Advanced Traveler Information Systems and Commercial Vehicle Operations Components of the Intelligent Transportation Systems: Head-Up Displays and Driver Attention for Navigation Information

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FOREWORD

This report is one of a series of reports produced as part of a contract designed to develop precise, detailed human factors design guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO). During the analytic phase of the project, research issues were identified and rated by 8 human factors experts along 14 separate criteria. The goal of the experimental phase was to examine the highest rated research issues that can be addressed within the scope of the project. The 14 experiments produced in that phase reflect the results of those ratings.

This report documents a study that was performed to determine the effects of an automotive HUD when used to present route guidance information.

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Director, Office of Safety
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NOTICE

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16. Abstract
Since the initial development of prototype automotive head-up displays (HUDs), there has been a concern that the presence of the HUD image may interfere with the driving task and negatively impact driving performance. The overall goal of this experiment was to examine the driving performance implications of an automotive HUD when used to present simple route guidance information. Of particular importance was how navigation aids (head-down display [HDD] vs. HUD) and drivers’ age interact to influence driver behavior. Twenty-four younger and older subjects participated in the study, which was conducted in the Battelle High-Fidelity Driving Simulator. Each subject drove three experimental scenarios--two urban and one rural. During the scenarios, subjects were required to adhere to posted speed limits and remain within their lane boundaries. They were also required to respond, as quickly as possible, to emergency incidents such as balls rolling into the road, a car crossing against a red light immediately in front of them, and a car in front of them suddenly braking to a stop. This study revealed no differences with respect to navigation performance, response to unexpected events, or driving performance as a function of navigation aid. Nonetheless, while performance (considered overall) was not better in the HUD condition than in the HDD condition, neither was the HUD associated with performance decrements. In particular, none of the results suggest that the HUD was a distraction to the subjects or that it was associated with any form of cognitive capture.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	**ha**
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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LIST OF ABBREVIATIONS

ANOVA . . . . Analysis of Variance
ATIS . . . . Advanced Traveler Information Systems
BRT . . . . Braking Response Times
CAS . . . . Collision Avoidance System
CVO . . . . Commercial Vehicle Operations
FHWA . . . . Federal Highway Administration
FOV . . . . Field of View
HFTC . . . . Human Factors Transportation Center
HDD . . . . Head-down Display
HUD . . . . Head-up Display
ITS . . . . Intelligent Transportation Systems
LCD . . . . Liquid Crystal Display
LOS . . . . Line of Sight
SD . . . . Standard Deviation
STWA . . . . Steering Wheel Angle
SWAT . . . . Subjective Workload Assessment Technique
UFOV . . . . Useful Field of View
VFD . . . . Vacuum-Fluorescent Display

EXECUTIVE SUMMARY

To date, head-up displays (HUDs) have been used primarily as secondary displays to provide drivers with status information such as speed, gauge information, and turn signal status. Such information is generally redundant with other head-down display (HDD) information and is considered to be non-critical; i.e., information that does not have direct or immediate safety implications. However, future applications of automotive HUDs may include collision avoidance system (CAS) warnings, night vision information, and navigation devices (Kaptein, 1994; Weintraub and Ensing, 1992). Thus, the HUD may be used as a primary display for the presentation of critical information requiring an immediate response by the driver.

Since the initial development of prototype automotive HUDs there has been a concern that the presence of the HUD image may interfere with the driving task and negatively impact driving performance. These concerns have developed from four main sources: 1) analogies to military HUD environments, 2) speculative common-sense notions that any image in the driver's forward line of sight (LOS) may affect visual performance and vehicle control judgments, 3) the subjective experience of some individuals indicating that the HUD image compels high visual attention on initial exposure to the display, and 4) suggestions that the HUD might represent a glare source that may decrease forward preview distance during very low ambient nighttime driving.

Overall, the literature on performance and attentional effects of automotive HUDs do not provide unequivocal guidance on the design of HUDs for ATIS applications. It would be helpful if the various uncertainties about automotive HUDs could be resolved by reference to prior use of HUD technology. For example, HUDs have been widely and successfully used in military fighter aircraft for years, primarily to provide aviators with flight and targeting information. Unfortunately, research findings, performance data, and design criteria from the military aviation environment cannot be confidently transferred to the commercial automotive environment. The objective of this study was to investigate the use of a HUD for an ATIS device. Of particular importance was how navigation aids (HDD vs. HUD) and drivers' age interact to influence driver behavior.

Twenty-four younger and older subjects participated in the study, which was conducted in the Battelle High-Fidelity Driving Simulator. The simulator vehicle was a 1994 Saturn Sedan, fully instrumented and linked to a host computer in order collect the appropriate driver performance measures. The simulator provides a 180° horizontal by 45° vertical forward scene, and a 60° by 45° rear scene, as well as a spatial sound system. Navigation information was presented on a 4-inch color liquid crystal display (LCD). In the HDD condition, the display was fixed to the top of the dashboard, to the right of the steering wheel. In the HDD condition, the same display was used to present a virtual image to the driver, approximately 35-38 inches from the nominal driver eye position. Navigation information consisted of a directional arrow, a street name and, as appropriate, messages such as "Approaching Destination," "At Destination," or "Beyond Destination."

Each subject drove three experimental scenarios—two urban and one rural. During the scenarios, subjects were required to adhere to posted speed limits and remain within their lane boundaries. They were also required to respond, as quickly as possible, to emergency incidents such as balls rolling into the road, a car crossing against a red light immediately in front of them, and a car in front of them suddenly braking to a stop. These incidents were timed such that avoiding a collision required a rapid braking and/or steering response from the subject.

Independent variables included driver age, driver gender, navigation aid (HDD vs. HUD), and incident type. Dependent measures included vehicle speed, lane position, steering wheel angle, and number of collisions.

This study revealed no differences with respect to navigation performance, response to unexpected events, or driving performance as a function of navigation aid. There were differences between younger and older drivers with respect to number of navigation errors and braking response times (BRTs) to unexpected events. However, these differences most likely reflect well-established cognitive and manual control limitations for older drivers and, in the absence of interactions with the navigation aid variable, have little implication for ATIS/CVO design.

Nonetheless, while performance (considered overall) was not better in the HUD condition than in the HDD condition, neither was the HUD associated with performance decrements. In particular, none of the results suggest that the HUD was a distraction to the subjects or that it was associated with any form of cognitive capture. Thus, the results suggest that a HUD may be safely used to present simple route guidance information to drivers.

INTRODUCTION

Recent advances in electronics and microcomputing have led to the feasibility of functionally-powerful, computer-based Advanced Traveler Information Systems (ATIS) as part of the automotive environment. Although these systems range in functionality, they all have the goal of acquiring, analyzing, communicating, and presenting information to assist travelers in moving from a starting location to a desired destination. While systems under development or in production promise to improve travel safety, efficiency, and comfort, they represent a new frontier in ground transportation. If not carefully developed, such systems could result in misapplied and unusable technology. In particular, there is a growing information gap between the advanced and diverse status of ATIS devices, and the availability of human factors design criteria that can be used during the ATIS design process.

Battelle's Human Factors Transportation Center (HFTC) is carrying out a study for the U.S. Federal Highway Administration (FHWA) to develop human factors design guidelines for the ATIS and Commercial Vehicle Operations (CVO) components of the Intelligent Transportation Systems (ITS). These systems are intended to provide a wealth of real-time information to the driver, including route guidance to avoid congestion and minimize travel time, safety and warning notices, and identification of desired motorist services, such as how to get to the nearest service station. While ATIS and CVO systems offer great potential benefits, their effectiveness depends on driver acceptance of the new technology, the ability of the system to integrate with other driving tasks, and the extent to which the systems conform to driver physical and cognitive limitations and capabilities. The guidelines that result from this effort will help designers produce ATIS and CVO systems that conform to human limitations and capabilities, enhance driver acceptance, and promote highway safety.

There are three technical phases associated with this project: 1) an analytical phase, 2) an empirical phase, and 3) an integrative phase. In this report, we summarize the rationale, methods, and results of the empirical phase of this effort, which focuses on HUDs and driver attention to ATIS information. The goal of this experiment was to examine the driving performance implications of an automotive HUD when used to present simple route guidance information.

RATIONALE FOR THE STUDY

In a previous project task, *Definition and prioritization of research studies* (Kantowitz et al., 1997), 91 research issues were rated by eight human factors experts along 14 separate criteria. One of the highest-rated issues resulting from this effort was issue *E2: Evaluate how different types of information, displayed using a HUD, affect cognitive attention devoted to the roadway.*

INTRODUCTION TO HEAD-UP DISPLAYS

Presenting navigation information to drivers through HUDs is possible due to recent developments in automotive design, electronic instrumentation, and optics. The automotive HUD is an electro-optical device that presents both static and dynamic symbology and/or graphics in the driver's forward field of view (FOV). A HUD consists of essentially four elements: a display source, a relay lens, a mirror, and a combiner. The display source is typically a CRT for military applications, but is more commonly a vacuum-fluorescent display (VFD) or a LCD for automotive applications. Together, the relay lens and folding mirror (to fold the optical path) serve to project the HUD image to an extended distance of 2-3 m. A combiner is a glass or mirrored see-through element that serves to reflect the HUD image back into the drivers's forward FOV within a specific range of driver head/eye positions. In automotive applications, the combiner may be either a separate, coated element that folds up or down into the driver's forward FOV, or (more often) the uncoated windshield of the HUD-equipped vehicle. Together, these HUD elements present drivers with a virtual image that is superimposed over some portion of the external driving scene.

To date, HUDs have been used primarily as secondary displays to provide drivers with status information such as speed, gauge information, and turn signal status. Such information is generally redundant with other HDD information and is considered to be non-critical; i.e., information that does not have direct or immediate safety implications. However, future applications of automotive HUDs may include CAS warnings, night vision information, and navigation devices (Kaptein, 1994; Weintraub and Ensing, 1992). Thus, the HUD may be used as a primary display for the presentation of critical information requiring an immediate response by the driver.

