheel position angle.** Research by Wierwille and Guttman (1978) shows that changes in driver steering behavior occurs when driver attention changes. In normal, low attention conditions, drivers make smaller, more frequent corrections in steering input to make up for roadway variance and driving conditions. As attention or workload demands increase, the frequency of steering corrections decreases. Since fewer steering corrections are being made, the vehicle tends to drift further from center, causing the driver to make larger steering corrections to center the vehicle. Since small corrections decrease and large corrections increase, an increase in steering wheel position variance indicates a high attention requirement and a deterioration in driving performance.

Variance in steering wheel position was one of several measures used to assess the effects of presenting timely information to elderly drivers. If important information can be presented in the vehicle without increasing attentional demands (i.e., increasing variance in steering wheel position), then systems such as the prototype HUD developed for this experiment may help elderly drivers overcome some age-related driving deficiencies. If these deficiencies can be eliminated or reduced, elderly drivers could retain their ability to drive safely until a greater age, thus increasing and prolonging mobility.

**Variance in vehicle curvature.** Vehicle curvature is defined as the radius of the curve the vehicle would follow if no steering corrections were made. Variance in vehicle curvature increases as attentional demands and workload
increase. For this experiment, all sections of roadway where driver performance measures were taken were perfectly straight. Therefore, any vehicle curvature measurements deviating from zero were due to driver corrections to reposition the vehicle after it had drifted from center.

**Variance in vehicle heading angle.** Vehicle heading angle is the angular deviation of the vehicle's heading with respect to the roadway. This measure is another indicator of how the subject is controlling the vehicle. Variance in vehicle heading angle will also increase as attentional demands and workload are increased. Again, the reasons described for variance in steering wheel angle apply.

**Variance in lane position.** Lane position deviation is a measure of how much the vehicle has deviated from the center of the lane. Deviation scores were calculated in feet from the discrepancy between the vehicle position and the center of the lane.

**Variance in speed.** Vehicle speed has to be maintained by the driver while operating the vehicle. The variance in speed will also be affected by changes in attention and workload. Drivers are required to make many small adjustments to the throttle input to maintain a constant speed while driving. As they are drawn away from the driving task more and more by a secondary task, the number of adjustments being made decreases. When the adjustments are being made less frequently, the changes required to correct the speed are greater. Research conducted by Monty (1984) found speed maintenance to be a sensitive measure to changes in the amount of attention demanded by secondary driving tasks.

**Throttle inputs.** Throttle inputs were recorded by the simulator and give an indication of how much effort was required to maintain vehicle speed. Smaller throttle inputs mean that drivers had to make small adjustments to keep the vehicle at the desired speed. Larger throttle input values mean that drivers had to make larger adjustment because they had deviated further from the target speed. Larger adjustments indicate higher attentional demands being created by the secondary task.

**Navigation performance measures**

The elderly often choose not to drive to unfamiliar destinations for a variety of reasons including difficulties in reading a map or directions while driving, difficulties reading road or street signs that provide navigation information, and a general aversion toward traveling in unfamiliar territory. If a system such as the prototype developed for this experiment were able to present navigation information to the driver without causing any serious degradation in driving performance, the potential exists to eliminate some of the fears or physical deficits that make elderly drivers choose not to drive. A system that could be relied on to take the driver to their desired destination could potentially make the elderly more willing to drive to unknown destinations, thus increasing their mobility.
**Number of correct turns.** The number of correct turns is a content-valid measure of a driver's ability to navigate under the given conditions. In this experiment, drivers were required to navigate during two of their experimental drives using either a paper map, a list of directions they had created, or the navigation information being presented by the heads-up prototype display. There were seven turns required for each navigation driving condition. A greater number of correct turns would suggest that drivers found it easier to navigate.

**Navigation time.** The experimental drives that included navigation tasks were of exactly the same length and had the same number of turns. If drivers reached their desired destination in a shorter amount of time, it indicated improved navigation efficiency. Subjects were told that they could stop the vehicle at any time to review their notes, paper map, or information being displayed on the HUD if necessary. Previous research by Antin et al. (1990) showed that drivers adapt to increased navigation-caused task demand by modifying their behavior and driving more cautiously. One way that this might be exhibited is by decreasing the vehicle velocity as the navigation task increases in complexity. Reduced vehicle velocity would directly result in longer drive times.

Due to the limitations of the simulator used in this experiment, drivers did not actually have to make the turns. Because they were not actually turning the vehicle onto different streets, there was no danger of getting off route. This eliminated the need to consider time that might have been lost for repositioning the vehicle back on route after an incorrect turn.

**Collision avoidance performance measures**

**Minimum following distance.** Each drive consisted of several following situations where drivers were required to follow a lead vehicle until told to pass. The minimum following distance was determined for each following event. This shows the minimum headway that drivers are willing to maintain while trying to follow a car safely. Smaller minimum headways indicated that drivers were more willing to follow close to the vehicle ahead. Larger minimum headways indicate that drivers were more cautious in their selection of following distance. A larger minimum headway might also indicate that drivers were more aware or better able to assess the distance to the lead vehicle.

**Braking inputs.** Large braking inputs indicate that drivers slowed the vehicle at a higher rate of deceleration. This would show that drivers generally decelerated the vehicle with abrupt control inputs or they were less prepared for events that caused them to slow the vehicle rapidly to avoid a collision. Decelerating the vehicle with abrupt control inputs might mean that drivers were having more difficulty maintaining proper speed or awareness of the driving environment. Drivers being less prepared for external events that required rapid deceleration is also a measure of the attentional demands of the secondary task.

**Minimum distance to lead vehicle during braking.** Two of the four experimental drives contained events where braking might occur. If the subject's vehicle closed to within a six second following distance, the lead vehicle would activate its brake lights and begin to decelerate at 20 ft/sec$^2$. This condition
forced the subject to apply heavy braking to avoid colliding with the lead vehicle. If the subject did not collide with the lead vehicle when the braking event was triggered, the minimum distance to the lead vehicle was recorded for this measure. This distance is an indicator of the driver's ability to be aware of the lead vehicle's behavior and react appropriately when the lead vehicle decelerates rapidly. A larger minimum distance shows that the driver was able to react to the braking situation better.

**Number of collisions.** The number of collisions that occurred during the braking events described above were recorded for this measure. This is clearly a valid measure of the ultimate goal of the collision avoidance system which is to reduce the number of collisions. Because this experiment involved the use of a simulator, the events could be modified to be more extreme than might be encountered in the normal driving environment. Because the braking events were more extreme and subjects were not receiving all of the perceptual cues that they would in a normal roadway driving environment, the number of collisions was also greater than would normally be seen in the normal driving environment. This measure is still a good indicator of the effects of the use of the prototype collision avoidance system on rear-end collision safety.

**Signing performance measures**

The difference between the vehicle speed and the speed limit is a measure of how aware the driver is of both the posted speed limit and their current speed. Smaller differences indicate that the driver was aware of the speed limit and able to control the vehicle's speed effectively. Larger differences indicate that the driver was either unaware of the speed limit or had difficulty maintaining the proper speed due to secondary task demands, or both.

**Workload assessment**

To assess the mental workload demand of the driving tasks, we used a modified version of the Subjective Workload Assessment Technique or SWAT (Reid, Eggemeier, and Nygren, 1982). Using this modified technique, subjective ratings were collected at the beginning, middle, and end of each experimental drive. The subjective scale used required the subject to rate three dimensions of driving workload (visual effort, time stress, and psychological stress) as high, medium, or low.

We obtained subjective workload measures by asking drivers to rate their level of effort in performing the driving task. In this context, effort refers to mental effort, not physical effort. Subjective measures of workload are used to express differences in effort at levels below which performance is reliably degraded. Thus, subjective workload measures may be sensitive to task differences that observable performance measures are not.

Subjects were asked to rate their workload on three dimensions: time stress, visual effort, and psychological stress. On each dimension, the ratings were expressed on a three point scale: "low", "moderate", and "high." For data analysis, low, medium, and high were coded as 1, 2, or 3, respectively.
Time stress was defined in terms of the amount of time available for completion of driving and navigation tasks. Anchors for the low, moderate, and high ratings were provided during the pre-experiment briefing. A low rating was assigned if there was time to spare, such as for carrying on conversation or tuning the radio. A moderate rating was assigned if there was just enough time to accomplish the driving and navigation tasks. It was suggested that with moderate time stress, the driver would avoid distractions such as conversation. A high rating was assigned if there was insufficient time to fully attend to driving and navigating. For example, if the driver stopped scanning for the next street to turn on or ignored a system message indicating an upcoming turn, it was considered to be a high time stress situation.

