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ATTENTIONAL DEMAND EVALUATION FOR AN AUTOMOBILE MOVING-MAP NAVIGATION SYSTEM

by

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(ABSTRACT)

A study was undertaken to test and evaluate the human factors design aspects of an automobile moving-map navigation system. The primary objective of the study was to assess the driver attentional demand required by the navigation system during vehicle operation. A secondary objective of the study was to assess design specifics and determine whether or not the design was optimal in terms of efficiency of use in an automotive environment.

Thirty-two driver-subjects drove a specially instrumented 1985 Cadillac Sedan de Ville on public roadways for this research. A cross-section of driver-subjects (both genders, ages 18 to 73, and driving experience from 2,000 to 40,000 miles per year) participated, and a cross-section of roadway types (residential, two-lane state route, and limited-access four-lane) and traffic conditions (light and moderate) were used as part of this research.

The driver-subjects were asked to perform a variety of tasks while operating the research vehicle. These tasks included navigation tasks normally performed while using

the navigation system, as well as a wide variety of conventional automotive tasks (e.g., tuning the radio or reading the speedometer) normally performed during vehicle operation. The purpose of asking the driver-subjects to perform a variety of conventional automotive tasks was so that direct comparisons in attentional demand could be made between tasks performed daily in an automotive environment and the navigation tasks.

Twenty-one performance and behavioral measures were collected and analyzed for this research. These measures included eye-scanning and dwell-time measures, task-completion-time measures, and a variety of measures indicating driver performance and behavior.

The data analyses for these measures focused on two major goals. First, the analyses determined which tasks (both navigator and conventional) required the highest attentional demand. Second, the analyses were used to determine groups of tasks which, for all practical purposes, required equivalent attentional demand.

The results of the analyses indicated that the navigation system is a relatively effective device, useful for its intended purpose. The results also indicated that a number of design improvements are required, however, to optimize the safety and efficiency of the device. An iterative process of design improvement and further research into the effects of improved design on required attentional demand is therefore recommended.

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NOMENCLATURE

TIMEST	- Task time from experimenter button press
TIMEGLANCE	- Task time from first display glance
RDTOT	- Total-road-glance time
DISTOT	- Total-display-glance time
RDGLANCE	- Number of road glances
DGLANCE	- Number of display glances
RDAVE	- Average-road-glance time
DISAVE	- Average-display-glance time
RDPER	- Road-glance time percentage
DISPER	- Display-glance time percentage
ACCRMS	- RMS accelerator velocity
ACCVAR	- Accelerator velocity variance
ACCPOS	- High-pass accelerator position variance
STVRMS	- RMS steering velocity
STVELVAR	- Steering-velocity variance
STEXT	- Steering-velocity deviation time
STPZAV	- Steering-velocity percent zero average
STPZVAR	- Steering-velocity percent zero variance
BRNUM	- Number of brake activations
BRTIME	- Average dwell-time per brake application
LANEX	- Average time out of lane-per-lane deviation

INTRODUCTION

Over the past ten years, the automobile control center has undergone significant changes. New display and control types and new features are now present in automobiles, especially in the more expensive end of many manufacturers' product lines. Many of these changes have come about due to advances in electronic technology. This technology has allowed a number of features to be practically included in the automobile environment that increase driver comfort and aid in vehicle operation (Yun, 1985).

Comfort and convenience features that now appear on many automobiles include automatic climate control, power mirrors, automatic mirrors which adjust the amount of light reflected, information centers including fuel consumption information, elapsed time and estimated time of arrival information, service information, and multi-feature, high-fidelity sound systems. Much of this information is being presented through different types of displays than just a few years ago. Many automobiles now have digital instruments such as speedometers available as options. CRTs, which present both alphanumeric and pictorial information to the driver, are also available on some models.

One of the latest convenience features to become available is the automobile navigation system. These systems have been under development for some time and have now become a reality with the availability of the ETAK Navigator (ETAK, 1985). Different navigation systems operate via different sources of navigation (e.g., satellite or dead reckoning). The basic functions, however, are the same: to provide the driver with continuously updated information regarding the vehicle's current location and a path (usually presented graphically) to any given desired location. Such systems generally present information to the driver visually via a CRT display.

All of these innovations have changed or will change elements of the driving task. Some of these advances have made the driving task easier. For example, Ishii (1980) found that the visual recognition time was approximately 0.1 second shorter for a digital speedometer (under some conditions) when compared to an analog speedometer. These advances in automotive displays and features, however, do not always make the driving task easier. For example, Monty (1984) found that a CRT/touch entry device (TED) system, when used for performing radio, climate control, and trip monitor functions, resulted in somewhat poorer driving performance and required longer visual fixation time than did the corresponding conventional control/display systems.

The driving task is very complex, albeit highly overlearned. The driver must perform a lane-keeping or -changing tracking task, and continually scan the environment in a search and recognition task to operate a vehicle safely. In addition to this "primary" driving task, the operator must also perform a variety of "secondary" tasks including speed maintenance, status monitoring, and gear shifting. If secondary tasks require sufficient attention such that a significant reduction in attention to the primary driving tasks of tracking and scanning the environment occurs, then driving may become dangerous. Therefore, changes or additions such as the innovations previously described must be carefully evaluated in terms of their effects on the composite driving task under all conditions.

Evaluation of some of these forthcoming changes to the composite driving task was the focus of this research.

LITERATURE REVIEW

The literature review for this research focused on two specific areas. First, literature describing the development and evaluation of in-dash electronic navigation systems and other automotive control/display systems was reviewed. The purpose of reviewing this research was to determine whether any formal or objective evaluations had been performed, and to evaluate the methodologies/apparati used for the evaluations if any had indeed been performed. Second, literature describing any assessment of the driving task in whole or in part was reviewed. The purpose of reviewing this research was to gain information regarding driving behavior under normal conditions, to determine what methodologies, apparati, and measures have been used successfully in the past, and to determine the effects of such factors as driver differences (e.g., sex and age) and environmental differences (e.g., road type and traffic) on the driving task.

To facilitate the organization of this information, four major subsections will be addressed. The first subsection includes an overview of techniques used in previous studies to assess the attentional demand of the driving task. The second subsection reviews studies specifically involving the development or evaluation of in-dash navigation systems. This subsection includes a description of the specific system that was evaluated for this research, the ETAK navigator. The third subsection reviews studies for which objective evaluations of automobile control/display systems (other than navigation systems) have been made. The fourth subsection includes a summary of the literature assessing the effects of various driver (e.g., age and driving experience) and environmental (e.g., road type and traffic) factors on the driving task.

Finally, a summary of useful measures of attentional demand, along with important driver and environmental factors that required assessment as part of this research, is presented.

Overview of Techniques Used to Assess Driving Performance and Attentional Demand

Techniques used to assess the attentional demand requirements of driving generally fall into two categories: eye-scanning measures and driving-quality measures. Some work has also been accomplished using several subjective and physiological measures. These techniques, however, apparently have not been as successful or as widely used as the eye-scanning and driving-performance/behavior measures.

Eye-scanning measures. Vision accounts for over 90 percent of the information input to the driver (Rockwell, 1972). Therefore, various measurements of driver visual observations can be used to assess the demands of the driving task. One method that has been used to assess attentional demand of driving in several studies is visual occlusion (Senders, Kristofferson, Levison, Dietrich, and Ward, 1966). For this method, the driver's vision is occluded either voluntarily (eyes closed) or periodically by the experimenter for some length of time. The percentage of time that the eyes can be occluded without degradation of driving performance indicates the spare visual capacity, and thereby the required attentional demand for the driving task. The utility of this method, although used in a number of studies, is limited due to the inherent intrusion and danger of introducing occlusion into the driving task.

A variety of other eye-measurement techniques have been used in the automobile environment, including cameras to determine approximate eye position and point-of-regard measurement in the form of eye-marker cameras (Young and Sheena, 1975). Monty (1984) successfully used a camera and recorder system to record eye-dwell times on the instruments and on the roadway.

Rockwell (1972) used an eye-marker camera to collect the eye-scan behavior of drivers. Rockwell found the eye-marker system to have the fewest artifacts and be relatively non-invasive to the driver. Rockwell also found that subjects adapted well to the system and could wear the apparatus for two or three hours.

Inherent problems exist with the collection of eye-measurement data for assessment of the driving task. Three such problems were outlined by Rockwell (1972).

1. Spare Visual Capacity
   The majority of interstate driving requires less than fifty percent of the visual capacity. The driver, therefore, samples a large amount of irrelevant information.
2. Extra-Foveal Vision
   Foveal vision may be less important for such driving aspects as accident avoidance than peripheral vision.
3. The driver may be staring at something without processing any information.

Therefore, some researchers have used additional measures to assess the attentional demand of the driving task. A class of these measures, which will be termed driving-performance/behavior measures, is described below.

Driving-performance/behavior measures. A second major class of measures collected in previous research to assess driving performance and/or attentional demand consist of driving performance/behavior measures. These measures consist primarily of performance measures and include lane position, steering behavior, velocity variance, accelerator pedal reversals, number of brake activations, and headway (distance from a leading car) mean and variance.

Monty (1984) found that lane keeping, velocity maintenance, the number of brake activations, and dwell time per brake activation were sensitive to the attentional demand required by various secondary tasks. A number of studies (e.g., Hicks and Wierwille, 1979 McLean and Hoffman, 1973; Wierwille and Gutmann, 1978) and have investigated changes in steering behavior due to increases in difficulty of the primary driving task, or due to the introduction of a secondary task. Wierwille and Gutmann (1978) found that the introduction of a random digit reading task while driving changed driver steering behavior in a driving simulator. The introduction of the digit reading task resulted in an increase in the number of steering reversals and an increase in a measure of high-pass steering deviation. These findings indicate that driver steering behavior became more "erratic" due to the increased driver attentional demand required by the introduction of the secondary task.

Driving-quality measures are important in the assessment of attentional demand while driving for two reasons:

1. Since a driver may have a large amount of spare visual capacity, the driving-performance/behavior measures aid in the differentiation between the driver processing irrelevant information or not processing information at all, and the driver being stressed due to high attentional demand. For example, if a driver glances at a particular instrument for a long period of time, the glance may be due to high attentional demand required by the instrument, or the glance may be due to a large amount of spare visual capacity. Theoretically, driving quality would only degrade in the case of high attentional demand.
2. Driving-performance/behavior measures provide a second, independent set of measures that can be used to determine when the attentional demand is at a critical point that results in a degradation in the performance of the primary driving task.

The measurement of attentional demand. For the current research, visual attentional demand was defined as the attention required of the driver for the total driving task including any secondary tasks. This attentional demand was measured as eye-dwell time spent viewing driving-related information, including the roadway and instruments, and non-driving related information. Several measures of driving-performance/behavior were used to aid in the assessment of attentional demand, primarily with regard to driving performance degradation due to the introduction of a secondary task.

Development/Evaluation Studies for In-Dash Navigational Systems

The concept of the in-dash electronic navigation system is not new. Several automobile manufacturers and independent companies have been developing such systems for several years. Numerous papers have been published describing the development of such systems, and a few were found that have actually evaluated navigation systems to some extent.

Of the papers reviewed, several were descriptions of system development and contained no information regarding the evaluation of such systems (Honey and Zavoli, 1985; Jarvis and Berry, 1984; Mitamura, Chujo, and Senoo, 1983). However, a number of human factors aspects were described with regard to the conceptual design of such devices. For example, Jarvis and Berry (1984) addressed such aspects as location, glare shielding, and optimization of information presentation through graphics and text, scale size, and color in the design of a navigation display system. Honey and Zavoli (1985) addressed some additional human factors design considerations such as road prioritization to minimize display clutter, the "locking out" of a number of system functions while the vehicle is moving to minimize potential unsafe distraction, and the differences of a vehicle heading up (as opposed to north up) presentation of the display information. These papers show that, at least in some instances, human factors design considerations have been incorporated at various stages of the design process.

One paper was found for which an on-the-road evaluation of a navigation system was performed. Tagami, Takahashi, and Takahashi (1983) evaluated a navigation system with on-vehicle tests. Tests were performed "... on crowded downtown streets, local roads, freeways, and mountain roads." The navigation system used consisted of a CRT showing the current location of the vehicle, direction, and route in a graphics format. Overlays were used in conjunction with the CRT for route selection and monitoring of progress along the route. No formal evaluation results were presented by Tagami et al. (1983). However, the device was apparently usable and useful as indicated by statements such as "... the system frees your mind of anxiety and performs well as a guide."

No publications were found reporting any formal human factors evaluations of navigation displays. To the best of the author's knowledge, the present research was the first such evaluation performed.

The ETAK Navigator. A review of the available literature involving the specific system to be evaluated in this study, the ETAK Navigator, was performed. A brief overview of the system features, configuration, and evaluations completed to date are described below.

The ETAK Navigator utilizes what is termed "augmented dead reckoning" to determine vehicle location along a route (ETAK, 1985a). Through the use of a compass to determine the vehicle direction, wheel sensors to gauge distance traveled and turns, and a custom microcomputer and map data base containing route information, the ETAK is able to determine and display a destination, and "follow" the vehicle location along a displayed route. The navigation information is presented to the driver via a 7.5 by 10.1 cm monochrome CRT mounted in the dash. The information is presented in a graphic format, with a choice of either driver heading or North maintained toward the top of the screen (Honey and Zavoli, 1985). Street labels also appear for selected streets along the route, and major roads are marked with lines brighter than those of secondary roads (ETAK, 1985b). Various levels of map detail can be obtained by the operator via "zoom-in" and "zoom-out" functions, with minor streets disappearing with a "zoom-out" function activation to avoid display clutter. A representation of information typically contained on the display is shown in Figure 1.

Control of the device is accomplished through menu-driven instantaneous pushbuttons. Labels describing the various functions associated with the device appear on the CRT next to the pushbuttons. The majority of ETAK operator functions, including programming a route, are locked out while the vehicle is moving. Only the zoom-in, zoom-out, and hop functions are available to the driver while the vehicle is in motion (Honey and Zavoli, 1985). The hop function allows the driver to correct the navigator when the location arrow is in error. Depressing the "hop-left" or "hop-right" buttons moves the location arrow to the next street in the direction selected.

An informal on-the-road evaluation of the ETAK Navigator has been accomplished. The initial evaluation of the device consisted of use and subjective evaluation by ETAK employees. Currently there are approximately 300 devices in use on the road. No formal or objective human factors evaluation of the ETAK Navigator has been accomplished to date.