The introduction of HUDs into the commercial automotive environment is not issue-free and has sparked considerable research and discussion into their utility and safety. Gish and Staplin (1995) provide a review of these issues and research to date. On the face of it, HUDs have the potential to improve driving performance and driver safety in a variety of ways. First, since the HUD is close to the drivers' nominal LOS, it allows the driver to sample both vehicle and driving information without the same accommodative shift required by conventional instrument clusters or HDDs. Thus, it reduces accommodation demands when shifting gaze between the visual scene and in-vehicle displays. Second, it has the potential to reduce eyes-off-the-road time, by presenting relevant driving information at or near the forward LOS. Presumably then, safety is increased because the more time a driver spends viewing the forward driving scene, the more likely he/she is to detect some situation or condition (e.g., a pedestrian crossing the street) requiring an immediate response. Third, older drivers in particular have reduced accommodative capabilities (many cannot even adequately see current HDDs presented at a typical 28-inch distance), and are expected to particularly benefit from the HUD, which is presented at an optical distance of 2-3 m.

However, since the initial development of prototype automotive HUDs, there has been a concern that the presence of the HUD image may interfere with the driving task and negatively impact driving performance. These concerns have developed from four main sources: 1) analogies to military HUD environments, 2) speculative common-sense notions that any image in the driver's forward LOS may affect visual performance and vehicle control judgments, 3) the subjective experience of some individuals indicating that the HUD image compels high visual attention on initial exposure to the display, and 4) suggestions that the HUD might represent a glare source that may decrease forward preview distance during very low ambient nighttime driving.

A brief summary of issues and research associated with automotive HUDs, with a focus on "cognitive capture" and older drivers follows.

HEAD-UP DISPLAYS AND COGNITIVE CAPTURE

Recent HUD research in the aviation literature indicated that HUDs may distract the vehicle operator. This phenomenon has been coined cognitive capture, and defined as a stimulus that draws a person's attention to it to the exclusion of other stimuli (Weintraub, 1987).

Much of the motivation for this concern derives from a study conducted by Fischer et al., 1980. Using an aircraft simulator, Fischer et al. investigated the ability of eight airline pilots to detect runway obstacles during a landing task both with and without an aviation HUD. They found that mean response time to the obstacles was longer with the HUD and that two of the eight pilots did not even see the obstacle when using the HUD. Although the authors were cautious about generalizing their simulator results to real-world conditions, they speculated that the HUD may restrict or even inhibit the pilot's perception of information from the exterior world. The authors also suggested that the relatively high workload levels associated with the experimental task may account for at least some of their results. Although the Fischer et al. study has questionable relevance to the automotive HUD situation, it raises an issue that should be investigated, i.e., how will an automotive HUD compare to a traditional head-down instrument panel display with respect to driving performance and external object detection.

An automotive HUD investigation was conducted by the General Motors Corporation (Kiefer, 1991) in order to study this very issue. This was a field study using a prototype HUD installed in a Pontiac 6000 STE. The study was conducted to provide data on driver eye movement (or visual sampling) behaviors and speed control performance while driving with and without a centered, secondary HUD under daytime, real-world conditions. The HUD-equipped vehicle was instrumented to collect videotaped records of driver eye movements as well as vehicle speed. The eye movement data indicated that, on average, speedometer scanning cycles (defined as the time required to look from the roadway to the speedometer; to fixate on the speedometer, and then to look back at the roadway) were reduced by approximately 144 ms while using the HUD as compared with the HDD. The glance frequencies to the HUD, as compared with the HDD, were significantly higher during the initial driving session but decreased to a non-significant but still slightly higher frequency during subsequent sessions. These results tend to confirm the anecdotal reports that a HUD compels higher visual attention upon initial exposure to the display, but that this phenomenon only lasts for a relatively short period of time. Overall, the GM study indicated that the percentage of total time spent by subjects in a scanning cycle was approximately equal between the HUD and the HDD. There were no differences between the HUD and the HDD conditions in terms of speed control performance.

These issues were further examined by Kaptein (1994), who used a medium-fidelity driving simulator to compare two analog versions of a HUD (a mirror system and a projection system) and a HDD for lane keeping and speed maintenance tasks. In the study, 24 subjects were to drive a simulated vehicle along a two-lane road while maintaining both lane integrity and specific target speeds (60 km/h and 100 km/h); unpredictable head winds were used to vary workload. Kaptein reported significantly more lane-keeping errors in the HDD condition than in the HUD conditions, as well as significantly more deviations from target speeds. Furthermore, Subjective Workload Assessment Technique (SWAT) scores were significantly higher (greater perceived workload) in the HDD condition than in either of the HUD conditions. Drivers also preferred driving with a HUD over a HDD.

In another study, Ward et al. (1995) examined attention to critical events in traffic while driving with a HUD in a simulated driving environment. They presented a low-probability event, an abruptly braking lead car with and without brake lights. Results showed that when driving with a HUD, longitudinal and lateral control accuracy deteriorated. Further, reaction times to the braking lead car were .38 s slower with a HUD than without one. Although the practical significance of the slowed braking response time is questionable, Ward et al. caution that for drivers already prone to higher percentile reaction times, such as older drivers, the effect of a HUD may lead to extreme delays. Further, the sample of young male participants consistently reported that the HUD was a source of distraction.

These and other automotive HUD studies (see also Gish and Staplin, 1995) suggest that the Fischer et al. results may not generalize to the automotive HUD because of differences in HUD design, use, and external scene characteristics (see also Hooey and Caird, 1996). Clearly, there is a need to better understand the phenomenon of cognitive capture and to determine if roadway events are likely to be missed by drivers using a HUD.

HEAD-UP DISPLAYS AND DRIVER AGE

In 1988, approximately 12 percent of the American population was over the age of 65 (Transportation Research Board, 1988)—and this is the fastest growing demographic group in the United States. By the year 2020, those over the age of 65 will constitute about 17 percent of the population. It is not surprising, then, that the number of drivers over the age of 65 has increased by 13.4 percent between 1970 and 1990 (U.S. Department of Transportation, 1991).

Older drivers, as a group, have distinct visual and cognitive limitations that affect their driving abilities. For example, Kline et al. (1992) examined self-reported visual problems of older drivers. They found that, as age increased, problems on the following five dimensions also increased: 1) being surprised by unexpected vehicles, 2) judging their vehicle speed, 3) reading dim displays, 4) seeing past glare and haze on the windshield, and 5) quickly reading street signs. Despite the rapidly growing numbers of elderly drivers on the road, and the distinct possibility that the benefits and problems of HUDs could be very different for this group, little is known about the effectiveness of HUDs as a function of driver age.

HUDs offer a potential solution to some of these problems. It is widely agreed in the HUD literature, for example, that HUDs, by virtue of their location in the visual field, reduce visual accommodation and scanning requirements of the driver. This may be particularly beneficial for the older driver as the ability to change visual focus declines linearly to a point where, by age 60, the eye has little accommodative ability at all (Kline and Scialfa, 1996). When information is presented using a HUD, older drivers may be able to retrieve it faster, and potentially detect and therefore respond to obstacles or dangers on the roadway faster. Also, road signs or route guidance information presented in the HUD would provide the information to the drivers sooner, such that older drivers would have enough time to safely execute the desired response.

On the other hand, considering the limitations of divided and selective attention (e.g., Parasuraman and Nestor, 1991; Somberg and Salthouse, 1982) of older drivers, HUDs may impair elderly driving. For example, a HUD could exacerbate some of the problems older drivers experience as a result of a more restricted useful field of view (UFOV), (Ball & Owsley, 1991).

UFOV is the visual field from which information can be acquired during a brief glance (Sanders, 1970). One factor that may affect the size of the UFOV is the attentional demands of a central task. Thus, as the cognitive demands of the HUD task increases, the UFOV may constrict, and objects in the periphery would be less likely to be detected. Other research has indicated that HUD information may distract older drivers, much more so than younger drivers. Rabitt (1965) found that in visual search tasks, older adults were slowed to a greater degree by the presence of irrelevant information than were younger adults. This suggests that irrelevant information, such as a navigation instruction that the driver has already processed and responded to, may continue to distract an older driver's attention away from the driving task. The present research will investigate whether navigation instructions presented in a HUD will help or hinder older drivers.

HEAD-UP DISPLAYS AND ATIS APPLICATIONS

In their review of the literature on human factors aspects of using HUDs in automobiles, Gish and Staplin (1995) state: "*To date, the research does not provide robust evidence for operationally significant performance advantages due to HUDs. However, conclusions are equivocal due to the interaction of independent variables such as workload, display complexity and age.*" (Gish and Staplin, 1995, p. I). In short, the literature on performance and attentional effects of automotive HUDs does not provide unequivocal guidance on the design of HUDs for ATIS applications. It would be helpful if these uncertainties about automotive HUDs could be resolved by reference to prior use of HUD technology. For example, HUDs have been widely and successfully used in military fighter aircraft for years, primarily to provide aviators with flight and targeting information. Unfortunately, research findings, performance data, and design criteria from the military aviation environment cannot be confidently transferred to the commercial automotive environment. This is due to the many differences between the operators, tasks, environment, workload levels, and levels of training associated with the military aviation environment versus the commercial automotive environment. Briefly, military aviators are highly trained, young, and frequently use the HUD to acquire and target external objects against an uncluttered background. By contrast, automotive HUD users can be of any driving age (i.e., aged 16 to 80, and even beyond), do not have high levels of HUD-specific training, and are required to switch their attention between the HUD and a rich and rapidly changing external visual scene.

OBJECTIVES AND HYPOTHESES OF THIS STUDY

The overall objective of this study was to investigate the use of a HUD for an ATIS device. Of particular importance are how display location and drivers' age interact to influence driver behavior. The following specific hypotheses guided the experimental method used in the study, as well as our subsequent analysis of the data:

Navigation

- A HUD will promote higher compliance to navigation messages than will a HDD.
- Older drivers will commit more navigation errors than will younger subjects.

Collisions

- The number of collisions with unexpected events will be higher in the HDD condition than the HUD condition.
- The number of collisions with unexpected events will be higher in the older age group than the younger age group.
- BRTs to an unexpected event will be longer in the HDD condition than the HUD condition.
- BRTs to an unexpected event will be longer for older subjects than younger.
- Time to first steering wheel reversal greater than 6 degrees after an unexpected event is triggered will be longer in the HDD condition than in the HUD condition.

Driving Performance

- Deviations in velocity will be greater with the HDD condition than the HUD condition.

METHOD

SUBJECTS

Twelve young drivers, six female and six male, ranging in age from 18 to 30 years old (mean = 23 years old), and 12 older drivers, six female and six male, ranging in age from 65 to 87 years old (mean = 76 years old), participated in this study. All subjects had a valid drivers license, and drove at least twice per week. The subjects were recruited from the University of Washington, local social clubs, and church groups, and were paid $5.00 per hour.

