Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): Human Factors Evaluation of the Effectiveness of Multi-Modality Displays in Advanced Traveler Information Systems

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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 experiment examined the design issue of which display modality (i.e. visual, auditory, or multi-modality) resulted in the best driving performance. Effects of driver age, driving load, and information complexity were evaluated.

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16. Abstract

To achieve the goals for Advanced Traveler Information Systems (ATIS), significant information will necessarily be provided to the driver. A primary ATIS design issue is the display modality (i.e. visual, auditory, or the combination) selected for providing this information. There were two objectives for this research. First, to what degree, and under which circumstances, are multi-modality displays beneficial? Second, for circumstances where multi-modality are not beneficial, which single display modality results in best performance? A simulator experiment was conducted to determine the effects of driver age, display modality, driving load, and information complexity on driving performance, navigation performance, driver workload, and driver performance.
Four primary findings from the study were that:

- For emergency response displays, the multi-modality and the auditory displays resulted in faster reaction times than the visual display for detecting warning information, while information presented on the multi-modality display resulted in fewer errors than the auditory display.
- For navigation tasks, the multi-modality display resulted in the best performance for both total correct turns and number of navigation-related errors.
- For driving performance, the multi-modality display generally resulted in better performance for both speed maintenance and safe driving behavior.
- For subjective workload and preference ratings, the multi-modality display and the auditory display received more preferable ratings than did the visual display.

17. Key Words
Advanced Traveler Information Systems (ATIS), Intelligent Transportation Systems (ITS), driver age, information complexity, driving load

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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

Symbol	When You Know	Multiply By	To Find	Symbol
		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
ATMS . . . . Advanced Traffic Management Systems
AVCS . . . . Advanced Vehicle Control Systems
CVO . . . . Commercial Vehicle Operations
GLM . . . . General Linear Model
IMSIS . . . . In-Vehicle Motorist Services Information System
ITS . . . . Intelligent Transportation Systems
IVSAWS . . . . In-Vehicle Safety Advisory and Warning Systems
LCD . . . . Liquid Crystal Display
MANOVA . . . . Multivariate Analysis of Variance
SAS . . . . Statistical Analysis Software
SNK . . . . Student-Newman-Keuls
STI . . . . Systems Technology, Inc.
SWAT . . . . Subjective Workload Assessment Technique

EXECUTIVE SUMMARY

The goals for Advanced Traveler Information Systems (ATIS) are to reduce traffic congestion, reduce energy consumption, increase mobility, and increase productivity, thereby reducing air pollution and enhancing driving safety (Lee, Morgan, Wheeler, Hulse & Dingus, 1996). To reach these goals, ATIS will have to provide substantial navigation information, road and traffic information, road-side information, and personal communication to drivers to help them make correct and timely driving decisions. Previous research has investigated the acceptability of visual and auditory information, although few have examined the benefits of multi-modal displays (i.e., visual and auditory information in one display). Additionally, although much of the previous ATIS research has focused on systems that provide navigation information, few have investigated issues related to other ATIS functions such as presenting signing and warning information.

There were two objectives for this research. First, to what degree, and under which circumstances, are multi-modality displays beneficial? Second, for circumstances where multi-modality displays are not beneficial, which single display modality results in best performance? These questions were addressed in two separate steps. In the first step, the optimum candidate information items for a multi-modality display were analytically determined, and designs of the multi-modality displays for presenting the information were conceived. In the second step, a driving simulator experiment was used to test the effectiveness of multi-modality displays compared to single-modality displays — auditory or visual — for the information identified.

To determine the effectiveness of multi-modality displays, a simulator experiment was conducted that included the following independent variables:

- Driver age - younger (from age 18 to 25 years) and older (over 60 years).
- Display modality - auditory, visual, and multi-modal (both auditory and visual).
- Driving load - low and high, as defined by lane width, road type, number of sharp curves, traffic density, speed limit, and number of intersections.
- Information complexity - simple (five or fewer information units) and complex (seven or more information units).

During the course of the experiment, a number of dependent measures were collected, consisting of:

MEASURES ADDED

Driving Performance Measures

- Variance in longitudinal velocity
- Mean longitudinal velocity
- Mean absolute longitudinal velocity deviation
- Variance in lateral lane position
- Frequency of major/minor lane deviations
- Variance in steering wheel position
- Frequency of large steering reversals

Navigation Performance Measures

- Number of correct turns
- Number of near-miss turns
- Number of missed turns
- Number of wrong turns

Secondary Task Performance Measures

- Reaction time
- Miss rate

Mental Workload and Performance Measures

- Time stress
- Visual effort
- Psychological stress
- Overall workload
- Preference and acceptance ratings

The driver's task in the experiment was to drive through six simulated scenarios that crossed the two driving load conditions with the three display modality conditions. In addition to safely operating their vehicle, drivers were required to navigate through the scenarios and respond to road and vehicle condition information presented on the ATIS.

PRIMARY FINDINGS

Four primary findings were determined:

- For emergency response displays, the multi-modality and the auditory displays resulted in faster reaction times than the visual display for detecting warning information, while information presented on the multi-modality display resulted in fewer errors than the auditory display.
- For navigation tasks, the multi-modality display resulted in the best performance for both total correct turns and number of navigation-related errors.
- For driving performance, the multi-modality display generally resulted in better performance for both speed maintenance and safe driving behavior.
- For subjective workload and preference ratings, the multi-modality display and the auditory display received more preferable ratings than did the visual display.

DESIGN GUIDELINES

Based on these findings, five ATIS design guidelines are proposed:

- The ATIS information should be designed to be as simple as possible. More complex information presented on either the single- or multi-modality displays will increase the driver's workload and can result in safety-related driving performance decrements. As a guideline, five or fewer information items (consisting of simple phrases, icons, sign graphics, etc.) should be presented at one time visually, and the auditory channel should be reserved for safety or time-critical messages, or simple auditory icons devoted to informing the driver of a change in visual display status.
- If complex information is inevitable, providing a multi-modality display will lower workload and will result in better performance than presenting the information on a single-modality display. However, it is still important to limit the complexity of information on the visual display. This guideline is especially true in high driving load situations.
- Critical ATIS information that requires the driver to respond quickly and correctly should be presented on a multi-modality display.
- In designing for older drivers, a multi-modality display to present the ATIS information has the additional benefit of improving safe driving behavior.
- To avoid annoying the users, the multi-modality display information presentation should be conservative. Use simple auditory cues for non-safety-related information or to inform drivers that there is information on the visual display.

CHAPTER 1: INTRODUCTION

Problems concerning traffic mobility, safety, and energy consumption have become more serious in most developed countries in recent years. Since 1980 when the first electronic map (the ETAK) was introduced in the U.S., major car manufacturers and other firms began developing computer-based in-vehicle navigation systems. Today, most developed/developing systems around the world have included more functions (in addition to the navigation function) to help people drive their vehicles safely and efficiently.

A more advanced total systems approach, referred to as Intelligent Transportation Systems (ITS), links the vehicle, driver, highway, and traffic management center to make it possible to achieve more mobile and safer traffic conditions by using state-of-the-art electronic communication and computer-controlled technology. The basic elements of the ITS, as defined by the Mobility 2000 Group and ITS America (Mast, 1991), are: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), and Advanced Vehicle Control Systems (AVCS). In this study, the research focuses on the evaluation of ATIS technology.

PURPOSE OF THE STUDY

The goals for ATIS are to reduce traffic congestion, reduce energy consumption, increase mobility, and increase productivity, thereby reducing air pollution and enhancing driving safety (Lee et al., 1993). To reach these goals, ATIS will have to provide substantial navigation information, road and traffic information, road-side information, and personal communication to drivers to help them make correct and timely driving decisions.

Traditionally, drivers largely depend upon their visual modality for driving-related information (Rockwell, 1972). However, with an ATIS in the vehicle, drivers are required to perceive a large number of different types of information, and a system's exclusive use of the visual modality may lead to driver overload. Some manufacturers have therefore considered auditory information presentation for their ATIS. Most research has focused on either the acceptability of either the visual or auditory modalities, or compared visual information presentation with auditory information presentation. Few have addressed multi-modality information display. In addition, most research to date has focused on navigation-related information, as opposed to other ATIS functions. Therefore, the primary objective of this study was to identify effective modalities and modality combinations for the purpose of displaying multi-function ATIS information.

To achieve the objective of the study, two issues were addressed. The first issue addressed performance on each of the display modalities and examines the following questions: 1) To what degree, and under which circumstances, are multi-modality displays beneficial? 2) For circumstances where multi-modality displays are beneficial, which single display modality results in the best performance? The second issue addressed the question of age and examines if there are any significant age-related performance differences between the different displays. These issues were addressed in two separate steps. In the first step, the optimum candidate information items for a multi-modality display were analytically determined, and designs of the multi-modality displays for presenting the information were conceived. In the second step, a driving simulator experiment was used to test the effectiveness of multi-modality displays compared to single-modality displays, and to examine age-related performance differences.

CHAPTER 2: DISPLAY ANALYSIS AND DESIGN

A design for the display of visual, auditory, and multi-modality ATIS information was accomplished using available human factors guidelines, and information from previous successful designs (e.g., TravTek). The resulting designs were reviewed by several experienced human factors professionals and were tested for usability with naive subjects. These designs are described below.

The visual display location can be seen in Figure 1. The display was located in a "head-up" position mounted on the central dashboard. The display was as close to the forward/center of the driver's field of view as possible without blocking the driver's view of the forward roadway. Unlike an actual head-up display, the display was not a see-through display. Black velvet-covered cardboard was used as a bezel in the simulator cab to prevent glare and reflection. (The video camera, buttons, and labels shown in Figure 1 will be discussed in the Method section.) The following sections describe the information presented on each display.

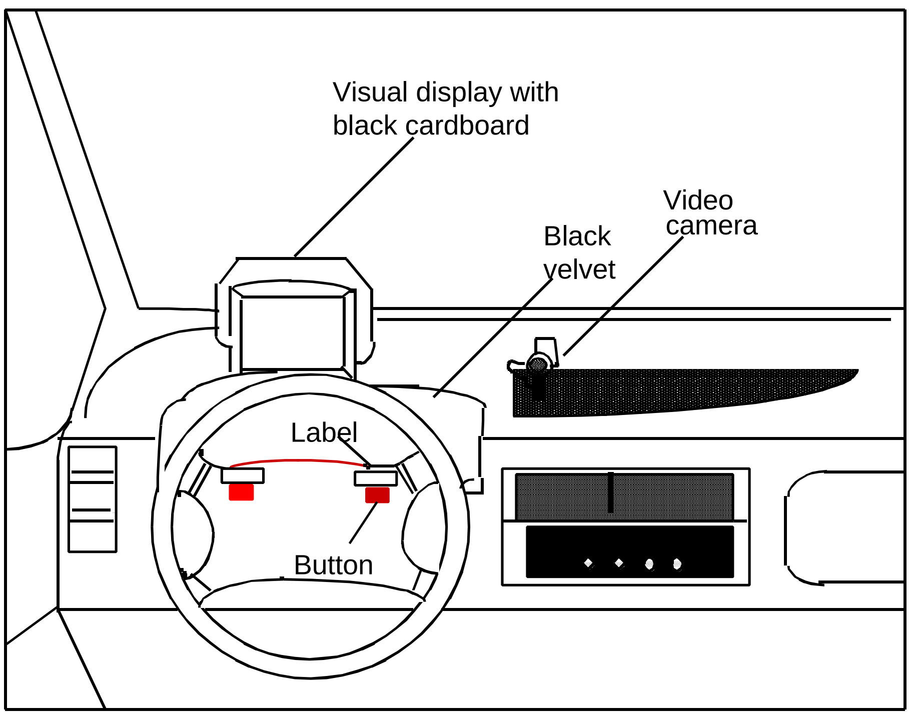

Figure 1. Interior simulator cab layout from driver's perspective.

DISPLAY INFORMATION

Standard Vehicle Information

The standard vehicle information displayed included the speedometer, turn signals, and high beam signal from the traditional dashboard display. The speedometer was always displayed on the LCD, regardless of which display modality was used (see Figure 2). The color used to display speed was white, while the turn signals and high beam signals were green and blue, respectively, as they are on a traditional dashboard.

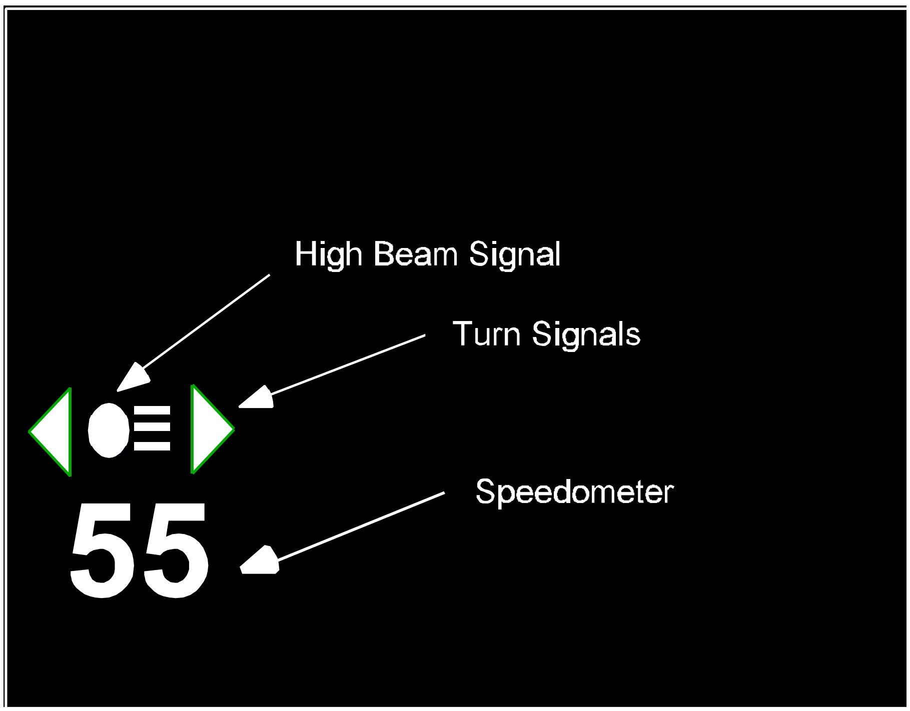

Figure 2. Visual display for standard vehicle information.

Route Guidance Information

For presentation of simple route guidance information, text directions were selected (for example, TURN NEXT RIGHT or TURN NEXT LEFT). The simple turn information appeared at specified distances before the turn and then disappeared after the vehicle completed the turn. For presentation of complex route information, a modified TravTek guidance map display format (Dingus et al., 1994) was chosen to make the navigation information format match the environment outside the car (see Figure 3). The information included a graph of an intersection, the name of the street to turn onto, the distance to the intersection, and an arrow showing which direction to turn. The distance to the next turn had two redundant display formats: one was a numerical distance in miles, and the other was a countdown in the form of a graphic bar. The graphic countdown bar included a total of six bars, and each bar disappeared (countdown) every one-sixth of the total distance to the next turn. For example, if the total distance to the next turn was 0.6 mile (3168 feet), one bar disappeared every 530 feet (0.6/6=0.1 mile = 530 feet). All six bars disappeared after the total distance to the turn had been driven.

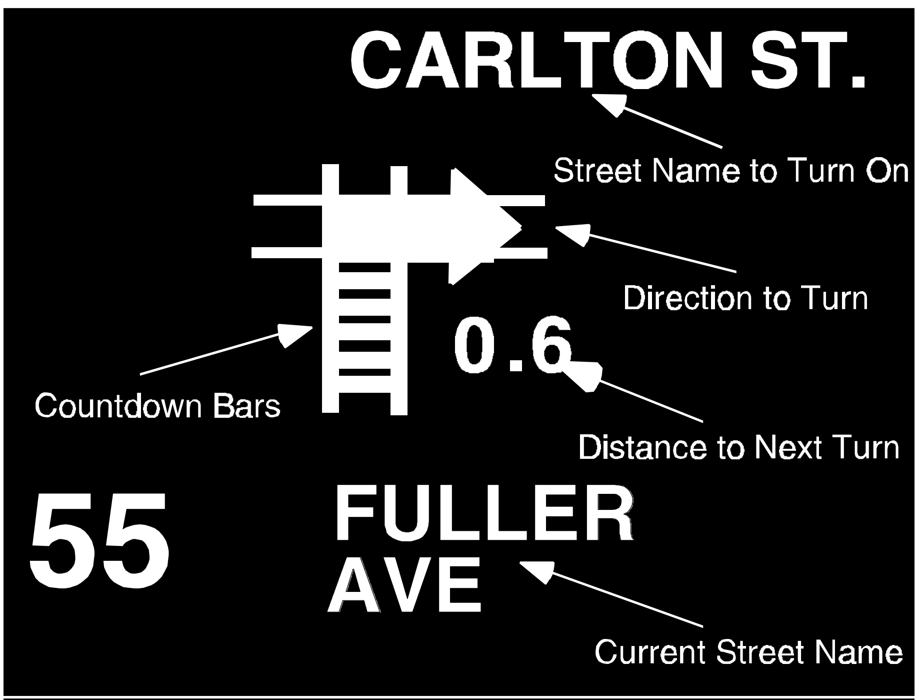

Figure 3. Visual display for complex navigation information.

Signing Information

Standard roadway icons and matching colors were used for the presentation of in-vehicle signs when available (e.g., STOP or NO RIGHT TURN signs); otherwise, text was used to present information (e.g., traffic congestion ahead). To maximize comprehension, information was modeled after actual road signs, including shapes, size, color, and content.

Vehicle Condition Monitoring Information

Because traditional vehicle condition icons used in an automobile are easily recognized by drivers (low oil pressure, low gas level, etc.), the same icons were used to inform drivers of the condition of the vehicle. To make this information both visible and representative, vehicle condition warning information was displayed in red with white background.

Road Condition Monitoring and Immediate Hazard Warning Information

Many of the information items in these categories do not have a standard iconic symbol (e.g., icy bridge, heavy fog, traffic accident ahead). Therefore, text messages were used to display the information. The color used for this text information was red. Figure 4 is an example of road condition monitoring information. The immediate hazard warning information was similar in size and color.

Figure 4. Visual display for road condition monitoring information.

Auditory Information

A human female digitized voice, with a speech rate of approximately 150 words per minute, was adopted for this system. The information content of the auditory display was equivalent to the visual display (the visual complex navigation information display excluded). The auditory display conceptual designs for each candidate subfunction are described below:

- For route guidance information, it was not feasible to express the complex visual navigation information in the auditory display due to the amount of information and the associated driver annoyance with the verbal equivalent of specific features. Therefore, the complex auditory navigation information display included only selected information in the equivalent visual display, with the route guidance map appearing first (e.g., YOU'RE ON FULLER AVE., NEXT TURN RIGHT TO CARLTON ST. IN 3500 FEET). The simple navigation information presented in the auditory display is the same as that presented in the visual display (e.g., TURN NEXT RIGHT).

- For signing information, the contents of aural messages were designed to parallel those of the visual display. A difference between the visual and auditory displays was in the speed limit information. In the visual display, the speed limit sign information was always available. In the auditory display, the speed limit information was presented to the driver at the beginning of each run and again when the speed limit changed during the run.
- For warning and condition monitoring information, the warning messages were preceded by the semantic alerting cue — WARNING. Therefore, candidate information from the three subfunctions was presented, for example, as WARNING! HEAVY FOG AHEAD, or WARNING! LOW OIL PRESSURE, etc.

Multi-Modality Displays

Some studies have recommended that an auditory prompt be provided to inform the driver that there is some change or upcoming information on the visual display, and have indicated that providing this prompt will reduce the duration of glances to the visual display (Dingus and Hulse, 1993). Other researchers recommend that a shorter auditory message be combined with a visual display for optimizing perceptual and cognitive performance (Labiale, 1990). Based on these recommendations, the visual and auditory display formats previously described were combined into multi-modality displays:

- For route guidance information in both the complex and simple information conditions, the visual portion of the multi-modality display presents the same information as the visual-only display. For the auditory portion of the multi-modality display, under complex navigation information, an auditory turn instruction was presented at the proper time in conjunction with the visual display (e.g., TURN RIGHT TO CARLTON STREET). For the complex information condition, both the auditory and visual modalities presented information redundantly (e.g., TURN NEXT RIGHT is spoken and is displayed in the text zone).
- For signing information in the simple information condition, the display format of the multi-modality display was the combination of formats used for both single-modality displays. For the complex information condition, an auditory tone was used as a prompt to inform the driver that there was updated sign information. If the incoming sign information was safety-related (e.g., SHARP RIGHT CURVE, SPEED LIMIT 40, STOP AHEAD, etc.), the auditory and visual modalities displayed that information redundantly.
- For vehicle, road condition monitoring, and hazard warning information, the multi-modality display format was always composed of the formats of the individual auditory and visual displays presented simultaneously.

Table 1 provides an overview of what the visual, auditory, and multi-modality displays consist of for each of the simple and complex conditions of the various information elements used in this study.

Table 1. Items presented in each type of display broken down by type of information.

	Visual	Auditory*	Multi-modality
Route Guidance Information	**Simple:** Text directions (e.g. "Turn next left")	**Simple:** Directions (e.g. "Turn next left")	**Simple:** Combination of visual and auditory displays
	Complex: Current street name; street name to turn on; direction to turn; distance to next turn; countdown bars	**Complex:** Selected information from visual display	**Complex:** Combination of visual and auditory displays, plus redundant auditory information just prior to turn intersection
Signing Information	**Simple:** One standard roadway icon or text	**Simple:** Content paralleled visual display, except for speed limit information	**Simple:** Combination of visual and auditory displays
	Complex: Two icons or icon and text	**Complex:** Content paralleled visual display, except for speed limit information	**Complex:** Combination of visual and auditory displays, plus auditory tone to indicate updated visual sign information
Vehicle, Road Condition, and Hazard Warning Information	Icons or text	Content paralleled visual display, preceded by "Warning!"	Combination of visual and auditory displays, plus auditory tone to indicate updated visual information

* The complex auditory condition also presented some IMSIS information

Variation of Information Complexity

Visual Information

To achieve the project goals of determining under what circumstances (if any) multi-modality displays are beneficial, it was necessary to create both simple and complex information considering both the information difference for each candidate sub-function, and the definition of the information complexity for the integrated visual display. Operationally, a complex visual display was defined as having more than seven information units, while the simple information condition is defined as having fewer than four information units. A single information unit was defined as the name of a geographic entity, a type of road, a position, or a direction. An example of a simple visual display used in this study is depicted in Figure 5. Figure 6 shows a typical complex visual display.

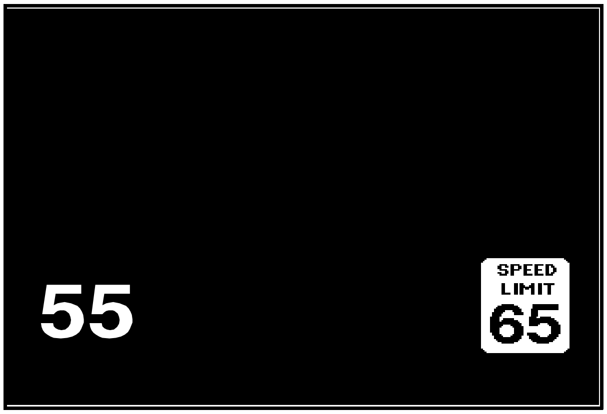

Figure 5. A simple visual display with two information elements: speedometer and speed limit.

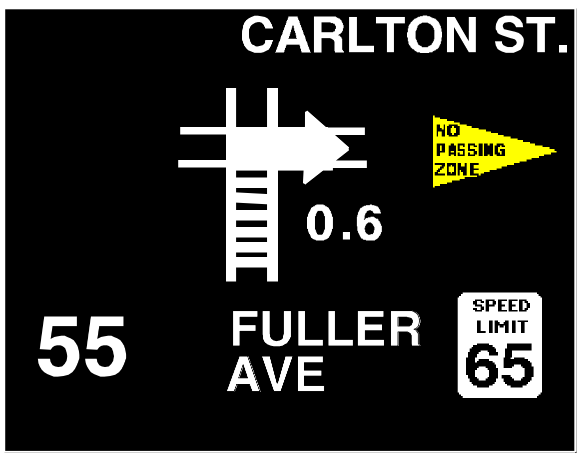

Figure 6. A complex visual display with eight information elements: street name to turn on, direction to turn, roadway sign, countdown bars, distance to next turn, speedometer, current street name, and speed limit.

<u>Auditory Information</u>

As stated in the previous section, with a few exceptions relating to complex information situations, most of the information displayed on the auditory channel was equivalent to that displayed on the visual display. However, due to the characteristics of presenting information serially on an auditory display, the definition of information complexity for the auditory display differs from the definition for the visual display. The difference between the simple and complex auditory displays as defined here is essentially the number of individual information units presented to drivers. Complex auditory displays presented more information units, which essentially translated to the frequency with which information units were transmitted. In the simple condition, on average one information unit was presented about every 20 seconds. In the complex condition, information units were presented about every 5-8 seconds throughout the drive.

In the simple auditory display condition, only safety-related information associated with driving to a destination was presented to the drivers. For the complex situation, some IMSIS information (e.g., HISTORICAL CENTER NEXT RIGHT) or non-destination-related information was presented (e.g., INTERSTATE 70 NEXT LEFT) in addition to safety information. In both conditions, speedometer information was always present on the LCD display.

Multi-Modality Displays

The prototype multi-modality display for simple information was simply the combination of both single modality displays. For the complex information situation, the visual component of the multi-modality display used the same format as that of the visual modality display. Auditory information was also presented redundantly with the visual component for safety-related and driving-to-destination-related information. For route guidance information, the auditory component provided redundant turn information just prior to a turn intersection. For the other conditions, a “chime” sound was used as an auditory cue to inform drivers that an update had occurred on the visual display.

CHAPTER 3: METHOD

EXPERIMENTAL DESIGN

The experimental design was a 2 x 3 x 2 x 2 mixed-factor, full factorial design. The independent variables were age (between subject), display modality (within subject), driving load (within subject), and information complexity (within subject), respectively. Drivers were also evenly divided by gender. Drivers were randomly assigned to treatment conditions (see Appendix E).

Independent Variables

The independent variables for this study were age group, display modality, driving load, and information complexity. Each is described below:

Age Group

Two age groups were represented: younger (from age 18 to 25) and older (over 60).

Display Modality

The modalities tested were auditory, visual, and multi-modal (auditory and visual).

Driving Load

The driving tasks were performed under two driving loads for each display modality. The load factors included lane width, road type, number of sharp curves, traffic density, speed limit, and number of intersections. The load factors were selected based on previous research findings (Wierwille et al., 1977; Dingus et al., 1989; Noy 1989; Walker et al., 1991; Dingus et al., 1994) and modified for feasibility with the STI simulation. The conditions are described in Table 2.

Table 2. Two levels of driving load.

Driving Load Factor	Driving Load Level	
	Low	High
Lane width	12 ft	11 ft
Road type	Straight multi-lane road	Curvy two-way road
Number of easy curves	None	6
Number of sharp curves	2	4
Degree of easy curve	—	3100 m (radius)
Degree of sharp curve	310 m (radius)	1500 m (radius)
Speed limit	45 mph in general	60 mph in general
Traffic density*	Light	Heavy
Number of intersections	17 on average	50 on average

*According to the definition of TravTek (Dingus et al., 1994):
Light — No other cars traveling in the same direction within approximately 10 car lengths, either laterally, longitudinally, or both.
Heavy — More than two other cars within 10 car lengths.

Information Complexity

Information complexity had two levels, simple and complex. According to Labiale (1990), an information unit is defined as the name of a geographic entity, a type of road, a position, or a direction. For the visual display, the simple information condition contained no more than five information units, and the complex information condition never contained fewer than seven information units.