Visual effort was defined in terms of the amount of visual scanning required. An example of low visual workload was feeling comfortable looking about, such as at objects in the simulation scenery. It was further suggested that under moderate visual effort, visual scanning necessary for driving and navigating could be accomplished comfortably, but that there was no spare visual capacity. Under high visual effort it was suggested that the driver would have to delay looking at things necessary for driving or navigation. As an example, it was suggested that under high visual effort the driver might have to ignore signs and concentrate solely on the forward roadway.

Psychological stress was defined in terms of feelings of confusion, frustration, danger, and anxiety. Low psychological stress was defined as feeling confident and secure. Moderate psychological stress was defined as mildly confused or frustrated, such as not being sure you are on your planned route, or feeling anxious about finding the next turn. High psychological stress was defined as feeling extremely stressed, as one might feel after a near accident or when totally lost and confused as to how to get home.

**Questionnaire**

A questionnaire was given to each subject after completing all of the experimental drives. The questionnaire consisted of 47 items on a five-point Likert scale. Questions were designed to determine the conditions under which subjects were generally unwilling to drive, the usefulness of the information provided by the prototype system, the willingness to drive under less than optimal conditions if they had the prototype system, and the amount of money subjects would be willing to pay for the prototype system.

**DATA COLLECTION**

**Driving performance data**

Driving performance data were automatically collected and stored in a text data file for each experimental drive that was completed for each subject. Performance measures collected and stored in the data file included vehicle speed (feet/second), vehicle curvature (1/feet), roadway curvature (1/feet), vehicle heading angle (radians), lateral lane position (feet), longitudinal distance
traveled (feet), steering wheel angle (degrees), acceleration due to throttle (g’s),
acceleration due to braking (g’s), and time since start of simulation (seconds). A
more detailed description of these measures is provided on pages 26–31. Data
were sampled approximately once every ten feet the vehicle traveled from the
start of the simulation. Each sample of data resulted in a line of data being
entered into the simulation data file.

The driving performance data files were later manually edited to remove driving
situations which may erroneously contribute to variance in the data. The driving
situations that were removed were caused by events that were inherent to the
experimental design. For example, after each car following event, the driver was
instructed to pass the lead vehicle and continue on. Lane position data collected
during these segments would show large deviations because the subject had to
drive in the opposite lane to complete the pass. Including this data in the
performance analysis would erroneously show larger variations in lane position.
To solve the problem, the data files were manually reviewed and passing events
were identified and deleted. Deleting the whole line of data assured that any
other variables that might show a difference during the pass would also be
deleted such as throttle inputs. Other events that were deleted include the
approach to intersections where stopping was required, the approach to
intersections where navigation turns were required, and braking events.

Further adjustments to raw data files included adding the speed limit that was in
effect for each line of data, adding the total time per drive, totaling the number
of collisions, and general formatting of the individual data items.

Navigation performance assessment

Navigation performance assessment was determined by collecting the total
number of correct turns and the total time required to complete the navigation
experimental drives. As subjects approached each turn, they were required to
prepare for the turn by slowing the vehicle and then verbally indicating which
direction they would turn. The turn was only marked as correct if the subject
slowed the vehicle to less than 20 miles per hour at the appropriate intersection
and correctly identified the direction of turn. We marked the turn on a data
recording sheet as either correct or incorrect. The total number of correct turns
was later summed and entered into a data file for analysis.

The time to complete the navigation condition experimental drives was
determined from the simulator’s driver performance data file for each run. Once
determined from the simulator’s driver performance data file, the navigation time
was entered into a separate navigation performance data file.

Collision avoidance performance assessment

The collision avoidance performance assessment was completed by looking at
the data file that was automatically created on the display PC. The display PC
was connected to the STI’s simulation PC through a serial interface. The
simulation PC continuously sent the display PC data during the experimental
drives. The data sent to the display PC included time, distance, lane position,
speed, distance to lead vehicle, speed of lead vehicle and time to collision with the lead vehicle. The data were first analyzed by the display program to determine whether any changes to the display were necessary and then were printed out to a text data file.

We also had the ability to put "marks" in the data file to mark the beginning and end of following and passing events. Each time we pressed the space bar on the display computer, a line of asterisks was written to the data file. Later, when the data were being reduced, minimum headways were determined by looking for the value of minimum distance to lead vehicle from the starting point to the ending point of the following event.

We pressed the space bar to start the following event when the lead vehicle had appeared and the subject began closing on the vehicle. Subjects had been instructed to follow the lead vehicle until told to pass. We waited until subjects had closed on the lead vehicle and matched the lead vehicle's speed before marking the end of the event and instructing the subject to pass the lead vehicle. As soon as the pass of the lead vehicle was completed, we would once again press the space bar and mark the end of the event.

**Workload assessment**

Workload assessment was accomplished by having subjects report out loud their ratings of workload. As discussed earlier in this report, a modified SWAT scale of workload assessment was used. A message was digitally recorded asking subjects to "please rate your visual effort...pause...please rate your time stress...pause...please rate your psychological stress." The pause between each question gave the subject ample time to verbally respond with either a high, medium, or low response. The responses were recorded on a data sheet and later entered into a text data file for analysis. The recording was played through the simulation PC and was triggered to go off at set distances near the beginning, middle, and end of each experimental drive.

During the practice session before the experimental drive, we delivered an in-depth explanation of the meaning of the different categories of stress. Subjects also practiced reporting their responses out loud during the practice session until they were comfortable with the procedure.

**PROCEDURE**

We assigned subjects to one of four groups, based on their age and gender, and we assigned each subject a unique number to identify all of their data. Within each group, we randomly assigned the order in which subjects were to drive the experimental conditions. The order of presentation was counterbalanced to insure that the effects of learning about the prototype system and the simulator would not have an effect on the overall results of the experiment.

Before proceeding, we gave subjects the Information Summary and Informed Consent forms to read and sign. The Information Summary and the Informed
Consent forms are presented in Appendix A and Appendix B, respectively. We checked each subject's driver's license and we performed a simple visual acuity test to ensure that the subject met the minimum requirements for the experiment. Subjects were also required to have driven over 300 miles in the past year.

A naive comprehension test was then given to subjects. During the naive comprehension test, display configurations were displayed on a 13" color monitor while the subject answered 12 multiple choice questions about the content of the display. We did not train subjects prior to this test. The purpose is to measure how obvious the meaning of the information is that is being displayed. The display configurations used in this test were identical to those that would be used in the experiment.

Next, subjects watched a training video that was approximately 20 minutes long. The training video explained in detail the individual components of the prototype heads-up display that would be used in the experiment. After individual components were explained, an example demonstration of the prototype system was shown in an attempt to enhance the subjects' understanding. Subjects could pause the video at any time to ask questions about the system.

With the training complete, subjects then moved to the simulation lab to drive the simulator. Subjects were seated in the driver's seat and the seat and tilt steering wheel were adjusted for their convenience. All controls were then pointed out and their functions explained.

We instructed subjects about how to report their workload ratings when requested to do so. The meaning of each category of workload (visual effort, time stress, psychological stress) was defined. Then subjects were instructed to rate the categories of workload with either a high, medium, or low response as the pre-recorded message was played. Examples of high, medium, and low levels of each stress category were provided to help convey the meaning of the ratings.

Next, subjects drove the simulator for a ten-minute practice session consisting of straight and curved roadway, intersections, and two car following events. The full display of information was available on the prototype HUD. We encouraged them to drive as normally as possible and also to try some hard braking and extreme steering. Subjects were tested on their ability to maintain target speeds and their ability to control the vehicle while passing a lead vehicle. The recording was played asking for ratings of workload and subjects practiced responding out loud. After the practice drive was complete, they were asked if they were comfortable driving the simulator or if they would like more practice. All subjects declined additional practice.

We then instructed subjects on how to complete the first experimental drive. The exact instructions depended on the order that would be used. The instructions for the baseline driving events with standard dash instruments were presented as follows:
In this first experimental drive, you will be driving through the simulation and looking for cross street names. The only instruments that will be available to you on the HUD will be the speedometer, fuel gauge, and temperature gauge. The street signs are the green signs with white lettering and may appear on either the right or left hand side of the road. I will give you the first street to look for as you begin to drive. When you see the cross street I have asked you to find, please tell me out loud that you see it. For example, if I ask you to find 8th Avenue, when you see it, you would say "here is 8th Avenue." If you happen to miss the cross street I have asked you to find, I will tell you and give you the next one to look for. The recording will ask you to rate your workload three times during this first drive. Remember to respond out loud with "high," "medium," or "low," whichever best describes how you are feeling when you are asked. Do your best to maintain the speed limit and do not pass any cars on the road in front of you until instructed to do so.