APPARATUS

The apparatus included the Battelle High-Fidelity Driving Simulator, two navigation aids including a HDD and a HUD, and three experimental driving scenarios. Each of these is described below.

Battelle High-Fidelity Simulator

The Battelle High-Fidelity Driving Simulator is housed within a mobile trailer and incorporates a Saturn sedan mounted on a "road feel" motion platform. The 180° horizontal by 45° vertical forward scene, and the 60° by 45° rear scene are generated by a Silicon Graphics Onyx Rack System with Reality Engine II graphics. A spatial sound system provides realistic engine, road, wind, and other-vehicle noises with appropriate direction cues, intensity levels, and Doppler shift. The entire simulator is controlled from a single operator workstation. The Battelle High-Fidelity Driving Simulator provides the capability to immerse drivers in a realistic environment where they can be safely exposed to a wide range of driving and traffic conditions.

The visual database provides the driver with a high-fidelity representation of the real world. The outside visual scene presents multi-lane highways, two-lane rural roads, residential roads, and downtown core roads with representative roadway features and changes in elevation and terrain. Also, homes and commercial buildings, functional traffic control devices, pedestrians, and a range of other vehicles are presented to the driver. All scenarios present the driver with a rich driving experience. Although the simulator provides full control over ambient conditions, such as time of day and weather conditions, the scenarios for this study were presented under bright skies with both daylight conditions and clear weather.

The simulator vehicle is a 1994 Saturn sedan, modified to meet a number of strict experimental requirements, and linked to the host computer. The 5-channel directional sound system provides engine, road, and tire noise for both the simulator vehicle and other vehicles in the visual database. All sounds are consistent with vehicle states, changes in road surfaces, and the location and distance of external sound sources. The "road feel" motion platform imparts high-frequency movements that are correlated with all visual and auditory cues. The reconfigurable display suite includes programmable, full-color LCDs presented in either a head-up or a head-down location. The vehicle dynamics, such as engine displacement, gear ratios, shift points, and vehicle constants, were consistent with those of a 1994 Saturn sedan.

In the simulator, the performance measurement subsystem measures, records, analyzes, and manipulates all data. All inputs to the steering wheel, accelerator, brake, and vehicle secondary controls (e.g., gear shift, headlights) are recorded. Additional equipment is used to obtain and store the performance measurements. For example, acceleration rates are measured with a linear potentiometer, and braking behaviors are measured by a strain gauge. Inputs into the devices are translated into a percentage of throttle and brake pressure. All driving performance measures, such as lane position and steering variability, are logged by a host computer. In addition, the locations and states of the autonomous objects within the visual database are recorded by the Onyx.

Navigation Aids

<u>HUD and HDD</u>

As subjects drove through the environment, navigation information was presented on a color LCD (Sharp Model 4M-T3OU) with a 4-inch diagonal screen size. In the direct-view, HDD condition, the display was fixed to the top of the dashboard 300 mm to the right of the steering wheel. The image position of the HDD was (depending on the adjusted seat position) 31-35 inches from the nominal driver eye position. For the HUD, the same display was placed face up and attached to the top of the dashboard directly behind the steering wheel. The physical display itself was shielded from the subject's view. The image was reversed on the display so that, after being reflected off of the windshield, the subject viewed the virtual image in its proper orientation. The projected image distance of the HUD was (depending on the adjusted seat position) 35-38 inches in front of the nominal driver eye position. The full symbology set, in both the HDD and HUD cases, subtended a visual angle of 3.9 degrees.

As subjects approached an intersection, two pieces of information were provided via the display: 1) a 41-mm directional arrow (straight, left, or right), and 2) an 11-mm road name corresponding to the arrow. For example, if subjects were required to turn right on Bay Street, the display would present a right arrow with the word Bay St., as seen in figure 1.

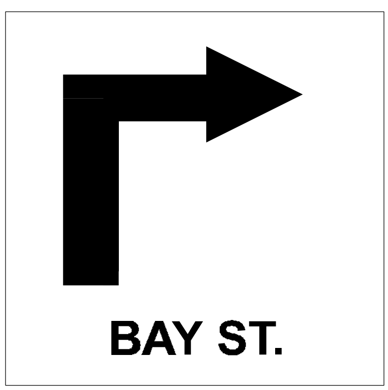

Figure 1. Example of navigation information displayed on the HDD and the HUD.

Additionally, the HUD and HDD presented destination information relevant to the driving task. Specifically, when the subject was within 300 m of the destination, the display presented the words “Approaching Destination.” When the subject was within a 50-m radius of the destination, the display presented the words “At Destination.” If the subject drove 50 m past the destination, the display presented the words “Beyond Destination.” The subject was instructed to stop the vehicle when the “At Destination” or the “Beyond Destination” message appeared.

Driving Scenarios

Subjects were asked to drive a total of six scenarios, three practice and simulator acclimation scenarios and three experimental scenarios. These scenarios are summarized in table 1 and described in more detail below.

Table 1. Summary of the six driving scenarios.

Scenario	Length of Scenario (m)	Time to Complete (approximate min)	Posted Speed Limit (mi/h/km/h)	Number of Objects Encountered	Number of Incidents
Practice 1	6600	5	45/70	0	n/a
Practice 2	6600	5	55/83	2	n/a
Practice 3	6600	5	55/83	2	n/a
Urban 1	3144	5	25/40	12	2
Urban 2	3311	5	25/40	12	1
Rural 1	10500	7	55/83	10	1

Drivers completed three 5-min practice scenarios to become familiar with the feel of the steering, accelerator, and brake characteristics of the simulator and to get accustomed to the simulated environment. These practice scenarios each consisted of 6,600 m of rural two-lane road, with a limited number of objects, such as pedestrians, traffic control devices, or other vehicles encountered along the route. The roadway included both straight and curved roadway elements, and trees, hills, and grass were included in the visual database. The third and final practice scenario introduced the driver to the navigational aid.

Following these practice scenarios, there were three experimental scenarios—two representing urban driving and one representing rural driving. Across the two urban scenarios, there were three incidents that required the driver to take action to avoid hitting an object or violating a traffic code. These incidents were a ball rolling onto the road, a vehicle crossing against a red light, and car in front braking to a stop. Each of these incidents were initiated by the subject vehicle as it crossed a “trigger line” that was placed in the driving database so that the subject, when driving at the posted driving speed, had 2.2 s to (as appropriate) bring the vehicle to a stop or to initiate a steering response.

For the rural scenario, the posted speed limit on the two-lane rural roads started at 55 mi/h (83 km/h) and later changed to 45 mi/h (68 km/h). Throughout this scenario there were 10 other vehicles and objects. Toward the end of the scenario, a car traveling in front of the subject began slowing to a stop. The velocity of the slowing vehicle was matched to the subject's velocity, so the vehicles were always the same distance apart.

EXPERIMENTAL DESIGN

Independent Variables

This study employed a mixed design with two between-subjects variables (driver age and navigation aid) and three within-subjects variables (incident location, incident type, and event-window). The independent variables are summarized in table 2; additional details are provided below.

Table 2. Summary of independent variables.

Variable Name	Levels	Description
Driver Age (between-Ss)	1) Young 2) Older	18 to 30 years 65 or more years
Navigation Aid (between-Ss)	1) HUD 2) HDD	Symbology displayed as virtual image and viewed through windshield. Symbology displayed as real image on direct view display located on top of dashboard.
Incident Object (within-Ss)	1) Ball 2) Car crosses road 3) Car in front brakes	Ball rolling on the roadway in front of vehicle. Car traveling through a red at intersection. Car brakes to a stop in front of vehicle.
Incident Type (within-Ss)	1) Control 2) Event	No action is required by subject in response to incident. Action is required to avoid the incident.
Event Window (within-Ss)	1) Pre-event 2) During event 3) Post-event	Data collected from trigger line to anticipated collision point (24 m in urban and 55 m in rural). Data collected from the anticipated collision point to 24 m past collision point. Data collected 4 m past the anticipated collision point to 24 m away.

The variable incident type had two levels: control or event. For each event incident that required a response from the subject, there was a prior control incident that took place that did not require a response. The control for the ball rolling across the road was a small child standing at the side of the road holding a ball. The control condition for the car crossing against the red light was a car waiting at the red light and obeying all traffic rules. The control condition for the car suddenly braking to a stop was a car in front of the subject's vehicle that did not brake. All incidents occurred when the subject crossed a trigger line. As long as the simulation vehicle was traveling at the posted speed limit, the events were triggered when the vehicle was 2.2 s away from the expected collision point.

Dependent Variables

<u>Performance Data</u>

Of particular interest were measures of steering wheel movements and velocity standard deviations (SDs). Research has shown that changes in driver steering behavior occurs when driver attention changes (Wierwille and Gutman, 1978). In driving situations that place low attentional demands on drivers, drivers typically make continuous, smaller steering corrections to make up for roadway variance and driving conditions. These corrections are generally within the range of 2 to 6 degrees. As attention or workload demands increase, the frequency of steering corrections tends to decrease. Since the small centering corrections decrease, the vehicle tends to drift farther from the lane center, and a larger steering input is required to correct the position. These larger steering inputs generally exceed 6 degrees and are referred to as large steering reversals. Since small corrections decrease and large corrections increase, an increase in the steering wheel position variance indicates high attention or workload requirements and a reduction in driving performance. A number of measures, including the number of steering reversals, the duration of each steering reversal, and the rate of reversals, were examined.

Vehicle speed, like lane position, can be considered a vehicle state, which at some level has to be held constant in most circumstances. Therefore, for the same reasons described above for steering reversals, variations in velocity are used to evaluate performance. Drivers are required to make continuous adjustments in pedal displacement to maintain correct speed. When driver attention is drawn away from the driving task, there is a tendency to maintain the foot in the same position. When drivers realize they are going (generally) too slow, the accelerator is depressed to a greater degree than is normal for a continuous adjustment. Research has found velocity maintenance to be a sensitive measure to changes in the amount of attention demands by secondary driving tasks (Monty, 1984).

In summary, the key variables of interest for this study were speed, throttle position, steering wheel angle (STWA), brake pressure, and lane deviation. Reaction times to reach braking criteria and to first steering wheel reversal were also calculated and recorded. In addition, information was collected that identified the closest object, the distance to the closest object, and the state of the traffic light when the subject’s vehicle crossed an intersection. All driver performance measures were collected during the simulation at a 30-Hz rate. Table 3 summarizes the performance measures that were available for analysis.

Table 3. Available dependent variables.