Automobile Control/Display Evaluation Studies

Although (as described above) no formal evaluations of navigation systems have been accomplished, several studies

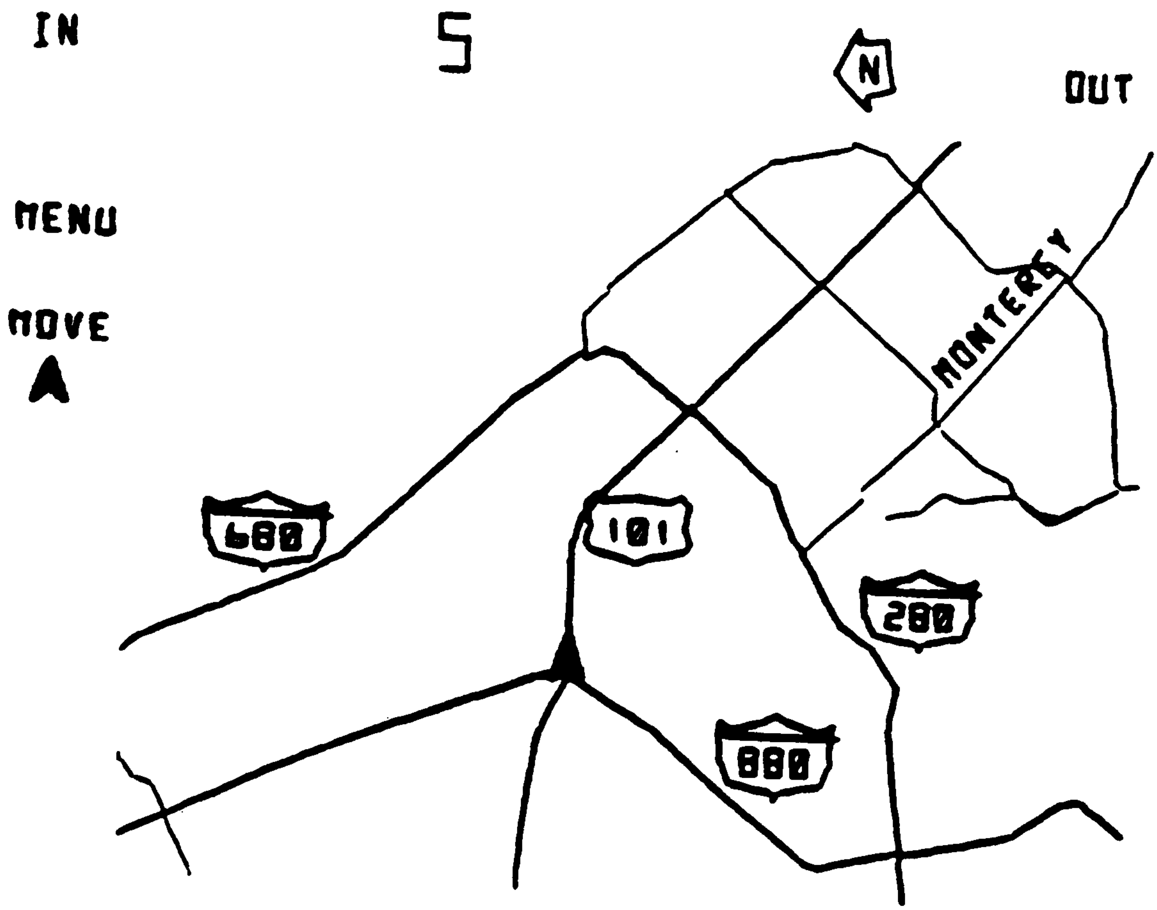


Figure 1. Typical information displayed by the ETAK Navigator.

exist which experimentally evaluate other automotive displays and controls. Bhise, Forbes, and Farber (1986) collected a large amount of data regarding the use of, and eye-scanning behavior for, a number of automobile controls and displays. The controls and displays evaluated include the speedometer, turn signals, radio, climate control, wipers, fuel gauge, and high beam. Bhise and his associates determined that for complex tasks, drivers time-share visually between the roadway and the task. A task can be considered complex if it requires more than one glance with glance times greater than one second. For example, Bhise et al. (1986) found that, for a driver to be able to read all of the button labels on a 12 button panel, 7 to 15 glances each lasting approximately one second were required. A summary of glance duration and number of glances for some common automobile tasks as found by Bhise and his associates is presented in Table 1. Bhise et al. (1986) also determined that the probability of a glance to a given control was dependent on the location of that control. The probability of a glance for a control near the steering wheel was between 0.03 and 0.14, while the probability of a glance to a panel control was between 0.35 and 0.72. A similar result was found by Mourant, Herman, and Moussa-Hamouda (1980). Mourant and his associates found that the driver's direct glances at a control

TABLE 1

Glance Duration Data for Common Automobile Tasks (from Bhise et al., 1986) at Speeds of 50 mph on the Open Road

Speed - 50 mph

Task	Mean Glance Duration
Speedometer	
-- Normal driving	0.4 to 0.7 s
-- Check reading	0.8 s
-- Exact value	1.2 s
Analog Fuel	1.3 s
Digital Clock	1.0 to 1.2 s
Mirrors	
-- Left outside	0.5 to 1.0 s
-- Inside	0.5 to 0.7 s
Radio on	1.1 s
Change fan speed	1.4 s
Turn radio	1.1 s (2 to 7 glances)
Read all labels on a twelve button panel	1.0 s (7 to 15 glances)

control increase as a function of hand travel distance to the control.

In addition to the above studies, which evaluated the attentional demand required of the driver for "conventional" automobile controls and displays, additional studies were found that evaluated in-dash CRT display systems. Although the CRT has been considered as a candidate automotive display for a number of years, only recently have technological advances allowed its practical use in automobiles (Dietch and Zeidler, 1981). As with the navigation systems previously discussed, a number of papers have been written describing the development of the CRT as an automotive instrumentation display; few, however, contain any information regarding evaluation of the display from a human factors standpoint. Williams and Macki (1983) performed an evaluation of a CRT display under automotive environmental conditions such as high glare and found it to be useful under these conditions. Formal experimentation regarding the effect of the display on the driving task in terms of factors such as legibility or attentional demand, however, has not been reported.

A study by Monty (1984) evaluated a CRT/TED control/ display system used for climate control, trip monitor, and radio functions in comparison with conventional control/ display devices for the same tasks. Monty used a number of objective measures to assess attentional demand and driving performance during the use of the various systems. These measures included eye-scanning data; driving performance data such as lane keeping, speed maintenance, and number/duration of brake actuations; and secondary task-completion time and number of errors. Monty found that, based on these measures, driving performance was degraded somewhat and attentional demand (as indicated by the eye measures) was increased for the CRT/TED systems when compared with conventional automotive instrumentation. It is interesting to note that both the eye measures and driving performance measures showed sensitivity to the differences in attentional demand. Another finding by Monty was that the radio tasks showed consistently poorer performance when compared to the trip monitor and HVAC tasks, regardless of the control/display configuration used. This result is in agreement with the Bhise et al. (1986) finding that radio tasks require greater attentional demand than many other automotive tasks (Table 1). Monty hypothesized that tasks requiring "multiple switch operation" or a "continuous control" (such as radio tuning) require greater attentional demand than tasks which do not.

Literature Describing the Effects of Driver and Environmental Differences on the Driving Task

Studies have shown that a number of driver-related differences (such as sex, age, and driving experience) and environmental differences (such as road type, traffic density, and rate of curvature) affect driving performance and required attentional demand. The literature associated with each of these factors is summarized below.

Driver differences - age. Rackoff (1975) conducted a study with two age groups (20s and 60s) where eye glances were recorded for one test and subjects voluntarily closed their eyes as much as possible in another test. Rackoff reported that in many cases the older drivers viewed the road a greater percentage of the time than the younger drivers to maintain vehicular control. Marsh (1960) and McFarland (1964) described a reduction in central capacities due to aging that is manifested in the age-related automobile accidents of failure to yield to the right-of-way, improper turning, and running stop signs and red lights.

Monty (1984) found that older drivers showed poorer driving performance than younger drivers during operation of several secondary automotive tasks involving conventional and CRT/TED systems. Monty also found that the older drivers had more brake applications and greater brake-time applications than younger drivers. A similar brake-application finding was also reported by Case, Hulbert, and Beers (1970).

Driver differences - gender. Generally speaking, findings of gender differences related to attentional demand and performance in driving are inconsistent. Monty (1984), while not finding many gender differences, did note that during conditions where secondary tasks were involved, females had a greater number of glances to the roadway than males.

Driver differences - driving experience. Cohen and Studach (1977), in an investigation of the difference in eye-movement patterns between inexperienced (less than 12,000 miles driven) drivers and experienced drivers, found some variations in patterns of eye glances based on experience. Findings indicated that experienced drivers glanced differently depending on whether they were approaching a curve to the right or a curve to the left. Inexperienced drivers showed no such differentiation.

Zell (1969) and Mourant and Rockwell (1970a) also reported significant changes in eye-movement patterns with driving experience. Findings indicate that experienced drivers concentrate on straight-ahead glances and use peripheral or extrafoveal vision for lane-position maintenance. Inexperienced drivers, on the other hand, scan laterally to maintain lane position.

Environmental differences - route familiarity. Mourant and Rockwell (1970) found that drivers' search-and-scan patterns became more "compact" and that the center of the eye-movement pattern shifted down and to the left as drivers became more familiar with a given route.

Environmental differences - road differences. Monty (1984) investigated eye-scanning and driving-quality measures associated with secondary tasks performed on conventional and CRT/TED systems (as previously discussed). One factor investigated in the study was four different road types: interstate highways, U.S. open four-lane, state routes, and city streets. Monty found that driving was generally poorer on the state routes than on the other three types of roads.

Evidence presented by Senders et al. (1966), Cohen and Studach (1977), and Mortimer and Jorgenson (1972) indicates that as a curve is approached the attentional demand of the driving task increases. Senders et al. (1966) also report that the radius of curvature is important with regard to attentional demand. As the radius of curvature of the roadway decreases, the attentional demand required increases.

In addition to the roadway factors described above, there is also an indication that the speed of the vehicle affects the attentional demand of the driving task. Data from Bhise et al. (1986) indicate that as speed increases, the driver's "eye-off-the-road" dwell time decreases from as high as 5.0 seconds at 20 mph or below to less than 2.0

seconds at 60 mph (on an empty road). A similar result was also reported by Cohen (1981).

Environmental differences - traffic density. Several studies have involved "car following" scenarios in an effort to assess situations where traffic is present. In one such study, Mourant and Rockwell (1970) found that car following increased required attentional demand as indicated by increased visual sampling rates and greater visual travel distances. Similar results have also been reported by Mortimer and Jorgenson (1972).

Environmental differences - day/night, weather. It is reasonable to assume that as the distance that a driver can see is reduced, the attentional demand (as evidenced by the eye-glance sampling frequency on the roadway) will increase. This assumption is supported for the case of night driving by data presented by Bhise et al. (1986). Bhise and his associates' data show that the average "eye off-the-road time" is less by approximately one second at night than during the day, regardless of vehicle speed. A study by Zwahlen (1981) indicates that, in addition, the durations of eye glances on road warning signs increase substantially at night. This increase in glance time indicates greater difficulty in recognition.

The results described above probably hold for conditions of inclement weather where vision is reduced as well as for night driving (e.g., fog, driving rain, etc.). No studies were found, however, for which weather conditions such as these were investigated as controlled experimental factors.

Summary

Although a number of studies have evaluated various aspects of the driving task, only a few have dealt specifically with the effect of a control/display or a new control/display technology, and none have formally evaluated an in-dash navigation system. Of the studies reviewed, the measurement of eye-scanning behavior was the most widely used, and was the most important measure considered for the assessment of attentional demand of the driving task. Driving-performance/behavior measures, although not as widely used, appear to be valuable measures (if attainable) for validation purposes and as an aid for interpretation of the eye-measurement data.

A number of factors must be considered when assessing the attentional demand of the driving task. Subject factors, such as age and driving experience, play an important role in assessing eye-movement data. In addition, environmental factors including route familiarity, road type (number of lanes, curvature, and speed), traffic density, and day/night/weather conditions all influence the attentional demand required for the driving task.

RESEARCH OBJECTIVES

The primary purpose of this research is to investigate the effect of navigation system operation on the performance of the driving task. As mentioned in the Literature Review section, several automobile manufacturers and independent companies are developing navigation systems. While several sources were found indicating that a number of human factors aspects have been taken into consideration for the ongoing design of these navigation systems, apparently this research is the first objective human factors evaluation of the effect of such a system on the driving task.

A second purpose of this research is to evaluate and compare additional secondary-driving tasks, some of which are relatively new to the automobile environment. Two of the new features evaluated are the fuel data center and the electronic climate control. Devices such as these have appeared in an increasing number of automobiles over the last several years and, to the best of the author's knowledge, few objective performance evaluations prior to this research have been accomplished (e.g., Monty, 1984).

The final objective of this research is to attempt to develop performance criteria for potential use in future automobile control/display evaluations. By evaluating such measures as eye-movements and eye-glance times, along with steering behavior, lane position, accelerator behavior, and brake behavior for a number of tasks of varying difficulty, it was hoped that objective criteria could be established for the maximum safe attentional demand required of any automotive-control display system.

METHOD

Experimental Design

The experimental design for this research is a 5 x 3 x 2 x 2 x 2 mixed-factor factorial design. The five factors were: task type, road type, traffic density, driving experience, and gender. An illustration of the experimental design is shown in Figure 2. Each factor, along with an explanation of how the effect of subject age was controlled, is described below.

Task type. Task type was a within-subject factor. Each subject was asked to perform a variety of secondary tasks. These tasks consisted of navigator tasks and conventional automotive secondary tasks such as reading the speedometer or tuning the radio. A list of the subject tasks, along with a description of required subject operations, appears in Table 2. An attempt was made to classify the conventional automobile tasks into categories of low, medium, and high attentional demand. These classifications were made so that comparisons between the attentional demand required by the navigator and "groups" of conventional tasks with specific attentional demand characteristics could be accomplished. The criteria for low, medium, and high attentional demand were based in part on the results presented by Bhise et al. (1986) with regard to total time and number of glances required of various

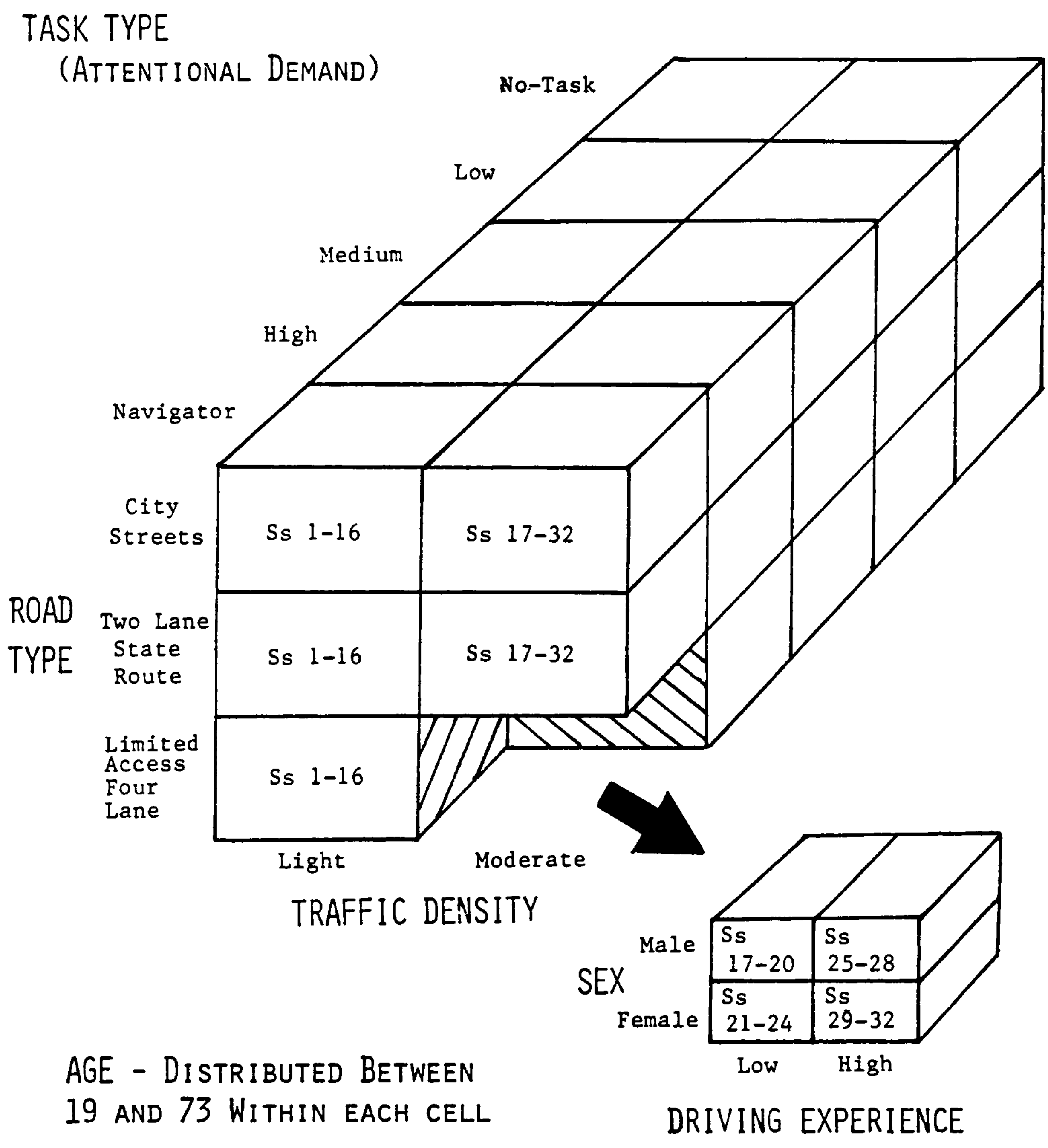


Figure 2. Experimental design.

TABLE 2

List of Subject Tasks and Descriptions of Subject Task Functions

Task	Classification and Abbreviated Name	Operator Requirements
Point in the direction of the destination	(Navigator) Destination Direction	-- Locate direction to destination arrows on Navigator (always displayed) -- Point out of window in arrow direction
Determine the distance to the destination	(Navigator) Destination Distance	-- Locate distance number on Navigator (always displayed) -- Read number
Determine the general vehicle heading	(Navigator) Heading	-- Locate North arrow on Navigator (always displayed) -- Judge current direction relative to North
Determine whether the direction of travel is appropriate to get to the destination	(Navigator) Appropriate Direction	-- Locate direction to destination arrow on Navigator (always displayed) -- Look at current roadway being traveled and associated near roadways (always displayed for this task) -- Judge whether current roadway and direction is appropriate

TABLE 2 (Continued)

List of Subject Tasks and Descriptions of Subject Task Functions

Task	Classification and Abbreviated Name	Operator Requirements
Set the proper zoom-Level based on the destination distance	(Navigator) Zoom-Level	-- Look at distance number on navigator (always displayed) -- Look at scale levels on navigator (always displayed) -- Depress next higher scale level number than destination distance number
Determine the name of the next cross street	(Navigator) Cross Street*	-- Look at scale level number on navigator (always displayed) -- Look at navigator map display (always displayed) and determine whether a cross street appears -- Judge whether any cross street that appears based on the current scale level is the next cross street based on the current scale level -- Zoom-in or zoom-out if cross street does not appear or if the cross street displayed is not likely to be the next cross street -- Read label if present or respond "no label appears"

* This task involves finding the next cross street, whether it would be used to get to the destination or not.