If the subject had no additional questions, he or she was told the name of the first cross street to find and the simulation was started. Workload assessments were recorded during the drive, and following events were marked with the space bar on the display computer, as described in previous sections of this report.

The experimental drive that combined navigation events with the standard dash instruments required that the driver navigate to a destination using a paper map or notes that had been prepared from the map. We showed the route to the subject while the subject took notes; we did not tell the subject the proper direction of turn or distances between turns. A small spotlight was adjusted so the notes or map could be read when the lights were dimmed for simulation. We gave the notes and map to the subject on a clipboard which could be positioned any way that felt comfortable. The instructions given just before the simulation was started are as follows:

During this experimental drive you will be navigating to the destination using the notes or paper map or both. The names of the cross streets will still appear on the signs as they did in the last experimental drive. The instruments that will be available on the HUD include the speedometer, fuel gauge and temperature gauge. When you come to a street that you need to turn on, I want you to prepare for the turn but I do not actually want you to make the turn. So you should slow the vehicle and say out loud the direction that you would turn, either right or left. I will tell you to continue driving straight if you are correct. If you miss a turn, I will tell you and we will reset you back on your route as if you made the proper turn. Continue driving and looking for the next turn on your route. If you need to stop the vehicle to review your notes or look at the map, you may do so at any time. Once again, the recording will ask you to rate your workload three times during this drive. Remember to respond out loud with "high," "medium," or "low," whichever best describes how you are feeling when you are asked. Do your best to maintain the speed limit and do not pass any cars on the road in front of you until instructed to do so.

We recorded workload assessments during the drive, and following events were marked with the space bar on the display computer, as described previously in
this report. The correctness of each turn was also recorded on the data sheet. After they completed the second experimental drive, we encouraged subjects to take a short break.

The next driving event incorporated baseline driving events with the full heads-up display of information. Once again, the driver was to locate cross streets while driving through the simulation. The instructions given for this event are as follows:

During this next drive, you will once again be looking for cross streets as you drive along. This time however, the HUD will be showing you all of the information that you saw in the training video with the exception of navigation information. So you will be seeing the speedometer, fuel gauge, temperature gauge, signs in the lower right hand corner, and the collision avoidance display. Instead of navigation information, you will be given the name of the next street that you will cross. So, effectively, it will be giving you the next cross street name on the HUD as you approach it. You may use the information on the HUD or look at the street signs to look for the next cross street. I will give you the first street to look for as you begin to drive. When you come to a street that you need to turn on, I want you to prepare for the turn but I do not actually want you to make the turn. So you should slow the vehicle and say out loud the direction that you would turn, either right or left. I will tell you to continue driving straight if you are correct. If you miss a turn, I will tell you and we will reset you back on your route as if you made the proper turn. Continue driving, doing your best to maintain the speed limit and do not pass any cars on the road in front of you until instructed to do so.

We gave the subject the name of the first cross street to find and the simulation was started. During the drive, we recorded workload assignments, and we marked following events with the space bar on the display computer, as described earlier.

The final experimental condition incorporated the navigation and braking events with the full heads-up prototype display. Subjects were required to navigate to their destination using the information on the HUD rather than the paper map or directions they had created. The instructions for this experimental condition are as follows:

During this experimental drive you will be navigating to the destination using the information provided on the prototype heads-up system. All of the information that was shown in the training video will be available as you drive to your destination. The names of the cross streets will still appear on the signs as they did in the last experimental drive. When you come to a street that you need to turn on, I want you to prepare for the turn but I do not actually want you to make the turn. So you should slow the vehicle and say out loud the direction that you would turn, either right or left. I will tell you to continue driving straight if you are correct. If you miss a turn, I will tell you and we will reset you back on your route as if you made the proper turn. Continue driving and looking for the next turn on your route. If you need to stop the vehicle to review your notes or look at the map, you may do so at any time. Once again, the recording will ask you to rate your workload three times during this drive. Remember to respond out loud with "high," "medium," or "low,"
whichever best describes how you are feeling when you are asked. Do your best to maintain the speed limit and do not pass any cars on the road in front of you until instructed to do so.

We recorded workload assessments during the drive and marked following events with the space bar on the display computer. The correctness of each turn was also recorded on the data sheet.

Finally, subjects completed a questionnaire to determine their opinions of the usefulness of the information provided by the prototype system, their willingness to drive in less than optimal conditions if they had a prototype system on their car, and which adverse conditions had the greatest effects on their willingness to drive. Each subject was compensated for a total of about two hours at the rate of $10.00 per hour.
CHAPTER 4

RESULTS OF THE EXPERIMENT

As explained previously, a variety of dependent measures were collected as part of this research. These measures make it possible to do a broad evaluation of the construct of primary interest to this study: improved mobility. These measures, defined in Chapter 3, are briefly summarized below.

Mental workload estimations. A modified version of the SWAT (Reid, Eggemeier, and Nygren, 1982) was used to assess the mental workload demand of the driving tasks.

Driving performance measures. We collected eight measures particularly useful for assessing driving task difficulty and secondary task distraction:

- lane position variance
- degree of projected vehicle curvature at a given point in time
- vehicle heading angle variance
- steering wheel position variance
- mean vehicle speed
- variance in vehicle speed
- deviation between vehicle speed and posted speed limit
- throttle position variance.

Navigation performance measures. Two measures indicated the ease of reaching the destination during the navigation conditions:

- time to complete the navigation condition drives
- number of correct turns

Collision avoidance measures. We collected three measures of the subject’s performance in accident avoidance circumstances:

- minimum headway under normal car following conditions
- minimum headway during lead vehicle slowing events
- number of collisions under lead vehicle slowing events

We subjected the experimental measures described above to several statistical analyses as appropriate to determine the presence of differences among the experimental treatments. These analyses generally included both descriptive and inferential statistics.
• **Descriptive statistics.** We computed descriptive statistics for measures of driving performance. These statistics included measures of central tendency (mean, mode, median), measures of variability (variance), and various distributions and graphs as appropriate. Several of the measures were frequency counts of driver errors and accidents. For these cases, simple sums of occurrences are reported.

• **Inferential statistics.** Inferential statistics included univariate analyses of variance (ANOVAs). ANOVAs were conducted utilizing the SAS General Linear Models procedure because cell sizes were rarely equivalent. Multivariate ANOVAs (MANOVAs) were not performed. MANOVAs often exhibit an increase in type II error for repeated measures designs. Fortunately, the majority of the univariate ANOVAs had p values that were well below the p<0.05 criterion value for significance selected for this research. The reader is cautioned, however, against placing too much weight on a single ANOVA with a p value approaching p=0.05 due to the possibility of a type I error. The results described in this report should be interpreted by looking for supporting evidence across all of the performance measures collected.

In several instances, the driving performance measures were not normally distributed. These instances occurred when a variance calculation was taken as part of the data reduction process. As a result the data were often substantially skewed. Although the ANOVA procedure is robust to the non-normality assumption, type II errors can readily occur under such cases. To alleviate the potential for type II errors, these data were ranked and an ANOVA was performed on the ranks of the data. This method has been shown to be more accurate than many nonparametric tests based on chi square (Conover and Iman 1981).

Nonparametric statistics were not conducted for the frequency data generated by the collision and error data for two reasons. First, typical analyses evaluated differences between many different conditions across the conditions of interest. Therefore, many different contrasts would be required to assess pairwise comparisons of interest. Since no nonparametric post-hoc test exists which holds type I error constant, the number of comparisons would either result in type I or type II errors depending on the strategy employed. Second, the comparisons of interest are repeated measures or mixed factors. These cases complicate the analysis of frequency data due to the violation of the assumption of independence required for many chi-square based tests.