Variable	Description
Speed	Measured in miles per hour, the mean travel speed over an event or sub-event window.
SD of Speed	Measured in miles per hour, provides an indication of the change in velocity over an event or sub-event.
Throttle Position	Recorded as the linear percentage of throttle pressure with the mean being taken over an event or sub-event (0-100%).
Throttle SD	Recorded as a linear percentage of throttle pressure, provides an indication of the change in throttle pressure over an event or sub-event (0-100%).
STWA	Measured in degrees, indicates the amount that the steering wheel was turned from center position. Positive STWA indicated a turn to the right, whereas negative STWA indicated a turn to the left.
STWA SD	Measured in degrees of STWA, indicates STWA deviation across an event or sub-event.
Brake Pressure	Recorded as the linear percentage of brake pedal pressure with the mean being taken over an event or sub-event.
Brake Pressure SD	Recorded as a percentage of brake pressure, indicates the fluctuation in brake pedal use for an event or sub-event.
Lane Deviation	Measured as the difference in feet between the intended route and lane position (center of lane) and the position of the driver.
Lane Deviation SD	The SD of the lane deviation in feet, indicates the amount the driver deviated from the proposed route.
Nearest Object	Object closest to driver's vehicle during the sub-event.
Distance from Object	Distance in meters of the driver's vehicle from the nearest object.
Collision	Object with which the driver collided.
Signal State	Indicates whether the traffic signal was green, amber, or red when the driver crossed the intersection.

PROCEDURE

Recruiting Subjects

The Subject Selection Phone Questionnaire and the Subject Demographic Characteristics questionnaires were administered by telephone as the initial screening for participant suitability (see appendices A and B). Individuals who experienced motion sickness, frequent migraines, serious heart condition, were pregnant, or suffered any medical condition or medications that predisposed them to nausea, blurred vision, or drowsiness were omitted from the study. The purpose of the screening procedure was to minimize the possibility of experimental subjects experiencing simulator sickness. Also, only individuals who were over 18 years of age, held an active driver's licence, and drove in Seattle at least twice per week were allowed to participate in the study.

Pre-data Collection

Upon arrival at the test site, subjects read and signed the "FHWA Research Participation Consent Form" (appendix C). The purpose of the study and a brief introduction of the simulator were provided (appendix D for experimenter's protocol). The symptoms and possibility of simulator sickness were explained to the subjects at this time. A Comfort Assessment (appendix E) questionnaire was administered to record the subjects' state of well-being. It was used both as a pre-screening tool and to compare the subjects' state of well-being after the experiment. Subjects were not permitted to enter the simulation room if their score did not meet pre-determined criteria (see appendix F). Also, a postural disequilibrium test was administered. In this test, subjects were asked to balance on one foot with their eyes closed and their arms folded across their chest. The experimenter recorded the length of time the subject balanced until they moved or opened their eyes. This was performed three times, and the mean scores were computed and subsequently compared with post-test results.

Data Collection

Subjects were tested in pairs so that they could alternate between driving and resting. While one subject drove throughout a scenario, the other subject rested at the rear of the simulator. Subjects waited outside of the simulation theater when they were not driving.

Each subject was randomly assigned to one of two navigation aid conditions; either HDD or HUD. The subject was escorted to the vehicle and asked to adjust the seat and mirrors to a comfortable position. The vehicle's controls and displays, including the navigation aid, were explained to the subject. The location and purpose of the navigation aid were explained so the subject would know what to expect during the study (see appendix G for Navigation Aid Instructions). Also, the location of a microphone was given so that the subject could speak to the experimenter if necessary.

The subject's primary task throughout the experiment was to operate the vehicle as if they were driving their own vehicle in the real world. The experimenter emphasized the importance of obeying all traffic rules, particularly posted speed limits. Each subject completed the three practice trials, which consisted of rural driving with very few objects or vehicles on the roadway. All subjects then drove the three experimental trials in the following order: Urban 1, Urban 2, Rural 1. Only one incident was presented in each scenario (see table 4).

Table 4. Incidents as a function of scenario.

Scenario Order	Ball rolls onto road	Car crosses against red	Car in front brakes to a stop
Urban 1	✓		
Urban 2		✓	
Rural 1			✓

At the beginning of each scenario, the subject was instructed (via the microphone located at the experimenter's workstation and a speaker located within the simulation vehicle) to drive to a specific location using the navigation aid (see appendix H for scenario instructions). The subject received directions via the HDD or HUD as they approached each intersection and their final destination. Verbal navigation instructions were provided by the experimenter only if the subject took a wrong turn and ventured into the downtown core. If this occurred, the experimenter told the subject how to return to the route. The experimenter monitored the subject's speed and verbally reminded the subject to slow down or speed up if he/she deviated from the posted speed limits. When the subject reached the destination, he/she was instructed to stop the vehicle and place the vehicle in park to end the scenario.

Post-Experiment

After the subject completed the three experimental scenarios, the Comfort Assessment Questionnaire and the Postural Disequilibrium Test were re-administered. These tests were administered to ensure that the subject was not negatively affected by the simulator experience and to determine if it was safe for them to drive home. If the difference between the pre-test and post-test was substantial (see appendix H), the experimenter recommended that the subject not leave the experiment site. Rather, the subject was encouraged to remain and rest for 30 min. After 30 min, the tests were re-administered. If the subjects met the criteria, they were permitted to drive home; if not, they were sent home in a taxi. All subjects were paid and a record of payment form was completed and signed before leaving.

RESULTS

Three types of data were examined: 1) navigation errors, 2) collision rate and BRTs to sudden events, and 3) driving performance data around message windows. The data analyses were conducted using the BMDP 7.0 statistical software package. An alpha level of .05 was selected as the criterion for statistical significance. Complete analysis of variance (ANOVA) tables can be seen in appendix I. The drivers' routes were traced using a play-back feature of the simulation software, and any deviations from the planned route were recorded as errors. The play-back feature was also used to record collisions with the event objects (ball or other vehicles).

To extract meaningful conclusions regarding drivers' reaction to events, it was imperative that drivers encountered the events while driving at approximately the same speed. A driver traveling at 10 mi/h when encountering a vehicle crossing against a red light would not experience the same sense of urgency, or may not even need to brake at all, as compared with a driver traveling at 35 mi/h. Each driver's speed was recorded at the instant that the event was triggered. Drivers outside of the acceptable range (23 to 35 mi/h in urban scenarios) were excluded from the analyses. Only one subject (an older female) was excluded from the analysis for this reason. Where appropriate, outliers (data points that were 3 SDs or more above the mean) were removed from the data set and replaced with the mean.

Navigation Errors

A navigation error was defined as a deviation from the directions provided by the HUD or HDD. Once a navigation error was committed, the experimenter provided directions via HUD or HDD to guide the subject back on route. In total, only nine drivers committed a navigation error, and each committed only one error (see table 5). Consistent with our hypothesis, older drivers committed more navigation errors than younger drivers, $F(1, 16) = 9.8$, $p<.01$. However, contrary to our hypothesis, no significant differences were observed between the navigation aid, HUD, and HDD.

Table 5. Number of navigation errors as a function of driver age and navigation aid.

Age	Navigation Aid		Total
	HUD	HDD	
Younger	0	1	1
Older	4	4	8
Total	4	5	9

Accidents and Collisions

Each subject encountered three events (ball rolls across road; car crosses against red; lead car brakes) that required some action by the driver in order to avoid a collision. In the first event, a child rolled a ball across the road in front of the subject's vehicle. In the second event, a vehicle crossed against a red light in front of the subject. In the third event, a lead car directly in front of the subject braked to a complete stop. The number of collisions and BRTs were examined. A braking response was defined as pressure on the brake pedal that exceeded a threshold value of 2 percent. Analyses were also conducted using a braking criterion value of 5 percent; however, the results were unchanged.

Ball Event

Table 6 shows that there were no significant differences in the number of drivers who collided with the ball as a function of driver age.[1]

Table 6. Number of drivers who collided with the ball as a function of navigation aid and driver age.

Age	Navigation Aid		Total
	HUD	HDD	
Younger	5	6	11
Older	4	3	7
Total	9	9	18

Car Crosses Against Red

Table 7 presents the number of drivers who collided with the car that crossed against the red light. All drivers received this event in Scenario 2 (Urban) with the simultaneous presentation of a navigation message. No significant differences in the number of collisions were observed as a function of driver age or navigation aid.

Table 7. Number of drivers who collided with the car as a function of navigation aid and driver age.

Age	Navigation Aid		Total
	HUD	HDD	
Younger	3	5	8
Older	4	4	8
Total	7	9	16

BRT was measured in seconds from the time the car event was triggered to cross the intersection to when the driver reached the braking criteria of 2 percent. Note that the data from three subjects were removed from the analysis, as one failed to reach the braking threshold level of 2 percent and two were already braking before they triggered the car. As was expected, older

[1] An error regarding this ball event was discovered during data analysis; the ball event did not reliably occur simultaneously with a navigation message, thus negating any comparison of navigation aid.

drivers were slower to brake for the car event (0.9 s) than were younger drivers (0.8 s). BRTs did not differ significantly as a function of gender or navigation aid.

Lead Car Brakes

For the last event in Scenario 3 (Rural), a lead vehicle braked to a complete stop directly in front of the driver. As all subjects stopped in time to avoid colliding with the lead vehicle, only BRTs to the onset of brake lights were examined. Data for one driver were removed from the analysis as she was already braking prior to the onset of the lead vehicle's brake lights. No main effects of driver age, gender, or navigation aid were observed.

Driving Performance

The SD of the STWA and the SD of velocity were examined for windows of time around navigation messages. Navigation messages that coincided with the planned events above were eliminated from these analyses. Driving performance as a function of driver age (young or older), gender (female or male), navigation aid (HUD or HDD), scenario (first, second, or third), turn direction (straight or turn), and message window (pre-display, during display, and post-display), was examined. Of primary importance was the hypothesized effects of driver age, gender, navigation aid, and message window. Although effects of scenario and turn direction were expected, they were not of particular experimental interest and thus are only reported when relevant. Complete ANOVA tables and post-hoc Tukey tests can be found in appendix I.

Standard Deviation of Velocity

Subjects in this study were required to maintain a relatively consistent speed for large portions of the driving task. Therefore, for the same reasons described above for steering reversals, variations in velocity have been used to evaluate performance. As in real-world driving, drivers were required to make frequent adjustments in pedal displacement in order to maintain correct speed. In general, when driver attention is drawn away from the driving task, there is a tendency to maintain the foot in the same position. When drivers realize they are going (generally) too slow, the accelerator is depressed to a greater degree than is normal for a continuous adjustment. Research has found the SD of velocity to be a sensitive measure to changes in the amount of attention demands by secondary driving tasks (Monty, 1984).