TABLE 2 (Continued)

List of Subject Tasks and Descriptions of Subject Task Functions

Task	Classification and Abbreviated Name	Operator Requirements
Determine the name of the appropriate near roadway to get to the destination	(Navigator) Roadway Name	-- Look at navigator map display and find the destination star (always displayed for this task) -- Plan route from current point to destination -- Judge whether a scale change is required to determine the appropriate near turn-off roadway -- Zoom-in or zoom-out if required to find roadway -- Read label if present or respond "no label appears"
Determine distance to the appropriate near roadway to get to the destination	(Navigator) Roadway Distance	-- Locate appropriate near turn-off roadway as described above -- Interpolate distance to near roadway from knowledge of map scale -- State distance
Determine the current speed	(Conventional) Speed	-- Locate and read the digital speedometer
Determine the remaining fuel	(Conventional) Remaining Fuel	-- Locate and read the digital fuel gauge
Determine the time of day	(Conventional) Time	-- Locate and read the digital clock

TABLE 2 (Continued)

List of Subject Tasks and Descriptions of Subject Task Functions

Task	Classification and Abbreviated Name	Operator Requirements
Determine if any information center lights are on	(Conventional) Info Lights	-- Locate and check the two information centers
Determine if any following traffic is present	(Conventional) Following Traffic	-- Check rear-view mirror(s)
Activate the turn signal	(Conventional) Turn Signal	-- Locate and activate turn signal stalk
Adjust the distance level on the dimming sentinal	(Conventional) Sentinal	-- Locate sentinal -- Adjust to maximum
Adjust heading/ air conditioning vent	(Conventional) Vent	-- Locate vent -- Adjust so that air flow is away
Check the fuel range	(Conventional) Fuel Range	-- Locate fuel range button -- Depress button -- Read digital meter
Check fuel economy	(Conventional) Fuel Economy	-- Locate specified economy button -- Depress button -- Read digital meter
Activate the climate control fan	(Conventional) Fan	-- Locate fan button -- Depress button

TABLE 2 (Continued)

List of Subject Tasks and Descriptions of Subject Task Functions

Task	Classification and Abbreviated Name	Operator Requirements
Activate windshield defrost	(Conventional) Defrost	-- Locate defrost button -- Depress button -- Locate fan button -- Depress button
Reset sound system balance controls	(Conventional) Balance	-- Locate balance control -- Adjust
Reset sound system tone controls	(Conventional) Tone Controls	-- Locate tone control -- Adjust
Adjust climate control temperature	(Conventional) Temperature	-- Look at digital display to determine current temperature -- Locate "cooler" or "warmer" button depending on specified temperature setting -- Depress button until specified temperature appears
Play a cassette tape	(Conventional) Cassette Tape	-- Locate tape -- Determine which side is side "A" -- Locate tape player -- Insert tape -- Press until tape latches

TABLE 2 (Continued)

List of Subject Tasks and Descriptions of Subject Task Functions

Task	Classification and Abbreviated Name	Operator Requirements
Adjust power mirror	(conventional) Power Mirror	-- Check mirror adjustment -- Locate mirror control -- Switch control to proper mirror -- Adjust mirror until line-of-sight is correct
Activate the cruise control	(conventional) Cruise Control	-- Locate activation switch (located to right of steering wheel on the dash) -- Activate switch -- Locate engage button (on turn signal stalk) -- Set speed with accelerator -- Press engage button

automobile controls and displays (see the Literature Review section and Table 1), and in part on a logical breakdown of the timesharing methodology used by drivers while performing secondary tasks. The criteria for these categories of attentional demand were operationally defined as follows:

Low attentional demand. Any task for which information could be gathered in a single glance lasting less than 1.0 s. Also, any task requiring a control manipulation but not requiring the driver to glance at the control in order to actuate it. The 1.0-s criterion was selected because when a driver is forced to timeshare between the roadway and a display, the display glances last approximately 1 s. Therefore, if a driver can extract the required information in one second or less, one glance at the display should be sufficient.

Medium attentional demand. Any task requiring a total glance time between 1.0 and 2.5 s (either in a single glance or multiple glances). Also, any task requiring a control manipulation that requires the driver to look at the control to find/operate it in single or multiple glances lasting between 1.0 and 2.5 s. The 2.5-s criterion was selected primarily based on the Bhise et al., statement that any single glance lasting greater than 2.5 s was dangerous. Setting the criterion at 2.5 s meant that by exceeding the criterion a subject would either have to extract the required information in multiple glances or in a single "dangerous" glance, according to the Bhise et al. finding.

High attentional demand. Any task requiring a total-glance time greater than 2.5 s (either in a single glance or multiple glances). Also, any task requiring a control manipulation that requires the driver to look at the control to find/operate it for a total-glance time (single or multiple glances) greater than 2.5 s.

Very high attentional demand. The categories discussed above were developed prior to the conduct of the study. After completion of the data collection, it was found that several tasks required much longer than 2.5 s of total-display-glance time. Therefore, to depict more accurately the visual attentional demand required, a very high attentional demand category was created. The criterion selected for this category was total-display-glance time greater than 4.0 s.

In addition to the low, medium, high, and very high attentional demand task classifications, there was also a no-task condition. Eye movement and driving quality data were collected periodically under the various roadway and traffic density conditions while no secondary tasks were being performed. These data served as a baseline condition for an overall comparison.

The presentation order of all the tasks was counterbalanced among subjects to minimize order effects. The counterbalancing consisted of tasks assigned in groups of five to two Latin squares. The Latin squares were constrained such that the most difficult tasks did not appear in succession, thereby minimizing carry-over effects. Tasks were assigned to a group from each attentional-demand category. In addition, group presentation order was counterbalanced for each subject run. A diagram outlining task presentation order appears in Appendix C.

Road type. Road type was a within-subject factor. A data run consisted of a drive along each of the preselected routes. The routes were selected such that one of three types of roadways was present: four-lane limited-access, two-lane state route, and residential streets. The routes were selected such that approximately equal time was spent on each type of roadway. The routes were also selected such that, via different directions and starting points, the presentation order of the road type was counterbalanced. Road type was fully counterbalanced. The six possible road-type orders were each presented five times.

In addition, two road-type orders were randomly selected and presented a sixth time.

The specifications associated with the road types described above are shown in Table 3 (from Monty, 1984). As shown in Table 3, relevant factors such as design speed, sight distance, number of lanes, lane width, maximum slope and curvature, usage, and access vary with each road type.

Traffic density. Traffic density was a between-subjects factor. In an attempt to evaluate the navigation system under varying conditions of traffic density, data runs were made during two different times of day. One-half of the subjects performed data runs when generally light traffic along the route (approximately 10 a.m.) was anticipated, while the other half of the subjects performed the data run when moderate traffic along the route (approximately 5 p.m.) was anticipated. The traffic density along the preselected routes was quite variable at a given time of day. Therefore, each data run was characterized by the experimenter as to whether the actual traffic density was light or moderate. Traffic density was considered moderate if the driver had to interact with other vehicles at least three times during a data run. A large proportion (approximately 40 percent) of the data had to be reclassified with regard to actual traffic density during a data run.

TABLE 3

Road Type Specifications (from Monty, 1984)

Road Type	Terrain Type	Design Speed	Sight Distance	# of Lanes	Lane Width	Type of Shoulder	Width of Shoulder	Max. Curve	Max. Slope	Daily Usage	Access
US four-lane	Rolling	60 mph	650 ft.	4	12'	Soft	13'	4°-30'	4%	16,151	L
State road	Rolling	50 mph	475 ft.	2	12'	Soft	8'	7°-30'	7%	2000-4000	U
	Mountain	40 mph	325 ft.	2	9-11'	Soft	9-8'	12°-0'	10%	2000-4000	U
City/Town	--	30 mph	200 ft.	2	11'	--	--	19°	15%	--	U

Subjects and subject factors. Thirty-two subjects participated in this study. The subjects were selected based on screening criteria described in the Procedure section.

Subject factors that were considered as part of the research included gender, driving experience, and age. Sixteen males and sixteen females participated in this study. Eight of the males and eight of the females were those who normally drove between 2,000 and 10,000 miles per year while eight of the males and eight of the females drove over 10,000 miles per year. Half of the drivers categorized by the two factors described above participated in the moderate-traffic-density situation and half participated in the low-traffic-density situation as previously described. Therefore, there were four subjects in each gender, driving experience, and traffic-density level cell as illustrated in Table 2. Age effects were also controlled. One subject in each cell was under the age of 25, one was between the ages of 25 and 35, one was between the ages of 36 and 49, and one was over 50.

Dependent measures overview. The measures of attentional demand for this study fell into three categories: eye-scanning measures, driving-performance/behavior measures, and task-completion measures. The eye-scanning measures consisted of the number of glances, dwell times per glance, and total dwell time on the instruments or controls and on the roadway. Driving-performance/behavior measures consisted of lane maintenance, steering-wheel velocity, accelerator pedal position and velocity, the number of brake applications, and the duration of each brake application. Task-completion measures consisted of secondary task-completion time (either navigator or conventional) and number of task errors. A detailed discussion of the collection and definition of each of the above measures appears in the Data Collection and Dependent Measures Definition section.

Apparatus

Experiment vehicle. The experimental vehicle was a 1985 Cadillac Sedan deVille. Options that were present on the test vehicle included power mirrors, fuel data center, stereo radio/cassette deck, digital dashboard, cruise control, and electronic climate control. The layout of the dashboard instruments appears in Figure 3 (adapted from the Cadillac Sedan deVille owner's manual, GM Corporation, 1985). Several of the cruise-control functions are located on the turn signal stalk and are not shown.

ETAK Navigator. The ETAK Navigator was installed in its normal operational configuration. The monochrome CRT screen on which the roadway map appeared was 2-7/8 inches (7.3 cm) high by 3-3/4 inches (9.5 cm) wide. The face of

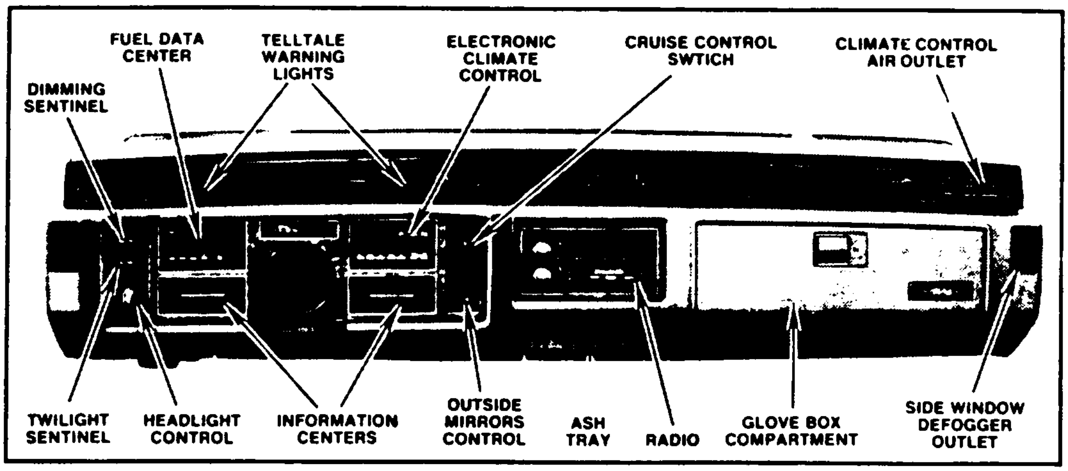


Figure 3. Experimental vehicle dashboard layout.

the display unit was 4-1/8 inches (10.5 cm) high by 5-1/8 inches (13.0 cm) wide, overall. The display unit was embedded in the center air-conditioning ducts in the upper dash as shown in Figure 4. The tape drive for the navigator was mounted on the floor under the center of the dashboard. The system computer was mounted in the trunk.

<u>Eye-scanning camera/recorder system</u>. The system consisted of two cameras, two recorders, and a monitor. One camera was mounted on the hood and recorded the subject's eye movements. A metal glare shield prevented windshield reflections from entering the camera lens. The hood-mounted camera is shown in Figure 5. The second camera was mounted on the roof and recorded a simultaneous view of the forward roadway. This camera was fitted with a wide angle lens so that a complete forward view of the roadway could be obtained. The roof-mounted camera is also shown in Figure 5.

Glance duration was recorded on-line by an experimenter in the back seat using a single pushbutton and video monitor. The monitor normally displayed the image produced by the hood-mounted camera. When the subject's eyes were stationary, the rear-seat experimenter depressed the pushbutton, and when the subject's eyes shifted, the pushbutton was released until the subject's gaze stopped on the next object. The time that the pushbutton was depressed and the

Figure 4. ETAK Navigator display mounted in the center of the dashboard.

Figure 5. Experimental vehicle including road-view camera mounted on the roof and subject-view camera mounted on the hood.

time that the pushbutton was released were recorded via custom interface and IBM PC. Figure 6 shows the custom-interface system, including the control boxes used by both experimenters. The video monitor used was a Setchell-Carlson 12M918 with a custom glare shield and is shown in Figure 7. To insure that glances could be uniquely identified on playback, tones of different pitch were associated with consecutive button presses. These tones were recorded on the audio channel of each video recorder. In addition, to insure that task presentations were identifiable, the experimenter in the front seat wore a microphone. The audio from the microphone was superimposed on the tones of the roof-camera video recorder.

Driving-performance/behavior measures. Four sources of data indicating driving-performance/behavior were collected for this research: lane maintenance, steering velocity, accelerator velocity and position, and brake actuation. Lane-maintenance data were collected by the experimenter in the front seat. The data were collected and stored on-line via a pushbutton that was depressed when any part of the vehicle exceeded a lane boundary. The signal from the pushbutton was stored in the IBM PC through the custom interface.

Steering-wheel velocity was measured with a tachometer mounted on the underside of the steering column. The mounted steering-velocity tachometer is shown in Figure 8.

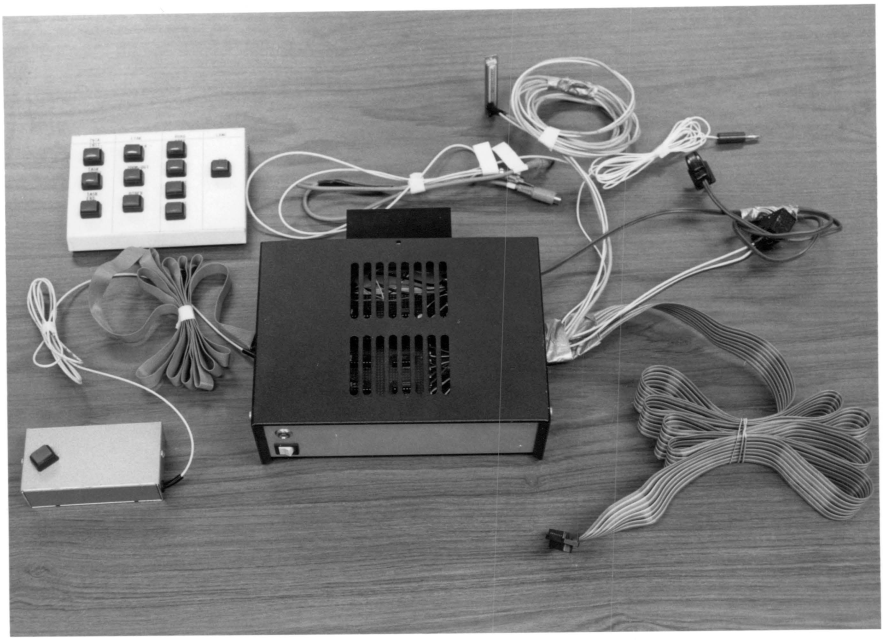


Figure 6. Custom IBM PC and video recorder interface system including the experimental control boxes and the interface unit.