Fortunately, most of the differences analyzed for these data are large enough, and the measures typically face-valid enough, that statistical inference is not required. However, we recommend against treating smaller frequency differences between conditions as statistically significant, particularly in the cases of smaller numbers of observation. The following presentation of results stresses those cases where caution is advised when interpreting results.
ANALYSIS OF DRIVER MENTAL WORKLOAD

As previously described, we asked drivers to provide a subjective workload rating at several points along each drive. The subjective workload rating scale is a three-dimensional scale which provides a subjective measure of the time stress, psychological stress, and mental effort load that the subject experienced. Each dimension of the subjective workload scale receives a rating of 1 (low), 2 (moderate), or 3 (high). Each one of these dimensions is reported below individually, as well as a sum of the individual scale ratings. [For a more detailed description of this rating system, see the detailed description of workload assessment in Chapter 3]. The ANOVAs for the overall subjective workload rating and the individual dimensions appear in Table 1.

Table 1 shows that the main effect event type for the time stress workload scale was the only measure indicating the presence of differences at the p< 0.05 level of significance. We stress that because only one of the measures is significant, and no type I error protection exists (as discussed above), this finding should be treated with caution.

The event type main effect shown in Table 1 is illustrated in Figure 8. Navigation and braking conditions were rated as having higher time stress (as indicated by the ranks shown) compared with baseline driving conditions. This result is intuitive; that is, navigation and braking conditions should have had higher workload than baseline conditions.

![Figure 8. Ranks of time stress ratings](image)

It is remarkable that more workload differences were not statistically significant. Particularly in the case of event type, where subjects were required to navigate in one condition and simply drive in the other, it is surprising that differences were not found. In investigating probable causes for this lack of significance, a
substantial “floor effect” was discovered. That is, many subjects reported that
ratings of workload were the lowest possible ratings for all three scales. These
low ratings may have been caused by the lack of task difficulty, a lack of
simulator fidelity (i.e. psychological stress is not as high in the real world), or a
combination of the two. In any event, the floor effect also resulted in highly
skewed, non-normal data, requiring that the data be treated nonparametrically.
The lack of differences perhaps can also be attributed to a loss of statistical
power resulting from the need to transform the original ratings to ranks.

Table 1. ANOVAs for workload assessment

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42
ANALYSIS OF DRIVING PERFORMANCE MEASURES

ANOVAAs were performed for a variety of measures indicative of driving performance. As discussed above, a test for normality showed that these variables, without exception, were not normally distributed. Therefore, the data were ranked, and an ANOVA was performed on the ranked data. The ANOVAAs for these variables appear in Table 2. As shown, a number of measures of lateral control indicated statistical significance. Note that some of these variables are physically related (e.g., heading angle and steering wheel angle) and therefore should not be treated as mutually exclusive evidence of differences.

Table 2. ANOVAAs for ranked driving performance measures

<table>
<thead>
<tr>
<th>Source for ranks of variance</th>
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<tr>
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<td>Subject × Display Status</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle curvature</strong></td>
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<td></td>
<td></td>
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<td><strong>Vehicle heading angle</strong></td>
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(continued over)
### Table 2. ANOVAs for ranked driving performance measures (continued)

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<tr>
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<td>Subject x Event Type x Display Status</td>
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</table>

**Ranks of variance in lane position**

One main effect (event type) was significant at the p<0.05 level as measured by the ranks of lane position variance. Not that age and gender could not be included in the model, as discussed above, since this would create a mixed factor model which can not be analyzed with nonparametric statistics. Note also that a higher ranked value of lane position variance is indicative of worse driving performance than a lower value. That is, if drivers successfully maintain their vehicle in the middle of the simulated lane, the variance (and the ranks of the variance) will be lower.

The means for the event type main effect are shown in Figure 9. Ranks of lane position variance were higher for the navigation and braking conditions. This indicates that as hypothesized, the navigation and braking tasks contributed to the overall difficulty of the driving task and resulted in poorer driving performance.
Figure 9. Ranks of lane position variance

Ranks of variance in vehicle curvature

As shown in Table 2, the event type, display status, and event type by display status interactions were significant at the \( p < 0.05 \) level. Vehicle curvature, as described earlier, is physically related to the other measures of lateral position and therefore is not independent. A larger rank in vehicle curvature variance indicates poorer driving performance since the vehicle path is more varied.

A graph depicting the interaction of event type and display status for the ranks of variance in vehicle curvature is shown in Figure 10. The measures for the baseline driving conditions were almost identical, while the full heads-up display was apparently lower for the navigation and braking condition when compared to the standard display condition. This result indicates that there is neither a fully functional ITS heads-up display cost nor benefit to driving performance for baseline driving. There apparently is a benefit with heads-up display when navigation and braking are required.

The main effect analysis reveals that the ranked variance of in-vehicle curvature was higher for the navigation and braking condition compared to the baseline driving condition. In addition, the standard display had poorer performance overall than the full heads-up display.

Ranks of variance in vehicle heading angle and steering wheel angle

Table 2 shows results for the variance in vehicle heading angle and vehicle steering wheel angle that are very similar to the results for variance in vehicle curvature. The reason for this similarity is that these three variables are highly related (although not identical). The significant event type by display status interaction for these variables is shown in Figures 11 and 12. As shown, the findings are almost identical to the results in Figure 10 and show a HUD benefit for the navigation and braking conditions.
Figure 10. Ranks of variance in vehicle curvature

Figure 11. Ranks of variance in vehicle heading angle
Ranks of variance in speed

Velocity variance, like lateral position variance, is indicative of increased driving difficulty and poorer driving performance. As shown in Table 2, however, velocity variance showed no significant differences unlike the lateral position variables. In fact, as indicated by the 0.0 mean squared value in Table 2, the mean ranks were identical for the two display status conditions.

Ranks of variance in throttle input

Variance in throttle input indicates the level of effort put forth by the driver to maintain a constant vehicle speed. A larger variance in throttle input would suggest that the driver was making larger adjustments to maintain a target speed and would indicate a high level of demand being placed on the driver’s resources by tasks other than simply driving the vehicle.

As shown in Table 2, the interaction between event type and display status was found significant at the p<.05 level. Figure 13 below shows the interaction. In the baseline driving conditions, the throttle input variance was the same when using the standard display as when using the HUD. Under navigation and braking conditions, the throttle input variance showed an increase when using the HUD. This increase is probably due in part to the increased amount of information being presented to the driver. As demands (due to navigation and braking events) were increased, the driver had less time to devote to maintaining a constant speed. The main effect analysis reveals that the ranked variance of throttle input was higher for the navigation and braking condition than for the baseline driving condition.
Figure 13. Ranks of variance in throttle input

Figure 14. Average speed
Average speed

When drivers find themselves under difficult or demanding situations, they tend to reduce their speed. Thus a lower average speed for a given condition is indicative of a more difficult driving task, all else being equal. The average speed ANOVA is shown in Table 3. Note that the average speed data were normal, and thus ranking was not required. This allowed the inclusion of the age and gender variables in the model as well. There was a significant interaction for event type by display status, as well a significant main effect of event type at the p<0.05 level.

Table 3. ANOVA for average speed

<table>
<thead>
<tr>
<th>Source</th>
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<th>F-level</th>
<th>p</th>
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</thead>
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<td>Gender</td>
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<td>0.2484</td>
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</table>

The significant event type by display status interaction is shown in Figure 14. The average vehicle velocity was slightly lower for the full HUD in baseline driving, but slightly higher in the navigation and braking conditions. This result may indicate a small cost of the additional information provided on the full HUD for normal driving, but a benefit for navigation and braking. Note that the
average speed would have likely been slower in the navigation and braking conditions, and a greater difference between the standard display and full HUD in the conditions, if error recovery had been required. Figure 14 also shows the baseline driving event was driven faster than the navigation and braking event. The cause for this difference is probably due to both the difficulty of the navigation task and the presence of braking events.

Deviation from speed limit

We instructed our subjects to drive at the speed limit whenever practical. Therefore, deviation from the posted speed limit is indicative of their performance of this task. The ANOVA for deviation from speed limit is shown in Table 4.

Table 4. ANOVA for deviation from speed limit

<table>
<thead>
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No significant interactions were found for deviations from the posted speed limit. The main effect of event type was found significant at the p < .05 level. The
average deviation from the posted speed limit was larger for the baseline driving conditions than with the navigation and braking conditions. A review of the data shows that in the baseline driving conditions, there were more positive deviations (i.e., driving faster than the speed limit) than in the navigation and braking conditions. This result shows that as subjects had fewer tasks to perform while driving (baseline driving condition), they tended to drive faster, causing greater deviations from the speed limit.