The auditory display, as previously described, was manipulated by varying the frequency of presentation of the information units. The frequency for the complex condition was approximately two and one-half times higher than that of the simple auditory display condition (message every 5-8 seconds vs. every 20 seconds).

Dependent Variables

Dependent variables included both objective and subjective measures. The objective measures included driving performance, navigation performance, and secondary task performance. The subjective measures included workload assessment and post-test questionnaires filled out by the drivers. The questionnaires addressed measures of acceptance, preference, and annoyance. Detailed descriptions follow.

Driving Performance Measures

Eight variables were used to evaluate drivers' driving performance. Each variable was calculated from the raw data set saved by the Systems Technology, Inc. (STI) simulator computers. These variables are described below:

- *Variance in longitudinal velocity, mean longitudinal velocity, and mean absolute longitudinal velocity deviation*. Drivers were required to maintain their vehicle speed, following the current speed limit as closely as possible. Increased variance in velocity reflects increased driving difficulty. The mean absolute deviation from the speed limit was another measure for determining performance in this speed maintenance task. Larger differences indicate that the driver was either unaware of the speed limit presented on the displays, had difficulty in maintaining the speed requirement due to secondary task demands, or both. Monty (1984) found speed maintenance to be a sensitive index in measuring the amount of attention demanded by secondary tasks. In addition to the research described above, average vehicle speed is a face-valid measure of task demands. Previous research (Antin et al., 1990) has shown that drivers adapt to increasing task demands by modifying their behavior and driving more "cautiously." One way this modification was exhibited was as a decrease in vehicle velocity with increasing task demand.
- *Variance in lateral lane position and frequency of major/minor lane deviations*. The lateral lane position is the position of the vehicle center with respect to the center of the lane. A major lane deviation was defined as any part of the vehicle exceeding either the central line or the roadside lane boundary by more than half of the vehicle width (greater than three feet). If the size of the deviation was less than half of the vehicle (less than three feet), it was considered a minor lane deviation. Unplanned lane deviations provide a valuable face-valid measure of driving task interference resulting in performance degradation. Both the frequency and variance in lane position were measured. Increases in either measure indicate a degradation in driving performance.
- *Variance in steering wheel position and the frequency of large steering reversals*. Research has shown that changes in driver steering behavior occur with changes in driver attention (MacDonald and Hoffman, 1980). In normal, low-attention circumstances, drivers make continuous, smaller steering corrections to correct for roadway variance and driving conditions. These corrections are typically within the range of two to six degrees. As attention or workload demands increase, steering corrections tend 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. This results in a larger steering variance calculation. These larger steering inputs also generally exceed six to twelve degrees and are referred to as large steering reversals. In this study, the steering wheel input to the STI simulator was calculated as the frequency of large steering reversals that exceeded 10 degrees.

Navigation Performance Measures

The navigation performance data was collected using a check sheet for each turn, which was marked by its turn direction and turn street name. Due to the limitation of the STI simulator, drivers did not actually make the turns. However, in addition to simulating normal turn behavior (slowing down), drivers also needed to respond verbally as to which direction and onto what street they were turning. Four variables were marked by the experimenter and used as navigation measures; their definitions are given below:

- *Number of correct turns*. A correct turn was counted only if drivers followed the turn instructions previously mentioned. The number of correct turns is a content-valid measure of the driver's ability to perform the navigation task under different conditions.
- *Number of near-misses*. Drivers who did not slow their vehicle when approaching the turn, but did respond verbally and correctly, and drivers who drove through the turn street and then remarked that they had just missed a turn (and identified the turn correctly) were counted as having a "near miss."
- *Number of missed turns*. If, both before and after the turn intersection, there was no behavioral or verbal response from the driver, then the incident was classified as a missed turn.
- *Number of wrong turns.* A wrong turn occurred when a driver made a wrong verbal response (either by indicating the wrong turn direction, or by giving the wrong street name).

Secondary Task Performance Measures

Drivers were periodically presented with information to which they were asked to respond. This information consisted of either vehicle status or In-Vehicle Signaling and Warning System (IVSAWS) messages that would normally require a slow down or a stop while driving. Two labeled buttons ("ROAD CONDITION" and "VEHICLE CONDITION") were located on the steering wheel for the purpose of obtaining reaction time and miss rate measures for the subject responses. Subjects were instructed to depress the pushbutton, as quickly as possible, that indicated the type of information presented. The response data were automatically saved by the visual display control computer:

- *Reaction time*. The time that elapsed between the presentation of information on the display and a driver's appropriate response to a given situation (pushing the correct button) was recorded as the reaction time to the task. In performing this task, drivers were not only required to detect the information quickly, but they were also required to identify and respond to it quickly and correctly. The inference is that the shorter the reaction time, the better the modality in informing drivers of urgent information.
- *Miss rate*. In addition to the reaction time measures, the miss rate is also important. Larger miss frequencies indicate that the display modality resulted in difficulty detecting the presented information.

Mental Workload and Preference Measures

A modified version of the Subjective Workload Assessment Technique (SWAT) (Reid and Nygren, 1988; Reid, Eggemeier, and Nygren, 1982) was used to assess the mental workload demand placed on the driver by the driving and secondary tasks. A SWAT check sheet was used to allow the experimenter to mark the ratings. The modified technique was used to collect subjective ratings at the middle (at the border of changing the information complexity) and end of each experimental scenario. The subjective scale used required the driver to rate three dimensions of driving workload (visual effort, time stress, and psychological stress) as high, moderate, or low.

Subjective workload measures were obtained by asking drivers to rate their level of effort in performing the driving task. In this context, effort referred to mental, not physical, effort. Subjective measures of workload were 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.

The three workload dimensions—time stress, visual effort, and psychological stress—are operationally defined below:

- *Time stress*. Time stress was defined in terms of the amount of time available for completion of the driving and navigation tasks. A low rating indicated that there was time to spare—time that could be used for carrying on a conversation or tuning the radio. A moderate rating indicated that there was just enough time to accomplish the driving and navigation tasks. It was suggested that with moderate time stress, the driver would avoid such distractions as conversation. A high rating indicated that there was insufficient time to fully attend to driving and navigating. Examples provided for high time stress were ignoring scanning for the next street on which to turn, or ignoring a system message indicating an upcoming turn.
- *Visual effort*. Visual effort was defined in terms of the amount of visual scanning required. An example of low visual workload was feeling comfortable looking about at objects in the simulation scenery. It was further suggested that under moderate visual effort, the 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*. 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 crash or when totally lost and confused about how to get home.
- *Overall workload*. This measure was the combination of all three subjective workload ratings and allows an overall workload assessment under different conditions.

Post-Test Questionnaire

A questionnaire was given to each driver after completion of the driving scenarios. Drivers answered seven questions based on their experiences during the experiment. These questions were designed to determine driver preferences by comparing the three display modalities used to present different information types (route guidance information, road sign information, hazard warning information, vehicle condition information) under different driving load conditions (low driving load, high driving load).

SCENARIO DESCRIPTIONS

The driving scenarios for this experiment were developed using the STI scenario language. The road environments manipulated in this study were based on the considerations of different driving loads. Street names were randomly selected from a city map of Philadelphia to assure that drivers would not be familiar with any routes they were asked to drive.

The basic visual scene created by the STI simulator consisted of a blue sky with two to three mountains in the far horizontal line and the roadway (represented by dark ash gray) divided by a yellow central line, surrounded by green grass cover. A few trees appeared on the left and right sides. In the visual scenes, only street signs appeared on the roadside (see Figure 7).

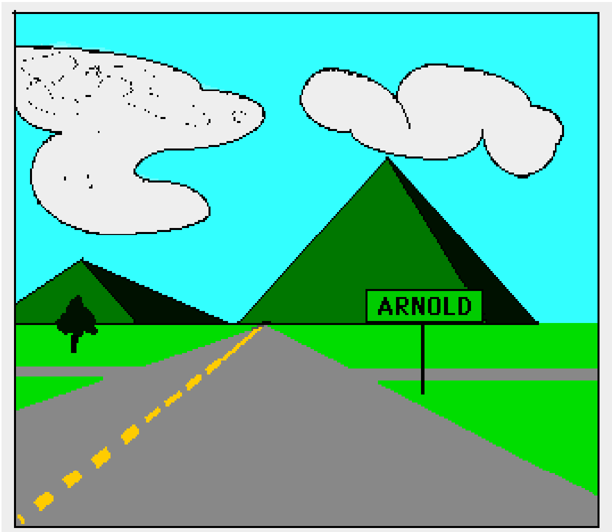

Figure 7. Sketch of the basic visual scenes.

For each display modality, there were two different scenarios, one for the low driving load and the other for the high driving load. Therefore, a total of six different scenarios were developed for the three display modalities.

The driving distance for each low driving load scenario was approximately three miles in length, and for each high driving load scenario, the driving distance was approximately five miles in length. As an example, Appendix D describes one of the scenario maps in detail.

The sequence of the simple and complex information conditions presented for each driving load were counterbalanced to minimize the presence of order effects. The sequences for the three display modalities are shown in Table 3.

Table 3. The sequence matrix of simple/complex information.

Driving Load	Display Modality		
	Auditory Display	Visual Display	Multi-modality
Low Driving Load	Simple, Complex	Complex, Simple	Simple, Complex
High Driving Load	Complex, Simple	Simple, Complex	Complex, Simple

SUBJECTS

Two age groups were represented: younger (from age 18 to 25) and older (over 60). Each age group consisted of 16 drivers for a total of 32 drivers. All drivers participating in this study were obtained from the Subjects' Database of the Iowa Driving Simulator, and each one passed a health screening test (which included an informal hearing test) and had normal vision or corrected to normal vision (20/40 or better, binocular, near/far field acuity). The experiment was gender balanced, although this factor was not analyzed as an independent variable due to the complexity of the model and the general lack of gender-related findings for similar studies in the past. In general, it took one and one-half hours for younger drivers to complete the study, and two hours for older drivers to complete the study. Each driver was paid at the rate of $10 per hour.

APPARATUS

This study used the STI simulator located in the Center for Computer-Aided Design at the University of Iowa. The simulator vehicle cab, a GM *Saturn*, included all normal automotive displays and controls. In addition, a programmable and adjustable liquid crystal display (LCD) mounted in the “head-up” position was used as the visual display. To simulate a passenger providing the auditory information sitting beside the driver and the car sound from the real engine position, three speakers were used to present aural sound and information. One provided auditory information and was housed in front of the passenger seat and facing the driver. A second speaker provided sound effects (e.g., engine, hard brake, crash, etc.) and was located just under the engine location of the cab. The third speaker was used to provide a “chime” sound as a feedback cue for push button tasks and was hidden just behind the LCD. Auditory information was generated using the SoundBlaster PC sound board. The ATIS stimulus materials were presented via these displays, as well as by the multi-modality display.

The Iowa STI simulator is a fixed-base, interactive driving simulator that produces computer-generated images of roadway scenes. The simulator uses three IBM 486 PCS for simulator control, scenario control, and visual display control. The simulator control computer is used for monitoring, which allows the experimenter to monitor the simulator conditions, such as the angle of steering wheel and current velocity. The scenario control computer has a high speed graphics board producing one forward channel of graphics. The graphics are projected onto a dome environment to produce 50 x 40 degree field of view. The STI system has its own scenario scripting language (STISIM, version 6.0) which allows us to develop a variety of specialized driving environments. As the driver drives the simulator through the scenario, this computer collects a variety of driving performance measures. This computer also has the ability to control the auditory information and other sound effects. The visual display control computer is responsible for presenting the information on the visual display and saving the data for push button tasks. Figure 8 shows the simulator configuration.

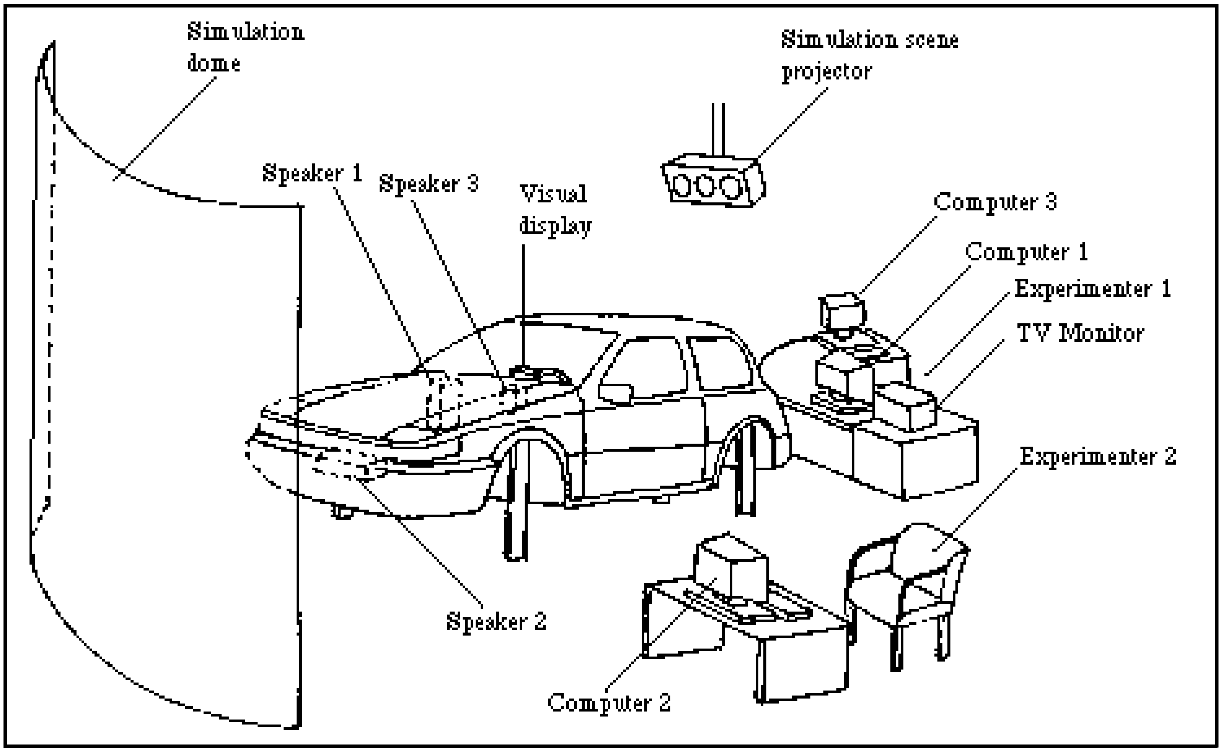

Figure 8. The STI simulator configuration and room layout.

Note:

- Speaker 1: The auditory display.
- Speaker 2: Generating the car sound.
- Speaker 3: Providing a CHIME sound for push button feedback.
- Computer 1: Scenario control.
- Computer 2: Visual display control.
- Computer 3: Simulator control
- Experimenter 1: Responsible for controlling computers 1 and 2, saving block data, and monitoring experimental conditions.
- Experimenter 2: Responsible for collecting SWAT, navigation performances, and push button task.

During each scenario, three video cameras were used to record the experimental conditions from three different angles. The first camera was located on the back seat on the driver's upper right hand side. This position allowed the camera to record the visual scenes and the push buttons located on the steering wheel. The second camera, located on the right side of the dashboard, was used to focus on the driver's face, allowing the experimenter to monitor the driver's physical condition in case of simulator sickness. The third camera focused on a small screen monitor which was connected to the LCD to record the visual display.

PROCEDURE

Before participating in the experiment, drivers were pre-screened to ensure that they possessed a current driver's license, met the age requirement, and could pass a vision and hearing test. Eligible drivers were asked to read the information summary (Appendix A), which addressed the purpose of the experiment, and then watch a 15-minute training video. The training video consisted of three sections. The first section described the three display modalities used in presenting different candidate information. Each simulated system was explained, and then any questions the drivers had were answered by the experimenter. The second section briefly depicted the six scenario scenes and the STI simulator as they would be used during the experiment. The third section explained the tasks and how to perform them. After watching the video, the three dimensions of the SWAT workload scale were explained. A description of the push button tasks was then read to the drivers. Finally, the drivers signed an informed consent form (Appendix B) and proceeded to the simulator room. In order to avoid bias towards one of the three displays, the project title shown in all documentation was labeled as "Human Factors Evaluation of Three Different Display Modalities."

At this point, the drivers began a practice drive. The experimenter informed the drivers that, once they felt comfortable in the car, their first priority was to drive the simulator as if under normal driving circumstances. A four-mile practice scenario was conducted to allow drivers to become familiar with the simulator controls and display modalities. Three display modalities separated the practice scenario into three sessions, each using one display. While driving the practice course, drivers were trained to use the different displays.

Each practice session consisted of straight and curvy road types. Navigation and push button tasks were also included. The practice scenario was designed to expose the drivers to the simulator and to help determine whether they could control the simulator reasonably well. The practice course continued until the drivers drove and performed selected tasks without error. At the end of the practice session, a practice SWAT workload evaluation was performed to ensure that the drivers understood the workload scale definitions.

After completion of the practice course, data collection began. For each scenario, drivers were instructed to gather information from the display and respond appropriately and quickly. Drivers performed specific tasks over six driving scenarios. These were:

- Driving task: All drivers were requested to drive as they usually do (i.e., to stay in the correct lane, and follow all traffic rules [signing information] and route guidance directions shown on the displays).
- Navigation task: There were a total of eight turns for each display modality (four turns for each scenario). For each turn, because the STI cannot actually make the turn, drivers were instructed to prepare for that turn (e.g., slow down as they approached the turn street) and verbally tell the experimenter which direction they would turn. The experimenter would inform drivers to continue driving straight.

! Push button task: Two back-lit red buttons were mounted on the steering wheel. A corresponding text label (ROAD CONDITION and VEHICLE CONDITION) was attached beside each button (refer to Figure 1). While driving through the scenario, drivers were instructed to detect, identify, and respond to the appropriate information by pushing the corresponding button on the steering wheel as quickly as possible. After pushing the button, a "chime" sound was provided to the drivers as feedback to inform them that the button had been pushed.

The push button task included both the detection and identification of vehicle or roadway condition (e.g., high engine temperature, traffic accident ahead), and depressing the correct push button. Table 4 lists the information used in the push button task.

Table 4. Information used in the push button tasks.

Vehicle Condition-Related	Road Environment-Related
High Engine Temperature	Road Construction 1000 ft Ahead
Low Tire Pressure	Traffic Accident Ahead
Low Gas Level	Heavy Fog Ahead
Low Oil Pressure	Icy Bridge Ahead
	Slippery Road Ahead

Two of the information items, the "Road Construction 1000 ft Ahead" and the "Traffic Accident Ahead," were used in conjunction with the scenario scenes. One-thousand feet before the drivers were to encounter these two potential road hazards, the hazard information was presented on the displays. The information remained on the visual display for approximately 1000 feet. These two information items appeared one time for each information complexity condition, in a random order.

The other information items were presented on the visual display for approximately three seconds (200 feet for the low driving load, and 300 feet for the high driving load). The elapsed time between the presentation of the information and the driver's response was recorded as the reaction time for this task.

There were eight push button tasks for each scenario condition, with four related to the vehicle condition information and the other four related to the road environment (the road construction and traffic accident were always included). The presentation was also balanced for each driving load and information complexity.

A short break was taken, if desired by the subject, after each scenario trial. At the end of the last trial, drivers exited the simulator and completed a post-test questionnaire to rate their preference and acceptance of the three display modalities.

CHAPTER 4: RESULTS

The data obtained from this study were separated into five data sets according to the different measures associated with driving performance, navigation performance, secondary task performance, subjective workload, and acceptance/preference. Two general statistical analysis methods were involved in this study:

- Descriptive Statistics: Descriptive statistics were used to measure the central tendency (mean), and to generate various distributions and graphics as appropriate for performance variables. Most of the variables related to navigation tasks and push button tasks were frequency counts (e.g., the number of correct turns, missed button-pushes). For these situations, sums of occurrences were reported.
- Inferential Statistics: Inferential statistics were used to perform the univariate analyses of variance (ANOVA) and the Student-Newman-Keuls (SNK) for post-hoc comparisons. ANOVAs were conducted utilizing two Statistical Analysis Software (SAS) procedures: the PROC ANOVA when data cells were balanced, and the PROC GLM (General Linear Model) when the data cells were unbalanced (Littell, Freund, & Spector, 1991). Examples of unbalanced cells were the driving performance data set and the reaction time data set. Multivariate-ANOVAs (MANOVAs) were not performed because they often exhibit an increase in type II error for repeated measure 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 several of the performance measures collected.

The SNK post hoc test was selected ($\alpha = 0.05$) because this method risks a type-I error with probability α for each null hypothesis that is tested, and thus provides a high degree of protection for the entire null hypothesis. In addition, when an interaction involving at least two treatments is significant, we know that some contrast for one treatment is different at two or more levels of the other treatments. Such interactions are called treatment-contrast interactions to distinguish them from omnibus interactions. In order to obtain better understanding of the interactions, instead of using the tests of simple effects, the tests of treatment-contrast and contrast-contrast interactions were chosen. This is because the latter approach can provide useful insights into the nature and sources of non-additivity in data (Kirk, 1982, pp. 365-379). This post hoc method was used to provide more useful information to the system designer. Therefore, from the system designer's point of view, the treatment-contrast interaction was tested under certain conditions to determine, for example, if there were any performance differences in using the three displays under the simple information condition. Complete ANOVA tables are shown in Appendix F.

SECONDARY TASK RESULTS

Reaction Time

There were eight push button tasks for each of six scenarios for a total of 48 push button tasks (four for each information complexity condition and sixteen for each display modality). The reaction time for pushing a button was the time that elapsed between the presentation of information on the display and the time the driver responded to a given situation by pressing one of the steering wheel buttons. The ANOVA Table for reaction time is listed in Appendix F, Table 8. Two three-factor interactions were significant: Age x Modality x Complexity [$F(2,60)=4.08$, $p=0.0218$], and the Modality x Load x Complexity [$F(2,58)=3.78$, $p=0.0285$]. These are depicted in Figures 9 and 10, respectively.

In Figure 9, the trend shown is that older drivers had slower reaction times than younger drivers. The most critical differences between younger and older drivers occurred while using the visual display. For older drivers, reaction time increased significantly for the visual display condition, especially under the complex information condition.

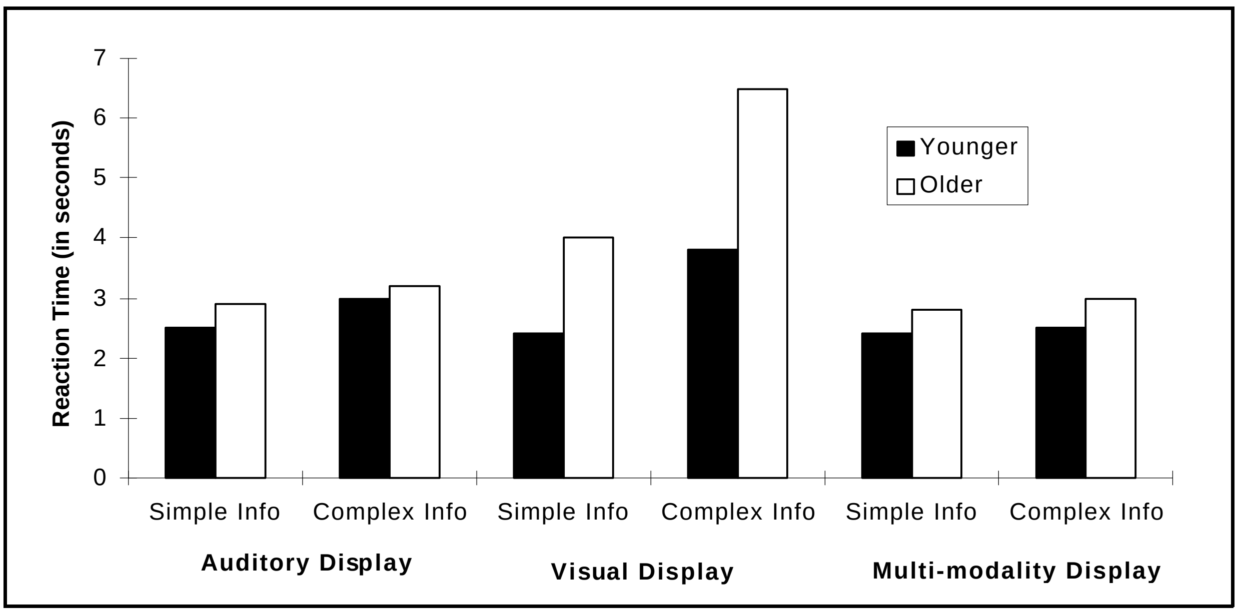

Figure 9. Reaction time for different display modalities broken down by information complexity and age group.

Figure 10 shows a similar trend for the three displays when the simple and complex information conditions were compared under different driving load conditions. Drivers tended to have slower reaction times when performing the push button tasks under the complex information condition. The complex information presented on the visual display resulted in a slower reaction time than was present with the other two display modalities. Under the low driving load condition, presenting complex information on the visual display caused the slowest reaction time. This may be due to decreased vigilance during the low driving load condition.

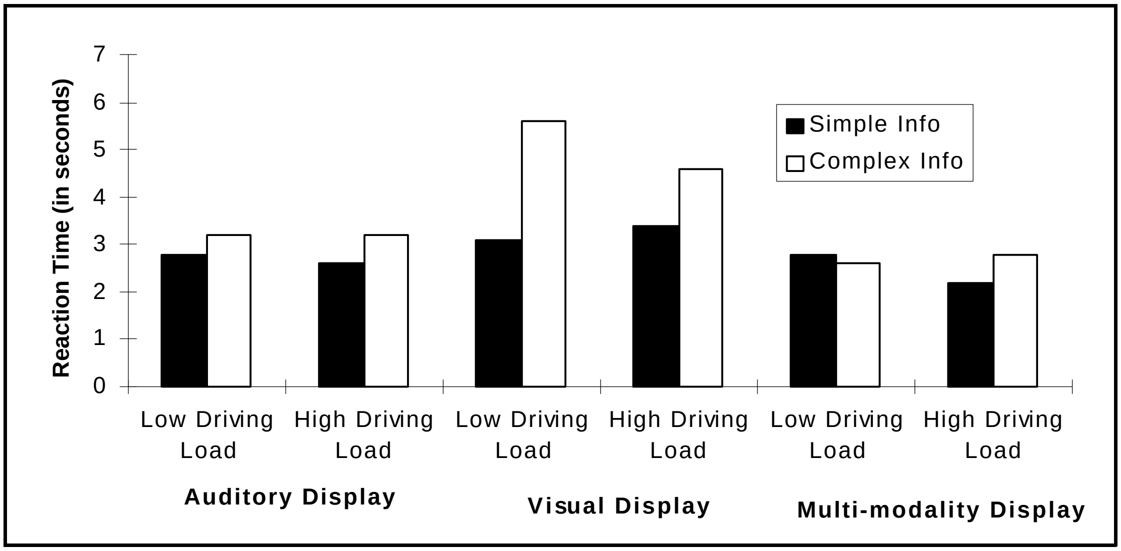

Figure 10. Reaction time for different display modalities broken down by driving load and information complexity.

There were two significant two-factor interactions. The Modality x Complexity interaction [F(2,60)=14.61, p=0.0001] is shown in Figure 11. The visual display resulted in the slowest reaction time for both levels of information complexity. The treatment-contrast tests showed that under the simple information condition, there were no significant differences among the three display modalities. For the complex information condition, drivers had faster reaction times when using either the auditory or multi-modality displays as compared to the visual display [F(1,186)=22.29, p= 0.0001 for Auditory vs. Visual; F(1,186)=35.02, p= 0.0001 for Visual vs. Multi-modality]. There was no significant difference when comparing the performance between the auditory display and the multi-modality display.