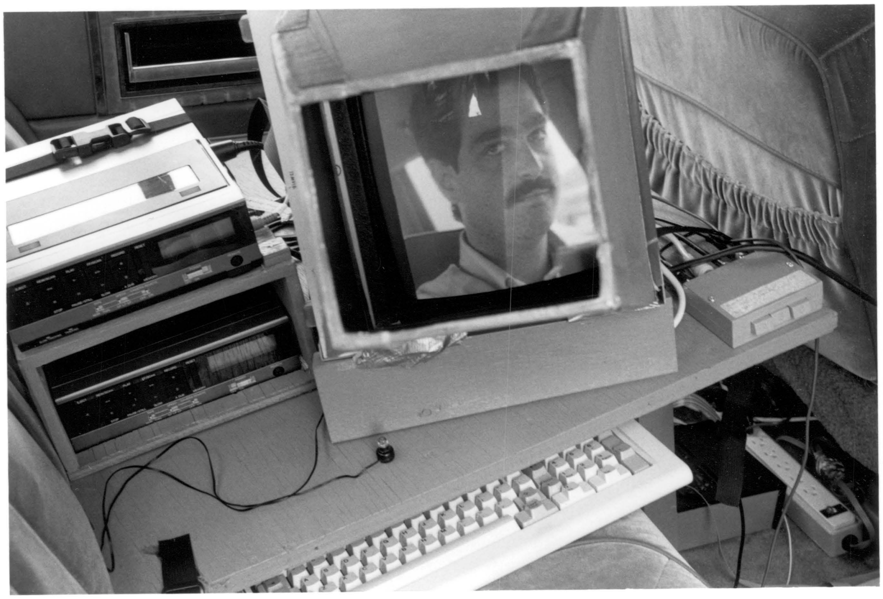


Figure 7. Rear seat experimenter's equipment including the video monitor, the video recorders for the hood and roof cameras, and the IBM PC.

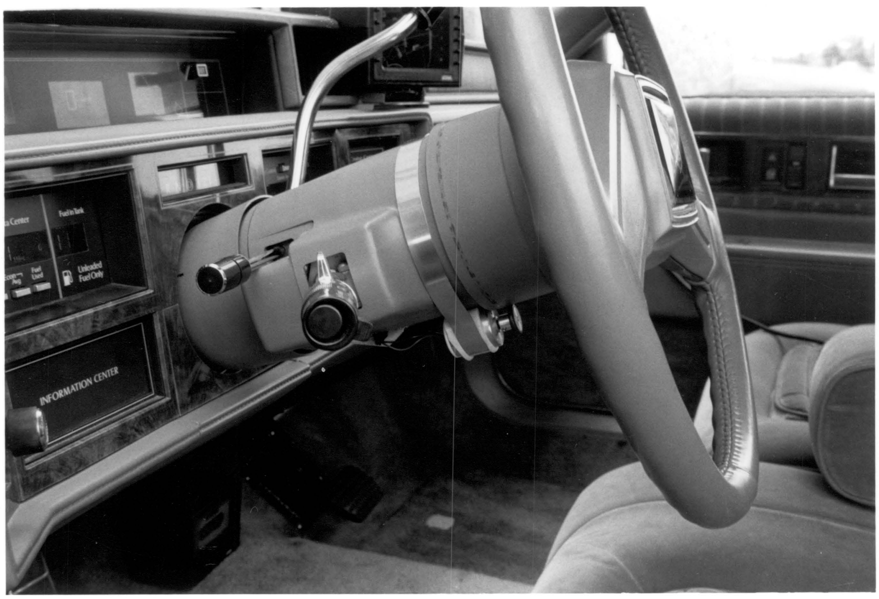


Figure 8. Steering-wheel tachometer mounted underneath the steering column.

The steering-velocity signal was conditioned and sent to the IBM PC through the interface.

Accelerator-pedal velocity and position data were recorded via a linear tachometer attached to the pedal assembly. The mounted tachometer is shown in Figure 9. The signal was sent to the IBM PC after conditioning by the interface.

Brake-activation data were collected from the tail-light signal. As with the other measures, this signal was conditioned by the interface and sent to the PC.

Task-completion and driving-classification measures. The experimenter in the front seat, in addition to being responsible for lane-maintenance data, collected the task time and error data, as well as the road-type classification data. Task errors were recorded via paper and pencil on a clipboard along with experimenter comments about the error.

Task time was computed and stored by the PC. The experimenter depressed a button when the instructions for a given task were initiated. A second button was depressed when the subject began the task, and a third button was depressed when the task was completed. The signals from each button were sent to the PC through the interface.

The road type was stored in the interface and simultaneously sent to the PC. The experimenter in the

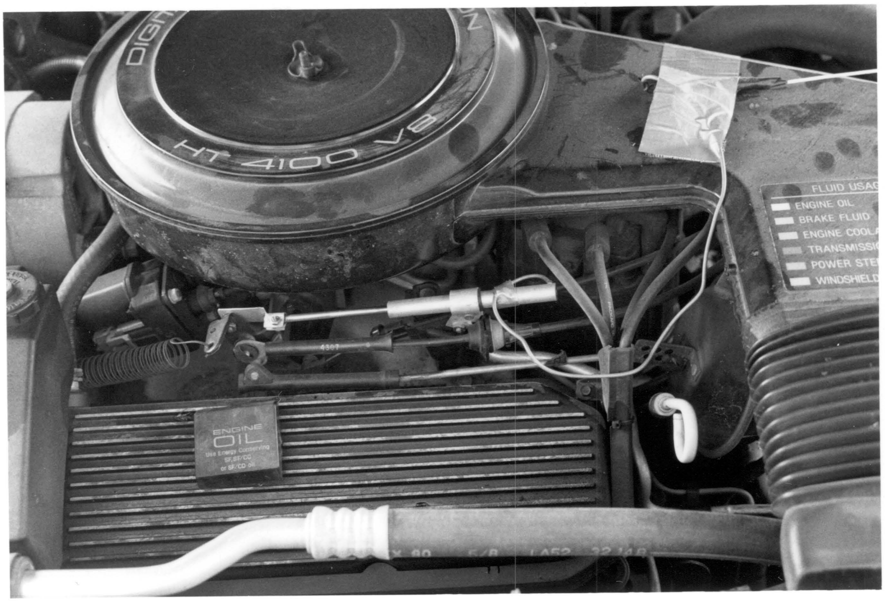


Figure 9. Accelerator tachometer mounted on the accelerator assembly (located in center of picture).

front seat set a memory pushbutton corresponding to the three roadway types that were investigated: four-lane limited-access, two-lane state route, and residential streets. The configuration of the control box that the experimenter in the front seat used to collect the task timing, lane-maintenance, and road-classification data appears in Figure 6.

Safety equipment. Several items of safety equipment were carried in the vehicle at all times: a fire extinguisher, a CB radio, and a first-aid kit. In addition, the experimenter in the front seat had access to a second brake pedal. The experimenter brake-pedal configuration is shown in Figure 10.

Data reduction equipment. The roadway and subject videotapes were reviewed in the laboratory via two video recorders and monitors. From these video tapes, subject glances were classified as roadway, display (instruments), or other. No problem was encountered in maintaining synchronization between the two recorders. The audio tones described previously were used as a means of checking synchronization.

Once the glances for each task were classified, the data were merged with the data collected in the automobile via a second IBM-PC microcomputer.

Figure 10. Experimenter's brake pedal mounted on passenger side of the experimental vehicle.

Procedure

Subject screening. Subjects were required to have a valid driver's license to participate in this study. Subjects were given a near-point and a far-point test of visual acuity using an Ortho-Rater vision testing device. Subjects were required to have corrected or uncorrected near-point visual acuity of 20/40 and far-point visual acuity of 20/40 to participate in this research. In addition, subjects were required to pass an informal hearing test to ensure that they could hear all verbal instructions presented. Subjects were not permitted to wear sunglasses or photo-grey glasses during the data collection runs.

Instructions and informed consent. Prior to participation, all subjects were required to read and sign the instructions and informed-consent form. The instructions and informed consent appear in Appendix A.

Training. The subjects were trained to use the navigator as outlined in the ETAK Navigator owner's manual (1985). This training entailed three steps. Step one consisted of reading relevant sections of the navigator owner's manual and operating instructions. Step two consisted of a "dry run" operation of all the navigator functions with the vehicle parked. Step three consisted of the operation of the navigator while driving on a straight road, at a slow speed, with no other traffic present. For each training step, the subject was required to demonstrate mistake-free system knowledge and proficiency to continue to the next training step. Training was judged to be complete when the subject was able to perform all navigator tasks safely and proficiently while driving. The training sessions took approximately two to four hours, depending on the subject.

In addition to the navigator training, the subjects were also familiarized with the other vehicle-specific controls and displays both while parked and while driving in a low attentional-demand situation as described above. When the driver was proficient and comfortable with the various vehicle subsystems (including the navigator), the data run was started.

Data-collection run. The data-collection run consisted of a drive along preselected routes as previously described. Periodically along the routes, the experimenter in the front seat asked the subject to perform a task from the list shown in Table 2. The task presentation orders were counterbalanced and randomly assigned to each subject as previously described. Between tasks, the experimenter collected several intervals of data, each lasting 5 to 20 seconds. These data served as a baseline no-task condition for analytical comparison. A data run on a particular road type lasted approximately 20 minutes. During this time, the subject performed 27 tasks. If a subject made a task error which, in the opinion of the experimenter, was a result of a lapse in memory from the training run, the subject was corrected and the task was replaced at a later time. Any other task errors were scored as such and the characteristics of the error recorded. The data runs for all three road types (including travel time between routes) lasted from approximately 60 to 90 minutes. After each of the three data runs, the subject was allowed to leave the car, stretch, use the restroom, or get a soft drink if he/she so desired.

Subject debriefing/payment. Upon completion of the data run, the subject was instructed to stop the vehicle at a safe and legal location. After all data runs were completed, the subject was driven by an experimenter back to the point of origin. Thereafter the subject was debriefed and paid.

DATA ANALYSIS OVERVIEW

Data Collection and Dependent Measure Definition

As previously discussed in the Apparatus section, all dependent measures were collected on-line by an IBM PC microcomputer. Each of these dependent measures is defined below. Each definition includes the description of the measure as it was collected and reduced by the PC into its final form.

Glances. A running record of the sequence of glances was kept for each task performed and each intermediate no-task data run. Glances were classified into three categories: roadway, display, and other. Since each instructed task required glances to specific objects (e.g., navigator display, speedometer, controls, mirrors, etc.), the word "display" is used to distinguish glances associated with those specific objects. For instance, when instructed to adjust the right rear-view mirror, glances at the mirror or the switch associated with the mirror were classified as "display" glances.

Each glance time (classified into one of the three categories) and transition time was recorded for each task and no-task data run. A glance time was defined as the time that that subject's eyes were stationary (discounting small movements) on a single object. The number of glances on the roadway (RDGLANCE) and on the given instrument or display of interest (DGLANCE), the dwell times per glance on the roadway (RDAVE) and on the instrument (DISAVE), the total dwell time on the roadway (RDTOT) and on the instrument (DISTOT), and the percentage of time during the task spent looking at the roadway (RDPER) and on the instrument (DISPER) were calculated.

Task-completion (or no-task data run) time. The time to complete each run and the exact time that a no-task data run lasted were recorded. The time from when the experimenter pressed the task start button (TIMEST) and the time from when the first glance at the instrument of interest (TIMEGLANCE) occurred until the task end were calculated. All other measures were directly synchronized to these times through the PC.

Task errors. Task errors were recorded with paper and pencil as previously described. Errors were categorized post-hoc and are discussed in the Results section.

Lane maintenance. Lane maintenance measurement consisted of on-line categorization of whether the car was in or out of the lane. The car was designated as exceeding the lane when any part of the car was on or over the lane edge. The number of lane deviations was recorded for each task data run and no-task data run. In addition, the average time spent out of the lane per lane deviation

(LANEX) for each of the different tasks was also calculated.

Accelerator pedal position and velocity. Three measures were calculated from the accelerator pedal velocity signal. These measures included accelerator pedal RMS velocity (ACCRMS), accelerator pedal velocity variance (ACCVAR), and a derivation of accelerator position high-pass variance (ACCPOS). Each measure was calculated on-line using the PC.

Steering-wheel velocity. Five measures were calculated from the steering velocity signal. These measures included steering-wheel RMS velocity (STVRMS), steering-wheel velocity variance (STVELVAR), percentage of the time that the steering-wheel velocity was zero (STPZAV), variance of the time that the steering-wheel velocity was zero (STPZVAR), and percentage of the time that the steering-wheel velocity exceeded a predetermined threshold (STEXT). This deviation value was set so that only a quick steering correction would exceed threshold. Each of these measures was calculated on-line using the PC.

Brake pedal activations. The number of brake pedal activations per unit time was collected (BRNUM). In addition, the mean brake pedal dwell time per activation (BRTIME) was also calculated using the PC.

A summary of the dependent-measure nomenclature appears on page xxi, following the Table of Contents.

The collection of the above measures was accomplished at a computational rate of 56 samples per second.

The hypotheses of expected results for the eye-scanning measures and task-completion measures are relatively straightforward -- the greater the attentional demand of the task, the greater the display-glance time, the less the roadway-glance time, and the greater the task-completion time. Perhaps less straightforward are the hypotheses associated with the driving-quality measures. Therefore, the attentional-demand hypothesis associated with each driving-quality measure is described as follows:

ACCRMS -- RMS Accelerator Velocity -- When attentional demand is high, ACCRMS would decrease due to removal of attention on speed maintenance and a resulting accelerator-pedal "hold."

ACCVAR -- Accelerator Velocity Variance -- ACCVAR would decrease with increasing attentional demand for the same reason described for ACCRMS.

ACCPOS -- High-Pass Accelerator Position Variance -- ACCPOS would decrease with increasing attentional demand for the same reason described for ACCRMS.

STVRMS -- RMS Steering Velocity -- STVRMS could potentially increase or decrease with increasing attentional demand. If a driver "held" the steering wheel instead of performing the normal small steering corrections when attentional demand was high, STVRMS would decrease. If, on the other hand, the car began to drift off the road and somewhat of a "jerk" was required during conditions of high attentional demand to correct vehicle tracking, STVRMS could increase.

STVELVAR -- Steering-Velocity Variance -- STVELVAR could increase or decrease with increasing attentional demand for the same reasons described for STVRMS.

STEXT -- Steering-Velocity Deviation Time -- STEXT is a steering-velocity deviation counter. When steering velocity exceeds a level equivalent to a "jerk," the counter is activated. STEXT could increase with increasing attentional demand since lane-tracking would likely degrade, thereby requiring steering-wheel "jerks" to correct lane position.

STPZAV -- Steering-Velocity Percent Zero Average -- STPZAV is essentially the average time that the steering wheel is "held" (i.e., no normal small control inputs) during a task. STPZAV would likely increase with increasing attentional demand since it is anticipated that small steering inputs disappear when attention is away from the lane-tracking task.

STPZVAR -- Steering-Velocity Percent Zero Variance -- STPZVAR is the variance of the time that the steering wheel is "held" during a task. STPZVAR would likely increase with increasing attentional demand since it is likely that steering behavior would become more erratic (i.e., "holds" followed by "jerks" to correct lane position).

BRNUM -- The number of brake activations -- BRNUM would likely increase with increasing attentional demand. Since driving in general would be erratic under conditions of high attentional demand, it is anticipated that more foot movements to the brake would be present due to a decreased perception of vehicular control.

BRTIME -- Average Dwell-Time Per Brake Application -- BRTIME would likely increase with increasing attentional demand for the same reason described for BRNUM.

LANEX -- Lane-Deviation Time -- LANEX is defined as the time that any part of the vehicle is on or over a lane boundary. LANEX would increase with increasing attentional demand since less attention would be allocated to the lane-tracking task.

Data Analysis Overview

Correlation analyses. Correlations were calculated between all pairs of the dependent measures for the entire data set. The purpose of these correlations was to determine which of the measures reliably covaried. Due to the large numbers of observations that existed in the data, only correlations (e.g., 0.3 to 0.6) much greater than normal significance levels are of interest. Any dependent measure containing a large number of zero values (e.g., number of lane deviations) was not used in the correlation analysis.

Ranking of attentional demand. The means and standard deviations for each of the tasks and each of the dependent measures were calculated. The tasks were then ranked from highest to lowest attentional demand based on the eye-glance measures. The task-completion time measures were also ranked from highest to lowest in terms of attentional demand.

Analysis of variance. A multivariate analysis of variance (MANOVA) was attempted for the five factors and 21 dependent measures associated with this experiment. Three problems were encountered while attempting to run this statistical analysis. First, since traffic density was characterized for each run, the variable could not be characterized as either a within-subject or between-subjects factor (i.e., both light and moderate traffic for different road types for one subject).

Second, the navigator tasks varied from low to very high attentional demand as indicated by several measures based on the a priori established criteria. Therefore, the original plan of running task difficulty as a five-level MANOVA factor (no-task, low, medium, high, and navigator) would not provide any information about navigator attentional demand due to the inherently large variability present between navigator tasks.