**Measures of braking and following performance**

We collected several measures to determine whether there were any differences in braking and following behavior between the standard display and the full HUD. Recall that the full HUD contained a headway maintenance/collision warning display component. The measures collected included number of collisions, minimum following distance, brake input and minimum following distance under braking conditions only. The ANOVAs for these measures (with the exception of number of collisions for which an ANOVA was not conducted) is shown in Table 5. As shown, none of the braking or following related measures indicated significance.

The total number of collisions were 17 and 20 for the standard display and full HUD conditions respectively. This result indicates that the full HUD display was not helpful in collision avoidance for the braking events.

**Measures of navigation performance**

Table 6 shows the ANOVA conducted to determine whether any navigation conditions differed for the measures of navigation performance. As shown in the table, the variables measured to indicate navigation performance included the time required to complete the drive and the number of correct turns that the subject made along the simulated drive was measured. Note that in all cases drivers succeeded in arriving at their destinations.

As shown in Table 6, there was a significant interaction between event type and display condition. This result is depicted in Figure 15, which shows that the navigation and braking drives took longer to complete than the baseline drives. In addition, there was apparently a slight cost associated with fully functional HUD use for the baseline conditions, but somewhat of a benefit of the HUD for the navigation and braking conditions.

Also shown in Table 6 is a main effect for the number of correct turns performed in the navigation and braking event. As shown in Figure 16, drivers had more correct turns when using the full HUD in comparison to the standard display and paper map. Note that due to the constraints of the simulation, subjects simply identified a turn as correct without actually executing the turn. Because subjects did not have the opportunity to make a wrong turn (or miss a correct turn), they also did not have to recover from such errors. As a result, the time benefits of the full HUD condition are probably greatly underestimated given that subjects, on average, made roughly 1.5 more navigation errors per drive with the standard display but were not given any time penalty to reflect these additional errors.
Table 5. ANOVAs for following and braking measures

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
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<th>F-level</th>
<th>p</th>
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<td>Gender</td>
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<td>0.4355</td>
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<tr>
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<td>0.4655</td>
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<td>1.12</td>
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<td><strong>Minimum following distance under braking</strong></td>
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<td>Subject x Display Status</td>
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Table 6. ANOVAs for navigation performance measures

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<th>F-level</th>
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<tr>
<td><strong>Total number of correct turns</strong></td>
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<td></td>
<td></td>
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<td><strong>Time to complete drive</strong></td>
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</table>
Questionnaire results

Appendix C contains the questionnaire with an indication of the mean response and standard deviation for each item. Subjects were generally favorable toward use of the integrated HUD. When asked about the navigation information that was presented on the HUD, subjects' mean responses indicated that the information was easy to learn, helped them find their way to their destination, helped them pay more attention to navigating, and did not interfere with their driving. Subjects also responded that they would be more willing to drive to unknown destinations in their own city and especially in cities that were more than fifty miles away if they had this system on their own vehicle. However, subjects indicated that they had no opinion about whether navigation information was important to their normal driving or whether they would drive more often if they had the system.

Subjects also felt positive about the collision avoidance information and road sign information that was presented on the HUD. Their mean responses indicated they felt the collision avoidance and road sign information would be important to their normal driving. Subjects also felt that they would be more willing to drive in conditions of poor visibility such as fog, rain, or snow, and especially after dark.

Figure 15. Total amount of time required to complete drives
Figure 16. Number of correct turns
CHAPTER 5

DISCUSSION

We now present the overall findings of the experiment and discuss how they relate to the issue of mobility for the elderly and associated hypotheses that were stated in the introduction of this report.

MENTAL WORKLOAD

Driver mental workload is an important issue when addressing elderly driver mobility. As drivers age, they typically become aware of their decrease in performance capability and will avoid situations where they feel confused, overwhelmed, or unsafe. These situations are often accompanied by or are a result of higher levels of driver mental workload. Subjective mental workload assessments were taken as part of this experiment. The results show that there was only one statistically significant finding: the main effect of event type was found significant for the ratings of time stress where the navigation and braking condition resulted in higher ratings. It is surprising that more significant differences were not found, especially for the independent variable of event type. The two event types differed substantially in the level of task complexity that the driver was asked to perform. In the baseline condition, drivers were asked to simply drive following the rules of the road. In the navigation and braking condition, drivers were asked to navigate to an unknown destination while avoiding collisions due to slowing vehicles.

As discussed earlier, there was a “floor effect” whereby subjects tended to subjectively rate their mental workload low for all conditions. This is an interesting result in itself. During this experiment, subjects were presented with many new pieces of information with a futuristic type of display that they had never encountered before in an automobile. It was thought that placing the elderly subjects in this situation might result in higher subjective workload reports. The results have indicated that this did not occur. This combined with the generally positive questionnaire responses about the integrated HUD indicates that elderly drivers who participated in this experiment were not overwhelmed by the use of this new technology. This result is encouraging because it may indicate that new technologies can be effectively applied to help solve elderly driver problems.

DRIVING PERFORMANCE

The hypothesis that performance would be worse under conditions of increased complexity is supported by many of the driving performance measures collected during this experiment. Several of the following measures such as vehicle
heading angle and steering wheel position angle are not altogether different. The reader is cautioned that the results from these variables should not be taken as independent pieces of evidence but instead should be thought of as contributing to a body of evidence regarding effects on general driving performance.

The ranks of variance in lane position, vehicle curvature, vehicle heading angle, steering wheel angle, and throttle input were all greater under the navigation and braking conditions. The larger ranks are associated with a greater amount of variance which indicates that the driver was not performing as well when subjected to the additional tasks. This result is not surprising because regardless of the type of display used during the experimental drives, the complexity of the tasks that the subject had to perform was greater under the navigation and braking condition than under the baseline driving condition. What this result shows is that elderly drivers need assistance when the driving tasks become especially difficult. If technological countermeasures are to be provided to the elderly driver, they should be applied in situations of increased complexity where the elderly driver needs assistance the most.

In the baseline condition, we asked subjects to simply drive to the destination following the rules of the road. In the navigation and braking conditions, subjects were asked to navigate to a destination and also to endure braking events where a car they were following would suddenly begin to decelerate. We expected that there would be some degradation from the baseline level of driving performance when additional tasks were added; the fact that this did occur contributes evidence to support the validity of the study.

Steering wheel angle

Analyzing the significant interactions between event type and display status for the rank of steering wheel angle, rank of variance in vehicle curvature, and rank of variance in vehicle heading angle revealed an interesting result. As discussed earlier, an increase in the mean ranks for these variables indicates a degradation in driving performance. Under baseline driving conditions where primary and secondary task demands were lower, there was no difference between the ranks of variance for the standard dash display and the integrated HUD. In other words, when driving task demands were lower, there was no apparent benefit from using the integrated HUD. Neither was there a cost associated with presenting the additional information on the HUD. However, in the navigation and braking conditions where primary and secondary task demands were higher, the variance for all three variables was lower when the integrated HUD was used rather than the standard dash display.

This reduction in variance shows that the integrated HUD provides a benefit under conditions of higher primary and secondary task demands. While there is no apparent driving performance cost associated with presenting the fully integrated HUD under baseline driving conditions, the real opportunity to show an enhancement in performance with the integrated HUD is in situations where the demands on the driver are high. The information presented on the integrated HUD was designed to assist drivers in their handling of conditions that make
task demands high (e.g., by providing navigation information or providing warning in collision avoidance situations).

**Throttle input**

We also found a significant interaction between event type and display status for the rank of throttle input variable. However, the exact opposite effect was seen for this variable than was indicated by measures of lateral control. Again, the variance in throttle input was the same between the standard display and the integrated HUD under baseline driving conditions. However, under navigation and braking conditions, variance in throttle input increased with the use of the integrated HUD. This reduction in performance could be the result of increased demands placed on the driver by the presentation of additional information. If so, we would expect the same results for the measures of variance in lateral control. Because this was clearly not the case, something else was apparently responsible for the increased variance in throttle input.

There are several possible explanations. While subjects were driving with the HUD, they were presented with information about the speed limit in the form of road sign icons. Because subjects were more aware of the speed limit, they may have tried harder to maintain it, resulting in increased throttle input variance. This explanation is supported by results showing that subjects deviated from the speed limit less while driving with the integrated HUD.