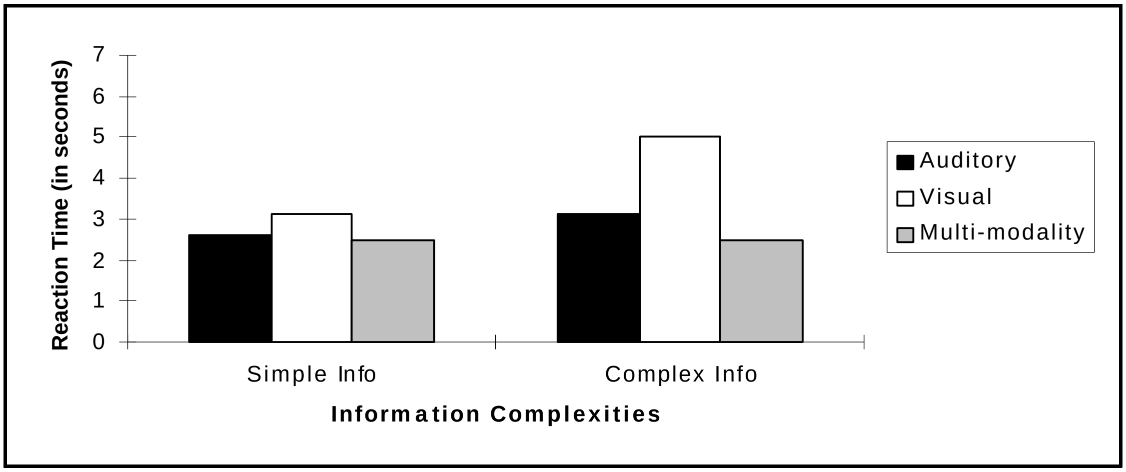

Figure 11. Reaction time for different display modalities under different information complexities.

Figure 12 shows the significant interaction of Age x Modality [F(2,60)=9.87, p=0.0002]. On average, the older group exhibited a slower reaction time (3.8 seconds) than the younger group (2.7 seconds). Treatment contrasts revealed no significant performance differences for the younger group between the three different displays. For the older group, the reaction time while using the visual display was found to be slower than while using the other two displays [F(1,90)=27.66, p= 0.0001 for the Auditory vs. Visual; F(1,90)=32.88, p= 0.0001 for the Visual vs. Multi-modality]. There was no significant difference between the auditory display and the multi-modality display task response times for the older drivers [F<1].

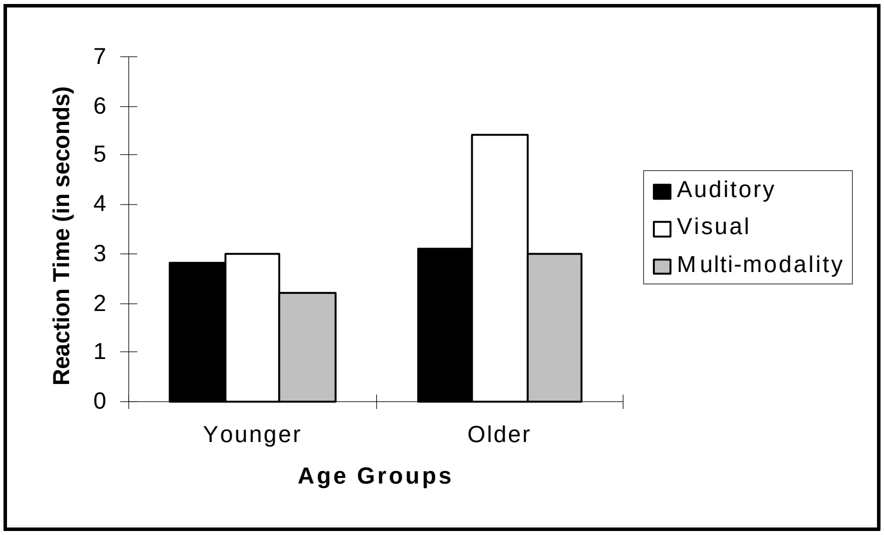

Figure 12. Reaction time for different display modalities under different age groups.

There were three significant main effects. As expected, older drivers had slower response times than younger drivers [F(1,30)=12.64, p=0.0013]. Also as expected, drivers in the complex information condition had slower reaction times than drivers in the simple information condition [F(1,30)=26.20, p=0.0001]. There was also a main effect of Modality [F(2,60)=18.82, p=0.0001]. Figure 13 shows the mean reaction time for each display. Differing letters in the Figure indicate statistical differences from the SNK post-hoc test at the $p<0.05$ level. Statistical analysis showed that the visual display resulted in significantly slower reaction time than the auditory or multi-modality display. There was no significant difference between the auditory display and the multi-modality display.

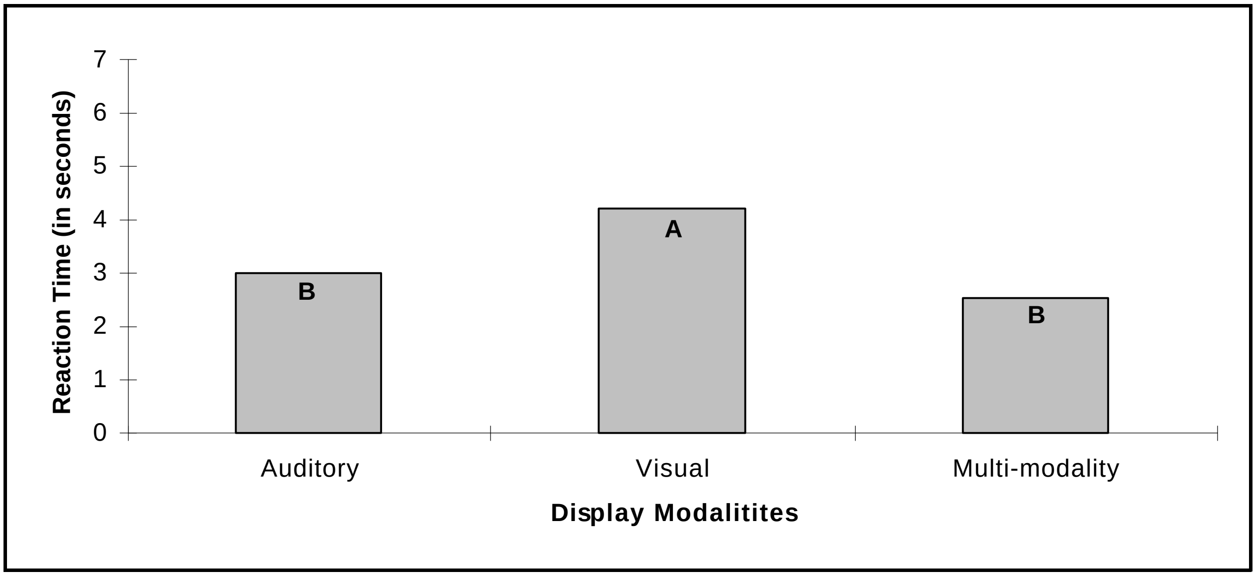

Figure 13. Reaction time for different display modalities.

Number of Missed Button Pushes

The second variable analyzed for the secondary tasks was the number of times the driver missed pushing the button in response to a stimulus. The number of misses when pushing buttons indicates, to some extent, which display modality presented warning information in a manner that was difficult to notice or detect. ANOVA results are listed in Appendix F, Table 9.

Figures 14, 15, and 16 show the three significant three-factor interactions, which are Age x Modality x Load [F(2,60)=5.54, p=0.0062], Age x Load x Complexity [F(1,30)=8.65, p=0.0063], and Modality x Load x Complexity [F(2,60)=20.67, p=0.0001], respectively. In Figure 14, three results can be found. Overall, the auditory display under the high driving load condition resulted in more misses than under the low driving load condition. The multi-modality display under both driving load conditions resulted in the fewest missed button presses for the older group. The visual display resulted in the largest number of missed button presses for older drivers. For the visual display under the low driving load condition, both the older and younger groups had the most number of missed button presses. This may have been due to the low driving workload, implying that both groups decreased their awareness in this condition. The same reasoning can also be applied to the younger group when using the visual display under the high driving load condition. In that condition, the younger group had a very small number of misses, implying that the higher driving workload raised their awareness of the visual display. For the older group, the higher driving workload may have made it more difficult to pay attention to the visual display, thereby increasing the number of misses.

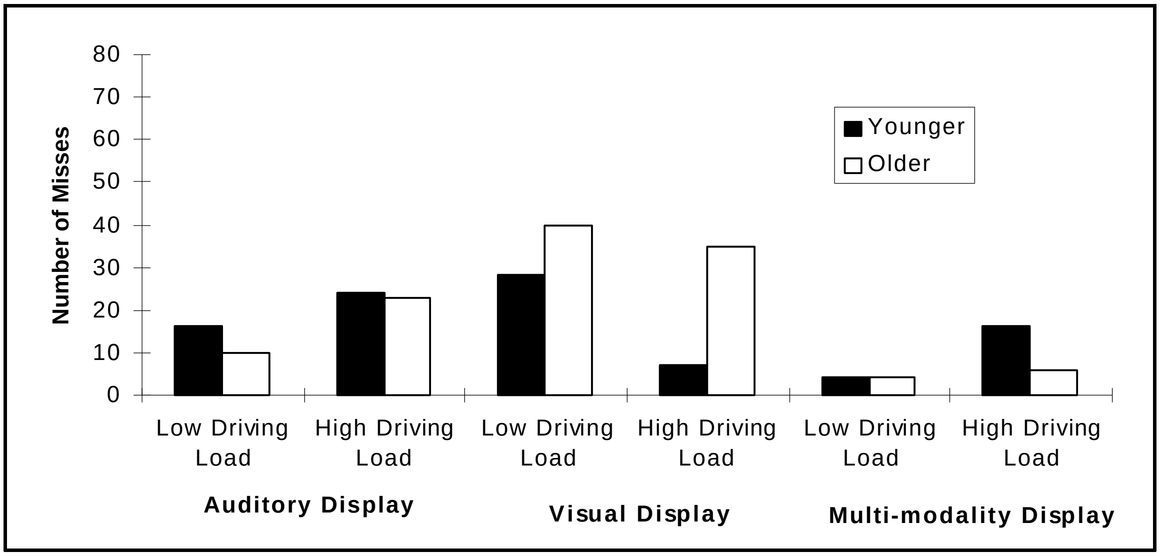

Figure 14. Total number of missed button pushes for different display modalities broken down by driving load and age group.

Figure 15 shows that, in general, the complex information condition caused more misses than the simple information condition for both the older and younger groups for each driving load condition. This Figure also reveals that the younger group missed many push button tasks under the complex information, low driving load conditions. By combining these results with those in Figure 14, we can see that a high number of misses occurred for both groups in the low driving load condition with complex information displayed on the visual display.

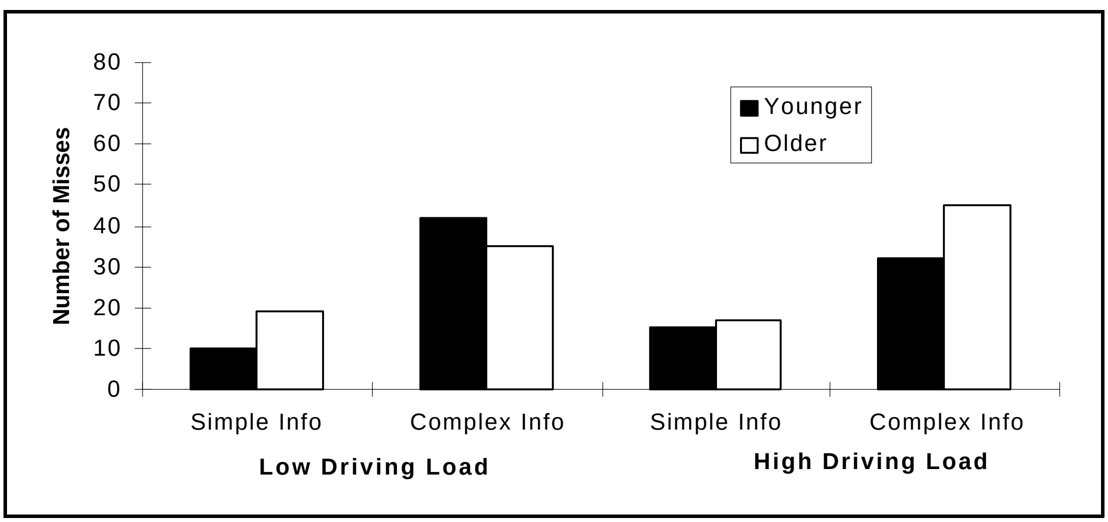

Figure 15. Total number of missed button pushes for different driving loads broken down by information complexity and age group.

Figure 16 also reveals that under different driving load conditions, the number of misses was larger in the complex information condition than in the simple information condition for each display modality. For the auditory display in the high driving load condition and the visual display in the low driving load condition, the differences in the number of misses between the complex information and the simple information were the largest. These results suggest that for the auditory display, when the information was complex and the driving load was high, drivers' awareness was low, which resulted in more missed button presses. For the visual display under the low driving load condition, the inverted U phenomenon (in a lower driving load condition, drivers decreased their driving caution/awareness and exhibited poorer performance) may explain the results. One intriguing result is that no misses occurred when using the multi-modality display under simple information, low driving load conditions. The characteristic of information redundancy for the multi-modality display may make this method of information presentation more desirable for these driving conditions.

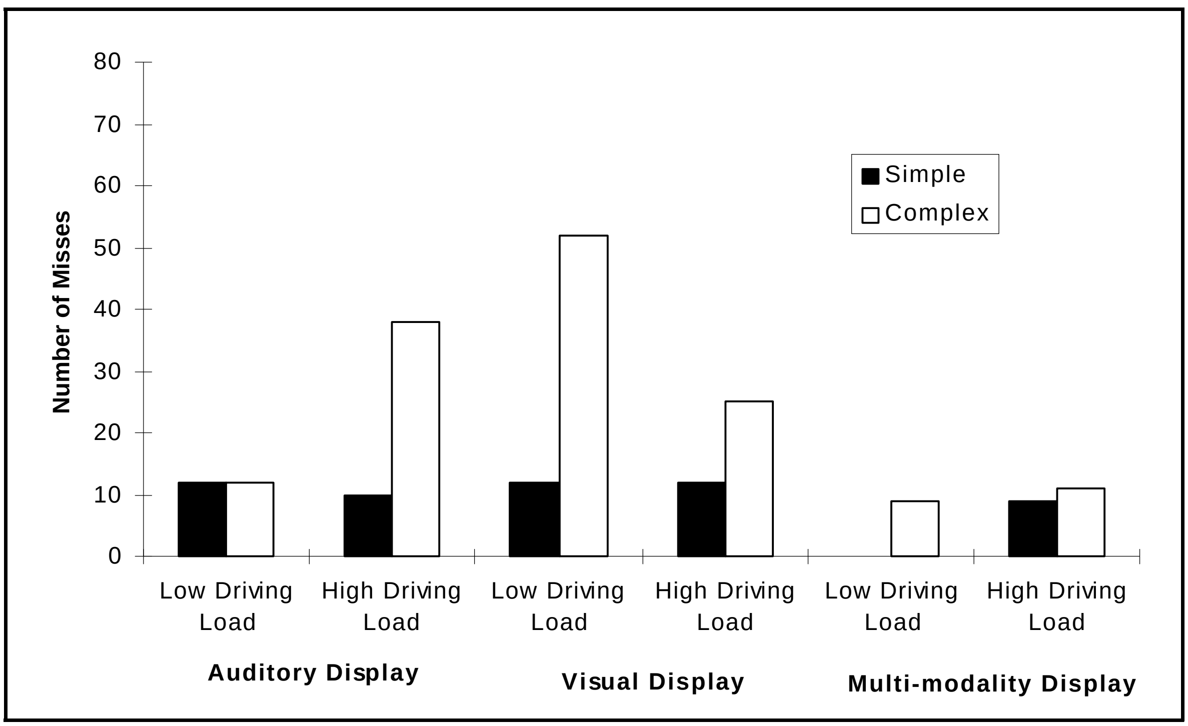

Figure 16. Total number of missed button pushes for different display modalities broken down by driving load and information complexity.

Figure 17 shows the significant Age x Modality interaction [$F(2,60)=14.60$, $p=0.0001$]. The multi-modality display resulted in the least number of misses, and the visual display was the least suitable display modality for older drivers to use. Analyzing the differences between each display for the younger group, it was found that the auditory display resulted in significantly fewer missed button presses than the visual display [$F(1,90)=5.96$, $p= 0.0166$]. In addition, the multi-modality display resulted in a significantly fewer number of missed button presses than the visual display [$F(1,90)=35.91$, $p= 0.0001$], as well as the auditory display [$F(1,90)=12.61$, $p= 0.0006$].

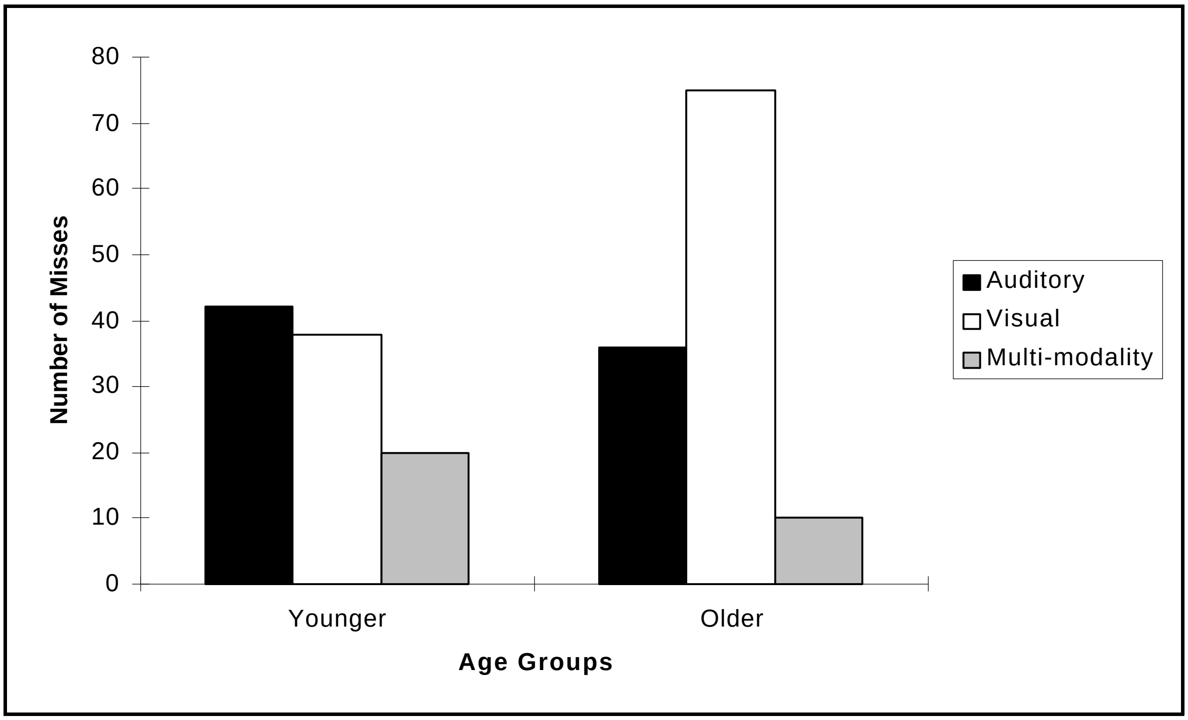

Figure 17. Total number of missed button pushes for different age groups broken down by display modality.

Figure 18 shows the significant two-factor interaction of Modality x Driving Load [F(2,60)=19.18, p=0.0001]. The multi-modality display appeared to be the most detectable display modality for both driving load conditions. Again, the visual display under the low driving load condition resulted in the most missed button presses. In the high driving load condition, the number of missed button presses when using the visual display or the auditory display was not significantly different [F<1], although the two displays resulted in significantly more misses than the multi-modality display [F(1,186)=9.95, p= 0.0019 for Auditory vs. Multi-modality; F(1,186)=5.89, p= 0.0162 for Visual vs. Multi-modality].

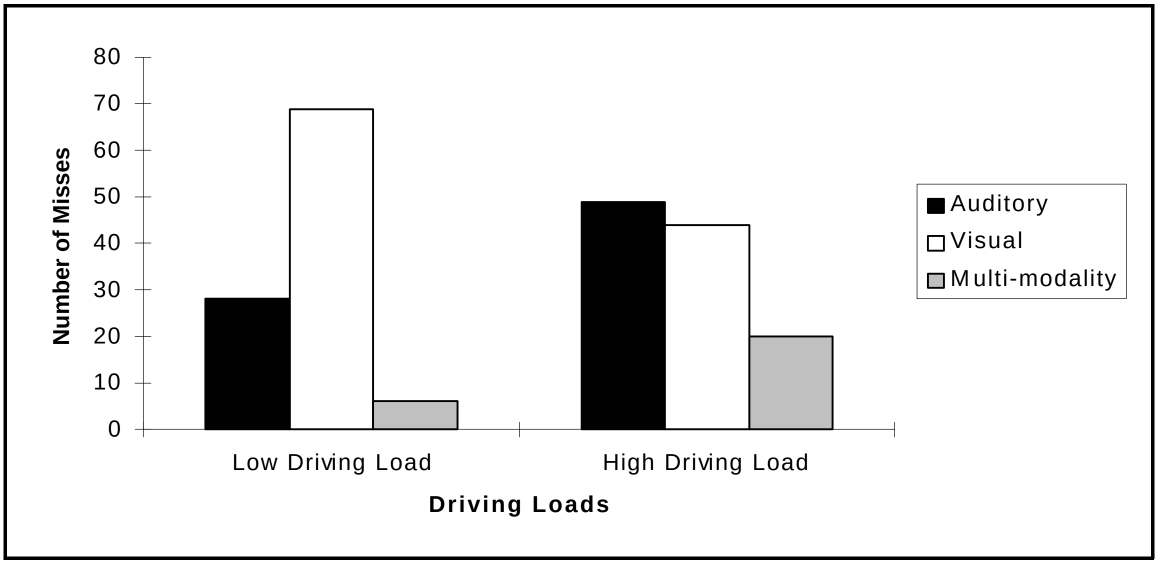

Figure 18. Total number of missed button pushes for different driving loads broken down by display modality.

The interaction of Modality x Complexity [F(2,60)=8.20, p=0.0007] is shown in Figure 19. This Figure reveals that, overall, the complex information condition resulted in decreased secondary task performance, especially for the visual display. Drivers in the complex information condition had a larger total number of misses (152) than those in the simple information condition (62). The treatment-contrast tests revealed that the performance when using the auditory display was not significantly different than when using the visual display or when using the multi-modality display. However, performance was significantly improved by using the multi-modality display instead of the visual display [F(1,186)=6.80, p= 0.0098].

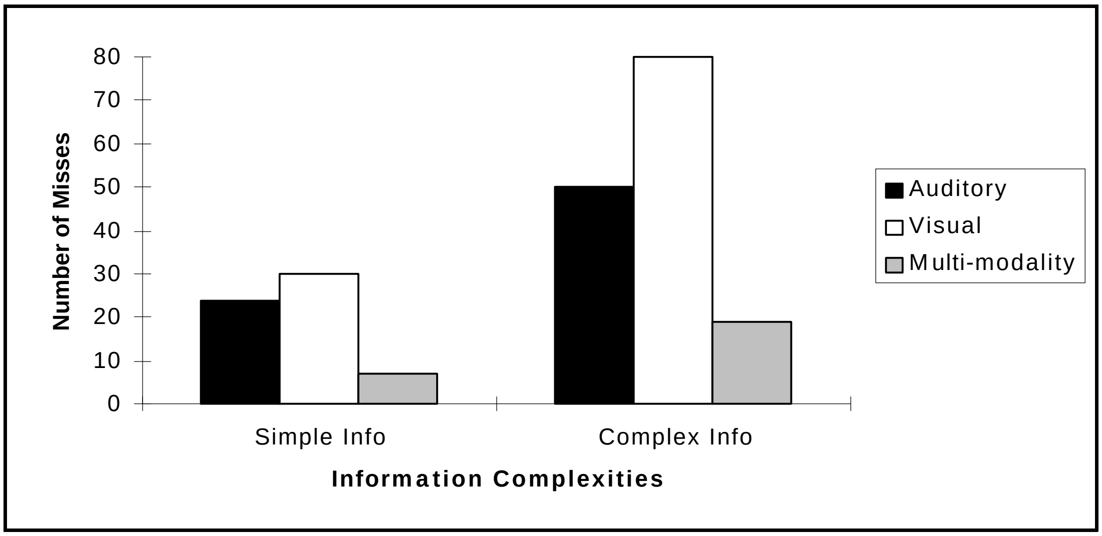

Figure 19. Total number of missed button pushes for different information complexities broken down by display modality.

Figure 20 shows the push button task performance differences between the three display modalities. The multi-modality display condition resulted in the fewest misses (29), followed by the auditory display (75), and then the visual display (110) [$F(2,60)=31.32$, $p=0.0001$]. Also, there was a main effect of complexity, with fewer misses in the simple information condition [$F(1,30)=47.24$, $p=0.0001$].

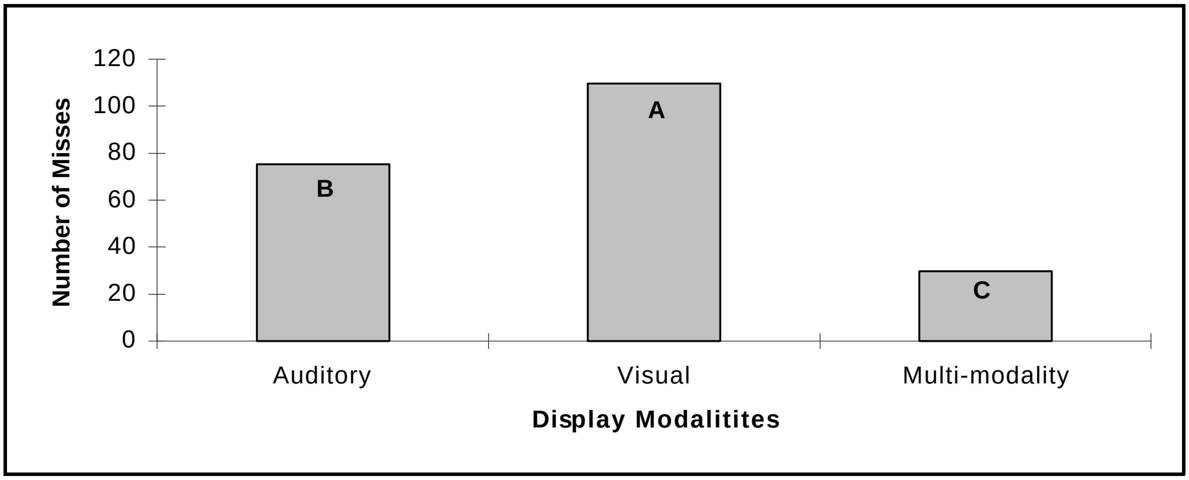

Figure 20. Total number of missed button pushes for different display modalities.

SUBJECTIVE WORKLOAD RESULTS

For each scenario, drivers were instructed by the experimenter to make a full stop and specify their subjective driving workload and display preference at two locations. One was in the middle of each scenario, between the changing of the information complexity, and the other was at the end of each scenario. The modified SWAT was used to evaluate each driver's driving workload from three dimensions. The dimensions were time stress, visual effort, and psychological stress. Drivers rated their workload by answering low, medium, or high for each dimension. Later, each dimension of the subjective workload scale received a rating number of 1 for low, 2 for medium, and 3 for high. ANOVA procedures were used to analyze each of the three dimensions individually and to analyze the sum of the individual scale ratings.

Time Stress Ratings

The results of the ANOVA for time stress ratings can be seen in Appendix F, Table 10. Figure 21 shows the two-factor interaction of Modality x Driving Load [F(2,60)=4.51, p=0.0149]. As shown, drivers ranked the visual display the most stressful under the high driving load condition. Follow-up tests for evaluating the three displays under each driving load condition were conducted. Results showed that there was no difference in the time stress rating using the three displays under the low driving load condition [F<1 for all]. However, under the high driving load condition, the visual display received a higher time stress rating than did the auditory display [F(1,186)=4.11, p= 0.0442], but the rating was not significantly different when compared with the multi-modality display [F(1,186)=3.70, p= 0.0558].