The hypothesized main effect of navigation aid was not substantiated by the data; no differences were observed between SD velocities with the HUD (M = 3.4) and with the HDD (M = 3.3). A Navigation Aid × Window Interaction was expected; specifically, it was hypothesized that the HDD would draw drivers' attention away from the driving task, and control inputs to the accelerator would be suppressed in the during-message window. This interaction was not significant. These results suggest that the HDD does not distract drivers' attention away from the driving task any more so than HUDs. Also, we hypothesized that older drivers may be drawn to the HUD more than the HDD and, as a result, would have lower SD velocity scores. Contrary to our hypothesis, there was no interaction between age, navigation aid, and message window.

Figure 2 illustrates the Age × Gender × Message Window Interaction, $F(4,64) = 6.78$, $p<.0001$. Tukey tests revealed no significant age or gender differences in the pre-message, baseline window. In the during-message window, younger males had significantly lower SD velocities than older males. One possible explanation is that during message presentation younger males were distracted by the display onset and control inputs to the accelerator were suppressed. No age or gender differences were observed in the post-message window. The Age × Gender × Message Window × Navigation Aid Interaction was not significant. There is no evidence that the ability to drive with HUD and HDD navigation aids was affected by driver characteristics such as age or gender.

There were also no significant main effects of driver age or gender. The main effect of message window, however, was significant $F(2,32) = 244.1$, $p<.05$. Post-hoc Tukey tests showed that SD velocities increased from the pre-message window to the during-message window, and from the during-message window to the post-message window. The most likely explanation for this finding is that drivers adjusted their speed as they neared the intersection and, in some cases, in order to complete a turn.

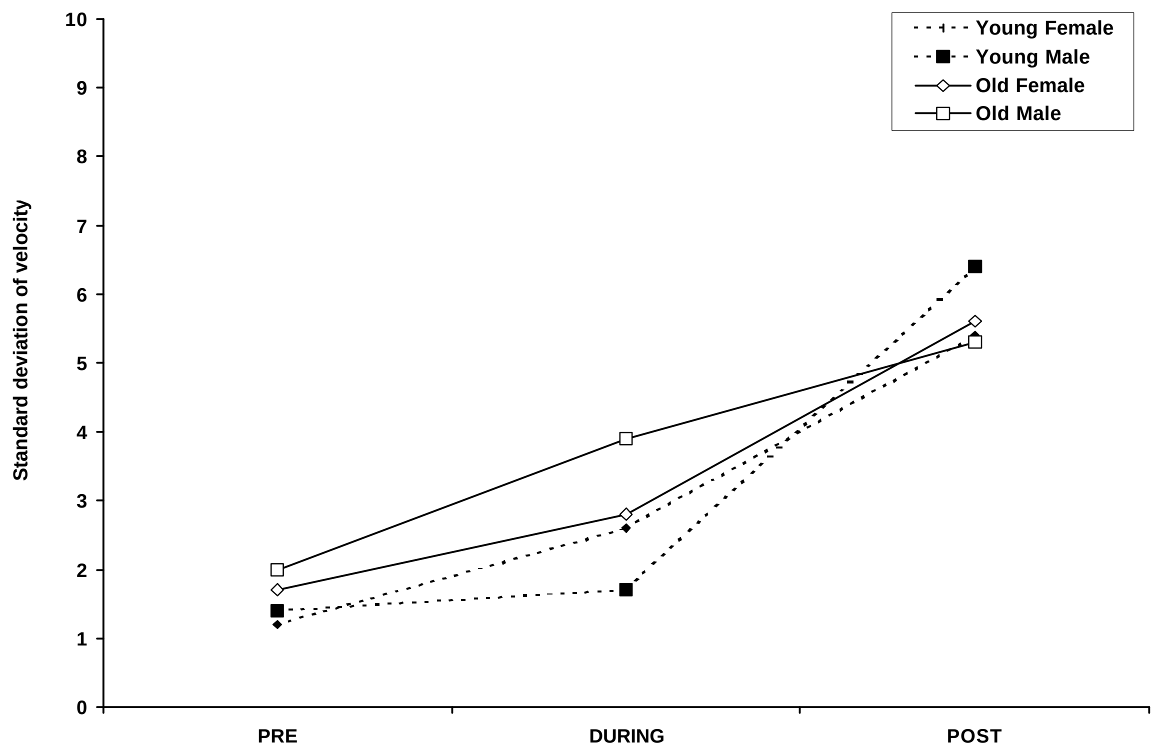

Figure 2. Standard deviation of velocity as a function of Age × Gender × Message Window.

STANDARD DEVIATION OF THE STWA

The SD of STWA is a measure of the variability of steering wheel movements. Research has shown that changes in driver steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). In normal, low attention, circumstances, drivers make continuous, smaller steering corrections to make up for roadway variance and driving conditions. These corrections are typically within the range of 2 to 6 degrees. As attention or workload demands increase, the frequency of steering corrections tends to decrease and this is reflected in lower SDs of the STWA.

Figure 3 depicts the effect of navigation aid and message window on SD STWA. The main effect of navigation aid was not significant; no differences were observed between the HUD (M = 9.8) and the HDD (M = 9.1). The Navigation Aid × Message Window Interaction was significant, $F(2,32) = 4.19$, $p<.05$. Post-hoc Tukey tests revealed no significant difference between HUD and HDD conditions in the pre-message and during-message windows. However, in the post-message window, drivers in the HDD condition had significantly lower SD STWAs (23.2) than those in the HUD condition (25.4). The reason for this result is unclear; it is possible that drivers were distracted by the HDD and therefore control inputs to the steering wheel were suppressed. However, it is puzzling that this effect was observed only in the post-message window (after the message had cleared) and not during message presentation.

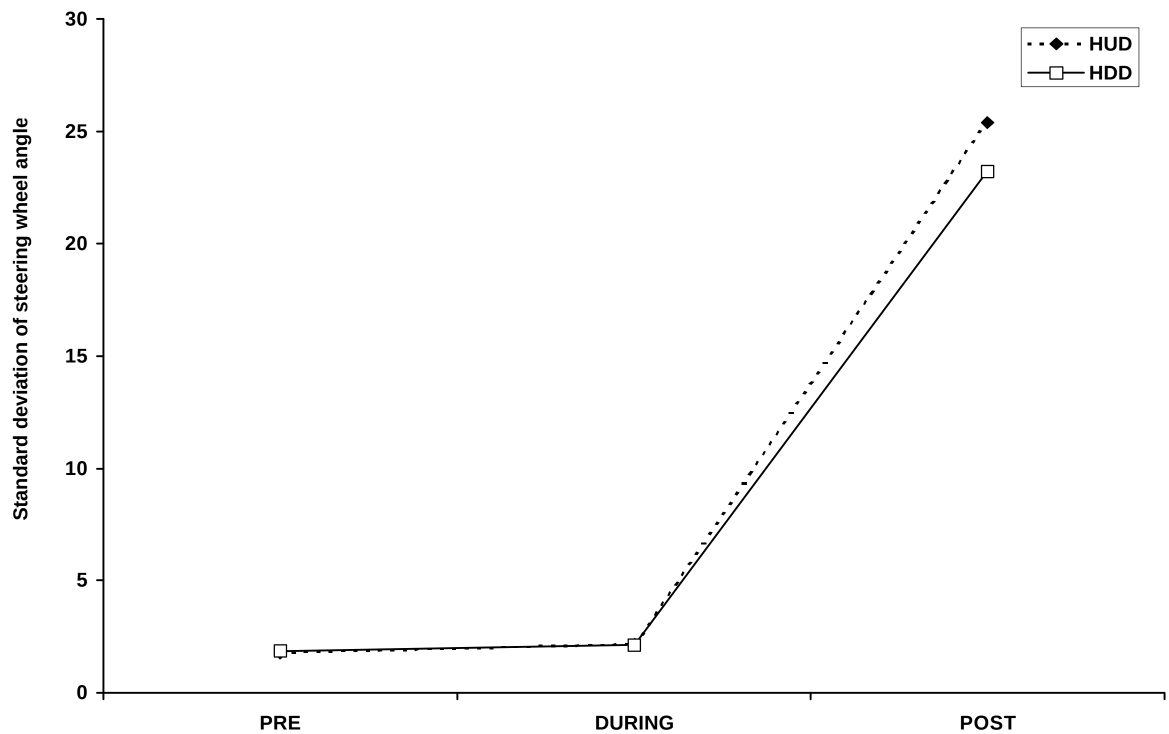

Figure 3. Standard deviation of steering wheel angle as a function of Navigation Aid × Message Window Interaction.

The Window × Age × Gender × Navigation Aid Interaction was significant, $F(2,32) = 4.45$, $p<.05$, but only in the post-message window, $F(1,16) = 4.48$, $p<.05$. Follow-up Tukey tests revealed that some drivers (specifically younger females and older males) had lower SD STWAs in the HDD condition than they did with the HUD. Older females shared this same tendency, but the difference was not significant. This suggests that these drivers were drawn to the HDD and, as a result, inputs to the steering wheel were suppressed. As can be seen in figure 4, young male drivers exhibited a different pattern of results. Though the difference was not significant, young males tended to have a lower SD STWA with the HUD than the HDD. This finding suggests that driver characteristics such as age and gender may differentially affect a driver's ability to use various navigation devices. This highlights the importance that ATIS designers consider user-defined features that allow each driver to optimize the system for their own use.