Another possible explanation of increased throttle input variance is that while using the integrated HUD, subjects began to use the collision avoidance display as a gauge to maintain their distance to the lead vehicle. Because they were receiving more salient, immediate feedback from the display regarding their headway to the lead vehicle, subjects made a greater effort to maintain an exact headway. In effect, the use of the display to maintain headway introduced a third task for the driver to perform. Subjects tended to close on the lead vehicle until the lowest level warning was presented on the display and then back off a short distance to clear the display. This behavior occurred multiple times during the following event resulting in a “jockeying” type of following behavior. This was not the case with the standard display that didn’t have the collision avoidance display. Without the collision avoidance display to use as a gauge, subjects approached the lead vehicle in a smoother manner, resulting in smaller throttle variances. The main effect of display type was not significant, but the mean throttle variance was slightly higher for the integrated HUD conditions. We found the main effect of event type to be significant for variance in throttle input. This indicates that the increased demands on the driver under navigation and braking conditions magnified the effects of the “jockeying” behavior, resulting in increased throttle variance while using the integrated HUD.

Average driving speed can indicate how difficult or demanding driving conditions are: lower speeds indicate higher demands on the driver. For average speed, there was a significant interaction between event type and display type. In this case, the results indicate that under baseline driving conditions, there is some cost to providing additional information on the integrated HUD. The
additional information presented to the driver under baseline conditions (where it did not have as much potential to provide positive benefits) served to increase driving complexity. However, when the information was provided under conditions where it was able to provide a positive benefit, the average speed was increased. This result suggests that information should not be provided just for the sake of making it available to the driver, but rather should be provided only in those situations where it has a stronger potential to reduce demands on the driver. This finding is probably more critical for elderly drivers than for the general driving population; reduced sensory and information processing capabilities make the potential for overloading the elderly driver greater.

Conclusions

The fact that driving performance (lateral control) was improved with the use of the integrated HUD indicates that the elderly drivers were able to make use of at least some of the information being displayed to help alleviate the conditions that made the driving and secondary tasks demands higher. If this were not the case, it would be expected that the presentation of the any additional information through the HUD would only serve to increase the complexity of the driving task causing an additional degradation in driving performance.

This finding has several implications toward the goal of increased elderly driver mobility. If the elderly are able to make use of information presented on an integrated display, their performance could potentially be enhanced in complex driving situations. As discussed earlier in this report, complex driving situations that require increased attentional awareness and increased cognitive processing are where the elderly show a susceptibility to accident involvement. If this system could be used to relieve some of the demands of the elderly driver in complex driving situations, it would have the potential to enhance their performance in complex situations and increase elderly driver safety. In this study, several measures of performance indicate that this is true because elderly subjects were able to drive better under conditions of high driving task demand while using the integrated heads-up display. The results of the driving performance measures for this experiment are encouraging in that while several measures showed an increase, none showed a decrease when using the integrated HUD with the exception of the variance in throttle input. Some of the evidence suggests that the decrement for this variable might be due more to the type of collision avoidance display that was used rather than to the integrated display as a whole. This result indicates that caution should be exercised not to create displays that introduce subtle additional demands on the driver as might have the case with the collision avoidance display used in this experiment.

The ability to navigate to unknown destinations can have a direct impact on driver mobility. Elderly drivers tend to gradually limit their driving to known destinations in part because of difficulties due to navigation in unfamiliar surroundings. This experiment compared elderly driver's abilities to navigate with a list of directions created from a paper map to using an in-vehicle navigation system. The time required to complete the navigation drive and
number of correct turns were the two measures used to determine if navigation performance would be better with conventional or in-vehicle methods.

The time to complete the navigation drive was lower when using the HUD navigation system. This would indicate that navigating with the integrated HUD placed lower demands on the driver than the conventional methods. This measure might have been higher if subjects would have been required to correct mistakes made while driving to the destination. As the experiment was run, if a subject deviated from the planned route, they were automatically reset on their route. Therefore, the time to correct navigation errors is not included as a part of this measure. It also might be an indicator of subject awareness of their position on the route and where to make turns. As part of the experimental protocol, subjects were allowed to stop at any time to review their direction list or paper map if necessary. While several of the subjects actually stopped the vehicle completely to do this, we also observed a number of instances where the subject proceeded on their route at a low rate of speed while trying to read the direction list or look at the paper map. This in itself presents a potentially dangerous situation in some circumstances. We detected no similar examples using the integrated HUD system.

The total number of correct turns was higher when using the integrated HUD as opposed to the conventional navigation methods. Even though subjects were driving with the integrated HUD system with only limited practice and minimal training, they were able to identify turns correctly more often than when using the conventional navigation methods. This result also has significance because by making more errors with the conventional methods of navigation, elderly drivers would be forced to make more corrective maneuvers, adding additional time to the drive and increasing the potential to be involved in an accident or become disoriented and lost.

Discussions with subjects revealed that most rarely ever drove to unknown destinations by themselves using just a map or list of directions. Many indicated that they avoided driving to unknown destinations or relied on a passenger such as a spouse or friend to ride along and do the navigating. If elderly drivers were able to become comfortable using an in-vehicle navigation system, they might be more willing to drive to unknown destinations when a passenger is not available to assist with navigation, thus increasing their mobility potential. This is supported by the responses given to a questionnaire item where subjects agreed with the statement that they would be more willing to drive to an unknown destination if they had a system like the prototype HUD that was used in this experiment.

Anecdotally, it was clear that the elderly subjects involved in this experiment were aware of the information being presented on the integrated HUD. Although it was not requested as part of our experimental protocol, subjects would sometimes “think out loud”, reporting the information that they were attending to on the HUD at any given time. Especially in the case of navigation information, subjects would read the display and say out loud something to the effect of “O.K., my next turn is Maple Avenue, it is a right turn, and it is four tenths of a
mile ahead." Several subjects mentioned that they liked the collision avoidance display but would like to be able to adjust it to activate at distances greater than those chosen for the prototype system. Also, as part of the experimental protocol, subjects would occasionally have to pass a slow moving vehicle that they had been following for some distance. On several occasions, we asked the subject to pass when the No Passing Zone sign was being presented on the HUD. In the majority of cases where this occurred, the subject would respond that they could not pass because they were currently in a No Passing Zone.

Due to the limitations of the simulation equipment used during this study, there were few empirical results that could be obtained to evaluate the effectiveness of the signing portion of the system. One measure that was collected was the driver's ability to adhere to the posted speed limit. A significant difference was found between the event types where the deviations were greater under the baseline driving conditions. This is somewhat counter intuitive because it was expected that as the task demands were made greater in the navigation and braking conditions, the deviation from the speed limit would be greater. A review of the data shows that because subjects drove faster in the baseline condition, the deviations for those conditions tended to be mostly positive in direction (over the speed limit) and greater in magnitude. Therefore, the addition of speed limit information to the integrated display did not have an impact on subjects' adherence to the speed limit.

Even though subjects didn't show any significant differences in their ability to maintain the speed limit, they apparently felt that there was some value to receiving road sign information via an in-vehicle display. Subjects who participated in this experiment strongly agreed with the statement that they would be more willing to drive after dark if they had a signing system installed on their vehicle similar to the prototype that was used in this experiment.

Theoretically, the signing portion of the system has the potential to help alleviate one of the elderly driver's biggest disadvantages, decreased visual capability. There are several factors that may have hidden any potential benefits of providing signing information on the integrated HUD. Adherence to speed limit may not have been a sensitive measure chosen because there were many other factors present in the experiment that had a significant effect on the speed that subjects drove. The lower fidelity of the simulator, demands placed on the driver through secondary tasks, and a general cautious approach to driving due to being in an experiment may have had an impact on the speeds driven. There also might have been an effect present where subjects have been conditioned to glance to a certain locations for road sign information (i.e., the road sides). Because the road sign information was not presented in a particularly salient manner on the integrated HUD, subjects may not have remembered to look at the display when this information was needed. It would have been interesting to see whether increasing the emphasis on signing information in the training and in the experimental protocol would have had any impact on these results.

The variables that were chosen as measures of performance for braking and following situations including minimum headway during following, minimum,
headway under braking, and the number of collisions showed no significant
differences. There are several reasons why this might have occurred in this
experiment. The display that was chosen for this experiment could perhaps be
improved to provide collision avoidance information. The display provided three
levels of warning to the driver. The activation criteria for these levels of warning
may not have been set at optimum levels for use with the dynamics model that
controls the simulated vehicle. The criteria for each level of warning was taken
from real-world following distance and reaction time data. After the experiment
was performed, it was found that the simulated vehicle didn’t reduce it’s speed
quite as quickly as a real vehicle would under heavy braking. The result was
that the display was effectively being activated later than it should have. Also,
the lower fidelity of the simulator may have masked important perceptual cues
that would have changed the following behavior of some subjects.