Third, the computational capability of the Virginia Tech Computing Center was too low (by a factor of 10) to manipulate a data set (131,000 lines) of this magnitude and a model of this complexity.

Because of these difficulties, analyses of variance (ANOVAs) were calculated based on the following scheme. First, ANOVAs were calculated for each dependent variable using road-type, gender, age, and driving experience factors. The purpose of these analyses was to determine which of the above effects and their interactions exhibited significant differences. The term "significant differences" is used with caution because type I error inflation is present in these analyses. Second, one-way ANOVAs were run to test for traffic-density differences. And, third, to determine whether task differences were actually present, one-way ANOVAs were run with each task as a level. For those ANOVAs that showed a high degree of significance ($p \leq 0.0001$), post-hoc multiple-comparison tests were conducted to determine which tasks differed and to aid in grouping tasks based on quantitative similarities.

The one-way ANOVAs, with each task as a level, violated the homogeneity of variance assumption for treatment conditions. Although the magnitudes of the variance differences for the tasks were substantial (as evidenced by the standard deviations and selected post-hoc multiple comparison tests discussed in the Results section), these differences did not affect the basic findings of the statistical tests. The reason for this is twofold. First, the violation of the homogeneity assumption causes the results to be biased in the conservative direction (Winer, 1971). Second, since significance levels of $p \leq 0.0001$ were found (as will be discussed in the Results section), it is apparent that, any conservative bias was not great enough to falsely indicate that differences were not present.

Cluster analysis. A multivariate cluster analysis was performed to determine if logical task groupings were present based on the information provided in the more promising dependent measures.

RESULTS

Correlation Analysis

As previously discussed in the Data Analysis Overview section, correlations were calculated between the eye-scanning measures and the task-completion time and driving-quality measures. The purpose of these analyses was to determine if any of the driving-performance/behavior and task-completion measures reliably covaried with the eye-scanning measures.

Correlations were also performed on portions of the data set associated with the different road types. The purpose of these analyses was to determine if differences were present in the way that specific measures (e.g., steering or accelerator-pedal measures) covaried with the eye-scanning measures on particular types of roads.

Correlations were performed using the majority of the driving-performance/behavior measures. The dependent variables LANEX, BRNUM, BRTIME, and STEXT were not used in the correlation analysis due to the large number of zero values in the data for these measures.

As a result of the large number of observations in the correlation analyses, only relatively high correlations (e.g., 0.20 and above) are of interest. Correlations above 0.20 indicate that at least some degree of meaningful covariance is present. Traditional significance levels, therefore, will not be addressed per se. (The values of correlation for significance at $p \leq 0.01$ in these analyses are substantially below 0.20.)

Correlations: full data set. The correlations between the eye-scanning measures and the driving-performance/behavior measures and task-completion time measures for the full data set appear in Table 4. In particular, DGLANCE (number of display glances), RDGLANCE (number of roadway glances), DISTOT (total display-glance time), and RDTOT (total roadway-glance time) show high correlations with TIMEST (task time from button press) and TIMEGLANCE (task time from first display glance). These high correlations indicate, at least in part, that longer task-completion times are associated with longer or more frequent glances.

The table also exhibits substantial correlations between several of the steering measures and the eye-scanning measures. In particular, STPZVAR, STVELVAR, and STVRMS are in many cases correlated with DGLANCE, RDGLANCE, DISTOT, and RDTOT. These correlations provide some validation of the hypotheses associated with steering that were presented earlier. Note that, unlike the time-dependence of the eye-scanning measures described above, there is no physical reason for these measures to be time dependent.

TABLE 4

Eye-Scanning Measure vs. Task-Completion Time and Driving-Performance/Behavior Measure Correlations. Full Data Set.*

	DGLANCE	RGLANCE	DISAVE	RDAVE	DISTOT	RDTOT	DISPER	RDPER
ACCRMS	-0.02	0.01	0.08	0.05	0.01	0.03	-0.04	0.05
ACCVAR	0.15	0.17	0.08	0.03	0.15	0.12	-0.06	0.05
ACCPOS	-0.03	-0.01	0.11	0.11	0.03	0.05	0.01	0.05
STPZAV	-0.14	-0.17	-0.03	-0.03	-0.13	-0.12	0.05	-0.04
STPZVAR	0.44	0.47	0.09	0.07	0.37	0.31	-0.19	0.12
STVRMS	0.17	0.20	0.03	0.10	0.14	0.19	-0.12	0.10
STVELVAR	0.24	0.26	0.08	0.04	0.22	0.18	-0.09	0.05
TIMEST	0.87	0.91	0.29	0.17	0.90	0.77	-0.21	0.15
TIMEGLANCE	0.90	0.89	0.30	0.11	0.92	0.73	-0.92	0.10

* Correlation values above 0.20 are underlined.

($r = 0.05$, $p = .01$; $r = 0.07$, $p = 0.001$)

Even though there is no reason to believe that these relatively high correlations exist due to a time dependency present for each correlated measure, a check on the correlations between the steering measures and the task-completion time measures revealed large correlations for the case of the four-lane limited-access roadway data. This relationship between steering and task time is probably due to the relatively long period of time required for a vehicle to drift off-track on a straight four-lane roadway. Therefore, large steering corrections would only be necessary for tasks of longer duration and higher attentional demand.

Correlation analysis: city (residential street) road type. The correlations between the eye-scanning measures, and the task-completion time and driving-performance/behavior measures for the city (residential) streets appear in Table 5. As shown, the steering measure STPZVAR (steering percent zero variance) is highly correlated with a number of eye-scanning measures. Unlike the correlations for the full data set, STPZVAR shows a highly positive correlation with DISAVE (average-display-glance time) and a highly negative correlation with RDAVE (average-roadway-glance time). This result is consistent with the hypothesis that steering behavior becomes more erratic when long glances at the display or short glances

TABLE 5

Eye-Scanning Measure vs. Task-Completion Time and Driving-Performance/Behavior Measure Correlations. City Road-Type Data.*

	DGLANCE	RGLANCE	DISAVE	RDAVE	DISTOT	RDTOT	DISPER	RDPER
ACCRMS	-0.04	0.10	-0.13	0.20	-0.10	0.22	-0.15	0.19
ACCVAR	0.04	0.12	-0.03	-0.07	-0.03	0.08	-0.05	0.04
ACCPOS	-0.12	-0.15	-0.18	0.41	-0.18	0.27	-0.20	0.25
STPZAV	-0.02	-0.08	-0.11	0.13	-0.07	0.07	-0.03	0.06
STPZVAR	0.40	0.50	0.34	-0.40	0.33	0.08	0.23	-0.30
STVRMS	0.04	0.08	0.14	-0.09	0.10	-0.05	0.03	-0.90
STVELVAR	0.10	0.06	0.17	-0.11	0.14	-0.04	0.07	-0.22
TIMEST	0.27	0.38	0.22	0.27	0.27	0.84	-0.03	0.05
TIMEGLANCE	0.81	0.29	0.62	-0.30	0.77	-0.00	0.58	-0.57

* Correlation values above 0.20 are underlined.

($r = 0.15$, $p = 0.01$; $r = 0.19$, $p = 0.001$)

at the roadway occur. A similar result was found for correlations among STPZVAR, RDPER (percentage of glance time on the roadway), and DISPER (percentage of glance time on the display). The other steering measure that had relatively high correlations in the full data set, STVELVAR (steering-velocity variance), had smaller correlations for the city road-type data.

One of the accelerator pedal measures, ACCPOS (accelerator high-pass position variance) exhibited several substantial correlations with the eye-scanning measures for the city road-type data. Notice that the hypothesized pattern of accelerator-pedal "holds" with high attentional demand is supported by the negative correlations between ACCPOS and DISAVE, DISTOT and DISPER, and the positive correlations between ACCPOS and RDAVE, RDTOT and RDPER. As glance time on the roadway increases, ACCPOS increases and as glance time on the display increases, ACCPOS decreases, indicating a greater number of accelerator-pedal "holds."

Correlation analysis: two-lane state route. The correlations between the eye-scanning measures, and the task-completion time and driving-performance/behavior measures for the two-lane roadway appear in Table 6. As shown, the correlations between the eye-scanning measures and some of the accelerator and steering measures are smaller for the two-lane roadway than for the city roadway

TABLE 6

Eye-Scanning Measure vs. Task-Completion Time and Driving-Performance/Behavior Measure Correlations. Two-Lane Road-Type Data.*

	DGLANCE	RGLANCE	DISAVE	RDAVE	DISTOT	RDTOT	DISPER	ROPER
ACCRMS	0.01	0.05	-0.05	-0.00	-0.01	0.03	-0.06	0.05
ACCVAR	0.21	0.18	0.04	-0.17	0.12	0.01	0.09	-0.12
ACCPOS	-0.16	-0.11	-0.06	0.18	-0.12	0.14	-0.16	0.20
STPZAV	0.13	0.08	0.00	-0.12	0.03	-0.08	0.06	-0.07
STPZVAR	0.34	0.38	-0.00	-0.38	0.16	-0.02	0.15	-0.17
STVRMS	-0.06	-0.12	0.07	0.10	0.06	0.05	0.00	0.03
STVELVAR	0.10	0.10	-0.00	-0.20	0.07	-0.08	0.07	-0.07
TIMEST	0.28	0.43	0.11	0.31	0.24	0.88	0.01	0.04
TIMEGLANCE	0.76	0.49	0.43	-0.36	0.70	0.14	0.55	-0.52

* Correlation values above 0.20 are underlined.

($r = 0.15$, $p = 0.01$; $r = 0.19$, $p = 0.001$)

or the full data set. Some of the same trends that supported the construct validity of some of the measures (e.g., ACCPOS and STPZVAR) are still present; however, the correlations are generally smaller in magnitude. The correlations between the eye-scanning measures and the task-completion time measures remain high.

The reductions in the correlation values for the two-lane roadway may be a result of inherent increases in steering and accelerator variance due to the road type. By nature, a two-lane state route requires more steering input because of changing curves and uneven surfaces. This type of road also requires more accelerator movement due to changing amounts of curvature that require the driver to change speed more often than other road types.

Correlation analysis: four-lane limited-access roadway. The correlations between the eye-scanning measures, and the task-completion time and driving-performance/behavior measures for the four-lane roadway appear in Table 7. The results are similar to the other roadway types previously discussed. The construct validity of the variables ACCPOS and STPZVAR is supported (in general) by the four-lane data although the correlations are not as high as the correlations for the city road-type data. The task-completion time data again show high correlations with many of the eye-scanning measures.

TABLE 7

Eye-Scanning Measure vs. Task-Completion Time and Driving-Performance/Behavior Measure Correlations. Four-Lane Road-Type Data.*

	DGLANCE	RGLANCE	DISAVE	RDAVE	DISTOT	RDTOT	DISPER	RDPER
ACCRMS	-0.13	-0.07	-0.12	0.01	-0.13	0.00	-0.11	0.10
ACCVAR	0.04	0.11	-0.06	-0.07	-0.02	0.22	-0.07	0.06
ACCPOS	-0.11	-0.18	-0.09	0.18	-0.10	0.02	-0.10	0.13
STPZAV	-0.00	-0.01	-0.11	0.16	-0.21	0.17	-0.17	0.17
STPZVAR	0.10	0.19	0.09	-0.27	0.20	-0.12	0.21	-0.23
STVRMS	0.00	0.08	0.02	-0.17	0.13	-0.10	0.06	-0.08
STVELVAR	-0.01	0.16	-0.03	-0.17	0.05	-0.05	0.02	-0.05
TIMEST	0.65	0.61	0.26	-0.05	0.64	0.74	0.24	-0.24
TIMEGLANCE	0.81	0.57	0.38	-0.34	0.76	0.37	0.53	-0.55

* Correlation values above 0.20 are underlined.

($r = 0.15$, $p = 0.01$; $r = 0.19$, $p = 0.001$)

Ranking of Attentional Demand

Several of the dependent variables collected have inherent face validity as well as theoretical construct validity with regard to attentional demand as it relates to this study. These measures include DISTOT (total display-glance time), DISAVE (average-display-glance time), DGLANCE (number of display glances), RDAVE (average-roadway-glance time), TIMEGLANCE and TIMEST (task-completion time), LANEX (time out of lane-per-lane deviation) the number of lane deviations, and the number of task errors. For each of these measures, means and standard deviations were calculated for each task, and the tasks rank-ordered from lowest to highest attentional demand based on the means.

Task ranking for total-display-glance time (DISTOT). The task ranking for DISTOT (from low to high) appears in Table 8. No surprises were found with regard to the conventional task rank, although some of the means were somewhat higher than a priori expectations based on the literature reviewed. The navigator tasks were interspersed in the ranking with the conventional tasks. The navigator tasks that required simple information retrieval (namely, destination direction and destination distance) were near the top of the ranking, which indicated that they required low attentional demand. The navigator tasks requiring some

TABLE 8

Total-Required-Display-Glance Time (DISTOT) for Each Task

Task	Display Glance Time (Mean)	Standard Deviation
Turn Signal	0.38	0.56
Speed	0.78	0.65
Following Traffic	0.98	0.60
Time	1.04	0.56
Vent	1.13	0.99
+Destination Direction	1.57	0.94
Remaining Fuel	1.58	0.95
Tone Controls	1.59	1.03
Info Lights	1.75	0.93
+Destination Distance	1.83	1.09
Fan	1.95	1.29
Balance	2.23	1.50
Sentinal	2.38	1.71
Defrost	2.86	1.59
Fuel Economy	2.87	1.09
+Correct Direction	2.96	1.86
Fuel Range	3.0	1.43
Cassette Tape	1.59 + 1.64*	0.96 (0.59)*
Temperature	3.50	1.73
+Heading	3.58	2.23
+Zoom Level	4.00	2.17
Cruise Control	4.82	3.80
Power Mirror	5.71	2.78
Tune Radio	7.6	3.41
+Cross Street	8.63	4.86
+Roadway Distance	8.84	5.20
+Roadway Name	10.63	5.80

* Time required to search for and orient cassette tape

+ Navigator tasks

judgement on the part of the subject (namely, correct direction, heading, and zoom level) fell near the middle of the task rankings. The remaining navigator tasks (roadway distance, roadway name, and cross street) were at the bottom of the list, which indicated long total-glance times and high attentional demand.

Large standard deviations were present for all of the tasks (as shown in Table 8), particularly the navigator tasks requiring large total-display-glance times. These large navigator standard deviations can be attributed (at least in part) to the fact that at times the information required by the subject was available on the screen, while at other times the subject was required to zoom in or zoom out to retrieve the information. This characteristic is an inherent part of navigating with the device. Therefore, whether or not information was immediately available to the subject was not manipulated as part of the experiment. (See Procedure section for more detail.) Information availability for these tasks, however, was recorded by the experimenter.

To examine differences in navigator tasks caused by differences in information availability, the data were separated into two categories. The first category contained data in which all necessary information was immediately available to the driver, and the second category contained data in which the driver had to use the zoom-in/zoom-out function to obtain the necessary information. The results of this division appear in Table 9. Note that when the information was immediately available to the subject, the navigator tasks in question required less display-glance time, on the average, than the conventional tune-radio task in the case of all three, and less display-glance time than the power-mirror or cruise-control tasks in the case of roadway name and cross street. When the information was not immediately available on the screen, all three navigator tasks required higher display-glance times than any of the conventional tasks.