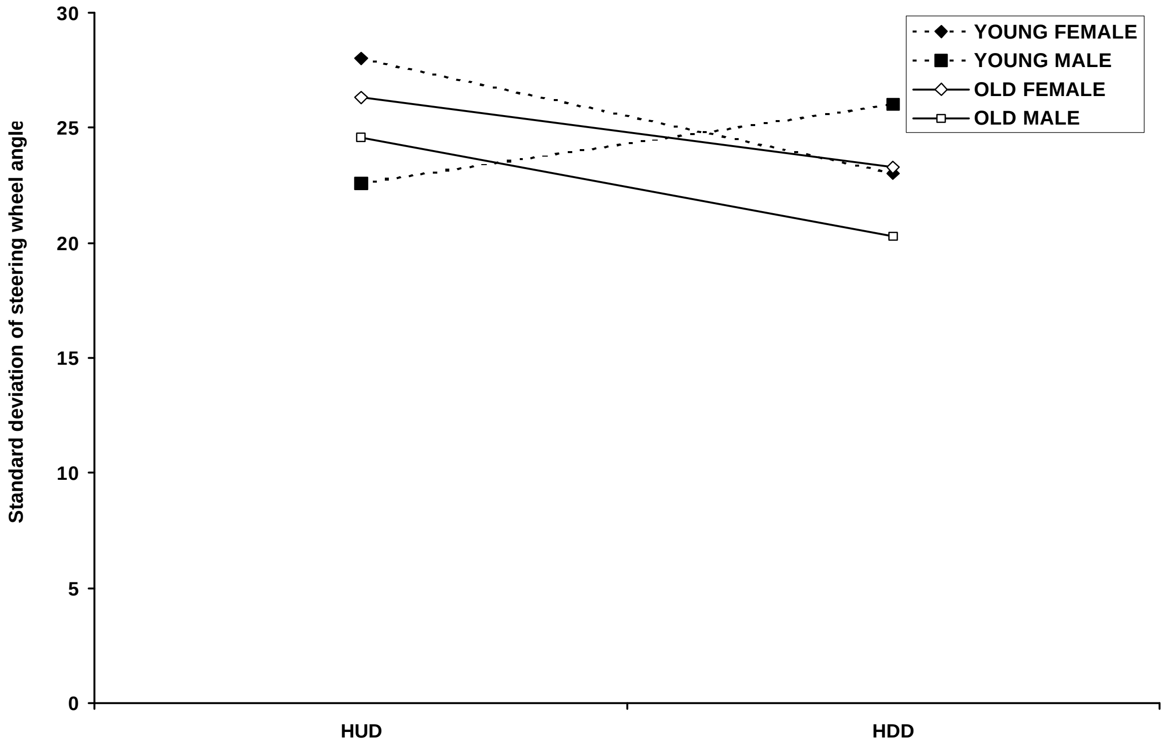

Figure 4. Standard deviation of steering wheel angle as a function of Age × Gender × Navigation Aid Interaction (Post-message window only).

The main effect of window was significant. Post-hoc Tukey tests revealed no differences between the pre-message window (M = 1.8) and the during-message window (M = 2.2). However the post-message window (M = 24.3) was higher than both the pre- and during-message windows, $p<.05$. That there was no difference between the pre- and during-message windows suggests that presenting the message did not distract drivers, at least to the extent that the SD STWA was affected. It was expected that the SD STWA would be higher in the post-window drivers, as drivers were instructed by the navigation aid to turn, thus inflating the SD STWA values.

DISCUSSION AND CONCLUSIONS

As described in the previous section, few of the research hypotheses put forth for this study were supported by the data. Below, we review each of these hypotheses and discuss the results and conclusions associated with them.

HYPOTHESES RELATED TO NAVIGATION

A HUD will promote higher compliance to navigation messages than will a HDD. This hypothesis was not supported by the data; there were no significant differences between the HUD and the HDD with respect to compliance to the navigation messages.

Older drivers will commit more navigation errors than will younger subjects. This hypothesis was supported by the data, but by itself, has little implication for ATIS/CVO design.

HYPOTHESES RELATED TO COLLISIONS

The number of collisions with unexpected events will be higher in the HDD condition than the HUD condition. This hypothesis was not supported by the data; there were no significant differences between the HUD and the HDD with respect to the number of collisions.

The number of collisions with unexpected events will be higher in the older age group than the younger age group. This hypothesis was not supported by the data; there were no significant differences between the younger and older drivers with respect to the number of collisions.

BRTs to an unexpected event will be longer in the HDD condition than the HUD condition. This hypothesis was not supported by the data; there were no significant differences between the HUD and the HDD with respect to BRTs.

BRTs to an unexpected event will be longer for older subjects than younger subjects. This hypothesis was supported by the data—older subjects braked, on average, 1/10th of a second slower than younger subjects. This finding however, has little implication for ATIS/CVO design.

Time to first steering wheel reversal greater than 6 degrees after an unexpected event is triggered will be longer in the HDD condition than in the HUD condition. Steering was not the typical response to unexpected events, thus this hypothesis could not be explicitly examined.

HYPOTHESES RELATED TO DRIVING PERFORMANCE

Deviations in velocity will be greater with the HDD condition than the HUD condition. This hypothesis was not supported by the data; there were no significant differences between the HUD and the HDD with respect to deviations in velocity.

SUMMARY AND IMPLICATIONS FOR DESIGN GUIDELINES

This study revealed no differences with respect to navigation performance, response to unexpected events, or driving performance as a function of navigation aid. There were differences between younger and older drivers with respect to number of navigation errors and BRTs to unexpected events. However, these differences most likely reflect well-established cognitive and manual control limitations for older drivers and, in the absence of interactions with the navigation aid variable, have little implication for ATIS/CVO design.

Nonetheless, while performance (considered overall) was not better in the HUD condition than in the HDD condition, neither was the HUD associated with performance decrements. In particular, none of the results suggest that the HUD was a distraction to the subjects or that it was associated with any form of cognitive capture. Thus, the results suggest that a HUD may be safely used to present simple route guidance information to drivers.

APPENDIX A. SUBJECT SELECTION PHONE QUESTIONNAIRE

Subject Name _____________________________ **Phone Number _____ ____**

Age _______ **Gender _______ (1=M, 0=F)**

1) Do you have an active driver's license? _____Yes (1) _____ No (2)
[Exclude subject if answer is NO]

2) How many times per week do you drive in Seattle?
_____< 1X (1) _____1X (2) _____2 or more (3)
[Exclude subject if answer is "Once or less."]

3) Do you ever experience motion sickness while driving or riding in a vehicle (e.g., car, bus, train, plane, boat)?
_____Never (1) _____Sometimes (2) _____ Often (3)

[If answer is "Sometimes" or "Often," inform subject of the following:
"One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Because you often experience motion sickness, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

4) Past research has suggested that this type of simulator research may not be suitable for individuals who experience migraine or tension headaches? Do you experience either of those? _____ No (1) _____Yes (2)

[If answer is "Yes," question the subject further. If they have experienced a migraine recently, or experience migraines frequently, inform subject of the following." One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Research shows that people who experience migraines or tension headaches may be more susceptible to simulator sickness. Because you often experience migraines, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

5) **Also, this type of simulator research may not be suitable for individuals who suffer from a serious heart condition. Do you suffer from a heart condition ?**

_____No (1) **_____Yes (2)**

[If "Yes," inform the subject of the following:
"Due to your heart condition, we must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

6) **If female: Also, simulator research may not be suitable for women who are pregnant. Are you pregnant?**

_____No (1) **_____Yes (2)**

[If "Yes," inform the subject of the following:
"One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Because you are pregnant, and therefore prone to nausea, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

7) **Do you suffer from any condition or take any medications that predispose you to nausea, blurred vision, or drowsiness?**

_____No (1) **_____Yes (2)**

[If "Yes," inform the subject of the following:
"One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some people experience when traveling in a vehicle. Because of your condition/medication, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies which do not involve the simulator, if you wish."]

APPENDIX B. DRIVER DEMOGRAPHIC CHARACTERISTICS PHONE QUESTIONNAIRE

Subject ID: __________

1. Age: _____

2. Number of years as a licensed driver: _____

3. Number of years driving in Seattle: _____

4. Number of years lived in Seattle _____

4. Town of residence: _________________________ Zipcode ________________

5. Gender: G Male G Female

6. What is the average number of miles you drive annually?

G less than 5,000
G 5,000 - 9,999
G 10,000 - 19,999
G 20,000 - 39,999
G 40,000 - 69,999
G 70,000 - 99,999
G more than 100,000

7. Where did you learn about this research? ____________________________________

APPENDIX C. RESEARCH PARTICIPATION CONSENT FORM

You have been recruited to participate in a study that will examine issues related to driver behavior, performance, and traffic safety with an in-vehicle navigation system. During this study, you will be “driving” under a range of driving situations, such as urban, rural, and suburban streets, as well as a range of driving conditions, such as daytime light levels, clear weather, and light to moderate levels of traffic congestion. You will also encounter potentially stressful driving situations, just as can happen in everyday driving, such as pedestrians or other objects entering the roadway and other vehicles ignoring a red traffic light at an intersection. This research will provide an important contribution to the development, design, and evaluation of advanced traveler information systems. If, at anytime, the driving situation becomes too stressful, please tell the experimenter and the simulation will be ended. For your participation in this experiment, you will be paid $5.00 per hour.

There is a risk that you may experience motion sickness similar to what you might experience when traveling in a moving vehicle. The chances of this happening are slight; most people enjoy driving the simulator and do not experience any discomfort. However, if you feel uncomfortable, you may withdraw from the study at any time without any penalty. If you withdraw, you will be paid for the time you have participated.

All data obtained are for research purposes only. Your name and this consent form will be kept separate from all data collected. No individual information will be reported to any licensing authorities or insurance companies. The information will be reviewed only by Battelle scientists, and the data will reside at Battelle.

By signing this form, you certify that, to your knowledge, you meet the following minimum requirements for simulator research participation:

- Over the age of 18.
- Not pregnant.
- No serious heart condition.
- No migraine or tension headaches.
- No conditions or medications that predispose you to nausea, blurred vision, or drowsiness.

If you have any questions or desire further information about this study, please contact Brian Gore at Battelle/Seattle (206) 528-3294, or Dave Snediker at Battelle/Columbus (614) 424-4633.

I have read the statement above and agree to permit the use of my responses for research purposes.

______________________________	____________	____________
Signature of Participant	Date of Birth	Today’s Date
______________________________		____________
Signature of Investigator		Today’s Date

RECORD OF PAYMENT

______________________________ ______________________________
Please Print Name Social Security Number

_____ hours @ $__.__ per hour = $__.__

______________________________ ___________
Signature of Participant Today's Date

_____________________________ __________
Signature of Investigator Today's Date

APPENDIX D. EXPERIMENTER'S PROTOCOL & INSTRUCTIONS

! Refer to other protocols and checklists (e.g., simulator sickness protocol).

! Meet participants at RealDrive simulator (on campus). Each session will have two scheduled subjects.

! Inform that there are rest rooms and drinking fountains in the office area nearby, and they should feel free to ask if they need either.

! Go into the simulator and have participants fill out the consent, demographic information, and other forms while waiting.

! Complete other pre-tests as needed.

! Read instructions.