An interesting observation that was noted as subjects were driving in the
experiment was that they tended to rely on the system to provide information
about the correct following distance. Many times, the subject would begin a
following event by closing on the lead vehicle at a high rate of speed until the
first level warning was activated. Once activated, they would become aware of
their rate of closure and apply heavy braking to avoid hitting the vehicle.
Because the simulated vehicle didn’t slow as quickly as it should have and
perceptual cues were not as salient as they are in the real world, the minimum
headways to the lead vehicle were shorter than would be expected in real world
driving situations.

In some cases it was obvious that the collision avoidance display was not giving
strong enough signals to the driver that braking was required. Even though the
two more extreme levels of warning were accompanied by auditory cues, the
warning did not seem to convey the urgency of the situation to the driver. Efforts
were made to review previous research on collision avoidance displays to create
a design that would satisfy the goal of assisting elderly drivers maintain safe
following distances and avoid rear-end collisions. Apparently, either the design
that was used for this experiment was not an effective means of achieving those
goals, or the methods used to test this system were not adequate. A different
type of collision avoidance display or a refined version of the display used in this
experiment may have shown completely different results. The lower fidelity of
the simulator that was used may have also contributed to the lack of results
found in this experiment. Due to the constraints and difficulties encountered
while testing this prototype system, the question of how presenting collision
avoidance information to elderly drivers would affect their mobility remains
largely unanswered.

**EVALUATION OF HUD BY SUBJECTS**

Subjects’ responses to items concerning navigation information indicated that
they felt the information was easy to learn, helped them find their way to their
destination, helped them pay more attention to navigating, and did not interfere
with their driving. Subjects also responded that they would be more willing to
drive to unknown destinations in their own city and especially in cities that were more than 50 miles away if they had this system on their own vehicle. This result indicates that having a navigation system might have a positive impact on the mobility of elderly drivers that had a need or desire to travel to unknown destinations.

Subjects also felt positively about the collision avoidance information and road sign information that was presented on the HUD. Responses to questions about these systems indicate that this type of information might be more important for normal driving than navigation information. Subjects also agreed that they would be more willing to drive in conditions of poor visibility such as fog, rain, snow, and especially after dark if they had a signing system. This is a positive result because it shows that subjects recognize their deficiencies in driving and have a positive attitude toward technologies that could be used to overcome them.

The questionnaire results that were gathered for this experiment indicate that the elderly subjects generally responded favorably toward the integrated HUD and the information that was presented. When asked about their willingness to pay for the different components of the system, the mean response for each is as follows; $601 for the navigation system, $590 for the collision avoidance system, and $529 for the signing system. These results seem to indicate that the elderly drivers that participated in this experiment recognized at least some value in using the technologies that were presented. Whether or not the technologies can be made available at the prices that they were willing to pay will have to remain to be seen.
CHAPTER 6

GENERAL CONCLUSIONS

The purpose of this research effort was to analyze the potential for advanced vehicle systems to increase the mobility of elderly drivers. A prototype system was developed for this experiment that integrated several emerging in-vehicle technologies. The technologies were chosen based on their potential to help the elderly overcome age-related deficiencies that affect driving safety and on their feasibility to become available in the near term. Our main hypothesis was that information could be presented to elderly drivers through an integrated in-vehicle display that would increase their driving performance and therefore, also increase driving safety. The results of this experiment suggest that there can be a benefit to elderly driver performance when information is presented during conditions when the demands of driving are higher. It is important to note, however, that this benefit does not occur when the demands on the driver are low.

This result is encouraging because it suggests that if the proper information is made available when it is needed, elderly drivers can make use of it to help increase their driving performance. If this is indeed true, additional systems that are beyond the reach of current technology could be developed that would be directed toward enhancing performance in other areas where the elderly are particularly susceptible to reduced performance (such as left turn decisions, etc.). Technologies to assist the elderly driver should be targeted toward reducing the complexity of the driving task, helping to reduce the affects of age-related perceptual and information processing deficits. If systems are successful at reducing driving complexity, elderly drivers may be able to continue driving longer and may also show an increased willingness to drive.

The signing system that was prototyped in this experiment has the ability to help reduced the most common self-reported driving problem of reduced visual capabilities. Conventional road signs and markings are often difficult for elderly drivers to read or detect. Even when they can be detected, they sometimes are placed in locations that do not provide enough time for the elderly driver to react with an appropriate maneuver. Subjects who participated in this experiment subjectively rated this system as having a high value to the driver. If the system could be used to help solve self-reported problems, the elderly may be more confident in their abilities as drivers and be more willing to drive.

A navigation system was tested as an example of one type of system that could increase the elderly drivers willingness to drive. Previous research has indicated that older drivers tend to avoid driving in unfamiliar surroundings or to unknown destinations. Navigation performance was increased while using the system when compared to using conventional navigation methods. If these systems were
made available to elderly drivers, they might be more willing to venture out to new destinations with increased confidence. Their ability to safely and efficiently travel new locations such as medical appointments, social gatherings, or shopping areas may serve to improve the quality of their lives.

The results of this experiment do not reveal any benefit to presenting collision avoidance information to elderly drivers. We believe that this result is more of a function of the performance of the particular prototype system and the fidelity of the equipment used in this experiment rather than the elderly drivers' ability to appropriately use the information. The ability of collision avoidance systems to reduce collisions for the general driving population is becoming an aggressively pursued research topic. If future research does show a benefit to using these systems for the general driving population, it is likely that the elderly driver population will also benefit. Reductions in the frequency and severity of collisions would be of great value for the elderly because they are often susceptible to more severe injuries during automobile accidents.
APPENDIX A

INFORMATION SUMMARY FORM
INFORMATION SUMMARY

Project title: The Potential for Advanced In-Vehicle Systems to Enhance the Safe Mobility of Elderly Drivers

Investigators: Tom Dingus, Melissa Hulse, and Mike Mollenhauer

Thank you for coming in today. The purpose of the study is to evaluate different information displays being considered for use in future automobiles. We will be gathering information and input to determine whether or not designs would be beneficial to drivers.

If you agree to participate, you will be asked to answer a few interview questions, complete a questionnaire concerning the displays you will be using while driving, review some of the concepts involved with driving using these displays, drive for approximately 45 minutes in the low cost simulator and complete a questionnaire that describes your reactions to the displays you will have used while driving. Your participation should take approximately 2 hours. For your participation you will receive $10 an hour.

You should know that a small number of people experience something similar to motion sickness when operating simulators. The effects are typically slight and usually consist of an odd feeling or warmth which lasts only 10-15 minutes. If you feel uncomfortable, you may ask to quit at any time. Most people enjoy driving the simulator and do not experience any discomfort.

All information gathered in this study will be kept confidential. Your participation is voluntary. You may discontinue participation at any time without penalty or loss of benefits to which you are entitled. You should understand that you have the right to ask questions at any time and that you can contact Melissa Hulse at 335-6403 for information about the study and your rights.

You should understand that in the event of physical injury resulting directly from the research procedures, no compensation will be available in the absence of negligence by a state employee. However, medical treatment is available at the University Hospitals and Clinics, but you will be responsible for making arrangements for payment of the expenses of such treatment. Further information may be obtained from Dorothy M. Maher, Division of Sponsored Programs, Office of the Vice President for Research, 319-335-2123.

A record of your responses and driving performance will be maintained for future use. This record will be kept confidential and will be stored without reference to your personal identity.

Again, thank you.
I have discussed the above points, including the information required by the Iowa Fair Information Practices Act, with the subject or the legally authorized representative, using a translator when necessary. It is my opinion that the subject understands the risks, benefits, and obligations involved in participation in this project.

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Date</th>
<th>Witness</th>
<th>Date</th>
</tr>
</thead>
</table>
APPENDIX B

INFORMED CONSENT FORM
INFORMED CONSENT FORM

Project title: The Potential for Advanced In-Vehicle Systems to Enhance the Safe Mobility of Elderly Drivers

Investigators: Tom Dingus, Melissa Hulse, and Mike Mollenhauer

I certify that I have been informed about the study in which I am about to participate. I have been told the procedures to be followed and how much time and compensation is involved. I have also been told that all records which may identify me will be kept confidential. I understand the possible risks and the possible benefits to me and the others from the research.