Task ranking for single-glance length and number of glances (DISAVE and DGLANCE). The task ranking for the both the single display-glance lengths and number of glances appears in Table 10. The rank used in Table 10 is the same as for the total display-glance time (DISTOT), which was discussed in the previous paragraph (since DISAVE times DGLANCE is approximately equal to DISTOT). The purpose of presenting this information is to investigate how the subjects extracted the information from the various displays. The navigator tasks, cross street, roadway distance, and roadway name had the longest average single display-glance times. These longer display-glance times are probably due to the complexity of the information extracted from the navigator for any portion of these tasks

TABLE 9

Navigator Tasks Roadway Name, Roadway Distance, and Cross Street Separated by Information Availability for the Dependent Variable DISTOT

	N	Mean	SD
Roadway Name			
Info Available	26	4.61	2.39
Zoom Required	68	12.12	5.36
Roadway Distance			
Info Available	46	6.77	4.03
Zoom Required	52	10.07	5.64
Cross Street			
Info Available	24	4.05	4.16
Zoom Required	72	8.91	4.48

TABLE 10

Display Single-Glance Length and Number of Display Glances by Task

Task	(DISAVE) Display single-glance length Mean	SD	(DGLANCE) Number of glances Mean	SD
Turn Signal	0.30	0.39	0.63	0.73
Speed	0.62	0.48	1.26	0.40
Following Traffic	0.75	0.36	1.31	0.57
Time	0.83	0.38	1.26	0.46
Vent	0.62	0.40	1.83	1.03
+Destination Direction	1.20	0.73	1.31	0.62
Remaining Fuel	1.04	0.50	1.52	0.71
Tone Controls	0.92	0.41	1.73	0.82
Info Lights	0.83	0.35	2.12	1.16
+Destination Distance	1.06	0.56	1.73	0.93
Fan	1.10	0.48	1.78	1.00
Balance	0.86	0.35	2.59	1.18
Sentinal	1.01	0.47	2.51	1.81
Defrost	1.14	0.61	2.51	1.49
Fuel Economy	1.14	0.58	2.48	0.94
+Correct Direction	1.45	0.67	2.04	1.25
Fuel Range	1.19	1.02	2.54	0.60
Temperature	1.10	0.52	3.18	1.66
Cassette Tape	0.80	0.29	2.06	1.29
+Heading	1.30	0.56	2.76	1.81
+Zoom Level	1.40	0.65	2.91	1.65
Cruise Control	0.82	0.36	5.88	2.81
Power Mirror	0.86	0.34	6.64	2.56
Tune Radio	1.10	0.47	6.91	2.39
+Cross Street	1.66	0.82	5.21	3.20
+Roadway Distance	1.53	0.65	5.78	2.85
+Roadway Name	1.63	0.80	6.52	3.15

+ Navigator tasks

(refer to Figure 1). For the conventional tasks having an average of two or more display glances, the single-glance time varied a relatively small amount (0.80 s to 1.19 s). Note that while the average single-glance time remained relatively constant, the number of glances varied widely. This result is consistent with previous research of this type (e.g., Bhise et al., 1986; Rockwell, 1972). Drivers sample display information at relatively constant single-glance lengths. The greater the complexity of the task, the greater the number of glances required.

While the number of glances increases with increasing attentional demand, the variation associated with the mean number of display glances (Table 10) for each task is relatively large. To get a better understanding of this variation, the sum of the number of trials requiring one, two, and greater-than-two glances for each task was calculated. As shown in Table 11, even the tasks requiring the least amount of attentional demand (e.g., speed and time) still had a number of trials when the subject had two glances at the display. Another interesting result shown in Table 11 is that some of the tasks in the middle of the attentional-demand range had approximately equal numbers of trials in the one, two, and greater-than-two glance categories. Note that for many of the trials, the turn-signal task did not require the driver to look away

TABLE 11

Number of Trials Requiring One, Two, and Greater Than Two Display Glances by Task

Task Name	Number of Trials Requiring One Display Glance	Number of Trials Requiring Two Display Glances	Number of Trials Requiring Three or more Glances
Turn Signal*	41	5	0
Speed	74	21	1
Time	72	23	1
+Destination Direction	71	22	3
Following Traffic	66	25	3
Remaining Fuel	56	28	9
+Destination Distance	49	32	15
Fan	46	35	15
+Appropriate Direction	43	24	27
Vent	43	33	20
Tone Controls	43	39	14
Info Lights	32	34	27
Cassette Tape	30	38	27
Sentinal	28	33	34
Defrost	23	35	38
+Heading	18	36	41
+Cross Street	13	10	73
Balance	12	41	43
+Zoom Level	11	41	44
Temperature	11	20	61
Fuel Range	10	42	44
Fuel Economy	9	49	38
+Roadway Distance	3	8	85
+Roadway Name	2	8	84
Tune Radio	1	--	95
Power Mirror	--	1	93

* Note: 40 trials required no glance
+ Navigator tasks

from the roadway. This causes dependent measures such as DISTOT to be somewhat misleading. Therefore, the turn-signal task is deleted from the subsequent analyses involving measures of this type.

Task ranking for average-roadway-glance time (RDAVE). The average-roadway-glance time means and standard deviations for each task appear in Table 12. Unlike the dependent measures previously discussed, the lengths of roadway glances are not ranked. As shown, the average length of roadway glances does not vary a great deal, especially when the size of the standard deviations is considered. There is also no apparent pattern of navigator vs. conventional tasks for RDAVE as was present for some of the display-glance dependent measures. The navigator tasks appear to fall somewhere in the middle of the RDAVE data with no apparent grouping.

It is interesting to speculate that while the attentional demand of the secondary tasks varied, the difficulty of the primary driving task (across road type and traffic density) remained relatively constant. Therefore, the roadway visual sampling remained relatively constant. Testing for specific roadway differences due to traffic density and road type is accomplished in the Analysis of Variance (ANOVA) section.

TABLE 12

Average-Roadway-Glance Length (RDAVE) by Task

Task	Mean	SD
Following Traffic	0.37	0.49
Remaining Fuel	0.37	0.60
Fan	0.52	0.69
Time	0.24	0.41
Info Lights	0.52	0.65
Speed	0.32	0.52
Fuel Range	0.53	0.39
Fuel Economy	0.57	0.48
Tone Controls	0.65	0.64
Defrost	0.54	0.56
Balance	0.82	0.63
Sentinal	0.76	0.85
Tune Radio	0.71	0.37
Vent	0.60	0.69
Temperature	0.59	0.41
Cassette Tape	0.90	0.48
Power Mirror	0.75	0.39
Heading	0.74	0.55
Destination Distance	0.40	0.52
Destination Direction	0.33	0.58
Roadway Name	0.65	0.44
Zoom Level	0.54	0.39
Roadway Distance	0.63	0.52
Cross Street	0.54	0.51
Correct Direction	0.58	0.74

Task ranking for task-completion time (TIMEST and TIMEGLANCE). The task-completion time data from the task-start button press (TIMEST) and from the first display glance (TIMEGLANCE) for each task are shown in Table 13. As shown, the navigator tasks are interspersed throughout the rank of tasks. As with the total-display-glance time data, the navigator tasks that required simple information retrieval (destination direction and destination distance) ranked fairly low. The navigator tasks that required some judgement on the part of the subject (correct direction, heading, and zoom level) ranked in the middle to high ranges. The remaining navigator tasks (cross street, roadway distance, and roadway name) ranked in the high range in terms of task-completion time. Note that roadway name stands out as requiring the longest amount of time to complete of any task. In terms of required task-completion time, cross street and roadway distance appear to be comparable to several conventional tasks (tune radio, cruise control, and power mirror).

As with the total required display-glance time data, the navigator tasks, cross street, roadway name, and roadway distance were separated, based on whether the information was immediately available on the display or a zoom in or zoom out was required. The results appear in Table 14. As shown, the differences in the task-completion times for these tasks based on information availability are

TABLE 13

Task-Completion Time for Each Task

Task	Time from first glance (TIMEGLANCE)		Time from button press (TIMEST)	
	Mean	SD	Mean	SD
Turn Signal	0.64	0.68	0.62	0.71
Speed	1.19	0.98	1.07	0.81
Time	1.40	0.99	1.36	0.84
Following Traffic	1.45	0.99	1.30	0.78
Destination Direction	1.99	1.28	1.99	1.29
Remaining Fuel	2.04	1.33	1.99	1.24
Vent	2.35	2.76	2.13	1.59
Info Lights	2.53	1.52	2.24	1.35
Destination Distance	2.58	1.70	2.34	1.56
Tone Controls	2.65	1.65	2.57	1.51
Fan	2.80	2.02	2.54	1.74
Cassette Tape	3.43	2.68	5.24	2.49
Defrost	3.89	2.40	3.56	2.12
Correct Direction	3.93	2.69	3.72	2.54
Balance	4.07	2.26	3.73	2.19
Sentinal	4.11	2.93	3.68	2.59
Fuel Economy	4.02	1.68	3.82	1.55
Fuel Range	4.21	1.81	3.95	1.60
Temperature	5.19	2.71	4.89	2.55
Zoom Level	5.64	3.43	5.27	3.31
Heading	5.62	4.16	5.72	4.11
Power Mirror	10.73	5.35	10.65	5.23
Cruise Control	10.47	7.30	11.88	7.96
Cross Street	11.59	7.41	11.08	7.50
Roadway Distance	13.23	8.11	13.04	7.84
Tune Radio	13.24	6.38	13.18	6.40
Roadway Name	16.04	10.22	15.87	10.26

TABLE 14

Navigator Tasks Roadway Name, Roadway Distance, and Cross Street Separated by Information Availability for the Task-Completion-Time Measures

	Time from first glance (TIMEGLANCE)		Time from button press (TIMEST)	
	Mean	SD	Mean	SD
Roadway Name				
Info Available	7.00	2.95	6.84	3.04
Zoom Required	19.49	9.90	19.31	10.00
Roadway Distance				
Info Available	9.36	5.28	9.31	5.01
Zoom Required	16.66	8.67	16.31	8.61
Cross Street				
Info Available	5.49	5.56	5.05	5.62
Zoom Required	13.62	6.82	13.48	6.86

generally quite large. For the navigator tasks with the information immediately available the task-completion times are lower than for several of the conventional tasks. The task-completion times of those navigator tasks for which the information is not immediately available are higher than for any of the conventional tasks. In the cases of roadway name and roadway distance, the navigator tasks without immediately available information apparently have substantially higher task-completion-time means (taking standard deviations into account) than any of the conventional tasks.

Task ranking by the number of lane deviations and the average time out-of-lane per exceedence (LANEX). The task ranking by number and average duration of lane deviations appears in Table 15. As shown, most of the tasks had few, if any, lane deviations for the 94 to 96 trials performed for each task. Several of the tasks for which the other measures have shown high attentional demand (temperature, cross street, roadway name, roadway distance, tune radio, cassette tape, and power mirror) had more lane deviations than the remainder of the tasks. Of particular interest is the power-mirror task, which had more lane deviations than the other tasks. Speculating on this difference, perhaps viewing a rear-view mirror moving into proper line of sight somehow gives a misperception about lane position. Some lane-tracking information is present when a mirror is

TABLE 15

Number of Lane Deviations and Average Time Per Deviation by Task

Task	# of Lane Deviations	(LANEX) Average Lane Deviation Time
Following Traffic	0	
Time	0	
Speed	0	
Vent	0	
+Destination Distance	0	
+Destination Direction	0	
Turn Signal	0	
Fan	1	0.46
Remaining Fuel	1	0.95
Tone Controls	1	0.97
+Correct Direction	1	1.0
Sentinal	2	0.28
Balance	2	0.55
Defrost	3	0.67
+Heading	3	0.62
Info Lights	3	0.83
Fuel Economy	3	2.25
+Zoom Level	4	0.94
Fuel Range	5	0.84
Temperature	8	0.65
+Cross Street	8	0.93
+Roadway Name	8	1.38
+Roadway Distance	9	1.17
Tune Radio	10	1.86
Cassette Tape	13	0.99
Power Mirror	21	1.10

+ Navigator tasks

viewed; therefore, perhaps the "swinging" of the lane as viewed through the mirror gives false information about the lane "track."

The navigator tasks that showed the highest attentional demand based on some of the other dependent measures (roadway name, roadway distance, and cross street) had approximately the same number and duration of lane deviations as the conventional tasks requiring high attentional demand.

Comparison between task data and no-task data runs. As previously discussed in the Procedure section, several intervals of data were collected while no secondary tasks were being performed. The purpose of these "no-task" data runs was to observe driver behavior under conditions of performing only the so-called primary task of driving. The means and standard deviations for each of the dependent measures that were inherently face valid (as previously defined) were calculated for the no-task data. To understand the behavior associated with the primary driving task under differing conditions with regard to these measures, the no-task data were separated by road type. These results appear in Table 16.

The TIMEST (task time from button press) data have no meaning (as no tasks were performed) other than to show the length of the no-task data run. Note that the mean length

TABLE 16

No-Task Condition Data for Selected Dependent Variables

	City		Two-Lane		Four-Lane	
	Mean	SD	Mean	SD	Mean	SD
TIMEST	7.91	2.98	9.21	4.20	9.94	4.26
DISAVE	0.48	0.60	0.52	1.17	0.69	0.59
RDAVE	3.33	2.79	3.97	3.62	2.06	1.99
DGLANCE	1.06	1.28	1.30	1.53	2.99	2.47
DISTOT	0.95	1.38	1.06	1.84	2.34	2.50
LANEX	0	0	0	0	0	0

of a no-task run varied from approximately 8 to 10 seconds, depending on the road type, with fairly large standard deviations. These times are approximately equal to some tasks requiring longer task-completion times as previously described. Therefore, some of the time-dependent measures such as DISTOT (total-display-glance time) and DGLANCE (number of display glances) should be comparable to those of the longer tasks.

Also, it is important to note that in the no-task runs, "display" is defined as any driving-relevant instrument or display. For example, if the driver observed the speedometer and the rear-view mirror, these would both be included in the calculation of DISAVE, DGLANCE, and DISTOT.

The average-display-glance time (DISAVE) mean for the no-task condition was less than many of the tasks previously discussed (0.48 to 0.69 s depending on the road type). As Table 16 also shows, the DISAVE mean was somewhat larger for the four-lane roadway than for the other roadway types. This result is in agreement with the previous finding that a four-lane roadway requires less visual attention than do other types of roadways. The slightly longer glance time may be attributed to the hypothesis that the driver was able to look at a given display more casually on the four-lane roadway.

The results for the variable RDAVE (average-roadway-glance time) for the no-task condition are quite interesting. In a comparison between Table 16 and Table 12, it is evident that the RDAVE mean for the no-task condition was three to four times greater than the RDAVE mean while tasks were being performed. Given that (in the opinion of the experimenters) the vast majority of the data runs were performed while drivers were operating the vehicle safely, this result supports previous findings that a large amount of spare visual capacity indeed exists for the driving task. It should be noted, however, that given an unexpected emergency situation requiring a driver response, the chances of immediately detecting the situation are much greater when no secondary tasks are being performed. Given the typical driver behavior of transitioning at approximately one-second intervals between a display and the roadway, it seems apparent that the worst case probability of immediately detecting something unexpected on the roadway is in the neighborhood of 0.5 for the length of the secondary task. The actual probability of detection is probably greater than 0.5 when the driver's peripheral vision and event anticipation from previous samples are considered; however, the probability of detection during a secondary task is undoubtedly much less than during primary task performance alone.

The mean length of roadway glances was longest for the two-lane roadway and shortest for the four-lane roadway. This result supports previous findings that visual attentional demand is greatest on two-lane roadways and least on four-lane roadways. Notice, however, that due to the large standard deviations associated with the RDAVE variable, these differences must be interpreted with caution. Formal tests of these differences will be addressed in the Analysis of Variance section.

The number of display glances (DGLANCE) for the no-task data also appears in Table 16. The number of display glances was substantially lower for the no-task condition than for tasks of comparable length. This result is consistent with the no-task data results previously discussed. The DGLANCE mean for the four-lane roadway appears to be substantially higher than the DGLANCE means for the two-lane and city roadway conditions. This result is again consistent with previous findings that four-lane roadways require less visual attentional demand than other roadway types.

The total-display-glance time (DISTOT) for the no-task data provides results consistent with the other no-task variables previously discussed. The DISTOT mean is quite low in comparison to secondary tasks of comparable length. In addition, the DISTOT mean for the four-lane roadway is larger than for the two-lane or city roadways, again indicating that the four-lane roadway requires less visual attentional demand than the other two road types.

The number of lane deviations is also shown in Table 16. These data were included to show that no lane deviations occurred during the no-task data runs as compared with as many as 21 deviations for the secondary task data runs.

Task Error Analysis

As previously discussed in the Procedure section, notes on driver errors were kept by the experimenter during a run. The number of mistakes associated with each task, along with a brief characterization of any errors that were recurrent, appear in Table 17. As shown, the conventional tasks generally had very few mistakes during the 94 to 96 trials performed. The two navigator tasks requiring only simple information retrieval (destination distance and destination direction) also had few errors (two each). The navigator tasks requiring the driver to use at least some judgement had a larger number of errors than the other tasks. As suggested by the characterizations associated with these tasks, design improvements could potentially alleviate some of these errors (e.g., heading arrow redesign). These issues will be addressed in detail in the Discussion section.