INSTRUCTIONS

Purpose of Study

Welcome to Battelle. The purpose of this study is to better understand how drivers navigate from one place to another. In this study, you will "drive" from one location to another using a navigation aid.

Driving Simulators

First of all, I would like to introduce you to the driving simulator. We believe that driving simulators are very useful for investigating various driving issues in a safe and controlled environment. One of the benefits of simulator research is that it allows researchers to investigate driving situations that are hazardous or which occur rarely. As such, though, we expect you to drive as you normally would in the "real-world." We do not want you to be distressed if confronted with a hazardous or rarely occurring event. If you anticipate this to be a problem, you are free to leave without loss of compensation for the time that you have spent up to that moment. In addition, you are free to end your participation at any time or for any reason without loss of compensation.

Two Participants (Optional)

As you can see, two participants have been scheduled for the same time. While one of you is driving, the other will be resting here at the back of the trailer.

Your Task

In this study, you will be told to drive to a certain destination. For example, you may be given an address and told to drive to that location. You will be given a navigation aid that will help you find this address. For example, you may be given a list of directions instructing you on how to navigate to your destination.

Your primary task in this study is to SAFELY OPERATE THE VEHICLE. The data from your session will only be of use to us if you drive safely, and as you would normally would in the "real-world." Therefore, it is important that you obey all driving laws. For example, you must obey the posted speed limits.

You will be driving seven different "scenarios" today. A "scenario" is simply a session where you will be driving from a start point to an end point. The first three scenarios will be for practice just so that you can get used to driving the vehicle. Each scenario typically lasts under 10 minutes.

At different times during your simulated drive, you may be required to quickly react to events that could occur in a real driving situation. For example, a car that you are following may suddenly, without the warning of brake lights, begin to brake. Despite this being a simulation of driving, please react as you would in a real driving situation. For the example I've just described, possible evasive actions would include braking and/or swerving.

You will begin your drive on a rural or country road. After several miles, this road will pass through a residential area. Please watch for speed limit signs and changes in the speed limit.

Your drive will take place on a clear day, and the roads will be dry. The "feel" of the vehicle will be similar to that of an actual Saturn.

If you have any concerns about the features of the driving situation that I've just described, please let me know now. If you feel that you no longer wish to participate, you may withdraw and I will pay you for the time you've already spent here.

This study should last approximately 2-½ to 3 hours. As you have read on your consent form, you may choose not to participate at any time. If you should stop prior to completing all the scenarios, you will be compensated at the rate of $5.00 per hour. You will be paid at the end of the session today.

Do you have any questions about your task?

BEGIN SCENARIOS

- During the simulation, monitor subjects for simulator sickness. Possible symptoms include, but are not limited to: complaints of feeling ill, closing eyes, sweating, yawning, frowning facial expression. See accompanying experimenter sickness protocol.

- While one subject is driving, the other subject should be sitting on the bench at the back or, preferably, waiting outside the trailer. After each subject has completed a scenario, the experimenter should ask "how are you doing?." If subject doesn't feel well, refer to sickness protocol.

Scenario 1 (Practice 1) -- Subject A
Scenario 1 (Practice 1) -- Subject B

Scenario 2 (Practice 2) -- Subject A
Scenario 2 (Practice 2) -- Subject B

Scenario 3 (Practice 3) -- Subject A
Scenario 3 (Practice 3) -- Subject B

Scenario 4 (Test 1) -- Subject A
Scenario 4 (Test 1) -- Subject B

Scenario 5 (Test 2) -- Subject A
Scenario 5 (Test 2) -- Subject B

Scenario 6 (Test 3) -- Subject A
Scenario 6 (Test 3) -- Subject B

Scenario 7 (Test 4) -- Subject A
Scenario 7 (Test 4) -- Subject B

DEBRIEF

- Complete required post-tests and forms.
- Ask if he/she has further questions.
- Complete payment form and pay.
- Ask if he/she would like to be on a list for future studies.
- Thank and escort out.

APPENDIX E. SUBJECT COMFORT ASSESSMENT

Subject ID: ________

SUBJECT COMFORT ASSESSMENT

Directions: Circle below if any symptoms apply to you right now.

Symptom	Pre-Experiment				Post-Experiment				Change
General discomfort	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Drowsiness	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Headache	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Sweating	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Nausea	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Blurred vision	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Dizziness when eyes open	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Dizziness when eyes closed	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Faintness	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
Stomach discomfort	None	Slight	Moderate	Severe	None	Slight	Moderate	Severe	________
								Total	________

APPENDIX F. POSTURAL DISEQUILIBRIUM TEST FORM

SUBJECT ID: ___________

POSTURAL DISEQUILIBRIUM TEST FORM		
	Pre-Test (sec/tenth)	**Post-Test (sec/tenth)**
Trial 1		
Trial 2		
Trial 3		
Mean		

FORMULA

$$\text{Percent Change} = \frac{\text{Pre-Trial Average - Post-Trial Average}}{\text{Pre-Trial Average}} \times 100$$

Percent Change = ________________ X 100

Percent Change =

PASSING CRITERIA

Percent change less than 50% PASS ____

Percent change greater than 50% FAIL ____

The following questions are to be asked after the tests have been completed.

a) How many hours of sleep do you normally get? _______________

b) How many hours of sleep did you obtain last night? _________________

c) Did you consume any alcohol the night before/last night? YES NO

Note: If subject does not meet the passing criteria, ask them to wait in the waiting room. Subjects can try the test again after 30 minutes. If they fail a second time, offer to call a taxi. Battelle will pay cab fare for the subject to return and pick up their car the next day.

Be sure to record the post-test results on the Subject Status Sheet.
This is required by Battelle's Human Subject Committee and Legal Department.

APPENDIX G. NAVIGATION AID INSTRUCTIONS

HEAD-UP DISPLAY

Today your navigation aid will be a Head-Up Display. It is called a Head-Up Display because the information is presented on the windshield, allowing the driver to read it with their 'head up." The display will provide you with instructions regarding the most optimal route for reaching your destination. For example, if an upcoming right turn is suggested that will take you on the optimal route, a message will appear indicating the street you might turn on to and the direction of that turn.

For these subjects, type in the following on the HUD computer:

1) exp13 hud.txt scen1.s01 s01 m 29 scen1
2) exp13 hud.txt scen2.s01 s01 m 29 scen2
3) exp13 hud.txt scen3.s01 s01 m 29 scen3
4) exp13 hud.txt scen4.s01 s01 m 29 scen4
5) exp13 hud.txt scen5.s01 s01 m 29 scen5
6) exp13 hud.txt scen6.s01 s01 m 29 scen6
7) exp13 hud.txt scen7.s01 s01 m 29 scen7

DASH-MOUNTED DISPLAY

Today your navigation aid will be a Dash-Mounted Display. As the name suggests, this display is mounted on the dash, right of the steering wheel. The display will provide you with instructions regarding the most optimal route for reaching your destination. For example, if an upcoming right turn is suggested that will take you on the optimal route, a message will appear indicating the street you might turn on to and the direction of that turn.

1) exp13 hdd.txt scen1.s02 s02 m 30 scen1
2) exp13 hdd.txt scen2.s02 s02 m 30 scen2
3) exp13 hdd.txt scen3.s02 s02 m 30 scen3
4) exp13 hdd.txt scen4.s02 s02 m 30 scen4
5) exp13 hdd.txt scen5.s02 s02 m 30 scen5
6) exp13 hdd.txt scen6.s02 s02 m 30 scen6
7) exp13 hdd.txt scen7.s02 s02 m 30 scen7

PAPER MAP

Today your navigation aid will be a paper map. The map outlines the road network that you will be driving on. Use it as you would normally use a paper map to find a destination that you are not familiar with. Please note that roads which are indicated to be under construction are NOT driveable surfaces and alternate roads should be chosen.

APPENDIX H. SCENARIO INSTRUCTIONS

Practice Scenario 1

- ! SUBJECT DOES NOT USE NAVIGATION AID.
- ! For this scenario, you will be beginning on Lee Road and you will want to make a right turn at the lights onto Highway 22. Proceed until you reach Bow Road. Stop at the intersection of Highway 22 and Bow Road.

Practice Scenario 2

- ! SUBJECT DOES NOT USE NAVIGATION AID.
- ! For this scenario, you will be beginning at the intersection of Bow Road and Highway 22. Go to the 7-11 convenience store on Highway 22 (it will be on the left side of the road). When you reach it, pull off onto the right shoulder.

Practice Scenario 3

- ! SUBJECT USES NAVIGATION AID. Explain to the subject what his/her navigation aid is (e.g., map, HUD, HDD). Tell the subject about the arrows and the "Approaching Destination," "Near Destination," "Past Destination" messages. (See Navigation Aid Instructions).
- ! For this scenario, you will be beginning at the May Road intersection on Highway 22. Now you will want to go to the Ranch House at 378 on Highway 22. Use the navigation aid to help you find your destination.

Test Scenario 2

- ! For this scenario, you will be beginning at a 7-11 on Ivy Avenue. Please go to the house that is located at #680 Ray Street. Please pull into the driveway of this house. Use the navigation aid to help you find your destination.

Test Scenario 3

- ! Now you will be starting off at the same point which you have just finished, #680 Ray Street. Go to the store that is located at #5 Ivy Avenue. Use the navigation aid to help you find your destination.

Test Scenario 4

- ! For this scenario, you will be starting off at #5 Ivy Avenue. You are now asked to go to the Ranch House that is located at #535 Highway 22; it is near Bow Road. Use the navigation aid to help you find your destination.

For the test scenarios, all the subjects will have a navigation aid given to them.

APPENDIX I. ANOVA TABLES

Table 8. Navigation error.

Source	SS	DF	Mean Square	F	P
Age	3.37	1	3.37	9.80	.0065
Gender	2.04	1	2.04	0.2	.66
Navaid	.04	1	.04	0.2	.66
Age × Gender	.04	1	.04	0.2	.66
Age × Navaid	.04	1	.04	0.2	.66
Gender × Navaid	.04	1	.04	0.2	.66
Age × Gender × Navaid	.04	1	.04	0.2	.66
Error	3.33	16	.21		
Total	8.94	23	5.82	11	3.9665

Table 9. Ball collision - groups 1 and 2.