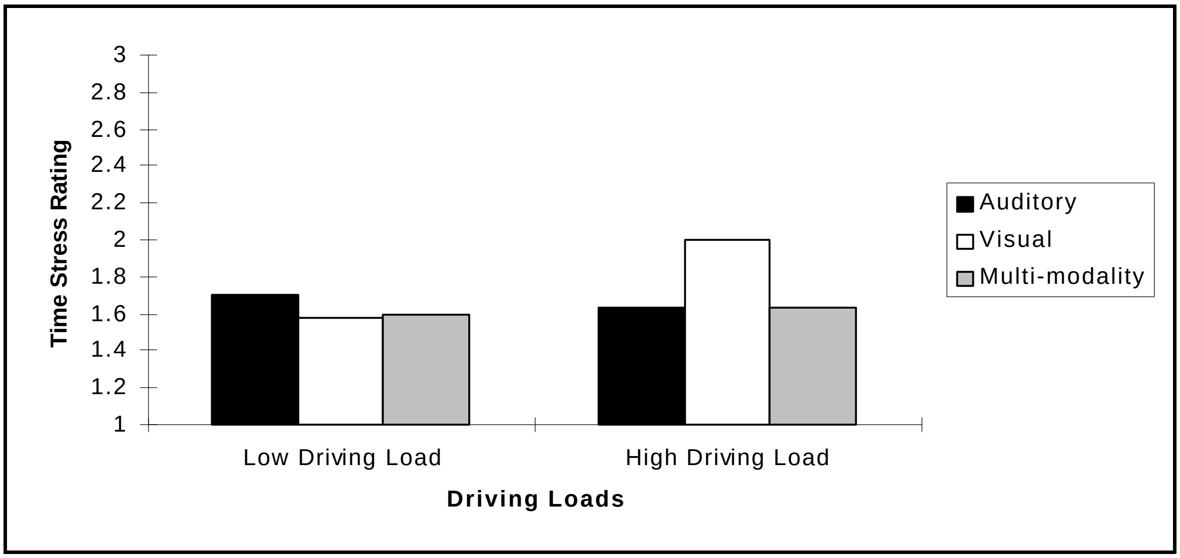

Figure 21. Time stress ratings for different driving loads broken down by display modality.

Three main effects were found to be statistically significant. The older subjects ranked time stress higher than the younger group [F(1,30)=9.82m p=0.0038], the time stress rating was higher under the complex information condition than the simple information condition [F(1,30)=10.20, p=0.0033], and time stress ratings were higher in the high driving load condition [F(1,30)=7.29, p=0.0113].

Visual Effort Ratings

The ANOVA results for the visual effort ratings can be seen in Appendix F, Table 11. Three main effects were found to be significant when rating this workload dimension. The rating of the visual display was deemed by subjects as requiring the greatest visual effort compared to the other two conditions [F(2,60)=15.45, p=0.0001]. The other two significant main effects were Complexity [F(1,30)=13.70, p=0.0001] and Driving Load [F(1,30)=9.42, p=0.0045]. The visual effort rating was higher for drivers when receiving the complex information, and was higher under the high driving load condition.

Psychological Stress Ratings

ANOVA results for the psychological stress ratings can be seen in Appendix F, Table 12. Figure 22 shows the significant three-factor interaction of Age x Driving Load x Complexity for the psychological stress rating [$F(1,60)=4.19$, $p=0.0496$]. The older drivers experienced higher psychological stress than did the younger drivers, especially under the high driving load condition.

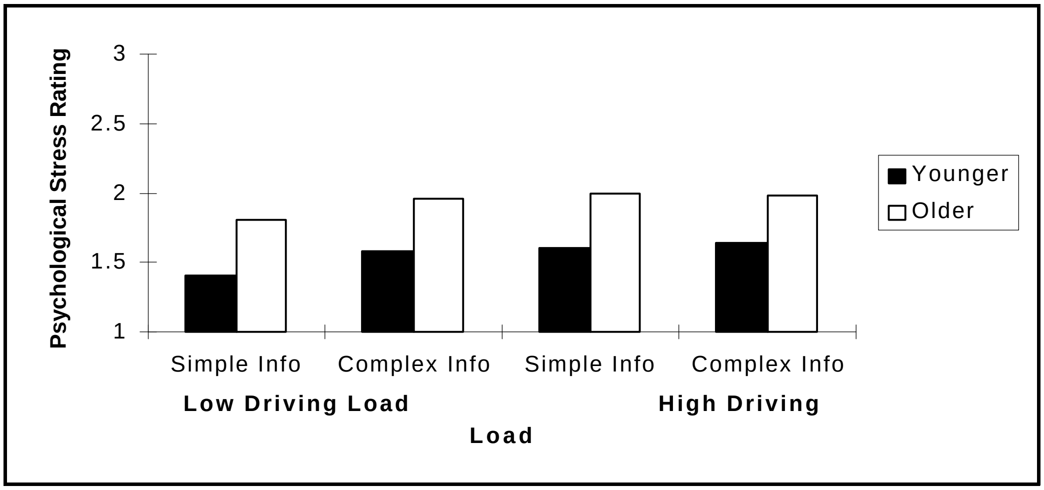

Figure 22. Psychological stress ratings for different driving loads broken down by information complexity and age group.

Figure 23 shows the significant two-factor interaction of Age x Complexity [F(1,30)=5.12, p=0.0311]. In rating the psychological stress, the older drivers had higher stress than the younger drivers, but that difference was less in the complex information condition than in the simple information condition. Post hoc tests examining the difference between the older and younger drivers for each information complexity condition showed no significant difference in psychological stress ratings in the complex information condition. Tests conducted to examine the rating differences for the two groups broken down by different driving load and information complexity conditions showed that the psychological stress ratings between the two groups were not statistically significant under the complex information, high driving load condition.

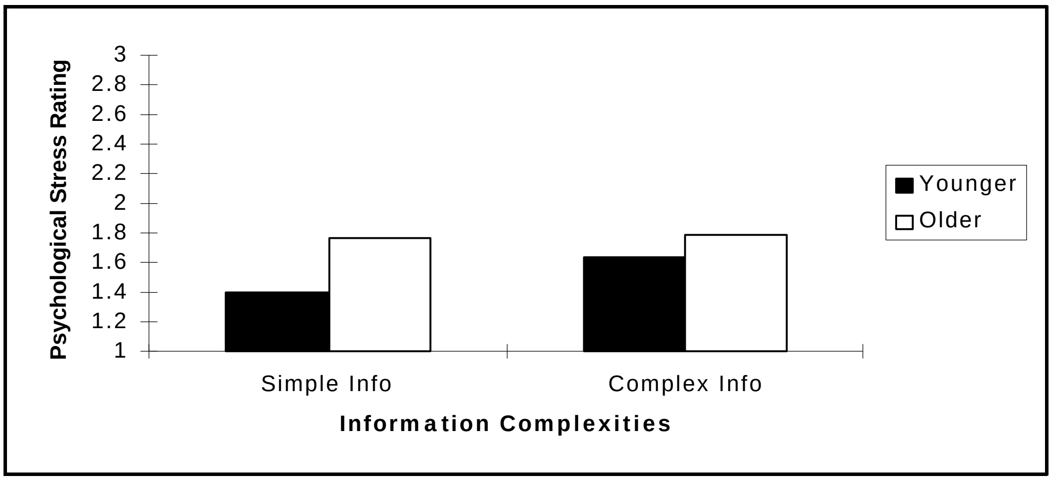

Figure 23. Psychological stress ratings for different information complexities broken down by age group.

There was a main effect of Age [F(1,30)=6.93, p=0.0133] as the older group overall rated items as more psychologically stressful. There was also a main effect of Complexity [F(1,30)=12.38, p=0.0014] as the complex information condition was rated as more stressful than the simple information condition. Figure 24 shows the significant main effect of Modality [F(2,60)=4.68, p=0.0129]. The multi-modality display was rated as causing the lowest psychological stress, and the visual display was rated as causing the highest psychological stress.

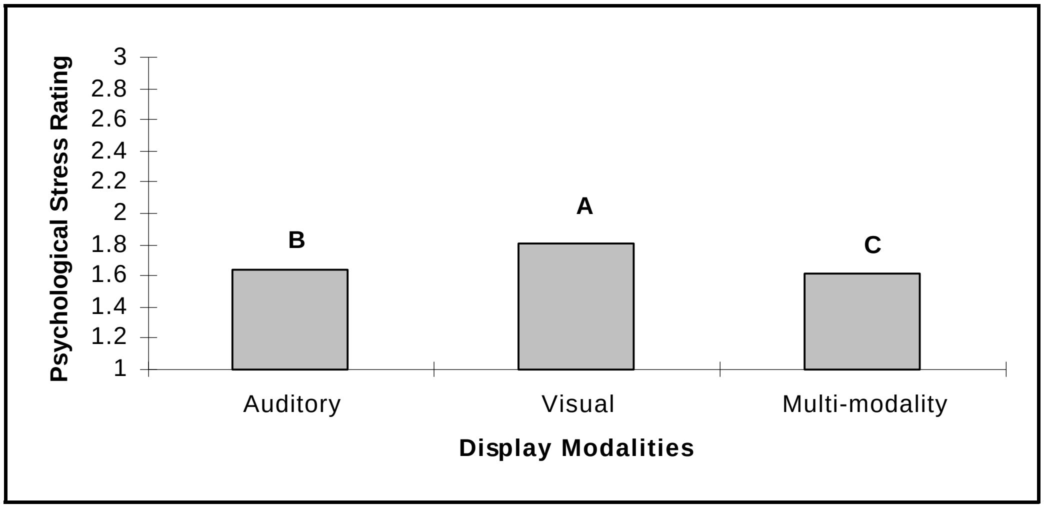

Figure 24. Psychological stress ratings for different display modalities.

Overall Workload Ratings

The ANOVA results for the overall workload ratings can be seen in Appendix F, Table 13. The ratings from the three dimensions were summed to become the overall workload rating. Four main effects were found to be significant. Drivers using the visual display had the highest workload [F(2,60)=7.44, p=0.0013]. The results from the other three main effects were consistent with the results found in previous paragraphs: the older drivers had a higher workload (mean value 5.7) than the younger drivers (mean value 4.7) [F(1,30)=6.15, p=0.0190]; the workload was higher under the high driving load condition (mean value 5.5) than under the low driving load condition (mean value 5.0) [F(1,30)=8.79, p=0.0059]; and the complex information increased driver workload more (mean value 5.5) than did the simple information (mean value 5.0) [F(1,30)=20.69, p=0.0001].

PREFERENCE ANALYSIS RESULTS

The ANOVA results for the preference ratings can be seen in Appendix F, Table 14. Drivers rated the displays using a seven-point Likert scale with anchors "Liked Very Much" (rated as a "7") and "Disliked Very Much" (rated as a "1"). Two main effects were found to be statistically significant: Modality [$F(2,60)=15.47$, $p=0.0001$] and Complexity [$F(1,30)=7.62$, $p=0.0097$]. Figure 25 shows the preference rating result for the three display modalities. Drivers most liked the multi-modality display, followed by the auditory display, and then the visual display. Information complexity also affected the preference rating. Drivers preferred the simple information (mean value 4.9) over the complex information (mean value 4.5).

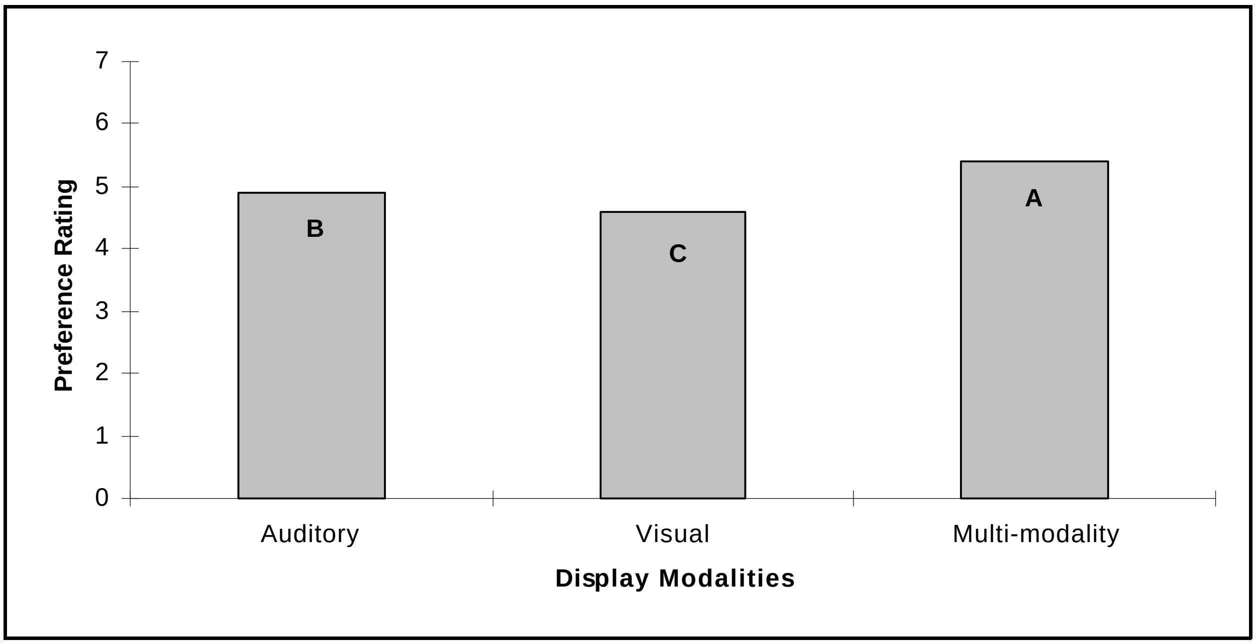

Figure 25. Preference ratings for different display modalities.

NAVIGATION PERFORMANCE RESULTS

In addition to performing the driving and secondary tasks, drivers were also required to follow the route guidance information presented on the three displays, and to make proper responses related to the turns. There were four turns for each of six scenarios, resulting in 24 turns total (two for each information complexity condition). In measuring navigation performance, four variables were selected: percentage of correct turns, number of near misses, number of misses, and number of wrong turns.

Percentage of Correct Turns

Appendix F, Table 15 shows the ANOVA results for the percentage of correct turns. Figure 26 shows the significant interaction of Modality x Driving Load [$F(2,60)=4.35$, $p=0.0173$]. As shown, the visual display resulted in the lowest percentage of correct turns under the high driving load condition [$F(1,186)=5.12$, $p= 0.0248$ for Auditory vs. Visual; $F(1,186)=9.68$, $p= 0.0022$ for Visual vs. Multi-modality]. Drivers had near perfect navigation performance (99.22 percent) when using the multi-modality display under the high driving load condition. No significant difference was found between drivers using the auditory display and the multi-modality display [$F<1$]. Under the low driving load condition, there was no significant difference in the drivers' navigation performance for the displays [$F<1$ for all]. Furthermore, overall younger drivers made more correct turns (97.92 percent) than the older drivers (92.19 percent) [$F(1,30)=15.25$, $p=0.0005$].

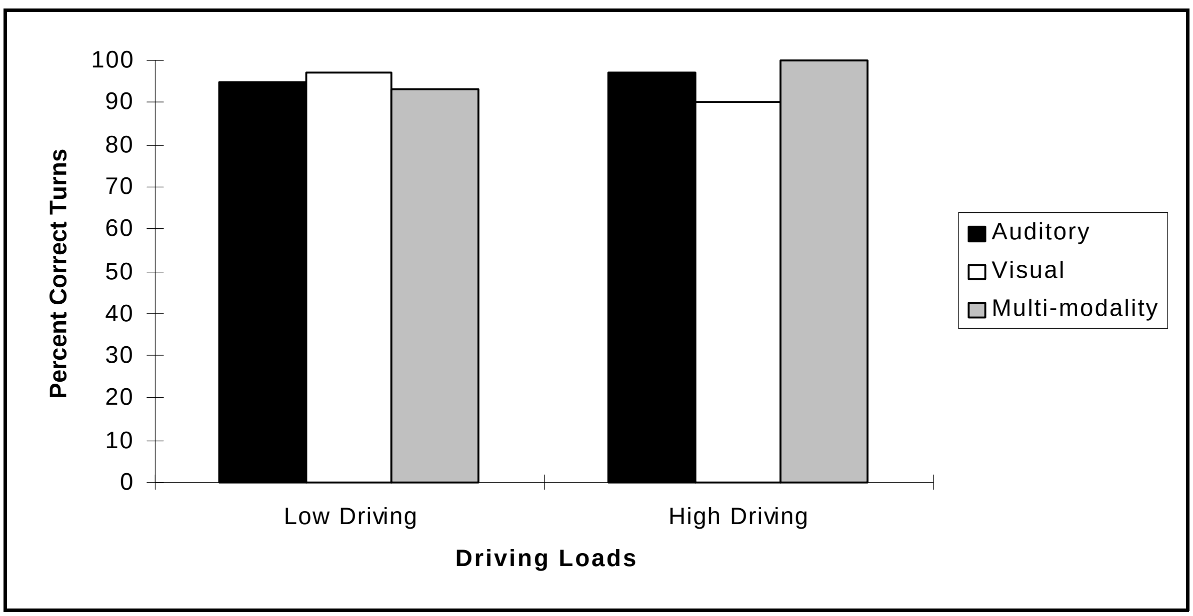

Figure 26. Percentage of correct turns for different driving loads broken down by display modality.

Navigation-Related Errors

The three measures (near miss, miss, and wrong turn) analyzed in this category enabled the assessment of drivers' navigation performance from the types of errors each driver made. Due to very small and unbalanced numbers for each of the three measures in this category, descriptive statistics were used to explain the data.

The auditory display under the complex information condition resulted in a large number of wrong turns. It may be that complex information disrupted a driver's ability to filter time-critical information when needed, such as route guidance information.

The visual display resulted in many more "miss" errors than did the other displays, especially under the high driving load condition. This indicated that information displayed via the visual display was more difficult to notice. Results from the secondary tasks also supported this finding since the total number of missed button pushes was significantly higher when using the visual display. However, for all six scenarios, the visual display resulted in only one instance of a wrong turn in the simple information, low driving load condition. This may indicate that the complex route guidance format (with turn arrow, countdown bar, etc.) designed for this study was efficient in helping drivers to make correct turns, if they had detected the information. The simple route guidance format designed for the visual display may explain why the near miss errors only occurred in the simple information condition.

Overall, the multi-modality display appeared to have generally small numbers of errors. Figure 27 shows the results after comparing the two age groups when using the three display modalities. Older drivers made more navigation-related errors than did the younger drivers under each display condition. The older drivers made the most wrong turn errors when using the auditory display, and the most "miss" errors when using the visual display.

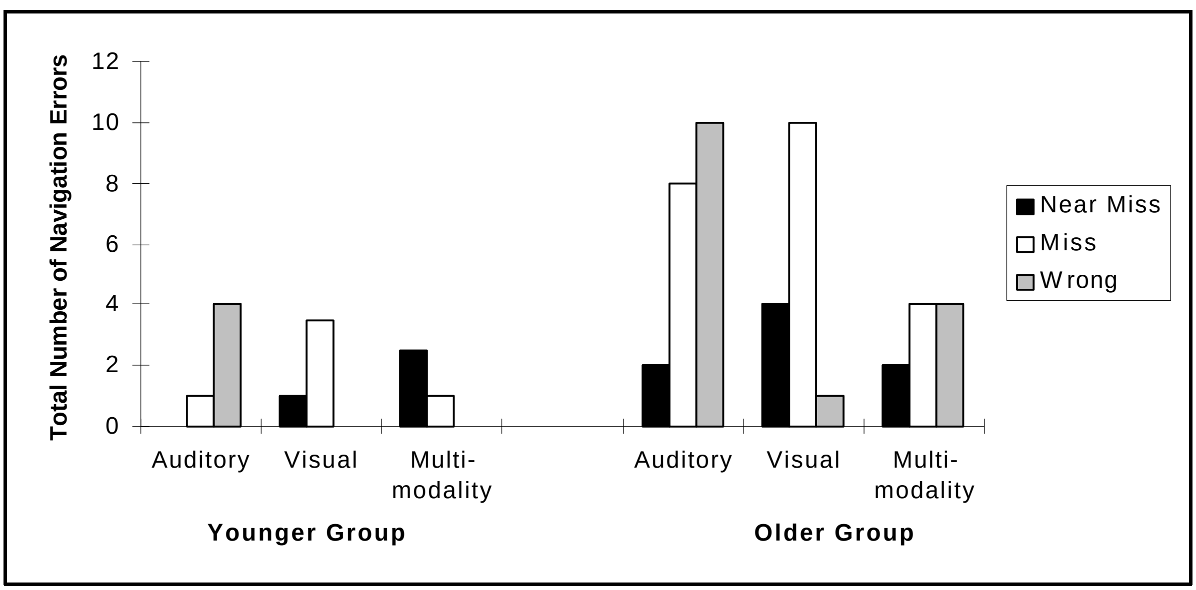

Figure 27. Total number of navigation-related errors for age groups broken down by display modality and error type.

DRIVING PERFORMANCE RESULTS

In reducing the raw data set for analyzing driving performance effects, data collected from three driving situations were removed: the turn situations, the stop sign situations, and the workload assessments, for which the driver was stopped in the middle of each scenario. Since these situations required slowing and/or large steering inputs, they serve to add "noise," potentially masking any differences between the conditions of interest.

In order to obtain the absolute mean longitudinal velocity deviation, the speed limits for different situations were added to the raw data set. The driving performance data were separated into two subsets by driving load conditions since the load factors selected to manipulate the two driving conditions were very different from each other. Since the load conditions were designed to induce very different driving behavior, it is meaningless to compare the driving performances between the two different driving conditions.

High Driving Load Condition — Results of the Velocity Assessments

Mean Longitudinal Velocity

Appendix F, Table 16 shows the ANOVA results for mean longitudinal velocity. Figure 28 shows the significant interaction of Modality x Complexity [$F(2,60)=8.44$, $p=0.0006$]. Treatment-contrast interaction tests revealed that under the simple information condition, a difference existed between the auditory display and the visual display [$F(1,186)=6.25$, $p= 0.0133$]. There was no significant difference between the Visual and Multi-modality [$F(1,186)=1.56$, $p = 0.2126$] or the Auditory vs. Multi-modality [$F(1,186)=1.89$, $p = 0.1707$].

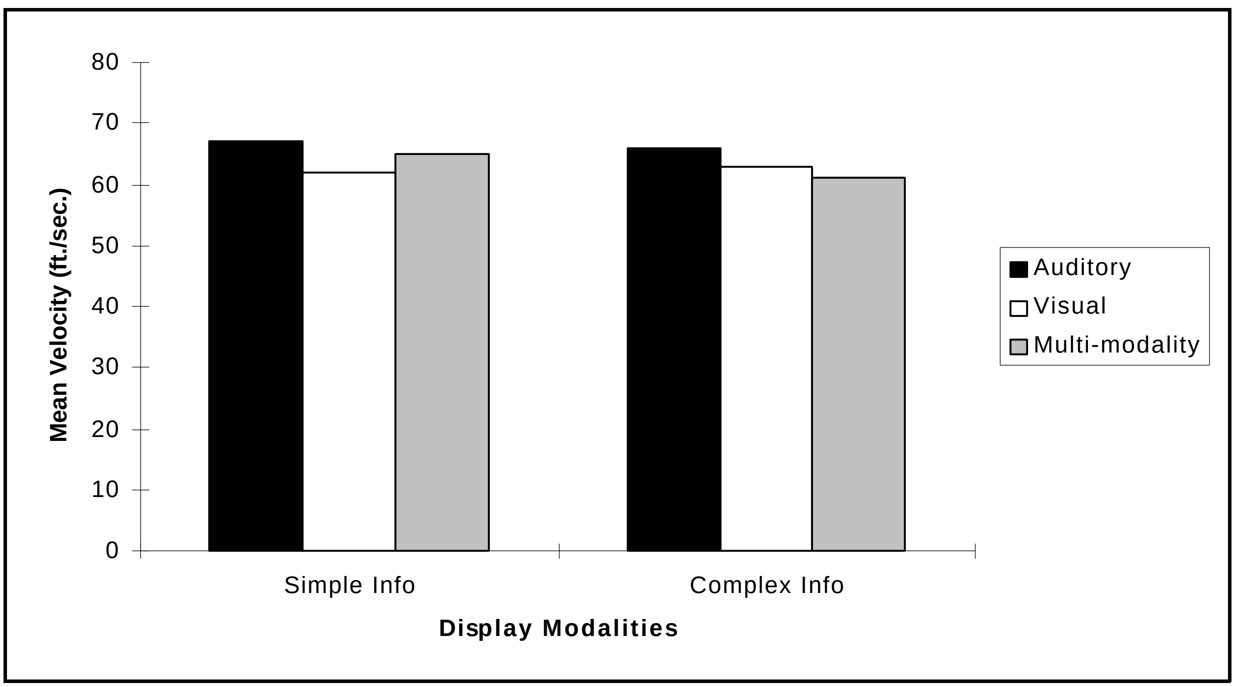

Figure 28. Mean velocity for different information complexities broken down by display modality.

Under the complex information condition, no significant differences between the three displays were found.

There was a main effect of Modality [$F(2,60)=4.07$, $p=0.0021$] as drivers tended to drive faster when using the auditory display than either of the other displays. There was also a main effect of Age [$F(1,30)=7.89$, $p=0.0087$], as younger drivers tended to drive faster (mean velocity = 65.0 ft./sec.) than older drivers (mean velocity = 60.0 ft./sec.).

Mean Absolute Velocity Deviation

Appendix F, Table 17 shows the ANOVA results for mean absolute velocity deviation. The velocity deviation refers to the difference between the posted speed limits and the speed drivers actually drove.

Figure 29 shows the significant Modality x Complexity interaction [$F(2,60)=4.23$, $p=0.0192$]. None of the differences between the auditory display and the visual display were found to be statistically significant under either complexity condition, while the difference between the multi-modality display and the other displays was greater in the simple information condition than in the complex information condition.

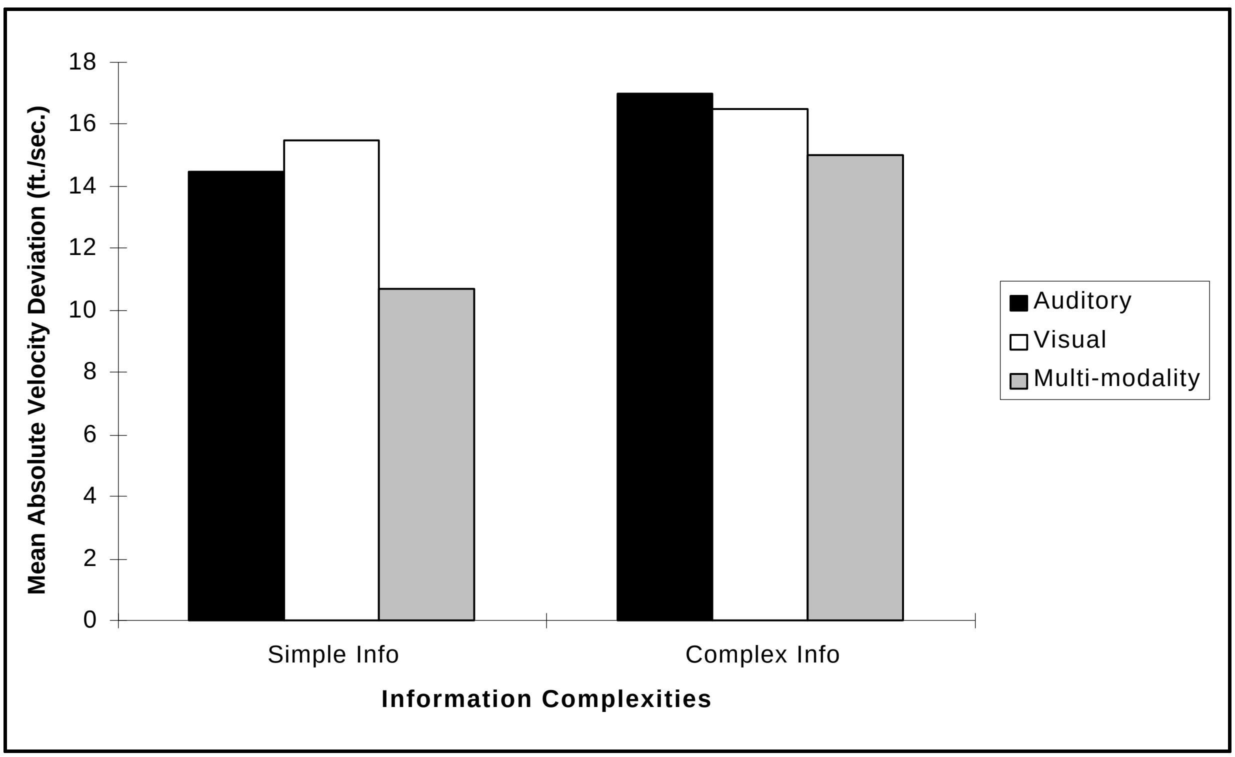

Figure 29. Mean absolute velocity deviation for different information complexities broken down by display modality.