The means and standard deviations were calculated by

TABLE 17

Number of Subject Errors and Error Characterization by Task

Task	Number of Mistakes	Characterization
Following Traffic	0	
Remaining Fuel	0	
Fan	0	
Time	0	
Info Lights	0	
Speed	0	
Fuel Range	0	
Fuel Economy	0	
Tone Controls	1	Adjusted wrong control.
Defrost	0	
Balance	0	
Sentinal	2	Adjusted twilight sentinal instead of dimming sentinal.
Tune Radio	2	Selected wrong frequency, off slightly (one click).
Vent	0	
Temperature	0	
Cassette Tape	0	
Power Mirror	0	

TABLE 17

Number of Subject Errors and Error Characterization by Task (Continued)

Task	Number of Mistakes	Characterization
Heading	22	Confused compass headings. Arrow difficult to interpret, especially SW or SE.
Destination Distance	2	Read scale value.
Destination Direction	2	Read wrong arrow.
Roadway Name	10	Often selected wrong roadway. Occasionally read wrong label.
Zoom Level	14	Sometimes had difficulty calculating next highest fraction, especially when very close to the destination.
Roadway Distance	20	Often forgot to check the displayed scale level. Some difficulty in interpolating distance.
Cross Street	14	Often close wrong zoom-level to select next cross street.
Correct Direction	5	Read wrong arrow.
Turn Signal	0	
Cruise Control	0	

task for a number of the dependent measures with the error data removed. Without exception, the removal of the error data had little effect on the means or the task rankings as previously discussed. As an example, the means and standard deviations for the variable DISTOT (total-display-glance time) with the error data removed appear in Table 18. When comparing the full data set (Table 7) to the error-free data set (Table 18) for DISTOT, it is apparent that no major changes occurred in the means of the data. This is especially evident when one considers the magnitude of the standard deviations associated with each task. Since removal of the error data apparently has little effect on the data set, all subsequent analyses are performed utilizing the full data set.

Analyses of Variance (ANOVAs)

As previously discussed in the Data Analysis Overview section, multivariate analyses could not be run on the full data set. Therefore, analyses of variance (ANOVAs) were calculated using the following scheme. First, ANOVAs were calculated for all the variables which had equal cell sizes (gender, age, driving experience, and road type). Second, one-way ANOVAs were calculated for traffic density. The ANOVA procedure used accounted for the unequal cell frequencies created by the run-by-run characterization of traffic density factor (SAS GLM, SAS Institute, 1985).

TABLE 18

Total-Display-Glance Time (DISTOT) by Task with Error Data Removed

	Mean	SD
Turn Signal	0.38	0.56
Speed	0.80	0.65
Following Traffic	0.98	0.60
Time	1.04	0.56
Vent	1.19	0.99
Destination Direction	1.51	0.94
Remaining Fuel	1.51	0.95
Tone Controls	1.57	1.03
Cassette Tape	1.59	0.96
Info Lights	1.64	0.93
Destination Distance	1.69	1.05
Fan	1.86	1.29
Balance	2.28	1.50
Sentinal	2.31	1.65
Defrost	2.58	1.59
Fuel Econ	2.62	1.09
Correct Direction	2.70	1.87
Fuel Range	2.81	1.43
Temperature	3.22	1.73
Heading	3.36	2.39
Zoom Level	3.39	1.96
Power Mirror	5.59	2.78
Tune	7.21	3.42
Cross Street	8.04	4.96
Roadway Distance	8.49	5.11
Roadway Name	9.64	5.78

Third, to address the question of task differences, one-way ANOVAs were run with each task as a level. Post-hoc multiple comparisons were then calculated to test for individual task differences. Through this method, comparisons could be addressed on a task-by-task basis without relying on task classifications such as navigator vs. conventional or degree of attentional demand.

There are two unavoidable disadvantages to dividing the analysis as previously described. First, since MANOVAs or even a single ANOVA model could not be run, the Type I (alpha) error is inflated due to the running of multiple independent tests on dependent data. The reader is therefore cautioned against using "standard" levels of significance (e.g., $p < 0.05$) when reviewing these analyses. To maintain a 0.05 probability of a Type I (alpha) error for the multiple ANOVAs in the study, the use of a value of $p \leq 0.001$ for an individual analysis is appropriate.

The second disadvantage is that some of the higher-order interactions cannot be addressed.

One-Way ANOVAs and Post-Hoc Comparisons to Assess Task Similarities

To quantitatively assess task differences, one-way ANOVAs were run with each task serving as a level. Not surprisingly, all of the one-way ANOVAs were significant with p-values less than 0.0001. Since all of the ANOVAs showed that differences were present for all of the dependent measures, post-hoc multiple-comparison tests were calculated to locate the differences. Through this approach, insight was gained into which tasks required the same attentional demand (for all practical purposes) and which tasks were different from one another.

Given that a large number of post-hoc comparison tests are available, and that the selection of an available test can affect the outcome of the results (since they range from very conservative to very liberal), two post-hoc tests were calculated. The first test selected was a t-test, since this test provides the most liberal results. The second test selected was the somewhat conservative Bonferroni multiple-comparison test.

Although multiple comparisons were calculated for all of the dependent measures, only five measures are discussed as part of this analysis. The five measures that are discussed in detail were selected based on the sensitivity that the measures showed in determining task differences. The measures showing sensitivity (for 95-percent confidence limits) were TIMEGLANCE (task time from first display glance), DISTOT (total-display-glance time), DGLANCE (number of display glances), DISAVE (average-display-glance time), and STPZVAR (steering-velocity percent zero variance). Based on the results of the previous analyses, it is not surprising that the measures listed above showed the greatest sensitivity to task differences. Notice that several of the measures that are addressed have inherent face validity as previously discussed in the Ranking of Attentional Demand section.

For interpretation of the multiple-comparison tables, each task in the left-hand column is marked with asterisks corresponding to tasks along the bottom of the tables that fall within the 95-percent confidence limits for that particular task. Note that each task will have asterisks in at least one column (task is the same as itself). Note also that tasks are rank ordered by means for each dependent variable and decrease from top to bottom and from left to right.

t-test multiple comparisons - TIMEGLANCE. The t-test multiple comparisons for the dependent variable TIMEGLANCE appear in Table 19. As shown, several of the tasks requiring the longest task-completion times are different (as indicated by the 95-percent confidence limits) from the tasks requiring less task-completion time. Notice that roadway name required the longest task-completion time and is different, as indicated by the t-test comparison, from all of the other tasks. Also noteworthy is the grouping of the other two navigator tasks indicating high attentional demand requirements. The task cross street is grouped with

Table 19. t-test Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable TIMEGLANCE.

	RN	TR	RD	CS	PM	ZL	H	T°	FR	S	B	FE	CD	D	CT	F	TC	DD	IL	V	RF	D^	FT	T	SP
Roadway Name (RN)	*																								
Tune Radio (TR)		*	*																						
Roadway Dist. (RD)		*	*																						
Cross Street (CS)				*	*																				
Power Mirror (PM)				*	*																				
Zoom Level (ZL)						*	*	*																	
Heading (H)						*	*	*																	
Temperature (T°)						*	*	*	*																
Fuel Range (FR)								*	*	*	*	*	*	*	*										
Sentinal (S)									*	*	*	*	*	*	*										
Balance (B)									*	*	*	*	*	*	*										
Fuel Economy (FE)									*	*	*	*	*	*	*										
Correct Direct. (CD)									*	*	*	*	*	*	*										
Defrost (D)									*	*	*	*	*	*	*										
Cassette Tape (CT)									*	*	*	*	*	*	*	*	*	*	*						
Fan (F)															*	*	*	*	*	*	*	*			
Tone Controls (TC)															*	*	*	*	*	*	*	*			
Dest. Dist. (DD)															*	*	*	*	*	*	*	*			
Info. Lights (IL)															*	*	*	*	*	*	*	*			
Vent (V)																*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)																*	*	*	*	*	*	*	*	*	
Dest. Direct. (D^)																*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																				*	*	*	*	*	*
Time (T)																				*	*	*	*	*	*
Speed (SP)																					*	*	*	*	*

the conventional task tune radio and the task roadway distance is grouped with the conventional task power mirror.

For the tasks requiring somewhat less completion time, apparent task groupings are as follows:

- zoom level, heading and temperature
- fuel range, sentinal, balance, fuel economy, correct direction, defrost
- cassette tape (not clear, could be grouped either above or below)
- fan, tone controls, destination distance, info lights, vent, remaining fuel, destination direction
- (some overlap with the group above) - following traffic, time, speed.

Although the above groupings are somewhat subjective and are not always clear-cut, a number of tasks do clearly group together based on the t-test results.

<u>t-test multiple comparisons: DISTOT</u>. The t-test multiple comparisons for the variable DISTOT (total display-glance time) appear in Table 20. As shown, the tasks roadway name and roadway distance required the longest display-glance time and are different from all other tasks (including each other) as indicated by the t-tests. The remaining navigator task indicating high attentional demand requirements, cross street, is grouped with the conventional task tune radio. The task groupings for the variable DISTOT are not as clear-cut as the task

Table 20. t-test Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable DISTOT.

	RN	RD	CS	TR	PM	ZL	H	T°	FR	CD	FE	D	S	B	F	DD	IL	CT	TC	RF	D^	V	T	FT	SP
Roadway Name (RN)	*																								
Roadway Dist. (RD)		*																							
Cross Street (CS)			*	*																					
Tune Radio (TR)			*	*																					
Power Mirror (PM)					*																				
Zoom Level (ZL)						*	*	*																	
Heading (H)						*	*	*	*																
Temperature (T°)						*	*	*	*	*	*														
Fuel Range (FR)							*	*	*	*	*	*	*	*											
Correct Direct. (CD)								*	*	*	*	*	*	*											
Fuel Economy (FE)								*	*	*	*	*	*	*											
Defrost (D)									*	*	*	*	*	*											
Sentinal (S)									*	*	*	*	*	*	*										
Balance (B)									*	*	*	*	*	*	*	*									
Fan (F)													*	*	*	*	*	*	*	*	*				
Dest. Dist. (DD)														*	*	*	*	*	*	*	*	*			
Info. Lights (IL)															*	*	*	*	*	*	*	*	*		
Cassette Tape (CT)															*	*	*	*	*	*	*	*	*		
Tone Controls (TC)															*	*	*	*	*	*	*	*	*	*	
Remaining Fuel (RF)															*	*	*	*	*	*	*	*	*	*	
Dest. Direct. (D^)															*	*	*	*	*	*	*	*	*	*	
Vent (V)																*	*	*	*	*	*	*	*	*	*
Time (T)																	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																			*	*	*	*	*	*	*
Speed (SP)																						*	*	*	*

groupings for the variable TIMEGLANCE. However, several apparent groupings follow:

- power mirror
- zoom level, heading, temperature
- fuel range, correct directions, fuel economy, defrost, sentinal, balance.

The tasks requiring less display-glance time are grouped with fairly large overlaps. Group division, therefore, was not attempted.

t-test multiple comparisons: DGLANCE. The t-test multiple comparisons for the dependent variable DGLANCE (number of display glances) appear in Table 21. Unlike the variables TIMEGLANCE and DISTOT, two conventional tasks -- tune radio and power mirror -- have the largest average number of display glances. Notice that tune radio and power mirror are grouped with roadway name based on the t-test confidence limits. Additional relatively clear-cut task groupings shown in Table 21 are as follows:

- zoom level, heading, balance, fuel range, sentinal, defrost, fuel economy
- cassette tape, correct direction, vent, fan, tone controls, destination distance, remaining fuel
- destination direction, following traffic, time, speed.

t-test multiple comparisons: DISAVE. The t-test multiple comparisons for the dependent variable DISAVE (average-display-glance time) appear in Table 22. Notice

Table 21. t-test Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable DGLANCE.

	TR	PM	RN	RD	CS	T°	ZL	H	B	FR	S	D	FE	IL	CT	CD	V	F	TC	DD	RF	D^	FT	T	SP
Tune Radio (TR)	*	*	*																						
Power Mirror (PM)	*	*	*																						
Roadway Name (RN)	*	*	*																						
Roadway Dist. (RD)				*																					
Cross Street (CS)					*																				
Temperature (T°)						*	*																		
Zoom Level (ZL)						*	*	*	*	*	*	*													
Heading (H)							*	*	*	*	*	*	*												
Balance (B)							*	*	*	*	*	*	*												
Fuel Range (FR)							*	*	*	*	*	*	*												
Sentinal (S)							*	*	*	*	*	*	*	*											
Defrost (D)							*	*	*	*	*	*	*	*											
Fuel Economy (FE)								*	*	*	*	*	*	*											
Info. Lights (IL)											*	*	*	*	*	*	*	*	*	*					
Cassette Tape (CT)														*	*	*	*	*	*	*					
Correct Direct. (CD)														*	*	*	*	*	*	*					
Vent (V)														*	*	*	*	*	*	*	*				
Fan (F)														*	*	*	*	*	*	*	*				
Tone Controls (TC)														*	*	*	*	*	*	*	*				
Dest. Dist. (DD)														*	*	*	*	*	*	*	*				
Remaining Fuel (RF)																	*	*	*	*	*	*	*	*	*
Dest. Direct (D^)																					*	*	*	*	*
Following Traffic (FT)																					*	*	*	*	*
Time (T)																					*	*	*	*	*
Speed (SP)																					*	*	*	*	*

Table 22. t-test Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable DIAVE.

	CS	RN	RD	CD	ZL	H	D^	FR	D	FE	TR	F	T°	DD	RF	S	TC	PM	B	T	IL	CT	FT	V	SP
Cross Street (CS)	*	*																							
Roadway Name (RN)	*	*	*																						
Roadway Dist. (RD)		*	*	*																					
Correct Direct. (CD)			*	*	*																				
Zoom Level (ZL)				*	*	*																			
Heading (H)					*	*	*	*																	
Dest. Direct (D^)						*	*	*	*	*	*	*	*												
Fuel Range (FR)						*	*	*	*	*	*	*	*												
Defrost (D)							*	*	*	*	*	*	*	*	*										
Fuel Economy (FE)							*	*	*	*	*	*	*	*	*										
Tune Radio (TR)							*	*	*	*	*	*	*	*	*	*									
Fan (F)							*	*	*	*	*	*	*	*	*	*									
Temperature (T°)							*	*	*	*	*	*	*	*	*	*									
Dest. Dist. (DD)									*	*	*	*	*	*	*	*									
Remaining Fuel (RF)									*	*	*	*	*	*	*	*	*								
Sentinal (S)											*	*	*	*	*	*	*								
Tone Controls (TC)															*	*	*	*	*	*	*				
Power Mirror (PM)																	*	*	*	*	*	*	*		
Balance (B)																	*	*	*	*	*	*	*		
Time (T)																	*	*	*	*	*	*	*		
Info. Lights (IL)																	*	*	*	*	*	*	*		
Cassette Tape (CT)																		*	*	*	*	*	*		
Following Traffic (FT)																		*	*	*	*	*	*	*	*
Vent (V)																							*	*	*
Speed (SP)																							*	*	*

that seven of the eight navigator tasks have the longest average-display-glance times. Four of those seven navigator tasks (cross street, roadway name, roadway distance, and correct direction) have higher average-display-glance times than any of the conventional tasks as indicated by the t-test confidence limits.

Although several of the task groups for the variable DISAVE are not as clear-cut as for the variables previously discussed, many of the tasks that formed apparent groups for the variables TIMEGLANCE, DISTOT, and DGLANCE still fall within the same confidence limits. Noteworthy differences that are apparent between DISAVE and the other dependent measures are the average-display-glance times for the power-mirror and tune-radio tasks. These two tasks, which were previously interspersed with the navigator tasks requiring high attentional demand, have relatively low average-display-glance times. This result appears to indicate that while these tasks require high attentional demand (since they require relatively complex control adjustment), they are different from the high attentional demand navigator tasks in that the required information retrieved in a single glance is less complex.

t-test multiple comparisons: STPZVAR. The t-test multiple comparisons for the dependent variable STPZVAR (steering-velocity percent zero variance) appear in Table 23. As shown, the overlap between the tasks is greater for

Table 23. t-test Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable STPZVAR.

	RN	RD	TR	PM	CS	T°	CT	ZL	FR	H	CD	FE	D	B	V	IL	TC	S	DD	F	D^	RF	FT	SP	T
Roadway Name (RN)	*	*	*	*																					
Roadway Dist. (RD)	*	*	*	*	*	*																			
Tune Radio (TR)	*	*	*	*	*	*																			
Power Mirror (PM)	*	*	*	*	*	*																			
Cross Street (CS)		*	*	*	*	*	*	*																	
Temperature (T°)		*	*	*	*	*	*	*																	
Cassette Tape (CT)					*	*	*	*	*	*															
Zoom Level (ZL)					*	*	*	*	*	*	*	*													
Fuel Range (FR)							*	*	*	*	*	*	*	*											
Heading (H)							*	*	*	*	*	*	*	*	*										
Correct Direct. (CD)								*	*	*	*	*	*	*	*										
Fuel Economy (FE)								*	*	*	*	*	*	*	*										
Defrost (D)									*	*	*	*	*	*	*	*									
Balance (B)									*	*	*	*	*	*	*	*									
Vent (V)										*	*	*	*	*	*	*	*	*	*	*					
Info. Lights (IL)													*	*	*	*	*	*	*	*	*	*			
Tone Controls (TC)															*	*	*	*	*	*	*	*	*		
Sentinal (S)															*	*	*	*	*	*	*	*	*		
Dest. Dist. (DD)															*	*	*	*	*	*	*	*	*		
Fan (F)															*	*	*	*	*	*	*	*	*		
Dest. Direct (D^)																*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)																*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																	*	*	*	*	*	*	*	*	*
Speed (SP)																					*	*	*	*	*
Time (T)																					*	*	*	*	*

STPZVAR than for the dependent measures previously discussed. The navigator tasks roadway name and roadway distance have the most "erratic" steering behavior as indicated by the means. Both of these tasks, however, fall within the confidence limits of the conventional tasks power mirror and tune radio.