Source	SS	DF	Mean Square	F	P
Age	.129	1	.129	.657	.430
Navaid	.0005	1	.0005	.003	.958
Group	.129	1	.129	.657	.430
Age × Navaid	.0465	1	.0465	.236	.633
Age × Group	.359	1	.359	1.824	.196
Navaid × Group	.0465	1	.0465	.236	.633
Age × Navaid × Group	.0005	1	.0005	.003	.958
Error	3.150	16	.197	.980	.479
Total	4.50	23	.196	4.596	4.717

Table 10. Ball collision (group 1).

Source	SS	DF	Mean Square	F	P
Navaid	.15	1	.148	.557	.471
Error	2.93	11	.266		
Total	3.08	12	0.414	.557	.471

Table 11. Ball collision (group 2).

Source	SS	DF	Mean Square	F	P
Navaid	.11	1	.11	1.23	.297
Error	.80	9	.09		
Total	.91	10	.20	1.23	.297

Table 12. Standard deviation of steering wheel angle.

Source	SS	DF	Mean Square	F	P
OBSERVATION					
Age	22.52	1	22.52	1.02	0.33
Gender	27.48	1	27.48	1.24	.28
Navaid	53.95	1	53.95	2.44	0.14
Age × Gender	19.11	1	19.11	0.86	0.37
Age × Navaid	64.68	1	64.68	2.93	0.11
Gender × Navaid	53.45	1	53.45	2.42	0.14
Age × Gender × Navaid	75.79	1	75.79	3.43	0.08
Error	353.75		22.11		
SCENARIO (S)					
(S) × Age	5.75	2	2.88	.17	0.85
(S) × Gender	155.57	2	77.79	4.56	0.02
(S) × Navaid	3.95	2	1.98	0.12	0.89
(S) × Age × Gender	14.42	2	7.21	0.42	0.66
(S) × Age × Navaid	8.22	2	4.11	0.24	0.79

Source	SS	DF	Mean Square	F	P
(S) × Gender × Navaid	12.33	2	6.16	0.36	0.70
(S) × Age × Gender × Navaid	46.78	2	23.39	1.37	0.27
Error	546.44		17.08		
TURN (T)					
(T) × Age	23.03	1	23.03	1.64	0.22
(T) × Gender	53.38	1	53.38	3.80	0.07
(T) × Navaid	85.48	1	85.48	6.09	0.03
(T) × Age × Gender	2.08	1	2.08	0.15	0.71
(T) × Age × Navaid	16.67	1	16.67	1.19	0.29
(T) × Gender × Navaid	16.36	1	16.36	1.17	0.30
(T) × Age × Gender × Navaid	72.88	1	72.88	5.19	0.04
Error	224.63		14.04		
WINDOW (W)					
(W) × Age	40.44	2	20.22	1.5	0.24
(W) × Gender	96.29	2	48.15	3.57	0.04
(W) × Navaid	113.05	2	56.53	4.19	0.06
(W) × Age × Gender	0.40	2	0.20	0.01	0.99
(W) × Age × Navaid	29.80	2	14.9	1.10	0.34
(W) × Gender × Navaid	56.09	2	28.05	2.08	0.14
(W) × Age × Gender × Navaid	120.20	2	60.10	4.45	0.02
Error	431.75		13.49		
SCENARIO X TURN (S x T)					
(S × T) × Age	3.45	2	1.73	0.10	0.91
(S × T) × Gender	134.09	2	67.05	3.90	0.03
(S × T) × Navaid	6.46	2	3.23	0.19	0.83
(S × T) × Age × Gender	5.33	2	2.66	0.15	0.86

Source	SS	DF	Mean Square	F	P
(S × T) × Age × Navaid	2.63	2	1.31	0.08	0.93
(S × T) × Gender × Navaid	12.91	2	6.45	0.38	0.69
(S × T) × Age × Gender × Navaid	16.13	2	8.07	0.47	0.63
Error	550.78		17.21		
SCENARIO X WINDOW (S x W)					
(S × W) × Age	31.48	4	7.87	0.48	0.75
(S × W) × Gender	283.57	4	70.89	4.28	0.004
(S × W) × Navaid	11.32	4	2.83	0.17	0.95
(S × W) × Age × Gender	4.48	4	1.12	0.07	0.99
(S × W) × Age × Navaid	17.31	4	4.33	0.26	0.90
(S × W) × Gender × Navaid	27.01	4	6.75	0.41	0.80
(S × W) × Age × Gender × Navaid	46.43	4	11.61	0.70	0.59
Error	1059.74		16.56		
TURN X WINDOW (T x W)					
(T × W) × Age	47.61	2	23.81	1.67	0.20
(T × W) × Gender	95.18	2	47.59	3.34	0.05
(T × W) × Navaid	119.65	2	59.83	4.19	0.02
(T × W) × Age × Gender	3.61	2	1.81	0.13	0.88
(T × W) × Age × Navaid	37.66	2	18.83	1.32	0.28
(T × W) × Gender × Navaid	81.74	2	40.87	2.86	0.07
(T × W) × Age × Gender × Navaid	115.84	2	57.92	4.06	0.03
Error	456.53		14.267		

Source	SS	DF	Mean Square	F	P
SCENARIO X TURN X WINDOW (S x T x W)					
(S ×T ×W) × Age	24.81	4	6.20	0.37	0.83
(S ×T ×W) × Gender	249.35	4	62.34	3.69	0.01
(S ×T ×W) × Navaid	8.45	4	2.11	0.13	0.97
(S ×T ×W) × Age × Gender	1.25	4	0.31	0.02	1.00
(S ×T ×W) × Age × Navaid	17.3	4	4.32	0.26	0.90
(S ×T ×W) × Gender × Navaid	21.52	4	5.38	0.32	0.86
(S ×T ×W) × Age × Gender × Navaid	42.82	4	10.71	0.63	0.64
Error	1080.37		16.88		

Table 13. Standard deviation of velocity.

Source	SS	DF	Mean Square	F	P
OBSERVATION					
Age	21.45	1	21.45	3.11	0.10
Gender	5.73	1	5.73	0.83	0.38
Navaid	0.67	1	0.67	0.10	0.76
Age × Gender	2.74	1	2.74	0.40	0.54
Age × Navaid	6.05	1	6.05	0.88	0.36
Gender × Navaid	1.17	1	1.17	0.17	0.69
Age × Gender × Navaid	0.005	1	0.005	0.00	0.98
Error	110.48		6.90		
SCENARIO (S)					
(S) × Age	2.40	2	1.20	0.59	0.56
(S) × Gender	0.46	2	0.23	0.11	0.89
(S) × Navaid	4.12	2	2.06	1.01	0.37

Source	SS	DF	Mean Square	F	P
(S) × Age × Gender	0.76	2	0.38	0.19	0.83
(S) × Age × Navaid	15.21	2	7.60	3.73	0.03
(S) × Gender × Navaid	1.01	2	0.51	0.25	0.78
(S) × Age × Gender × Navaid	0.65	2	0.32	0.16	0.85
Error	65.15		2.04		
TURN (T)					
(T) × Age	1.19	1	1.19	0.88	0.36
(T) × Gender	0.84	1	0.84	0.63	0.44
(T) × Navaid	2.42	1	2.42	1.80	0.20
(T) × Age × Gender	2.51	1	2.51	1.87	0.19
(T) × Age × Navaid	0.62	1	0.62	0.46	0.51
(T) × Gender × Navaid	2.09	1	2.09	1.56	0.23
(T) × Age × Gender × Navaid	4.49	1	4.49	3.34	0.09
Error	21.49		1.34		
WINDOW (W)					
(W) × Age	53.83	2	26.91	10.33	0.0003
(W) × Gender	1.05	2	0.52	0.20	0.82
(W) × Navaid	7.06	2	3.53	1.36	0.27
(W) × Age × Gender	43.85	2	21.92	8.42	0.0012
(W) × Age × Navaid	0.88	2	0.44	0.17	0.84
(W) × Gender × Navaid	1.25	2	0.62	0.24	0.79
(W) × Age × Gender × Navaid	0.40	2	0.20	0.08	0.93
Error	83.35		2.60		
SCENARIO X TURN (S x T)					
(S × T) × Age	4.18	2	2.09	2.31	0.12
(S × T) × Gender	2.89	2	1.44	1.60	0.22
(S × T) × Navaid	0.01	2	0.005	0.01	0.99

Source	SS	DF	Mean Square	F	P
(S × T) × Age × Gender	0.96	2	0.48	0.53	0.59
(S × T) × Age × Navaid	0.37	2	0.18	0.20	0.82
(S × T) × Gender × Navaid	0.36	2	0.18	0.20	0.82
(S × T) × Age × Gender × Navaid	0.75	2	0.37	0.41	0.66
Error	28.89		0.90		
SCENARIO X WINDOW (S x W)					
(S × W) × Age	12.14	4	3.03	2.29	0.07
(S × W) × Gender	2.56	4	0.64	0.48	0.75
(S × W) × Navaid	5.64	4	1.41	1.06	0.38
(S × W) × Age × Gender	35.95	4	8.99	6.78	0.0001
(S × W) × Age × Navaid	4.90	4	1.22	0.92	0.46
(S × W) × Gender × Navaid	2.64	4	0.66	0.50	0.74
(S × W) × Age × Gender × Navaid	0.40	4	0.10	0.08	0.99
Error	84.85		1.33		
TURN X WINDOW (T x W)					
(T × W) × Age	58.13	2	29.07	13.36	0.0001
(T × W) × Gender	3.53	2	1.77	0.81	0.45
(T × W) × Navaid	0.11	2	0.06	0.03	0.98
(T × W) × Age × Gender	14.99	2	7.49	3.44	0.04
(T × W) × Age × Navaid	1.91	2	0.95	0.44	0.65
(T × W) × Gender × Navaid	1.58	2	0.79	0.36	0.70
(T × W) × Age × Gender × Navaid	0.98	2	0.49	0.23	0.80
Error	69.61		2.18		

Source	SS	DF	Mean Square	F	P
SCENARIO X TURN X WINDOW (S x T x W)					
(S ×T ×W) × Age	19.07	4	4.77	3.24	0.02
(S ×T ×W) × Gender	4.59	4	1.15	0.78	0.54
(S ×T ×W) × Navaid	8.64	4	2.16	1.47	0.22
(S ×T ×W) × Age × Gender	18.75	4	4.69	3.18	0.02
(S ×T ×W) × Age × Navaid	11.34	4	2.83	1.92	0.12
(S ×T ×W) × Gender × Navaid	3.99	4	1.0	0.68	0.61
(S ×T ×W) × Age × Gender × Navaid	3.76	4	0.94	0.64	0.64
Error	94.29		1.47		

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