I have been given adequate time to read the attached summary. I understand that I have the right to ask questions at any time and that I can contact Melissa Hulse at 335-6403 for information about the research and my rights.

I understand that my participation is voluntary and that I may refuse to participate or withdraw my consent and stop taking part at any time without penalty or loss of benefits to which I may be entitled. I hereby consent to take part in this project.

____________________________________    ____________
Signature of the Participant              Date
APPENDIX C

QUESTIONNAIRE RESULTS
POST EXPERIMENT QUESTIONNAIRE

Subject #________

Please answer the following questions about the simulated drive that you just participated in. Make a mark on the horizontal line that best represents your opinion regarding the statement.

For example:

| Strongly disagree | No opinion | Strongly agree |

Each of the responses was recorded using a scale from 1 to 5. Any mark between the first two vertical lines was scored as 1, any mark between the second two vertical lines was scored as 2, and so on. Means and standard deviations for each question were calculated and are reported in Table A-1.

Scale:

| 1 | 2 | 3 | 4 | 5 |

| Strongly disagree | No opinion | Strongly agree |

In a few cases, an alternate scale was used to ascertain responses in terms of willingness to pay. For these questions (45, 46 and 47) the following alternate scale was used:

| $0 | $500 | $1,000 | $1,500 | $2,000 | $2,500+ |

| Strongly disagree | No opinion | Strongly agree |
Table C-1. Questionnaire results

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) The heads-up display was easy to read while driving.</td>
<td>4.03</td>
<td>1.21</td>
</tr>
<tr>
<td><strong>During the simulated drive, the collision avoidance information:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Helped you avoid collisions.</td>
<td>4.03</td>
<td>1.05</td>
</tr>
<tr>
<td>3) Was easy to learn.</td>
<td>4.38</td>
<td>1.08</td>
</tr>
<tr>
<td>4) Interfered with your driving.</td>
<td>2.50</td>
<td>1.35</td>
</tr>
<tr>
<td>5) Helped you pay more attention to your driving.</td>
<td>4.13</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>During the simulated drive, the navigation information:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) Helped you find your way to the destination.</td>
<td>4.40</td>
<td>0.92</td>
</tr>
<tr>
<td>7) Was easy to learn.</td>
<td>4.40</td>
<td>1.02</td>
</tr>
<tr>
<td>8) Interfered with your driving.</td>
<td>2.43</td>
<td>1.28</td>
</tr>
<tr>
<td>9) Helped you pay more attention to navigating.</td>
<td>4.27</td>
<td>0.81</td>
</tr>
<tr>
<td><strong>During the simulated drive, the display of sign information:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10) Was useful for helping you be aware of road sign information.</td>
<td>4.43</td>
<td>0.56</td>
</tr>
<tr>
<td>11) Was easy to learn.</td>
<td>4.43</td>
<td>0.72</td>
</tr>
<tr>
<td>12) Interfered with your driving.</td>
<td>2.50</td>
<td>1.35</td>
</tr>
<tr>
<td>13) Helped you pay more attention to road signs.</td>
<td>4.34</td>
<td>0.77</td>
</tr>
<tr>
<td>14) You would drive more often if you had a collision avoidance system installed on your vehicle.</td>
<td>3.03</td>
<td>1.15</td>
</tr>
<tr>
<td>15) You would drive more often if you had a navigation system installed on your vehicle.</td>
<td>3.35</td>
<td>1.18</td>
</tr>
<tr>
<td>16) You would drive more often if you had a road signing system installed on your vehicle.</td>
<td>3.13</td>
<td>1.29</td>
</tr>
<tr>
<td><strong>Please rate the following items on whether you Disagree or Agree that they are important considerations when deciding to drive.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17) The amount of traffic is an important consideration.</td>
<td>4.48</td>
<td>0.67</td>
</tr>
<tr>
<td>18) Your familiarity with how to get to the destination is an important consideration.</td>
<td>4.58</td>
<td>0.83</td>
</tr>
<tr>
<td>19) Driving after dark is an important consideration.</td>
<td>4.23</td>
<td>1.31</td>
</tr>
<tr>
<td>20) Driving in the rain is an important consideration.</td>
<td>4.32</td>
<td>1.00</td>
</tr>
<tr>
<td>21) Driving in the fog is an important consideration.</td>
<td>4.65</td>
<td>0.74</td>
</tr>
<tr>
<td>22) Driving in snow is an important consideration.</td>
<td>4.48</td>
<td>1.01</td>
</tr>
<tr>
<td>23) Driving alone is an important consideration.</td>
<td>3.75</td>
<td>1.20</td>
</tr>
<tr>
<td>24) Driving in a large city is an important consideration.</td>
<td>4.66</td>
<td>0.64</td>
</tr>
<tr>
<td>25) Having to drive on a freeway is an important consideration.</td>
<td>4.28</td>
<td>1.18</td>
</tr>
<tr>
<td>Question</td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>------</td>
<td>--------------------</td>
</tr>
<tr>
<td><strong>Answer the following questions as if you had a heads-up display installed in your vehicle, similar to the one that you saw during this experiment.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26) Navigation information would be important to your normal driving.</td>
<td>3.93</td>
<td>0.93</td>
</tr>
<tr>
<td>27) Collision avoidance information would be important to your normal driving.</td>
<td>4.20</td>
<td>0.75</td>
</tr>
<tr>
<td>28) Road sign information would be important to your normal driving.</td>
<td>4.43</td>
<td>1.05</td>
</tr>
<tr>
<td><strong>If you had a navigation system similar to the one you used in the experiment, you would be more likely to drive to:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29) Familiar destinations in your town that you normally drive to.</td>
<td>3.10</td>
<td>1.25</td>
</tr>
<tr>
<td>30) Familiar destinations in towns more than 50 miles away.</td>
<td>3.35</td>
<td>1.40</td>
</tr>
<tr>
<td>31) Unfamiliar destinations in your town.</td>
<td>4.06</td>
<td>1.27</td>
</tr>
<tr>
<td>32) Unfamiliar destinations in towns more than 50 miles away.</td>
<td>4.32</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>If you had a collision avoidance system in your vehicle similar to the one in the experiment, you would be more likely to:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33) Drive in heavy traffic.</td>
<td>3.45</td>
<td>1.16</td>
</tr>
<tr>
<td>34) Drive on a freeway.</td>
<td>3.65</td>
<td>1.03</td>
</tr>
<tr>
<td>35) Drive during rush hour.</td>
<td>3.35</td>
<td>1.15</td>
</tr>
<tr>
<td>36) Drive in a large city.</td>
<td>3.68</td>
<td>0.96</td>
</tr>
<tr>
<td>37) Drive on a freeway.</td>
<td>3.71</td>
<td>1.05</td>
</tr>
<tr>
<td>38) Drive on a rural highway.</td>
<td>3.39</td>
<td>1.16</td>
</tr>
<tr>
<td>39) Drive when visibility is poor.</td>
<td>3.77</td>
<td>1.36</td>
</tr>
<tr>
<td><strong>If you had a road sign information system in your car similar to the one in this experiment, you would be more likely to:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40) Drive after dark.</td>
<td>4.87</td>
<td>1.16</td>
</tr>
<tr>
<td>41) Drive when it is raining.</td>
<td>4.00</td>
<td>1.14</td>
</tr>
<tr>
<td>42) Drive when it is foggy.</td>
<td>3.71</td>
<td>1.32</td>
</tr>
<tr>
<td>43) Drive when it's snowing.</td>
<td>3.74</td>
<td>1.27</td>
</tr>
<tr>
<td>44) Drive when it is very bright and sunny.</td>
<td>3.68</td>
<td>1.28</td>
</tr>
<tr>
<td>45) How much would you be willing to pay for a navigation system similar to the one in the experiment?</td>
<td>$601.61</td>
<td>$392.53</td>
</tr>
<tr>
<td>46) How much would you be willing to pay for a collision avoidance system similar to the one in the experiment?</td>
<td>$590.32</td>
<td>$414.01</td>
</tr>
<tr>
<td>47) How much would you be willing to pay for a road sign information system similar to the one in the experiment?</td>
<td>$529.03</td>
<td>$361.89</td>
</tr>
</tbody>
</table>

*These questions used the alternate scale.*
REFERENCES


The Potential for Advanced Vehicle Systems to Increase the Mobility of Elderly Drivers was prepared for the Midwest Transportation Center by the University of Iowa Public Policy Center. The Public Policy Center is an interdisciplinary research unit dedicated to the scholarly examination of social and economic policy alternatives.