The mean absolute velocity deviation was also influenced by different information complexity conditions [F(1,30)=115.97, p=0.0001]. The complex information condition resulted in larger mean deviations (16.50 ft./sec.) than those of the simple information condition (13.49 ft./sec.). The multi-modality display appeared to be the most effective in helping drivers to maintain speed [F(2,60)=21.31, p=0.0001]. Younger drivers stayed closer to the speed limits (mean value 14.15 ft./sec.) than did the older drivers (mean value 15.92 ft./sec.) [F(1,30)=21.51, p=0.0001]. When the driving load was high, both age groups kept their speed below the speed limits. The younger group averaged 3.30 ft./sec. below the speed limit, and the older group was 8.47 ft./sec. below the speed limit.

Variance in Longitudinal Velocity

Appendix F, Table 18 shows the ANOVA results for variance in longitudinal velocity. A three-factor interaction, Age x Modality x Complexity, was found to be significant [F(2,60)=4.92, p=0.0105]. Three situations resulted in the younger group showing larger variances than the older group: one was in the complex information, auditory display condition; the second was in the simple information, visual display condition; and the third was in the complex information, multi-modality display condition.

The contrast tests for the younger group under the simple information condition revealed no significant differences among each pair of displays [F<1 for all]. The same results were also found for the younger group under the complex information condition [F<1 for all].

For the older group, under the simple information condition, a significant difference was found between the visual display and the multi-modality display [F(1,180)=4.38, p= 0.0378]. This significant result was also found in the complex information condition between the visual display and the multi-modality display [F(1,180)=6.8, p= 0.0099]. In the other comparison tests, no significant differences were found.

These test results indicate that for the younger group, in each information complexity condition, no significant velocity variance differences resulted from the use of the three different displays. However, for the older group, using the visual display resulted in the smallest velocity variance when compared to using the multi-modality and the auditory displays in the simple information condition; on the contrary, using the multi-modality display caused the smallest variance values when compared to the visual display in the complex information condition.

High Driving Load Condition — Results of the Lateral Lane Position Assessments

Variance in Lateral Lane Position

Appendix F, Table 19 shows the ANOVA results for variance in lateral lane position. Figure 30 shows the two-factor interaction of Modality x Complexity [F(2,60)=6.75, p=0.0023]. The largest difference appears in the visual display, complex information condition. There appeared to be very little difference among the three displays under the simple information condition. This implies that when presenting complex information, the visual display may take much of the driver's attention away from the road.

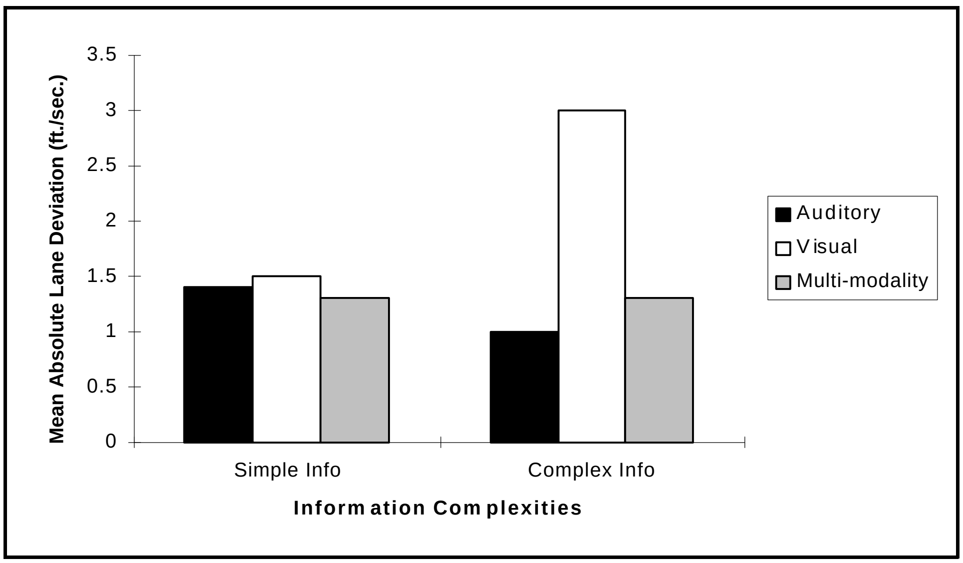

Figure 30. Variance in lateral lane position for different information complexities broken down by display modality.

Frequency of Major Lane Deviations

Appendix F, Table 20 shows the ANOVA results for frequency of major lane deviations. The major lane deviations refer to the number of times the vehicle deviated more than one-half of the vehicle's width across either the central line or the road boundary.

Figure 31 shows the significant interaction of Modality x Complexity [$F(2,60)=4.92$, $p=0.0105$]. It shows that when complex information was presented on the visual display, drivers made major lane deviations more frequently than when such information was presented on the other two displays. For the simple information condition, the frequency differences among each pair of displays were not significant.

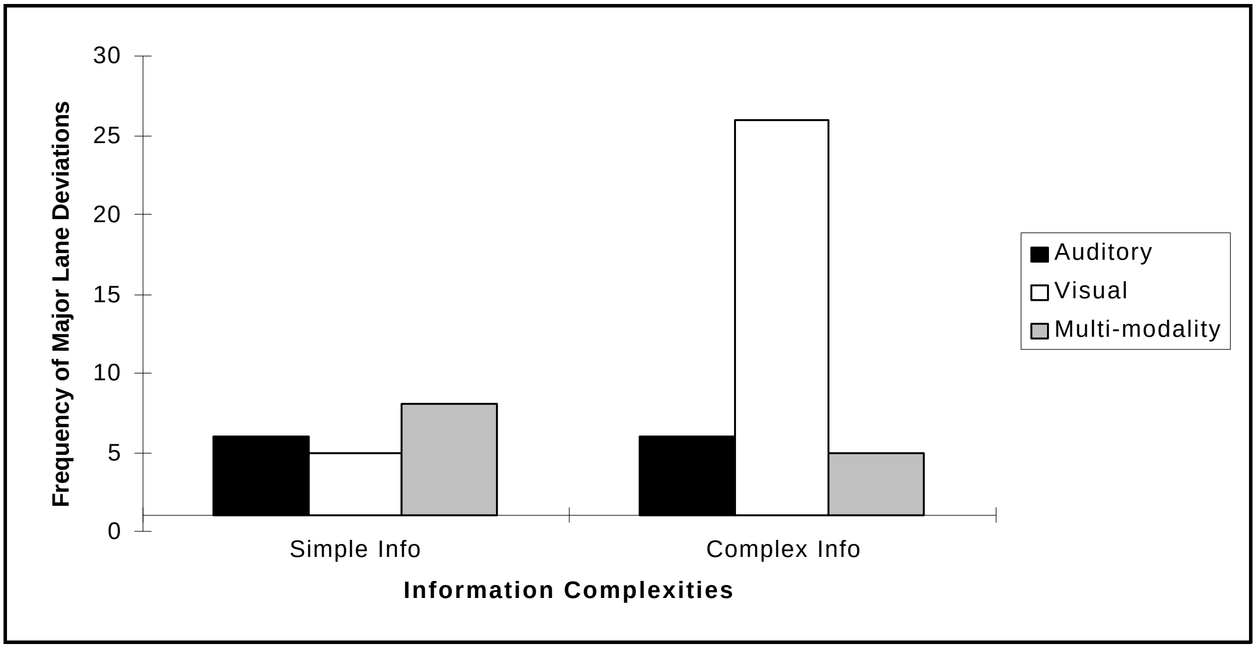

Figure 31. Frequency of major lane deviations for different information complexities broken down by display modality.

Frequency of Minor Lane Deviations

Appendix F, Table 21 shows the ANOVA results for the frequency of minor lane deviations. Minor lane deviations occurred when the vehicle crossed either the central line or the road boundary by less than half of the vehicle's width. Figure 32 shows the significant three-factor interaction of Age x Modality x Complexity [$F(2,60)=4.28$, $p=0.0183$]. As can be seen, the older drivers tended to make more minor lane deviations than did the younger drivers. Two large frequency differences were found: one in the visual display, complex information condition, and the other in the multi-modality display, simple information condition.

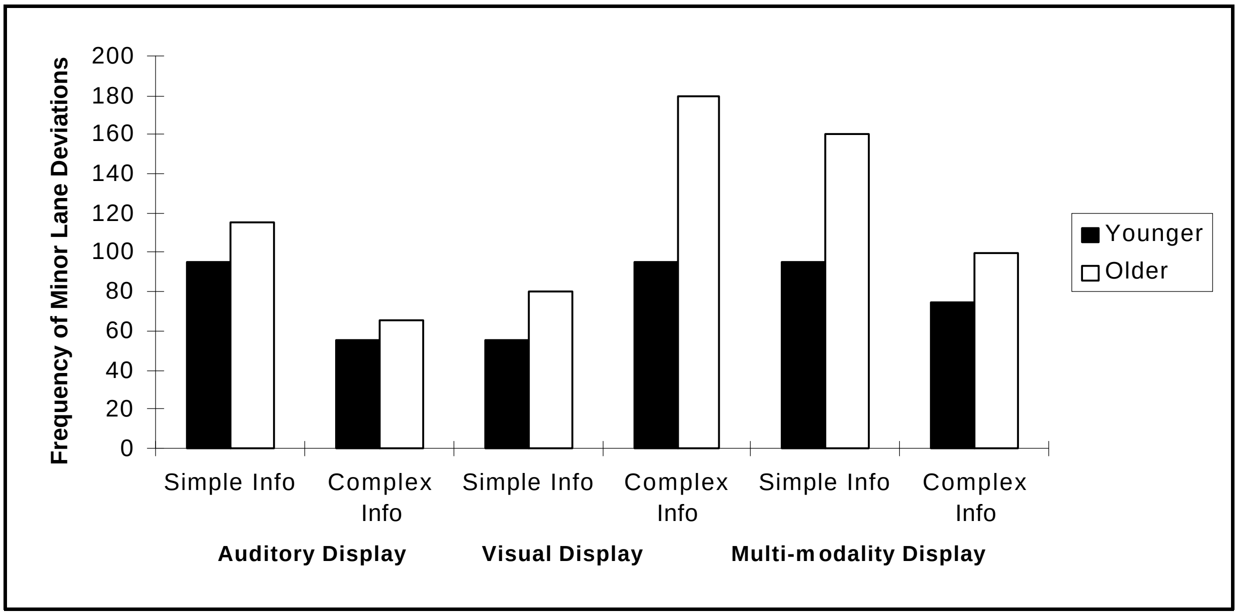

Figure 32. Frequency of minor lane deviations for different display modalities broken down by information complexity and age group.

Under the complex information condition, without exception, the older drivers exhibited the poorest performance when using the visual display. In addition, under the complex information condition, there were no significant differences between older and younger drivers when using the auditory display and the multi-modality display. Conversely, under the simple information condition, the older drivers made the largest number of minor lane deviations when using the multi-modality display, while no differences were found when compared to using the auditory display. The results also appear to support the hypothesis mentioned previously that older drivers depended essentially on the auditory part of the multi-modality display to receive information.

For the younger group, despite the fact that the trend for each information condition was similar to the older group (for the simple information condition, the multi-modality display had the highest frequency of minor lane deviations; for the complex information condition the visual display had the highest frequency), the contrasts tests indicated that no differences existed among the displays under each information complexity condition. In the simple information condition, the contrast test showed no frequency difference between the auditory display and the multi-modality display. The same test result was found in the complex information condition between the auditory display and the multi-modality display.

In addition, when using the auditory display, the drivers made fewer minor lane deviations in the complex information condition than in the simple information condition. The same result was found for the multi-modality display condition. This implies that complex information presented on the two displays may raise drivers' driving awareness, and that the complex information does not overload the drivers. However, for the visual display, the complex information increased drivers' workload and thus caused the largest number of minor lane deviations. It is plausible that the drivers' driving strategies differed with the attention demands of the displays.

High Driving Load Condition — Results of the Steering-Related Assessments

Variance in Steering Wheel Position

Appendix F, Table 22 shows the ANOVA results for variance in steering wheel position. Figure 33 shows the variance of steering wheel position for the three displays broken down by information complexities and age groups. The older drivers had particular difficulty, as evidenced by the significant Age x Modality x Complexity interaction [F(2,60)=3.21, p=0.0476], in the complex information, visual display condition. Overall, the older group had larger variance than the younger group [F(1,30)=23.36, p=0.0001].

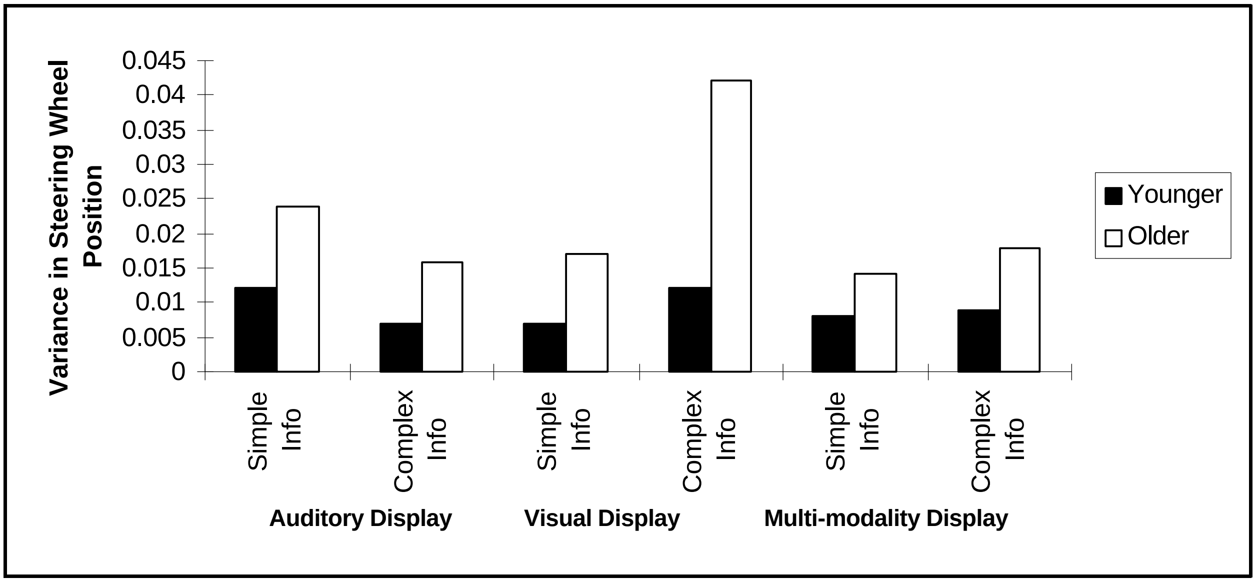

Figure 33. Variance in steering wheel position for different display modalities broken down by information complexity and age group.

The follow-up contrast tests indicated that the younger group, under each information condition, had no significant differences in steering wheel handling among the three displays. In the older group, there were no significant differences in the variance of the steering wheel position when comparing the three displays for each information condition, with the exception of the visual display, complex information condition described above.

The two age groups had different steering wheel angle variances when using the three displays (see Figure 34). For the younger group, no significant differences were found when using the three displays. However, the contrast tests showed that the older group had the largest steering wheel angle variance when using the visual display [F(1,90)=6.03, p= 0.0160 for Auditory vs. Visual; F(1,90)=10.40, p= 0.0018 for Visual vs. Multi-modality], and the difference between the auditory display and the multi-modality display was not statistically significant [F<1].

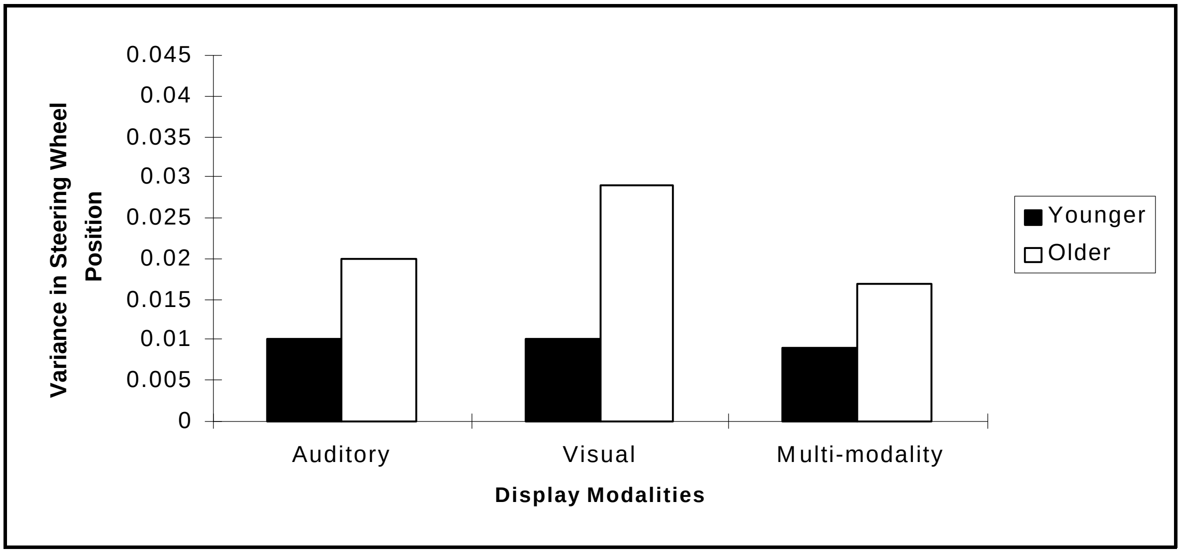

Figure 34. Variance in steering wheel position for different displays broken down by age group.

Figure 35 depicts the significant two-way interaction of Modality x Complexity [$F(2,60)=9.63$, $p=0.0002$]. Overall, the largest variance occurred in the visual display, complex information condition. For the differences among the three displays in the simple information condition, the contrast tests indicated that there were no significant differences. The auditory display had lower variance when presenting the complex information than when presenting simple information. This may indicate that the auditory display in the complex information condition raised drivers' driving awareness without overloading them. The different driving strategies drivers chose may also explain this result. The results obtained in this assessment all indicate that when the visual display presented complex information, the attention demands for older drivers increased significantly, and thus their driving performance decreased to an unsafe level.

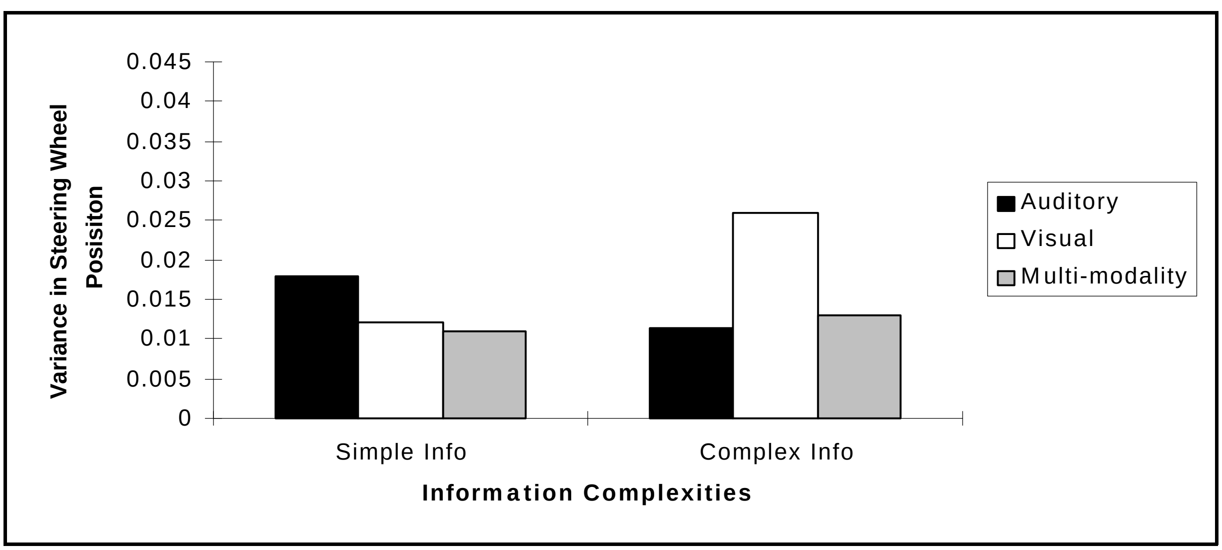

Figure 35. Variance in steering wheel position for different information complexities broken down by display modality.

Frequency of Large Steering Reversals

Appendix F, Table 23 shows the ANOVA results for the frequency of large steering reversals. The number of steering reversals greater than ten degrees was counted as this frequency measure. Figure 36 shows the significant three-way interaction, Age x Modality x Complexity [$F(2,60)=9.18$, $p=0.0003$]. Overall, the older group had more large steering reversals than the younger group [$F(1,30)=25.53$, $p=0.0001$]. Note that the visual display, when presenting the complex information, resulted in a larger number of large steering reversals for the older drivers. In the same complex information condition, the older group made fewer steering wheel reversals when using the auditory display than when using the multi-modality display [$F(1,180)=8.22$, $p= 0.0046$ for Auditory vs. Multi-modality]. The same result was found for the younger group. The multi-modality display with information presented visually may have the potential of distracting drivers' visual attention away from the roadway. In the simple information condition, the visual display resulted in the fewest steering reversals for the younger and older groups.

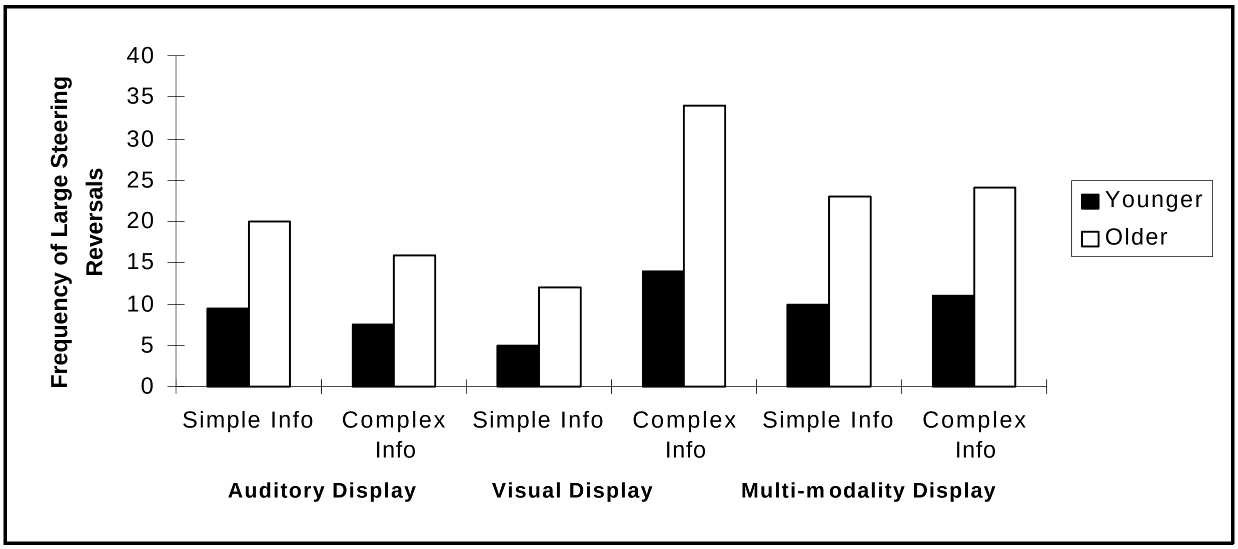

Figure 36. Frequency of large steering reversals for different display modalities broken down by information complexity and age group.

Figure 37 shows the significant Age x Complexity interaction [F(1,60)=4.75, p=0.0374]. The complex information condition resulted in more reversals than did the simple information condition, and this difference was greater among the older group than the younger group.

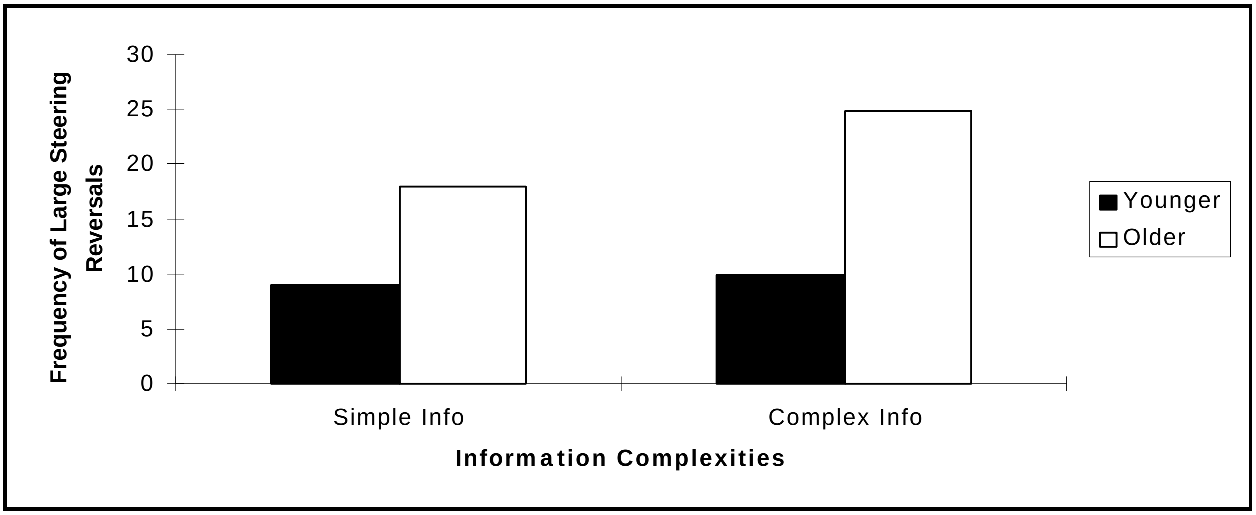

Figure 37. Frequency of large steering reversals for different information complexities broken down by age group.

Figure 38 shows the Modality x Complexity interaction [F(2,60)=59.77, p=0.0001]. This Figure shows that, as with many of the other measures, the visual display presenting the complex information still caused the most reversals. There was no difference between the auditory display and the multi-modality display in the simple information condition, but in the complex information condition, the auditory display resulted in fewer large steering reversals than the multi-modality display [F(1,186)=6.33, p= 0.0127 for Auditory vs. Multi-modality]. It is suggested that this result was due to the multi-modality display drawing drivers' attention away from the roadway and toward the display more so than the auditory-only display.

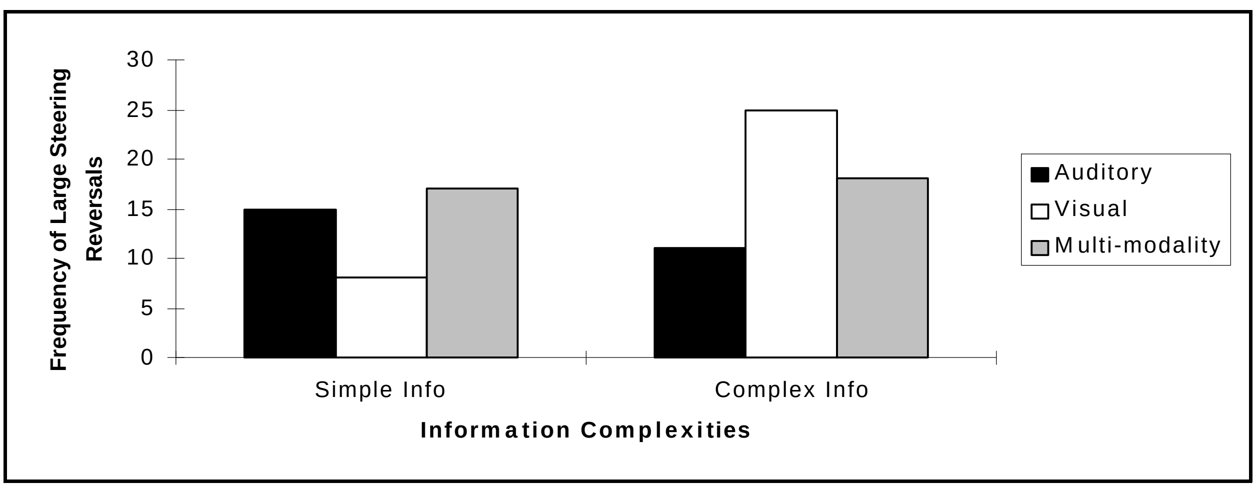

Figure 38. Frequency of large steering reversals for different information complexities broken down by display modality.

Low Driving Load Condition — Results of the Velocity Assessments

The driving environment in the low driving load condition was very different from the environment in the high driving load condition. For example, very little traffic was present in this condition. Therefore, the assessment results (e.g., lane position assessments), which are statistically significant and indicate, to some extent, poorer driving performances in this condition, may not be as dangerous as in the high driving load condition.

Mean Longitudinal Velocity

Appendix F, Table 24 shows the ANOVA results for mean longitudinal velocity. Figure 39 shows the significant three-factor interaction of Age x Modality x Complexity [$F(2,57)=3.52$, $p=0.0362$]. Overall, the younger drivers drove faster (mean value 53.578 ft./sec.) than did the older drivers (mean value 49.32 ft./sec.) [$F(1,30)=5.45$, $p=0.0264$]. The younger drivers also tended to drive faster in the simple information condition than in the complex information condition. Also, the younger group tended to drive above the speed limit (mean value 2.236 ft/sec.), while the older drivers, on average, tended to drive below the speed limit (mean value -2.05 ft./sec.). There were no significant mean velocity differences within each information condition for the age groups. This may reflect that the older drivers are used to driving slowly and younger drivers are used to driving faster.

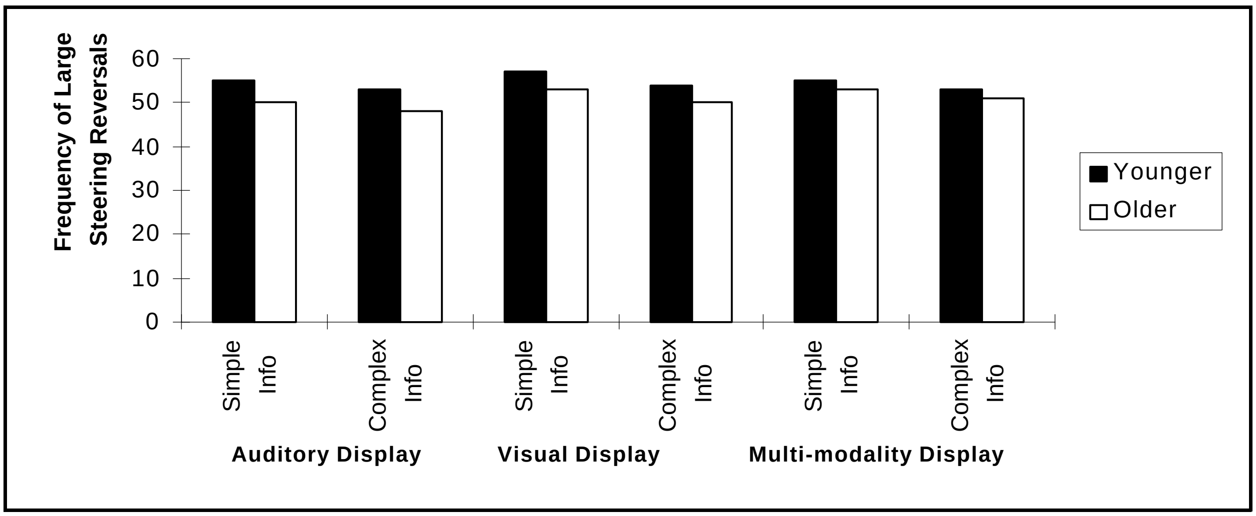

Figure 39. Mean longitudinal velocity for different display modalities broken down by information complexity and age group.

Mean Absolute Velocity Deviation

Appendix F, Table 25 shows the ANOVA results for mean absolute velocity deviation. Figure 40 depicts the significant Modality x Complexity interaction [F(2,57)=9.36, p=0.0003]. The visual display in the complex information condition resulted in the largest mean absolute velocity deviation values. However, there were no significant differences among the three displays in the simple information condition. Comparing the two information conditions, the complex information condition resulted in larger deviations than the simple information condition [F(1,30)=11.17, p=0.0022]. The largest deviations were made when using the visual display in the complex information condition, implying that the visual display is the least efficient in helping drivers to maintain the speed limit requirement (see Figure 41).

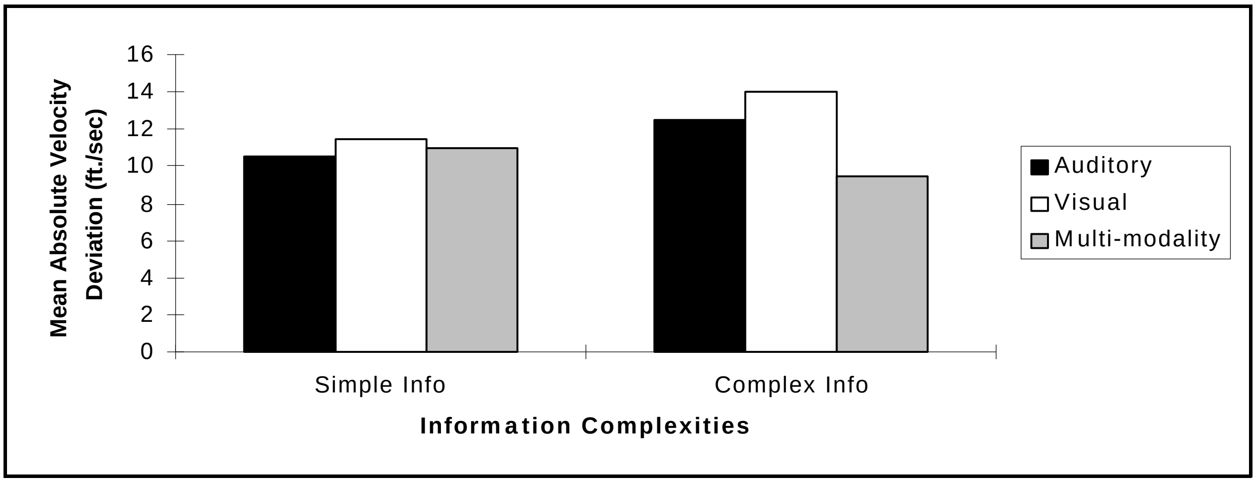

Figure 40. Mean absolute velocity deviation for different information complexities broken down by display modality.

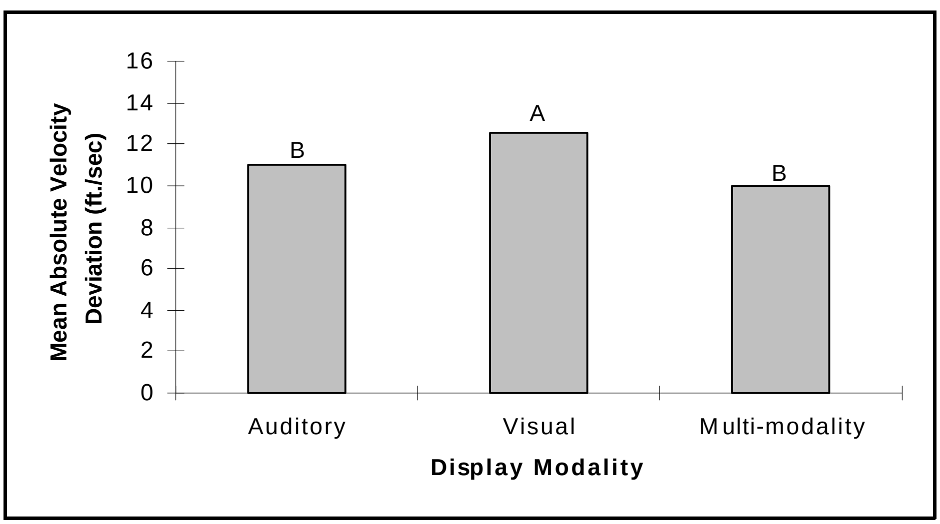

Figure 41. Mean absolute velocity deviation for different display modalities.

Variance in Longitudinal Velocity

Appendix F, Table 26 shows the ANOVA results for variance in longitudinal velocity. The significant two-factor interaction, Age x Complexity [F(1,30)=5.68, p=0.0237], is depicted in Figure 42. This Figure shows that the older drivers' velocity variance was larger in the complex information condition as opposed to the simple information condition. There was no significant difference between the two groups in their velocity variances under either information condition.

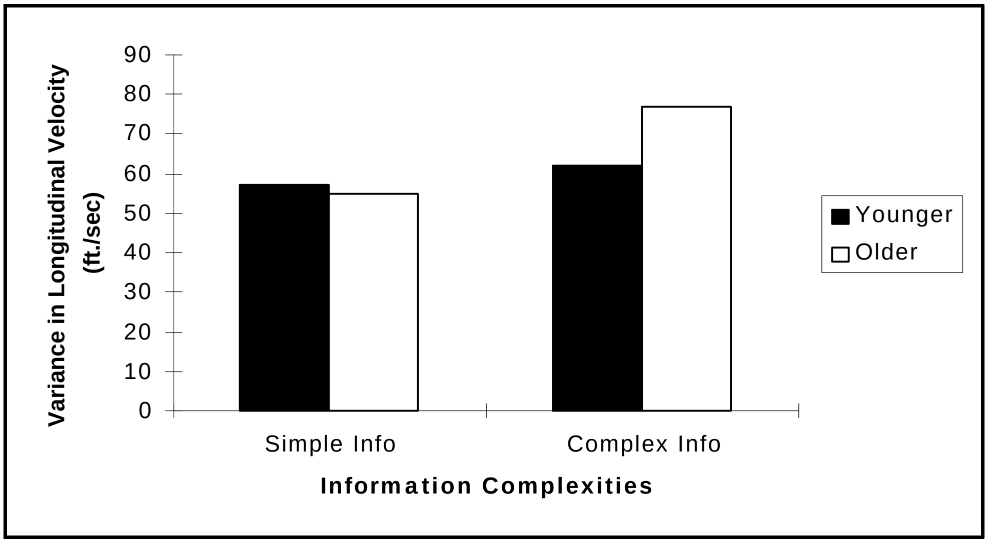

Figure 42. Variance in longitudinal velocity for different information complexities broken down by age group.

The contrast tests indicated that the variance values for the younger group between the simple and the complex information conditions were not significantly different [F<1], while for the older group, there was a significant difference [F(1,60)=9.97, p= 0.0025]. Overall, the complex information condition had larger variances than the simple information condition [F(1,30)=30.29, p=0.0001].

Low Driving Load Condition — Results of Lane Position Assessments

Variance in Lateral Lane Position

Appendix F, Table 27 shows the ANOVA results for variance in lateral lane position. The only main effect that influenced drivers' variance in lateral lane position was information complexity [F(1,30)=8.79, p=0.0059]. In the complex information condition, drivers had larger lane position variance (mean value 3.6) than in the simple information condition (mean value 2.1).

Frequency of Major Lane Deviations

Appendix F, Table 28 shows the ANOVA results for frequency of major lane deviations. Figure 43 shows the frequency of major lane deviations for the three display conditions. Surprisingly, drivers made the largest number of major lane deviations in the multi-modality display condition [F(2,60)=3.92, p=0.0251].

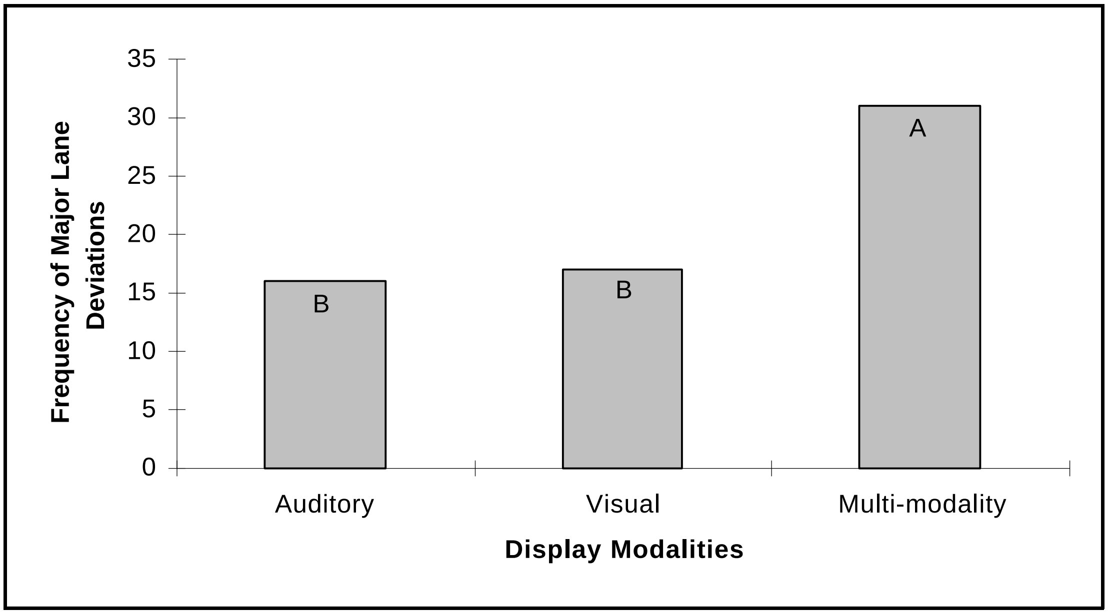

Figure 43. Frequency of major lane deviations for different display modalities.

Frequency of Minor Lane Deviations

Appendix F, Table 29 shows the ANOVA results for frequency of minor lane deviations. Figure 44 depicts the significant Modality x Complexity interaction [$F(2,58)=7.08$, $p=0.0018$]. This Figure shows that in the simple information condition, the auditory display had the smallest number of minor lane deviations. For the simple information condition, there was no significant difference between the visual display and the multi-modality display. However, in the complex information condition, the fewest deviations occurred when using the visual display. There was no significant difference between the auditory display and the multi-modality display .

A possible explanation for both lane deviation results could be related to workload. Perhaps drivers paid more attention to the multi-modality display in the simple roadway condition because they had the time and capacity to do so. It seems plausible that the multi-modality display would provide more system novelty than an auditory counterpart, and alert the driver to the presence of new information to a greater extent than the auditory display. In addition, previous studies (e.g., Dingus et al., 1994) have shown that lane deviations increase in conditions of low traffic density. Therefore, perhaps drivers were devoting more “spare” capacity to this display because they felt that it was safe to do so.

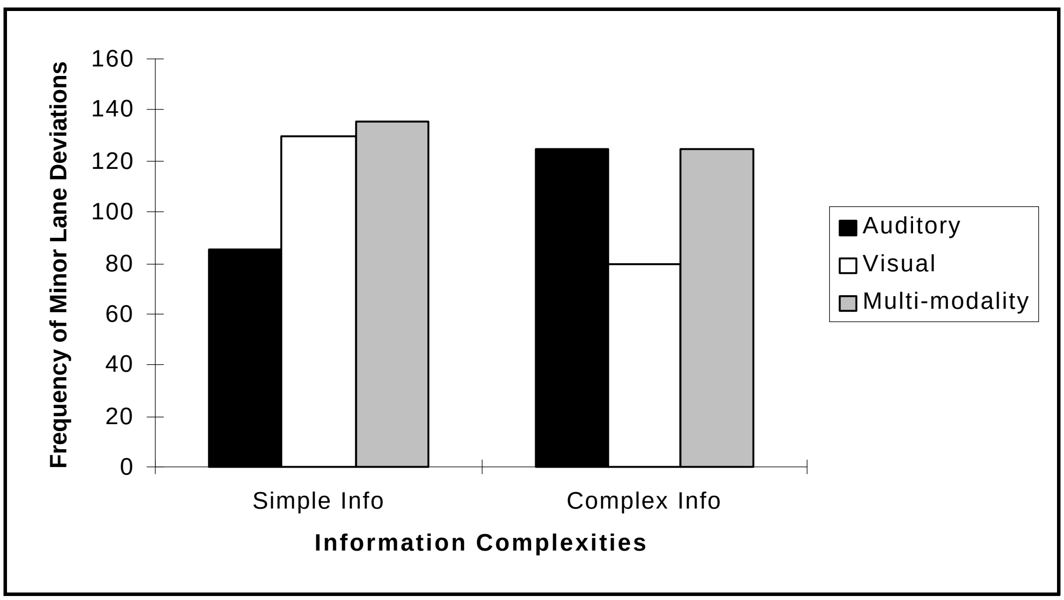

Figure 44. Frequency of minor lane deviations for different information complexities broken down by display modality.

Low Driving Load Condition — Results of the Steering-Related Assessments

Variance in Steering Wheel Position

Appendix F, Table 30 shows the ANOVA results for variance in steering wheel position. Figure 45 shows the interaction of Modality x Information Complexity. Note that for each display, the variance in the simple information condition was less than in the complex information condition. The contrasts tests indicated that for the simple information condition, there were no significant differences among the three displays. For the complex information condition, there was a significant difference between the visual display and multi-modality display [F(1,183)=4.67, p= 0.0320].

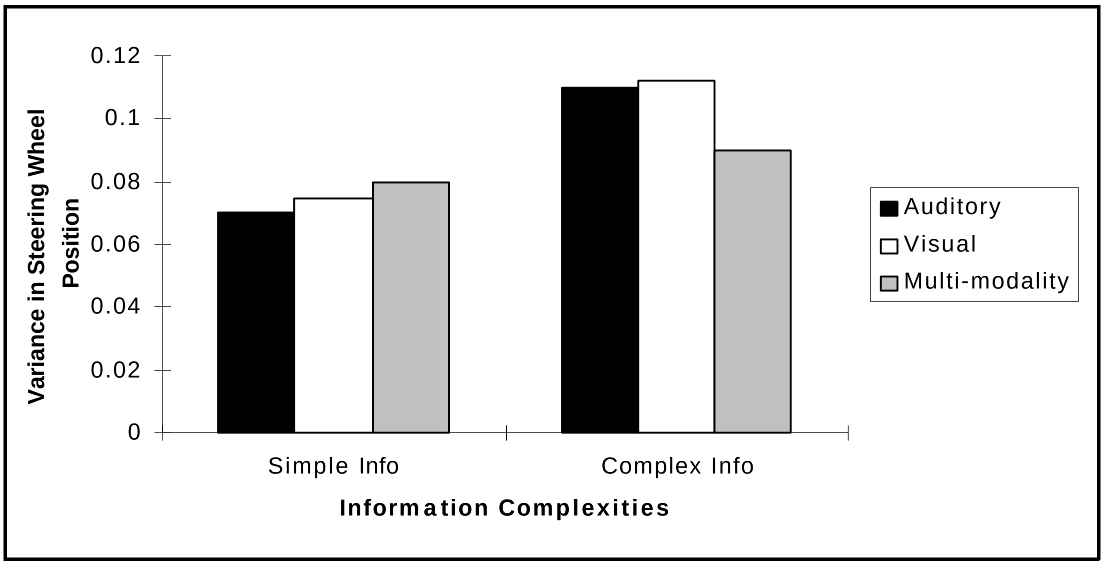

Figure 45. Variance in steering wheel position for different information complexities broken down by display modality.

Overall, the complex information condition resulted in a larger variance in steering wheel position than did the simple information. As expected, this suggests that the complex information condition demanded higher attention or causes more distraction than does the simple information condition.

Frequency of Large Steering Reversals

Appendix F, Table 31 shows the ANOVA results for the frequency of large steering reversals. Figure 46 depicts the significant two-way Modality x Complexity interaction [F(2,57)=7.68, p=0.0011].

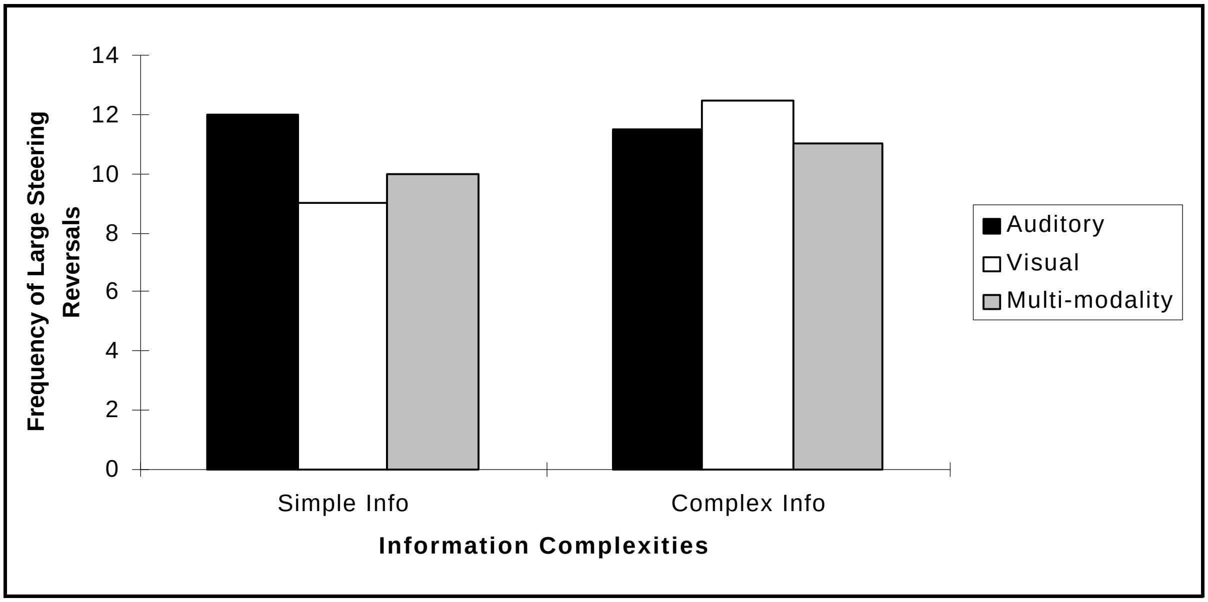

Figure 46. Frequency of large steering reversals for different information complexities broken down by display modality.

The treatment-contrast tests used to examine the differences among the three displays for the complex information condition revealed no significant differences. In the simple information condition, the only significant difference was found for the auditory display versus visual display [F(1,183)=5.74, p= 0.0176]. There were no significant differences for the visual display as compared to the other two displays for the complex information condition. For the simple information condition, the visual display resulted in the fewest number of steering reversals.

Age was another significant factor influencing the frequency of large steering wheel reversals [F(1,30)=16.94, p=0.0003]. On average, the younger drivers made fewer (mean value 9) reversals than did the older drivers (mean value 13).

POST-TEST QUESTIONNAIRE RESULTS

The results of the ANOVA for the post-test questionnaire are shown in Appendix F, Table 32. After finishing the simulator experiment, each driver was requested to fill out a post-test questionnaire containing seven comparison questions (see Appendix C). Drivers were instructed to compare the three display modalities based on their experiences during the experimental drive and to mark "one" for the most preferable display, a "two" for the second most preferred display, and a "three" for the least preferred display.

Results showed that the main effect, Modality, was significant in questions one [$F(2,58)=9.63$, $p=0.0002$], three [$F(2,58)=15.82$, $p=0.0001$], five [$F(2,58)=18.55$, $p=0.0001$], and seven [$F(2,58)=15.26$, $p=0.0001$]. Figure 47 shows that drivers had equal preferences for presenting the route guidance information on the multi-modality display and the auditory display. Figure 48 reveals that drivers preferred using the multi-modality display or the auditory display for the presentation of hazard warning information. There was no preference difference under the low driving load condition, but Figure 49 shows that under the high driving load condition, drivers preferred using the multi-modality display or the auditory display over the visual display. However, Figure 50 reveals that in an overall preference rating of the three different display modalities, the multi-modality display was preferred to the auditory display. The visual display received the lowest score, both from the preference rating done in the subjective workload section and from the post-test questionnaire.

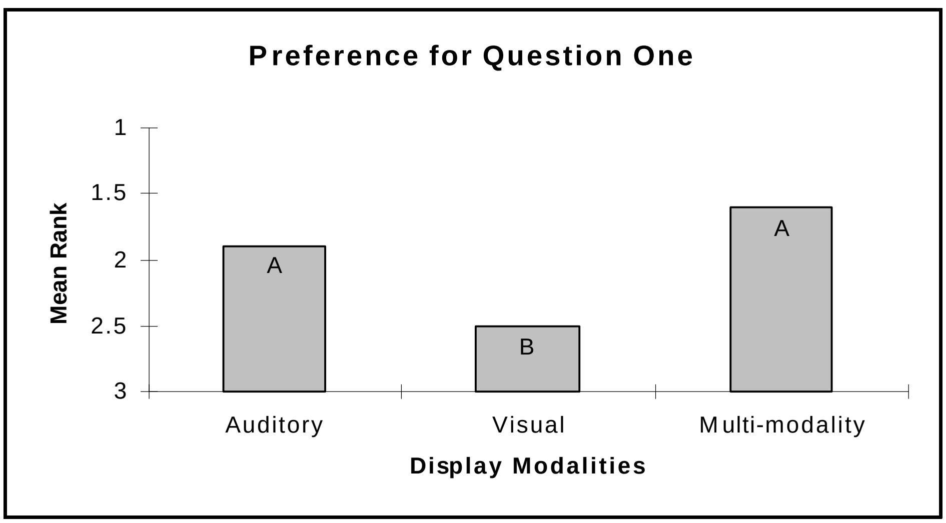

Figure 47. Subjective preference for different display modalities in presenting route guidance information.

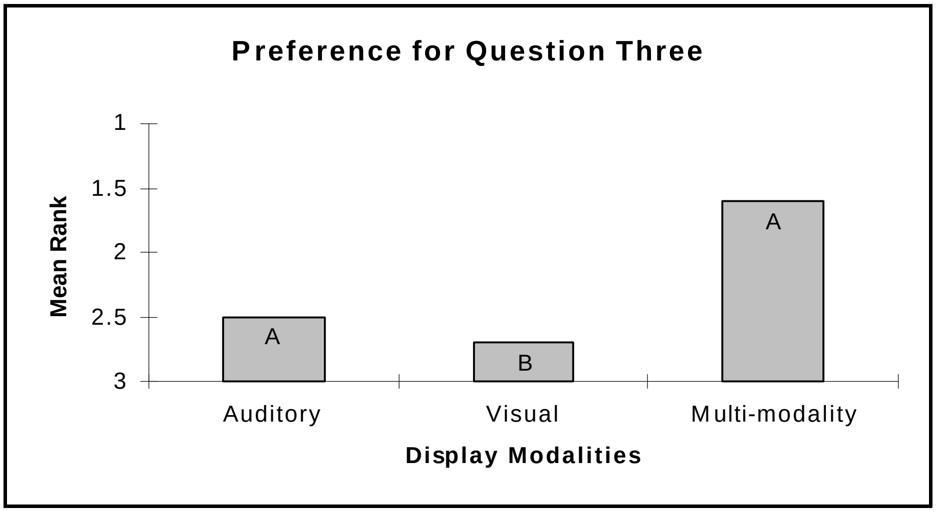

Figure 48. Subjective preference for different display modalities in presenting hazard warning information.

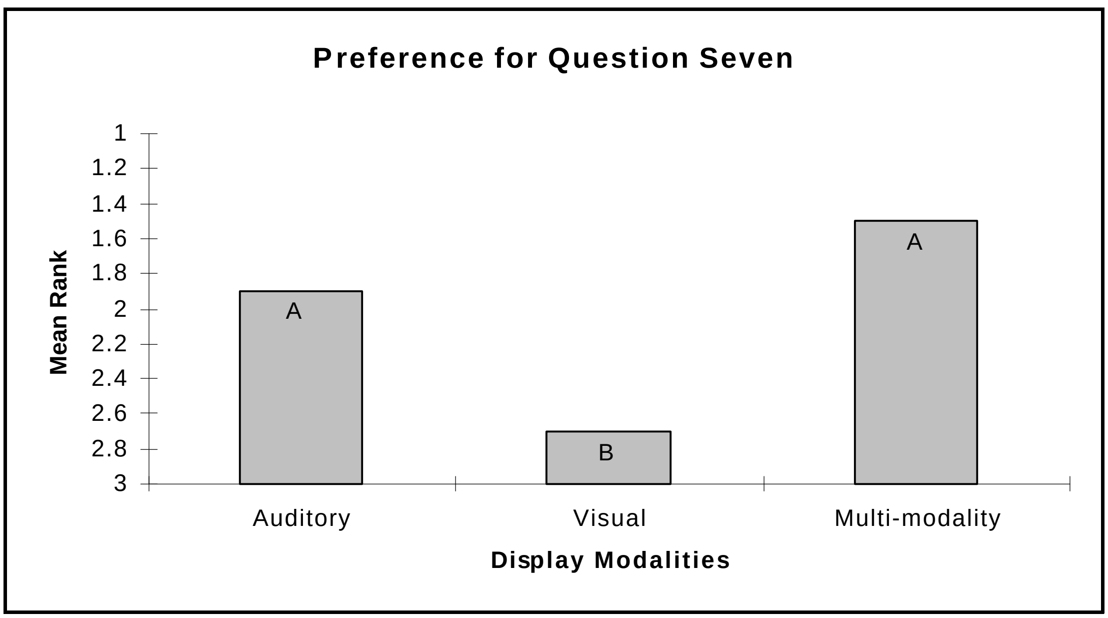

Figure 49. Subjective preference for different display modalities under the high driving load condition.

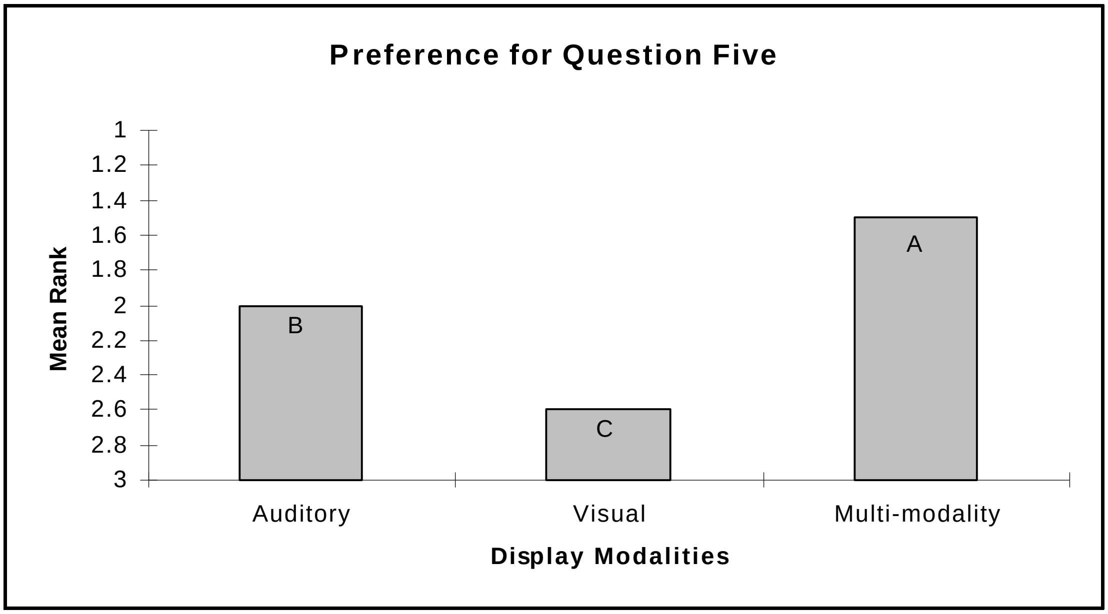

Figure 50. Subjective preference for different display modalities in an overall rating.

CHAPTER 5: DISCUSSION

Based on the objectives of this study and the experimental results, two issues are addressed as they help explain the effectiveness of each display modality and the effect of age on different task performances. The first issue encompasses the two objectives of this study stated earlier. The second issue is raised based on the experimental results. The two issues are: 1) Which display modality results in the best performance; and 2) Are there any significant age-related performance differences between different displays?

Tables 5 summarizes the results for the high driving load condition while Table 6 summarizes the low driving load condition. Those cells marked with "●" indicate the display modalities that have better performance results. Note that due to the many measures of driving performance used in this study, the safety-related driving performance results in the driving task are general conclusions based on the results of these measures. Therefore, a display with a greater number of marks is not necessarily significantly better in every performance measure.

Table 5. The matrix of performance results for different display modalities under the high driving load condition.

Tasks	High Driving Load Condition					
	Complex Information			Simple Information		
	Auditory Display	Visual Display	Multi-modality Display	Auditory Display	Visual Display	Multi-modality Display
Push Button Task						
Reaction Time	!		!	!		!
Number of Misses			!	!		!
Navigation Task						
Total Correct Turns		!	!	!		!
Number of Navigation Errors			!	!		!
Driving Task						
Speed Limits Maintenance			!			!
Safety-related Driving Performance	!		!		!*	!

*Visual displayed information had support from some, but not all, measures.

Table 6. The matrix of performance results for different display modalities under the low driving load condition.

Tasks	Low Driving Load Condition					
	Complex Information			Simple Information		
	Auditory Display	Visual Display	Multi-modality Display	Auditory Display	Visual Display	Multi-modality Display
Push Button Task						
Reaction Time	!		!	!		!
Number of Misses	!		!			!
Navigation Task						
Total Correct Turns		!	!	!	!	
Number of Navigation Errors		!	!	!	!	
Driving Task						
Speed Limits Maintenance			!	!	!	!
Safety-related Driving Performance	!		!	!	!	

ISSUE 1: WHICH DISPLAY MODALITY RESULTS IN THE BEST PERFORMANCE?

Regarding which display modality results in the best performance, there are two specific research questions:

1. To what degree, and under which circumstances, are multi-modality displays beneficial?
2. For circumstances where multi-modality displays are not beneficial, which single display modality results in the best performance?

Subjective Workload Measures

Of the three displays, the visual display was given the highest workload scores for time stress, visual effort, psychological stress, and overall workload. The results indicate that using the visual display to present ATIS information does increase drivers' driving mental workload, especially when the driving load is high and the information is complex. In addition, it should be noted that the position of this visual display was "optimal" in that it was very close to the forward field of view. Other display locations would undoubtedly amplify this negative effect. In addition, there was very high contrast and no glare in these simulated conditions. The possibility that these factors may contribute to further increases in subjective workload should be considered in future visual display designs.

Some of the rating values of the multi-modality display are a little higher than those of the auditory display. Unlike the multi-modality display, the auditory display does not make drivers look away from the roadway, possibly explaining the fact that the auditory display received the lowest workload ratings for time stress in the high load condition. The multi-modality display is designed to present safety information redundantly. For non-safety-related information, the display is designed to provide a “chime” sound and then present the information visually. Therefore, drivers still had to process some information visually.

Effectiveness in Emergency Response — Secondary Task Performance

Based on the measures of reaction time and the number of missed stimuli, the multi-modality display is the best solution to help the driver detect and respond to emergency information. Furthermore, changing the information complexity and the driving load condition resulted in only slightly reduced performance when using the multi-modality display. This may be due to the fact that the multi-modality display presents the information redundantly, making it easier for the driver to detect and interpret the information, and react to it more quickly.

Because of its omnipresence, the auditory display should help drivers respond to information quickly; however, considering the number of missed button presses, the auditory display appears to be less efficient in helping drivers to respond to the information. Noise related to the simulator and lack of attention to the auditory display may explain why drivers had more misses with the auditory display than when using the multi-modality display, especially when the information was complex and the driving load was high. In this study, complex auditory information is defined as frequently occurring serial information. In the high driving load condition, it may be difficult for drivers to pay attention to the display all the time (although in this study, a verbal cue—WARNING—is used) because of higher workload, making it inevitable that they will miss some of the information. Noise is more of a problem in a real driving environment than with a simulator (e.g., trucks passing, stereo playing). Therefore, without improving the auditory display or solving on-road noise issues, presenting important information on the auditory display during high workload or high noise periods may cause some driver error on the roadway.

The display modality that elicited the slowest performance for responding and detecting emergency information was the visual modality. Drivers can detect and respond to visual information based on a residual visual capacity which will allow them to look away from the roadway; however, the worst detection performance with visual display occurs for presenting complex information. Therefore, complex information still should not be presented via the visual modality alone.

Effectiveness in Route Guidance — The Navigation Task Performance

In the high driving load condition, performance (as measured by the number of correct turns) is best with the multi-modality display and worst with the visual display. However, with complex information, drivers make more correct turns with the visual display than with the auditory display. The results show that only one wrong turn occurred by a driver using the visual display, during the simple information, low driving load condition. These good performance results may be credited to the complex navigation information format designed for the visual display, which has the advantages of being compatible with the real roadway environment and easy to understand. Most of the navigation-related errors caused by using the visual display occurred when the information was simple and driving load was high, many of which were misses and near misses. It may be that because of the design of the visual display and the high workload, it was difficult for users to notice simple navigation information on the visual display.

The auditory display resulted in better navigation performance in the simple information condition; however, when complex information was presented in either the simple or complex driving load condition, drivers made the most turn errors. This implies that when complex navigation information is presented on an auditory display, drivers easily forget it or are confused by it, and thus make more wrong turns. Therefore, system designers must be careful to organize auditory information items in a way that does not confuse/interfere with the driver's memory and optimizes the display's navigation-aid efficiency.

Effectiveness in Safe Driving Behavior — The Driving Task Performance

Under the High Driving Load Condition

From most of the attention-related performance measures, the visual display, despite making drivers drive slowly or cautiously, required more attention and caused more safety-related errors than did the other two displays in the complex information/high driving load condition. Complex information had the worst performance impact on drivers using the visual display. Results indicate that with complex information, the visual display resulted in higher variance in lateral lane position, higher frequencies of major/minor lane deviations, higher variance in steering wheel reversals, and higher frequencies of larger steering wheel reversals. Since it appears very easy to overload drivers with complex information in the high driving load condition, complex information should be limited on a visual display.

Complex information on the auditory display resulted in slower driving speed. Slower driving speed significantly decreased the variance in longitudinal velocity and acceleration. This indicates that complex information on the auditory display, to some degree, still increased drivers' mental workload (e.g., psychological stress), resulting in more cautious driving than in the simple information condition. This may also explain why the auditory display results, in some performance measures related to the driving attention demands, were inconsistent with previously mentioned results. It was clear from these results that multi-modality displays provide a clear benefit over other modalities when the driver's total workload is relatively high.

Under the Low Driving Load Condition

In the complex information condition, the multi-modality display was the best for maintaining the speed limit requirements, and the visual display was the worst. In addition to the largest speed deviations, the visual display condition resulted in more lane deviations, more large steering wheel reversals, and larger variance in the steering wheel reversals. The driving task requires considerable visual effort, and complex information on the visual display reduced drivers' visual attention to the roadway, especially when risk perception was low. The results shown here indicate that even in the low driving load condition, which includes straight and multi-lane roads, complex information on the visual display increased unsafe driving behavior.

In most of the measures for the auditory display in the high driving load condition, the complex information raised drivers' caution/awareness and thus improved their performance. However, in the low driving load condition, complex information presented on the auditory display appears to have worsened their performance. Conversely, simple information on the auditory display, in conjunction with low driving load, appears to improve performance.

For the multi-modality display, the performance differences between the simple information and the complex information were not so distinctive. The information complexities did not appear to significantly change the workload when using the multi-modality display. However, some performance measures in the simple information condition (e.g., the frequency of the major/minor lane deviations) show that the multi-modality display resulted in unsafe driving behaviors. This may have been due to a combination of display novelty and omnipresence, in conjunction with a reduced risk perception associated with the low driving load (e.g., no traffic) condition.

Therefore, overall it appears that in virtually every circumstance, multi-modality displays are more beneficial than either of the single modality displays. Multi-modality displays exhibited safer driving behavior under both driving load conditions, were more effective in route guidance, and more effective in emergency response. Multi-modality displays also exhibited better scores on many subjective workload measures, except for a few rating values in which ratings for multi-modality displays were slightly higher than those for auditory displays.

ISSUE 2: ARE THERE ANY SIGNIFICANT AGE-RELATED PERFORMANCE DIFFERENCES BETWEEN DIFFERENT DISPLAYS?

It was hypothesized that age would significantly affect the drivers’ performance when using the different displays. It was also hypothesized that the multi-modality display would improve performance, especially for the older drivers, because of its information redundancy.

The issue of age is important in designing the ATIS displays since the number of older drivers on the road is increasing. Previous studies show that older drivers have less residual attention (Dingus et al., 1989) and poorer perceptual/cognitive abilities (Temple, 1989). The results reported from this research appear to confirm those findings.

In general, the older drivers had poorer task performance results and gave higher workload ratings than did the younger drivers. The older drivers also had slower reaction times; more missed button pushes; fewer correct turns and more navigation-related errors; and higher time stress, psychological stress, and overall workload. Performance degraded more in the high driving load condition. In each driving load condition, the older drivers showed poorer performance with complex information than with simple information. Performance degradation also occurred during higher information complexity with the younger group. Therefore, when designing ATIS displays, system designers should present the information as simply as possible.

Both age groups using the multi-modality display had better performance, but this was especially true of the older group. For the secondary task, older drivers using the auditory and the multi-modality displays had faster reaction times than when using the visual display, and had the fewest number of missed button pushes when using the multi-modality display. In the navigation task, the older drivers made significantly more navigation-related errors (wrong or missed turn) when using the auditory display, and missed more turns when using the visual display. The benefits of using the multi-modality display for the older drivers are more pronounced when the driving load condition is high and the information is complex.

Regarding driving behavior, the older drivers tended to drive more slowly and cautiously, especially when using the visual display, to compensate for the increased mental workload. Slower driving contributed to a smaller variance in longitudinal velocity and acceleration. It is possible that because the younger drivers may have low risk perception or felt low mental workload, they tended to drive faster and thus have higher variance values in the longitudinal velocity and the acceleration.

The performance results indicate that in the high driving load condition/complex information condition, the older drivers using the visual display made more safety-related errors and experienced more attention demands than older drivers using the other two displays. The older drivers made a greater number of minor lane deviations, had more variance in steering wheel reversals, and made a greater number of larger steering wheel reversals. However, some performance measures (e.g., frequency of minor lane deviations, variance in the steering wheel reversals) show that in the simple information, high driving load conditions, the older drivers made few safety errors. As mentioned above, driving slowly and cautiously, and missing critical ATIS information, are the costs of better safety-related performance. This finding indicates that the older drivers may not have enough residual attention for both the roadway and the visual display, even in the simple information condition. However, a correct trade-off between driving safely and perceiving/detecting the information on the visual display still apparently exists, even in the simulation environment.

CHAPTER 6: CONCLUSIONS AND GUIDELINES DEVELOPMENT

Based on study results, four primary findings of this research are summarized:

- For emergency response displays, the multi-modality and the auditory displays resulted in faster reaction times than the visual display for detecting warning information, while information presented on the multi-modality display resulted in fewer errors than the auditory display.
- For navigation tasks, the multi-modality display resulted in the best performance for both total correct turns and number of navigation-related errors. More wrong turns and miss/near-miss turns are made when using the auditory display and the visual display, respectively. More wrong turns occurred when using the auditory display in the complex information condition, indicating that memory interference is a considerable problem for designing an auditory display. However, the complex navigation information (featuring a route guidance graphic that shows a large turn direction arrow, turn intersection, and distance to turn) on the visual display resulted in significantly fewer wrong turns (only one wrong turn in this study). This implies that the visual display has the advantage of presenting information compatible with the road environment.
- For driving performance, the multi-modality display generally resulted in better performance for both speed maintenance and safe driving behavior. Because of its relatively low attention demands, it increased driving safety. Conversely, the visual display condition required more attention from drivers and caused more safety-related errors than the other two displays, thus causing the least safe condition.
- For subjective workload and preference ratings, the multi-modality display and the auditory display received more preferable ratings than did the visual display. Drivers also prefer the auditory display and the multi-modality display for presenting hazard warning and route guidance information.

The findings comparing the three display modalities are more pronounced in the complex information condition. Information complexity has the greatest impact when using the visual display.

Age differences were seen in the performance results. Both age groups benefited by using the multi-modality display. It is important to note that using the multi-modality display significantly improved the older drivers' performance when conducting the secondary and navigation tasks. The older drivers' poorest performance occurred when using the visual display, especially when the information was complex and the driving load was high.

GUIDELINES DEVELOPMENT

Based on the conclusions listed above, the following guidelines for an ATIS designer were developed:

- The ATIS information should be designed to be as simple as possible. More complex information presented on either the single- or multi-modality displays will increase the driver's workload and can result in safety-related driving performance decrements. As a guideline, five or fewer information items (consisting of simple phrases, icons, sign graphics, etc.) should be presented at one time visually, and the auditory channel should be reserved for safety or time critical messages, or simple auditory icons devoted to informing the driver of a change in visual display status.

- If complex information is inevitable, providing a multi-modality display will lower workload and will result in better performance than presenting the information on a single-modality display. However, it is still important to limit the complexity of information on the visual display. This guideline is especially true in high driving load situation.
- Critical ATIS information that requires the driver to respond quickly and correctly should be presented on a multi-modality display.
- In designing for older drivers, a multi-modality display to present the ATIS information has the additional benefit of improving safe driving behavior.
- To avoid annoying the users, the auditory component of the multi-modality display should be used in a conservative way. Use simple auditory cues for non-safety-related information or to inform drivers that there is information on the visual display.

Appendix A — INFORMATION SUMMARY

Project Title: Human Factors Evaluation of Three Different Display Modalities
Investigators: Tom Dingus and Yung-Ching Liu

Thank you for coming in today. The purpose of this study is to evaluate the effectiveness of three different display modalities: auditory, visual, and auditory + visual. We will be gathering information and input to determine the advantages/disadvantages of each display modality.

If you agree to participate, you will be asked to drive a low cost simulator and answer questionnaires after each test section. Your participation should take approximately 1.5 hours (approximately 6.5 minutes in driving the simulator for each test section, and there will be 6 sections total). 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 Tom Dingus at 335-5696 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.

______________________ _______ __________________________ _______

Investigator Date Witness Date

Appendix B — INFORMED CONSENT FORM

Project Title: Human Factors Evaluation of Three Different Display Modalities
Investigators: Tom Dingus and Yung-Ching Liu

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 that may identify me will be kept confidential. I understand the possible risks and the possible benefits to me and 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 Tom Dingus at 335-5696 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 — POST-TEST QUESTIONNAIRE

Post-Experiment Questionnaire

Date : ---------------
Experiment # ----------
Subject # -----------

Comparison Questions

Please **compare the displays** based on your personal experiences during the whole experiment.

Please give your preference priority **(1 = the most you prefer; 2 = the display is OK for you; and 3 = the display you don't like)** on the horizontal line that best represents your opinion regarding the statement.

Thank you!

1. **For the route guidance information** (e.g., turn right, name of street to turn, etc.), which modality display do you prefer?
    ___ the Visual display
    ___ the Auditory display
    ___ the Auditory + Visual display

2. **For the road sign information** (e.g., curve, speed limits, road construction, etc.), which modality display do you prefer?
    ___ the Visual display
    ___ the Auditory display
    ___ the Auditory + Visual display

3. **For the hazard warning information** (e.g., ICY ROAD AHEAD, TRAFFIC ACCIDENT AHEAD etc.), which modality display do you prefer?
    ___ the Visual display
    ___ the Auditory display
    ___ the Auditory + Visual display

4. **For the vehicle condition monitoring information** (e.g., engine temperature too high, low gas level, etc.), which modality display do you prefer?
    ___ the Visual display
    ___ the Auditory display
    ___ the Auditory + Visual display

5. In your **overall evaluation,** which modality display do you prefer?

___ the Visual display
___ the Auditory display
___ the Auditory + Visual display

6. **Under easy driving condition** (straight road, light traffic), which modality display do you prefer?

___ the Visual display
___ the Auditory display
___ the Auditory + Visual display

7. **Under difficult driving condition** (curvy road, heavy traffic), which modality display do you prefer?

___ the Visual display
___ the Auditory display
___ the Auditory + Visual display

Appendix D — EXAMPLES OF SCENARIO MAPS

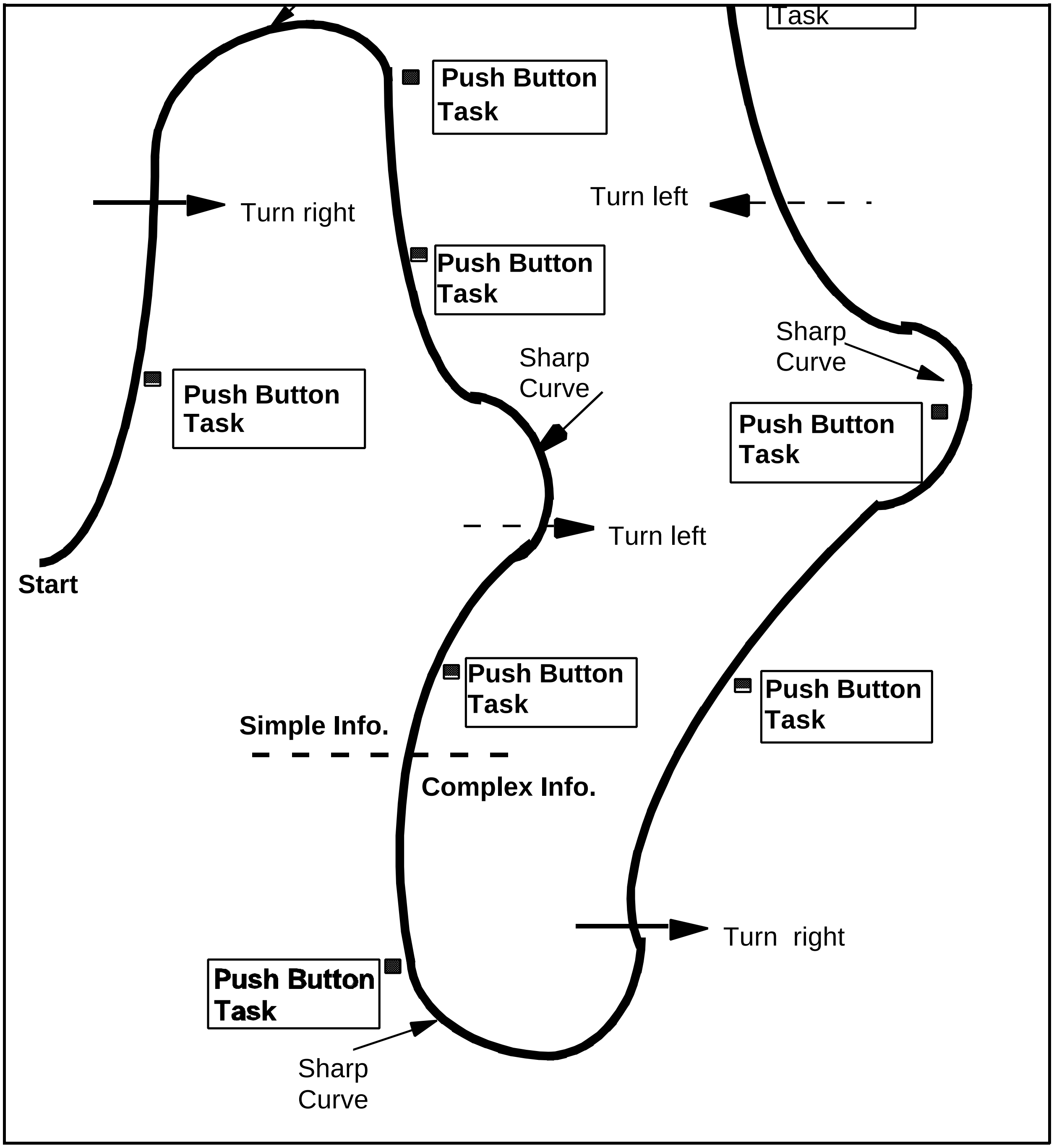

Figure 51. Example of scenario map in high driving load condition.

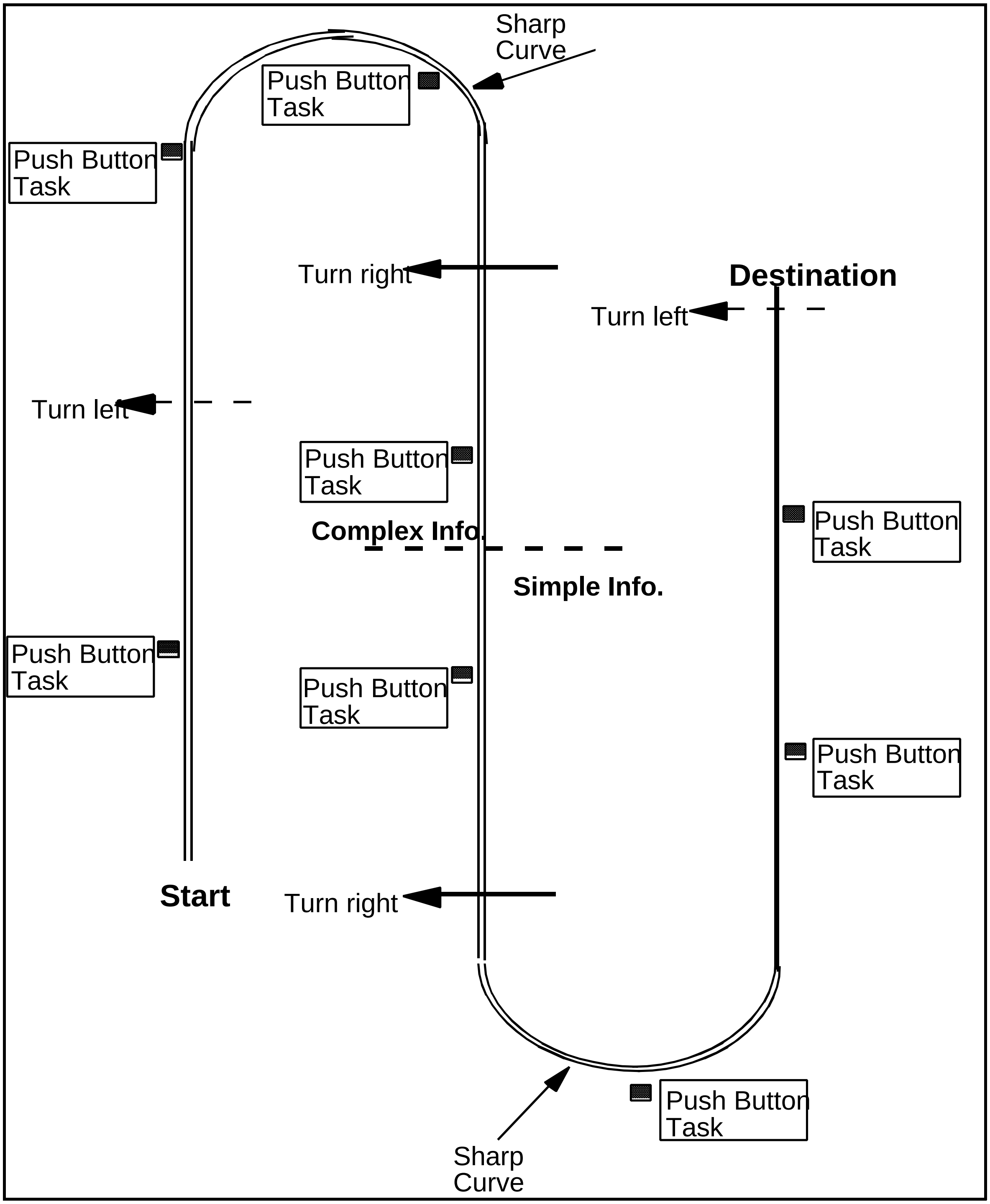

Figure 52. Example of scenario map in low driving load condition.

Appendix E — TEST ORDER

Table 7. Test order.

GROUP	SUB. #	SEX	TEST ORDER
Younger	1	M	*AL, AH, VL, VH, ML, MH*
	2	F	*AH, VL, VH, ML, MH, AL*
	3	M	*VL, VH, ML, MH, AL, AH*
	4	F	*VH, ML, MH, AL, AH, VL*
	5	M	*ML, MH, AL, AH, VL, VH*
	6	F	*MH, AL, AH, VL, VH, ML*
	7	M	*AH, AL, VL, VH, ML, MH*
	8	F	*VL, AH, VH, ML, MH, AL*
	9	M	*VH, VL, ML, MH, AH, AL*
	10	F	*ML, VH, MH, AL, AH, VL*
	11	M	*MH, ML, AL, AH, VL, VH*
	12	F	*AL, MH, AH, VL, VH, ML*
	13	M	*VL, AH, AL, VH, ML, MH*
	14	F	*VH, VL, AH, ML, MH, AL*
	15	M	*ML, VH, VL, MH, AL, AH*
	16	F	*MH, ML, VH, AL, AH, VL*
Older	101	M	*AL, MH, ML, AH, VL, VH*
	102	F	*AH, AL, MH, VL, VH, ML*
	103	M	*VH, VL, AH, AL, ML, MH*
	104	F	*ML, VH, VL, AH, MH, AL*
	105	M	*MH, ML, VH, VL, AL, AH*
	106	F	*AL, MH, ML, VH, AH, VL*
	107	M	*AH, AL, MH, ML, VL, VH*
	108	F	*VL, AH, AL, MH, VH, ML*
	109	M	*ML, VH, VL, AH, AL, MH*
	110	F	*ML, MH, VH, VL, AH, AL*
	111	M	*AL, MH, ML, VH, VL, AH*
	112	F	*AH, AL, MH, ML, VH, VL*
	113	M	*VL, AH, AL, MH, ML, VH*
	114	F	*VH, VL, AH, AL, MH, ML*
	115	M	*MH, ML, VH, VL, AH, AL*
	116	F	*AL, MH, ML, VH, VL, AH*

AL Auditory, Low Driving Load
AH Auditory, High Driving Load
VL Visual, Low Driving Load
VH Visual, High Driving Load
ML Multi-modality, Low Driving Load
MH Multi-modality, High Driving Load

Appendix F — ANOVA TABLES

Table 8. ANOVAs for the performance of reaction time.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	105.0808	12.64	**0.0013**
Modality	2	73.0150	18.82	**0.0001**
Load	1	6.7821	2.70	0.1109
Complexity	1	65.3678	26.20	**0.0001**
Age x Modality	2	38.3008	9.87	**0.0002**
Age x Load	1	0.3005	0.12	0.7319
Age x Complexity	1	4.3780	1.75	0.1953
Modality x Load	2	0.8938	0.34	0.7155
Modality x Complexity	2	20.6331	14.61	**0.0001**
Load x Complexity	1	1.3855	0.98	0.3308
Age x Modality x Load	2	4.3041	1.62	0.2062
Age x Modality x Complexity	2	5.7651	4.08	**0.0218**
Age x Load x Complexity	1	1.6401	1.16	0.2907
Modality x Load x Complexity	2	6.0918	3.78	**0.0285**
Age x Modality x Load x Complexity	2	2.0533	1.28	0.2870
Subject (Age)	30	8.3105		
Modality x Subject (Age)	60	3.8804		
Load x Subject (Age)	30	2.5134		
Complexity x Subject (Age)	30	2.4952		
Modality x Load x Subject (Age)	60	2.6547		
Modality x Complexity x Subject (Age)	60	1.4126		
Load x Complexity x Subject (Age)	30	1.4176		
Modality x Load x Complexity x Subject (Age)	58	1.6097		

Table 9. ANOVAs for the performance of total number of missed button pushes.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	0.8438	0.78	0.3838
Modality	2	12.8932	31.32	**0.0001**
Load	1	0.0417	0.13	0.7182
Complexity	1	21.0938	47.24	**0.0001**
Age x Modality	2	6.0078	14.60	**0.0001**
Age x Load	1	0.3750	1.19	0.2831
Age x Complexity	1	0.0104	0.02	0.8796
Modality x Load	2	5.1120	19.18	**0.0001**
Modality x Complexity	2	2.7266	8.20	**0.0007**
Load x Complexity	1	0.0417	0.18	0.6774
Age x Modality x Load	2	1.4766	5.54	**0.0062**
Age x Modality x Complexity	2	0.0495	0.15	0.8620
Age x Load x Complexity	1	2.0417	8.65	**0.0063**
Modality x Load x Complexity	2	5.9245	20.67	**0.0001**
Age x Modality x Load x Complexity	2	0.8932	3.12	0.0516
Subject (Age)	30	1.0799		
Modality x Subject (Age)	60	0.4116		
Load x Subject (Age)	30	0.3139		
Complexity x Subject (Age)	30	0.4465		
Modality x Load x Subject (Age)	60	0.2665		
Modality x Complexity x Subject (Age)	60	0.3325		
Load x Complexity x Subject (Age)	30	0.2361		
Modality x Load x Complexity x Subject (Age)	60	0.2866		

Table 10. ANOVAs for the time stress ratings.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	18.3750	9.82	**0.0038**
Modality	2	0.6563	1.12	0.3327
Load	1	2.3438	7.29	**0.0113**
Complexity	1	2.3438	10.20	**0.0033**
Age x Modality	2	0.0313	0.05	0.9481
Age x Load	1	0.0104	0.03	0.8584
Age x Complexity	1	0.0938	0.41	0.5279
Modality x Load	2	1.6250	4.51	**0.0149**
Modality x Complexity	2	0.0938	0.38	0.6885
Load x Complexity	1	0.0000	< 0.01	1.0000
Age x Modality x Load	2	0.3229	0.90	0.4133
Age x Modality x Complexity	2	0.0000	< 0.01	1.0000
Age x Load x Complexity	1	0.6667	3.75	0.0623
Modality x Load x Complexity	2	0.0313	0.18	0.8392
Age x Modality x Load x Complexity	2	0.3854	2.17	0.1233
Subject (Age)	30	1.8708		
Modality x Subject (Age)	60	0.5854		
Load x Subject (Age)	30	0.3215		
Complexity x Subject (Age)	30	0.2299		
Modality x Load x Subject (Age)	60	0.3601		
Modality x Complexity x Subject (Age)	60	0.2497		
Load x Complexity x Subject (Age)	30	0.1778		
Modality x Load x Complexity x Subject (Age)	60	0.1778		

Table 11. ANOVAs for the visual effort ratings.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	1.8984	1.16	0.2896
Modality	2	8.7057	15.45	**0.0001**
Load	1	3.9609	9.42	**0.0045**
Complexity	1	3.5651	13.70	**0.0009**
Age x Modality	2	0.4766	0.85	0.4342
Age x Load	1	0.0026	0.01	0.9378
Age x Complexity	1	0.2109	0.81	0.3751
Modality x Load	2	0.1016	0.26	0.7691
Modality x Complexity	2	0.0339	0.16	0.8556
Load x Complexity	1	0.0234	0.10	0.7494
Age x Modality x Load	2	0.4245	1.10	0.3389
Age x Modality x Complexity	2	0.0547	0.25	0.7776
Age x Load x Complexity	1	0.1276	0.57	0.4578
Modality x Load x Complexity	2	0.3047	1.77	0.1796
Age x Modality x Load x Complexity	2	0.4401	2.55	0.0863
Subject (Age)	30	1.6332		
Modality x Subject (Age)	60	0.5634		
Load x Subject (Age)	30	0.4207		
Complexity x Subject (Age)	30	0.2602		
Modality x Load x Subject (Age)	60	0.3852		
Modality x Complexity x Subject (Age)	60	0.2165		
Load x Complexity x Subject (Age)	30	0.2255		
Modality x Load x Complexity x Subject (Age)	60	0.1724		

Table 12. ANOVAs for the psychological stress ratings.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	15.8438	6.93	**0.0133**
Modality	2	1.5703	4.68	**0.0129**
Load	1	1.0417	3.34	0.0777
Complexity	1	2.0417	12.38	**0.0014**
Age x Modality	2	0.1953	0.58	0.5619
Age x Load	1	0.0938	0.30	0.5877
Age x Complexity	1	0.8438	5.12	**0.0311**
Modality x Load	2	0.5495	1.31	0.2770
Modality x Complexity	2	0.1745	0.96	0.3894
Load x Complexity	1	0.0000	< 0.01	1.0000
Age x Modality x Load	2	0.3828	0.91	0.4065
Age x Modality x Complexity	2	0.1953	1.07	0.3486
Age x Load x Complexity	1	0.5104	4.19	**0.0496**
Modality x Load x Complexity	2	0.0078	0.04	0.9616
Age x Modality x Load x Complexity	2	0.1745	0.87	0.4222
Subject (Age)	30	2.2871		
Modality x Subject (Age)	60	0.3356		
Load x Subject (Age)	30	0.3122		
Complexity x Subject (Age)	30	0.1649		
Modality x Load x Subject (Age)	60	0.4189		
Modality x Complexity x Subject (Age)	60	0.1821		
Load x Complexity x Subject (Age)	30	0.1219		
Modality x Load x Complexity x Subject (Age)	60	0.1995		

Table 13. ANOVAs for the overall workload ratings.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	93.0234	6.15	**0.0190**
Modality	2	24.2995	7.44	**0.0013**
Load	1	20.6276	8.79	**0.0059**
Complexity	1	23.5026	20.69	**0.0001**
Age x Modality	2	0.9141	0.28	0.7568
Age x Load	1	0.0651	0.03	0.8688
Age x Complexity	1	2.8359	2.50	0.1246
Modality x Load	2	4.8932	2.17	0.1231
Modality x Complexity	2	0.2370	0.26	0.7693
Load x Complexity	1	0.0234	0.03	0.8701
Age x Modality x Load	2	0.2682	0.12	0.8881
Age x Modality x Complexity	2	0.4453	0.50	0.6120
Age x Load x Complexity	1	3.5651	4.14	0.0508
Modality x Load x Complexity	2	0.2891	0.29	0.7469
Age x Modality x Load x Complexity	2	1.7995	1.83	0.1700
Subject (Age)	30	15.1255		
Modality x Subject (Age)	60	3.2651		
Load x Subject (Age)	30	2.3464		
Complexity x Subject (Age)	30	1.1359		
Modality x Load x Subject (Age)	60	2.2557		
Modality x Complexity x Subject (Age)	60	0.8995		
Load x Complexity x Subject (Age)	30	0.8609		
Modality x Load x Complexity x Subject (Age)	60	0.9859		

Table 14. ANOVAs for the subjective preference ratings.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	0.8438	0.09	0.7698
Modality	2	32.2975	15.47	**0.0001**
Load	1	2.5026	2.34	0.1368
Complexity	1	13.1276	7.62	**0.0097**
Age x Modality	2	2.6035	1.25	0.2947
Age x Load	1	0.7526	0.70	0.4084
Age x Complexity	1	3.5651	2.07	0.1606
Modality x Load	2	0.1452	0.19	0.8286
Modality x Complexity	2	1.1647	1.26	0.2909
Load x Complexity	1	0.6667	1.40	0.2454
Age x Modality x Load	2	0.5163	0.67	0.5151
Age x Modality x Complexity	2	0.3639	0.39	0.6762
Age x Load x Complexity	1	0.0417	0.09	0.7691
Modality x Load x Complexity	2	0.5163	1.07	0.3495
Age x Modality x Load x Complexity	2	1.0788	2.25	0.1139
Subject (Age)	30	9.6729		
Modality x Subject (Age)	60	2.0880		
Load x Subject (Age)	30	1.0707		
Complexity x Subject (Age)	30	1.7227		
Modality x Load x Subject (Age)	60	0.7696		
Modality x Complexity x Subject (Age)	60	0.9241		
Load x Complexity x Subject (Age)	30	0.4750		
Modality x Load x Complexity x Subject (Age)	60	0.4789		

Table 15. ANOVAs for the total number of correct turns.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	1.2604	15.25	**0.0005**
Modality	2	0.1745	1.63	0.2047
Load	1	0.0417	0.45	0.5053
Complexity	1	0.2604	3.50	0.0710
Age x Modality	2	0.1120	1.05	0.3579
Age x Load	1	0.0417	0.45	0.5053
Age x Complexity	1	0.0104	0.14	0.7107
Modality x Load	2	0.3464	4.35	**0.0173**
Modality x Complexity	2	0.2370	2.81	0.0679
Load x Complexity	1	0.0417	0.52	0.4776
Age x Modality x Load	2	0.0964	1.21	0.3056
Age x Modality x Complexity	2	0.2370	2.81	0.0679
Age x Load x Complexity	1	0.0417	0.52	0.4776
Modality x Load x Complexity	2	0.0964	1.55	0.2215
Age x Modality x Load x Complexity	2	0.0339	0.54	0.5837
Subject (Age)	30	0.0826		
Modality x Subject (Age)	60	0.1071		
Load x Subject (Age)	30	0.0917		
Complexity x Subject (Age)	30	0.0743		
Modality x Load x Subject (Age)	60	0.0797		
Modality x Complexity x Subject (Age)	60	0.0842		
Load x Complexity x Subject (Age)	30	0.0806		
Modality x Load x Complexity x Subject (Age)	60	0.0623		

Table 16. ANOVAs for driving performance measure of mean longitudinal velocity — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	5993.0854	7.89	**0.0087**
Modality	2	603.7010	4.07	**0.0021**
Complexity	1	32.4526	0.50	0.4851
Age x Modality	2	66.5672	0.45	0.6408
Age x Complexity	1	56.1283	0.86	0.3600
Modality x Complexity	2	447.1311	8.44	**0.0006**
Age x Modality x Complexity	2	17.7908	0.34	0.7162
Subject (Age)	30	759.444		
Modality x Subject (Age)	60	148.463		
Complexity x Subject (Age)	30	64.947		
Modality x Complexity x Subject (Age)	60	53.006		

Table 17. ANOVAs for driving performance measure of mean absolute velocity deviation — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	1464.8589	21.51	**0.0001**
Modality	2	802.9394	21.31	**0.0001**
Complexity	1	2236.4936	115.97	**0.0001**
Age x Modality	2	54.0548	1.43	0.2462
Age x Complexity	1	2.2855	0.12	0.7331
Modality x Complexity	2	80.2480	4.23	**0.0192**
Age x Modality x Complexity	2	6.7579	0.36	0.7020
Subject (Age)	30	68.1057		
Modality x Subject (Age)	60	37.6746		
Complexity x Subject (Age)	30	19.2845		
Modality x Complexity x Subject(Age)	60	18.9890		

Table 18. ANOVAs for driving performance measure of variance in longitudinal velocity — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	15445.346	0.63	0.4339
Modality	2	3174.736	0.38	0.6824
Complexity	1	12955.678	1.67	0.2059
Age x Modality	2	5132.691	0.62	0.5404
Age x Complexity	1	26447.296	3.41	0.0746
Modality x Complexity	2	22361.31	2.14	0.1261
Age x Modality x Complexity	2	51361.38	4.92	**0.0105**
Subject (Age)	30	24545.97		
Modality x Subject (Age)	60	8253.95		
Complexity x Subject (Age)	30	7748.50		
Modality x Complexity x Subject(Age)	60	10432.25		

Table 19. ANOVAs for driving performance measure of variance in lateral lane position — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	0.9954	0.09	0.7612
Modality	2	8.4163	5.76	**0.0051**
Complexity	1	7.8000	4.06	**0.0222**
Age x Modality	2	3.4025	2.33	0.1061
Age x Complexity	1	1.2139	0.63	0.4329
Modality x Complexity	2	7.7948	6.75	**0.0023**
Age x Modality x Complexity	2	0.8853	0.77	0.4691
Subject (Age)	30	10.5847		
Modality x Subject (Age)	60	1.4608		
Complexity x Subject (Age)	30	1.9212		
Modality x Complexity x Subject(Age)	60	1.1548		

Table 20. ANOVAs for driving performance measure of frequency of major lane deviation — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	1.2812	1.45	0.2372
Modality	2	0.4317	2.73	0.0736
Complexity	1	0.4228	2.34	0.1370
Age x Modality	2	0.2894	1.83	0.1697
Age x Complexity	1	0.2807	1.55	0.2227
Modality x Complexity	2	0.8157	4.92	**0.0105**
Age x Modality x Complexity	2	0.0899	0.54	0.5842
Subject (Age)	30	0.8809		
Modality x Subject (Age)	60	0.1584		
Complexity x Subject (Age)	30	0.1811		
Modality x Complexity x Subject(Age)	60	0.1658		

Table 21. ANOVAs for driving performance measure of frequency of minor lane deviation — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	75.2573	4.00	0.0545
Modality	2	11.5900	5.51	**0.0063**
Complexity	1	1.1857	0.64	0.4294
Age x Modality	2	6.1351	2.92	0.0617
Age x Complexity	1	0.1172	0.06	0.8029
Modality x Complexity	2	69.6203	22.09	**0.0001**
Age x Modality x Complexity	2	13.4866	4.28	**0.0183**
Subject (Age)	30	18.7982		
Modality x Subject (Age)	60	2.1016		
Complexity x Subject (Age)	30	1.8474		
Modality x Complexity x Subject(Age)	60	3.1522		

Table 22. ANOVAs for driving performance measure of variance in steering wheel position — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	0.0331	23.36	**0.0001**
Modality	2	0.0033	4.18	**0.0199**
Complexity	1	0.0027	3.07	0.0902
Age x Modality	2	0.0025	3.16	**0.0494**
Age x Complexity	1	0.0018	2.07	0.1604
Modality x Complexity	2	0.0074	9.63	**0.0002**
Age x Modality x Complexity	2	0.0025	3.21	**0.0476**
Subject(Age)	30	0.0014		
Modality x Subject(Age)	60	0.0008		
Complexity x Subject(Age)	30	0.0009		
Modality x Complexity x Subject(Age)	60	0.0008		

Table 23. ANOVAs for driving performance measure of frequency of large steering reversal (greater than 10 degrees) — Under high driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	26214.587	25.53	**0.0001**
Modality	2	1423.8237	8.51	**0.0006**
Complexity	1	4241.6107	31.24	**0.0001**
Age x Modality	2	224.1297	1.34	0.2695
Age x Complexity	1	644.3157	4.75	**0.0374**
Modality x Complexity	2	7183.391	59.77	**0.0001**
Age x Modality x Complexity	2	1103.878	9.18	**0.0003**
Subject (Age)	30	1026.688		
Modality x Subject (Age)	60	167.246		
Complexity x Subject (Age)	30	135.787		
Modality x Complexity x Subject(Age)	60	120.183		

Table 24. ANOVAs for driving performance measure of mean longitudinal velocity — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	2722.3239	5.45	**0.0264**
Modality	2	15.9138	0.08	0.9199
Complexity	1	2046.2070	40.60	**0.0001**
Age x Modality	2	146.3947	0.77	0.4681
Age x Complexity	1	41.5645	0.82	0.3710
Modality x Complexity	2	17.6279	0.50	0.6068
Age x Modality x Complexity	2	123.0893	3.52	**0.0362**
Subject (Age)	30	499.167		
Modality x Subject (Age)	60	190.449		
Complexity x Subject (Age)	30	50.398		
Modality x Complexity x Subject(Age)	57	34.973		

Table 25. ANOVAs for driving performance measure of mean absolute velocity deviation — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	119.8006	1.13	0.2970
Modality	2	580.3690	10.69	**0.0001**
Complexity	1	282.2257	11.17	**0.0022**
Age x Modality	2	106.4569	1.96	0.1497
Age x Complexity	1	9.0290	0.36	0.5545
Modality x Complexity	2	180.6313	9.36	**0.0003**
Age x Modality x Complexity	2	23.1583	1.20	0.3087
Subject (Age)	30	106.3375		
Modality x Subject (Age)	60	54.3022		
Complexity x Subject (Age)	30	25.2712		
Modality x Complexity x Subject(Age)	57	19.2981		

Table 26. ANOVAs for driving performance measure of variance in longitudinal velocity — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	5177.5400	0.67	0.4189
Modality	2	742.7760	0.38	0.6874
Complexity	1	38972.074	30.29	**0.0001**
Age x Modality	2	4053.2915	2.06	0.1366
Age x Complexity	1	7309.448	5.68	**0.0237**
Modality x Complexity	2	5881.54	2.71	0.0751
Age x Modality x Complexity	2	2243.921	1.03	0.3622
Subject (Age)	30	7708.61		
Modality x Subject (Age)	60	1969.12		
Complexity x Subject (Age)	30	1286.61		
Modality x Complexity x Subject(Age)	57	2170.31		

Table 27. ANOVAs for driving performance measure of variance in lateral lane position — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	180.2944	1.16	0.2879
Modality	2	26.1815	1.33	0.2714
Complexity	1	414.0850	8.79	**0.0059**
Age x Modality	2	16.3079	0.83	0.4409
Age x Complexity	1	164.0511	3.48	0.0718
Modality x Complexity	2	51.3391	2.71	0.0750
Age x Modality x Complexity	2	0.4832	0.03	0.9748
Subject (Age)	30	155.2075		
Modality x Subject (Age)	60	19.6406		
Complexity x Subject (Age)	30	47.0968		
Modality x Complexity x Subject(Age)	57	18.9307		

Table 28. ANOVAs for driving performance measure of frequency of major lane deviation — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	0.7932	1.60	0.2157
Modality	2	0.3991	3.92	**0.0251**
Complexity	1	0.0001	< 0.01	0.9789
Age x Modality	2	0.2083	2.05	0.1381
Age x Complexity	1	0.0861	0.89	0.3519
Modality x Complexity	2	0.4053	2.49	0.0919
Age x Modality x Complexity	2	0.1662	1.02	0.3668
Subject (Age)	30	0.4958		
Modality x Subject (Age)	60	0.1018		
Complexity x Subject (Age)	30	0.0962		
Modality x Complexity x Subject(Age)	58	0.1629		

Table 29. ANOVAs for driving performance measure of frequency of minor lane deviation — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	5.0412	0.84	0.3674
Modality	2	5.0986	3.44	**0.0385**
Complexity	1	0.0970	0.14	0.7076
Age x Modality	2	1.5177	1.02	0.3654
Age x Complexity	1	0.2625	0.39	0.5381
Modality x Complexity	2	8.3775	7.08	**0.0018**
Age x Modality x Complexity	2	1.8593	1.57	0.2165
Subject (Age)	30	6.0198		
Modality x Subject (Age)	60	1.4821		
Complexity x Subject (Age)	30	0.6769		
Modality x Complexity x Subject(Age)	58	1.1834		

Table 30. ANOVAs for driving performance measure of variance in steering wheel position — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	0.0229	1.99	0.1691
Modality	2	0.0027	0.66	0.5205
Complexity	1	0.1676	52.11	**0.0001**
Age x Modality	2	0.0009	0.23	0.7973
Age x Complexity	1	0.0075	2.35	0.1361
Modality x Complexity	2	0.0158	3.56	**0.0351**
Age x Modality x Complexity	2	0.0072	1.61	0.2095
Subject (Age)	30	0.0115		
Modality x Subject (Age)	60	0.0040		
Complexity x Subject (Age)	30	0.0032		
Modality x Complexity x Subject(Age)	57	0.0045		

Table 31. ANOVAs for driving performance measure of frequency of large steering reversal (greater than 10 degrees) — Under low driving load condition.

Independent Variable	df	Mean Square	F Value	p Value
Age	1	2536.7040	16.94	**0.0003**
Modality	2	102.5078	1.85	0.1667
Complexity	1	191.9086	5.56	**0.0251**
Age x Modality	2	57.2796	1.03	0.3627
Age x Complexity	1	0.3321	0.01	0.9225
Modality x Complexity	2	268.8660	7.68	**0.0011**
Age x Modality x Complexity	2	33.7627	0.96	0.3874
Subject (Age)	30	149.7023		
Modality x Subject (Age)	60	55.5282		
Complexity x Subject (Age)	30	34.5309		
Modality x Complexity x Subject(Age)	57	35.0288		

Table 32. ANOVAs for post-test questionnaire.

Independent Variable	df	Mean Square	F Value	p Value
Question 1				
Age	1	0.0688	2.26	0.1431
Modality	2	7.4893	9.63	**0.0002**
Age x Modality	2	0.2606	0.34	0.7166
Subject (Age)	30	0.0304		
Modality x Subject (Age)	58	0.7774		
Question 2				
Age	1	0.1078	2.13	0.1546
Modality	2	2.0915	2.15	0.1256
Age x Modality	2	0.0258	0.03	0.9738
Subject (Age)	30	0.0506		
Modality x Subject (Age)	58	0.9724		
Question 3				
Age	1	0.0091	1.34	0.2559
Modality	2	10.7946	15.82	**0.0001**
Age x Modality	2	0.4747	0.70	0.5027
Subject (Age)	30	0.0068		
Modality x Subject (Age)	58	0.6822		
Question 4				
Age	1	0.1824	2.23	0.1459
Modality	2	0.9655	0.97	0.3865
Age x Modality	2	0.3840	0.38	0.6826
Subject (Age)	30	0.0818		
Modality x Subject (Age)	58	0.9990		
Question 5				
Age	1	0.0129	0.28	0.6000
Modality	2	11.7761	18.55	**0.0001**
Age x Modality	2	0.2327	0.37	0.6948
Subject (Age)	30	0.0460		
Modality x Subject (Age)	58	0.6349		
Question 6				
Age	1	0.0101	0.94	0.3414
Modality	2	0.7525	0.76	0.4741
Age x Modality	2	0.6859	0.69	0.5061
Subject (Age)	30	0.0108		
Modality x Subject (Age)	58	0.9953		
Question 7				
Age	1	0.0000	0.47	0.4977
Modality	2	10.4757	15.26	**0.0001**
Age x Modality	2	0.6036	0.88	0.4206
Subject (Age)	30	0.0000		
Modality x Subject (Age)	58	0.6866		

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