Since the overlap in confidence limits is greater for the variable STPZVAR than the other dependent measures, task groupings are not as apparent. The order of the tasks and the confidence limits, however, support the task groupings that were apparent for several of the other dependent measures (e.g., DISTOT) to some degree.

Bonferroni multiple comparisons: TIMEGLANCE. The Bonferroni multiple comparisons for the dependent variable TIMEGLANCE (task time from first display glance) appear in Table 24. As was previously discussed, greater task overlap will be present for the Bonferroni post-hoc test because it is more conservativei than the t-test. As expected, the task separations for the Bonferroni test shown in Table 24 are not as apparent as the task separations for the corresponding t-test. Clear-cut breaks, however, do occur for some of the tasks which have indicated high attentional demand for previous analyses. The navigator task roadway name required the longest task-completion time and does not overlap with any other task

Table 24. Bonferroni Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable TIMEGLANCE.

	RN	TR	RD	CS	PM	ZL	H	T°	FR	S	B	FE	CD	D	CT	F	TC	DD	IL	V	RF	D^	FT	T	SP	TS
Roadway Name (RN)	*																									
Tune Radio (TR)		*	*	*																						
Roadway Dist. (RD)		*	*	*																						
Cross Street (CS)		*	*	*	*																					
Power Mirror (PM)				*	*																					
Zoom Level (ZL)						*	*	*	*	*	*	*	*	*												
Heading (H)						*	*	*	*	*	*	*	*	*												
Temperature (T°)						*	*	*	*	*	*	*	*	*	*											
Fuel Range (FR)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Sentinal (S)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Balance (B)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Fuel Economy (FE)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Correct Direct. (CD)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Defrost (D)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cassette Tape (CT)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Fan (F)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Tone Controls (TC)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Dest. Dist. (DD)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IL)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Vent (V)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Direct (D^)													*	*	*	*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)															*	*	*	*	*	*	*	*	*	*	*	*
Time (T)																*	*	*	*	*	*	*	*	*	*	*
Speed (SP)																*	*	*	*	*	*	*	*	*	*	*
Turn Signal (TS)																		*	*	*	*	*	*	*	*	*

confidence limits. The tasks tune radio, roadway distance, cross street, and (to a lesser extent) power mirror also form a clear group separated from the remaining tasks.

Bonferroni multiple comparisons: DISTOT. The Bonferroni multiple comparisons for the dependent variable DISTOT (total-display-glance time) appear in Table 25. As shown, the results are quite similar to the variable TIMEGLANCE discussed above because the tasks roadway name, roadway distance, cross street, tune radio, and power mirror are separated from the remaining tasks.

Bonferroni multiple comparisons: DGLANCE. The Bonferroni multiple comparisons for the dependent variable DGLANCE (number of display glances) appear in Table 26. As with the other two measures discussed, TIMEGLANCE and DISTOT, the only clear separation that occurs is between a group formed by the tune radio, power mirror, roadway name, roadway distance, and cross street tasks, and the remaining tasks. Note that for the variable DGLANCE, the two conventional tasks tune radio and power mirror had, on the average, the largest number of display glances. The navigator task roadway name, however, fell within the confidence limits for both of those conventional tasks.

Bonferroni multiple comparisons: DISAVE. The Bonferroni multiple comparisons for the dependent variable DISAVE (average-display-glance time) appear in Table 27.

Table 25. Bonferroni Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable DISTOT.

	RN	RD	CS	TR	PM	ZL	H	T°	FR	CD	FE	D	S	B	F	DD	IL	CT	TC	RF	D^	V	T	FT	SP	TS
Roadway Name (RN)	*																									
Roadway Dist. (RD)		*	*																							
Cross Street (CS)		*	*	*	*																					
Tune Radio (TR)			*	*																						
Power Mirror (PM)					*																					
Zoom Level (ZL)						*	*	*	*	*	*	*														
Heading (H)						*	*	*	*	*	*	*	*	*												
Temperature (T°)						*	*	*	*	*	*	*	*	*												
Fuel Range (FR)						*	*	*	*	*	*	*	*	*	*	*										
Correct Direct. (CD)						*	*	*	*	*	*	*	*	*	*	*	*	*	*							
Fuel Economy (FE)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Defrost (D)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Sentinal (S)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Balance (B)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Fan (F)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Dest. Dist. (DD)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Info. Lights (IL)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Cassette Tape (CT)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Tone Controls (TC)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Remaining Fuel (RF)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Direct (D^)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Vent (V)														*	*	*	*	*	*	*	*	*	*	*	*	*
Time (T)														*	*	*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)															*	*	*	*	*	*	*	*	*	*	*	*
Speed (SP)															*	*	*	*	*	*	*	*	*	*	*	*
Turn Signal (TS)																				*	*	*	*	*	*	*

Table 26. Bonferroni Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable DGLANCE.

	TR	PM	RN	RD	CS	T°	ZL	H	B	FR	S	D	FE	IL	CT	CD	V	F	TC	DD	RF	D^	FT	T	SP	TS
Tune Radio (TR)	*	*	*																							
Power Mirror (PM)	*	*	*	*																						
Roadway Name (RN)	*	*	*	*																						
Roadway Dist. (RD)			*	*	*																					
Cross Street (CS)				*	*																					
Temperature (T°)						*	*	*	*	*	*	*	*													
Zoom Level (ZL)						*	*	*	*	*	*	*	*	*												
Heading (H)						*	*	*	*	*	*	*	*	*	*	*										
Balance (B)						*	*	*	*	*	*	*	*	*	*	*	*									
Fuel Range (FR)						*	*	*	*	*	*	*	*	*	*	*	*	*								
Sentinal (S)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Defrost (D)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Fuel Economy (FE)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Info. Lights (IL)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Cassette Tape (CT)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Correct Direct. (CD)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Vent (V)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Fan (F)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Tone Controls (TC)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Dest. Dist. (DD)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Remaining Fuel (RF)														*	*	*	*	*	*	*	*	*	*	*	*	
Dest. Direct (D^)															*	*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)															*	*	*	*	*	*	*	*	*	*	*	*
Time (T)																*	*	*	*	*	*	*	*	*	*	*
Speed (SP)																*	*	*	*	*	*	*	*	*	*	*
Turn Signal (TS)																						*	*	*	*	*

Table 27. Bonferroni Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable DISAVE.

	CS	RN	RD	CD	ZL	H	D^	FR	D	FE	TR	F	T°	DD	RF	S	TC	PM	B	T	IL	CT	FT	V	SP
Cross Street (CS)	*	*	*	*																					
Roadway Name (RN)	*	*	*	*	*																				
Roadway Dist. (RD)	*	*	*	*	*	*																			
Correct Direct. (CD)	*	*	*	*	*	*	*																		
Zoom Level (ZL)		*	*	*	*	*	*	*	*	*															
Heading (H)			*	*	*	*	*	*	*	*	*	*	*	*											
Dest. Direct (D^)				*	*	*	*	*	*	*	*	*	*	*	*	*									
Fuel Range (FR)					*	*	*	*	*	*	*	*	*	*	*	*									
Defrost (D)					*	*	*	*	*	*	*	*	*	*	*	*	*								
Fuel Economy (FE)					*	*	*	*	*	*	*	*	*	*	*	*	*								
Tune Radio (TR)						*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Fan (F)						*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Temperature (T°)						*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Dest. Dist. (DD)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Remaining Fuel (RF)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Sentinal (S)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Tone Controls (TC)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Power Mirror (PM)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Balance (B)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Time (T)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IL)														*	*	*	*	*	*	*	*	*	*	*	*
Cassette Tape (CT)																*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																	*	*	*	*	*	*	*	*	*
Vent (V)																	*	*	*	*	*	*	*	*	*
Speed (SP)																	*	*	*	*	*	*	*	*	*

As shown, overlap occurs throughout the spectrum of tasks, which renders clear groupings difficult. One noteworthy fact that was discussed for the t-test of the same dependent variable is that seven of the eight navigator tasks have the longest average-display-glance times. Although the confidence limits overlap for many tasks, the navigator tasks do have longer single-glance times than many of the conventional tasks as indicated by the confidence limits.

Bonferroni multiple comparisons: STPZVAR. The Bonferroni multiple comparisons for the dependent variable STPZVAR (steering-velocity percent zero variance) appear in Table 28. As was true for the variable DISAVE, large overlaps are present for STPZVAR, masking task groupings difficult. It is clear, however, that some differences between tasks are present even with the large overlap. By way of example, task differences are evidenced by the separation between the top eight tasks and the bottom four tasks shown in Table 28.

Post-Hoc Multiple Comparisons with Navigator Tasks Divided by Information Availability and with the Addition of the Cruise-Control Task

As was previously done in the Ranking of Attentional Demand section, the navigator tasks roadway name, roadway

Table 28. Bonferroni Multiple Comparisons by Task. 95% Simultaneous Confidence Limits for the Dependent Variable STPZVAR.

	RN	RD	TR	PM	CS	T^{o}	CT	ZL	FR	H	CD	FE	D	B	V	IL	TC	S	DD	F	D^	RF	FT	SP	T	TS
Roadway Name (RN)	*	*	*	*	*	*	*	*																		
Roadway Dist. (RD)	*	*	*	*	*	*	*	*																		
Tune Radio (TR)	*	*	*	*	*	*	*	*																		
Power Mirror (PM)	*	*	*	*	*	*	*	*																		
Cross Street (CS)	*	*	*	*	*	*	*	*	*	*	*	*	*	*												
Temperature (T^{o})	*	*	*	*	*	*	*	*	*	*	*	*	*	*												
Cassette Tape (CT)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*											
Zoom Level (ZL)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*											
Fuel Range (FR)					*	*	*	*	*	*	*	*	*	*	*	*	*	*								
Heading (H)					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Correct Direct. (CD)					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Fuel Economy (FE)					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Defrost (D)					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Balance (B)					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Vent (V)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IL)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tone Controls (TC)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sentinal (S)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Dist. (DD)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Fan (F)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Direct (D^)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)															*	*	*	*	*	*	*	*	*	*	*	*
Speed (SP)															*	*	*	*	*	*	*	*	*	*	*	*
Time (T)															*	*	*	*	*	*	*	*	*	*	*	*
Turn Signal (TS)															*	*	*	*	*	*	*	*	*	*	*	*

distance, and cross street were divided according to whether the information was immediately available on the display or a zoom in or zoom out was required. In addition, the cruise-control task, which was only performed on the four-lane roadway, was also added to the multiple comparison analyses. As with the undivided set of tasks, both t-test and Bonferroni multiple comparisons were calculated so that comparisons between a liberal and a more conservative test could be made. It should be noted that for these multiple-comparison tests, the number of observations for the information-separated tasks and the cruise-control task are no longer equal. This observation inequality will cause the comparisons to be somewhat more liberal (SAS Institute, 1985). The reader is therefore advised to interpret these results with caution.

The t-test and Bonferroni multiple comparisons for the divided tasks and the dependent variables TIMEGLANCE, DISTOT, DGLANCE, DISAVE, and STPZVAR appear in Tables 29 through 38. All tasks are shown for each table to provide referencing ease. The confidence limits for tasks that have not changed from the previous analyses, however, will not be subsequently discussed.

The t-test multiple comparisons for the dependent variables TIMEGLANCE, DISTOT, DGLANCE, DISAVE, and STPZVAR appear in Tables 29 through 33. For the dependent

Table 29. t-test Multiple Comparisons by Task Including Navigational Tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable TIMEGLANCE. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	RD+	CS+	TR	PM	CC	RD*	RN*	ZL	H	CS*	T°	FR	S	B	FE	CD	D	CT	F	TC	DD	IL	V	RF	D^	FT	T	SP
Roadway Name+ (RN+)	*																												
Roadway Dist.+ (RD+)		*																											
Cross Street+ (CS+)			*	*																									
Tune Radio (TR)			*	*																									
Power Mirror (PM)					*	*																							
Cruise Control (CC)					*	*	*																						
Roadway Dist.* (RD*)						*	*																						
Roadway Name* (RN*)								*	*		*																		
Zoom Level (ZL)								*	*	*	*	*																	
Heading (H)									*	*	*	*																	
Cross Street* (CS*)								*	*	*	*	*	*	*															
Temperature (T°)									*	*	*	*																	
Fuel Range (FR)											*		*	*	*	*	*	*	*										
Sentinal (S)											*		*	*	*	*	*	*	*										
Balance (B)													*	*	*	*	*	*	*										
Fuel Economy (FE)													*	*	*	*	*	*	*										
Correct Direct. (CD)													*	*	*	*	*	*	*										
Defrost (D)													*	*	*	*	*	*	*										
Cassette Tape (CT)													*	*	*	*	*	*	*	*	*	*							
Fan (F)																			*	*	*	*	*	*	*	*			
Tone Controls (TC)																			*	*	*	*	*	*	*	*			
Dest. Dist. (DD)																			*	*	*	*	*	*	*	*			
Info. Lights (IF)																				*	*	*	*	*	*	*			
Vent (V)																				*	*	*	*	*	*	*			
Remaining Fuel (RF)																				*	*	*	*	*	*	*	*	*	*
Dest. Direct. (D^)																				*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																									*	*	*	*	*
Time (T)																									*	*	*	*	*
Speed (SP)																									*	*	*	*	*

Table 30. t-test Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable DISTOT. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

Task	RN+	RD+	CS+	TR	RD*	PM	CC	RN*	CS*	ZL	H	T°	FR	CD	FE	D	S	B	F	DD	IL	CT	TC	RF	D^	V	T	FT	SP
Roadway Name+ (RN+)	*																												
Roadway Dist.+ (RD+)		*																											
Cross Street+ (CS+)			*																										
Tune Radio (TR)				*	*																								
Roadway Dist.* (RD*)				*	*																								
Power Mirror (PM)						*	*																						
Cruise Control (CC)						*	*	*																					
Roadway Name* (RN*)							*	*	*																				
Cross Street* (CS*)								*	*	*	*																		
Zoom Level (ZL)									*	*	*	*																	
Heading (H)									*	*	*	*																	
Temperature (T°)										*	*	*	*																
Fuel Range (FR)												*	*	*	*	*	*												
Correct Direct. (CD)													*	*	*	*	*	*											
Fuel Economy (FE)													*	*	*	*	*	*											
Defrost (D)													*	*	*	*	*	*											
Sentinal (S)													*	*	*	*	*	*											
Balance (B)														*	*	*	*	*	*										
Fan (F)																		*	*	*	*	*	*	*	*				
Dest. Dist. (DD)																			*	*	*	*	*	*	*				
Info. Lights (IL)																			*	*	*	*	*	*	*	*			
Cassette Tape (CT)																			*	*	*	*	*	*	*	*			
Tone Controls (TC)																			*	*	*	*	*	*	*	*			
Remaining Fuel (RF)																			*	*	*	*	*	*	*	*	*		
Dest. Direct. (D^)																			*	*	*	*	*	*	*	*	*		
Vent (V)																					*	*	*	*	*	*	*	*	*
Time (T)																								*	*	*	*	*	*
Following Traffic (FT)																										*	*	*	*
Speed (SP)																										*	*	*	*

Table 31. t-test Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable DGLANCE. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	TR	RD+	PM	CS+	CC	RD*	T°	RN*	ZL	H	B	FR	S	D	FE	CS*	IL	CT	CD	V	F	TC	DD	RF	D^	FT	T	SP
Roadway Name+ (RN+)	*																												
Tune Radio (TR)		*	*	*																									
Roadway Dist.+ (RD+)		*	*	*																									
Power Mirror (PM)		*	*	*																									
Cross Street+ (CS+)					*	*																							
Cruise Control (CC)					*	*																							
Roadway Dist.* (RD*)							*																						
Temperature (T^o)								*	*	*																			
Roadway Name* (RN*)								*	*	*	*	*	*	*	*	*	*												
Zoom Level (ZL)								*	*	*	*	*																	
Heading (H)									*	*	*	*	*	*	*	*	*												
Balance (B)									*	*	*	*	*	*	*	*	*												
Fuel Range (FR)									*		*	*	*	*	*	*	*												
Sentinal (S)									*		*	*	*	*	*	*	*												
Defrost (D)									*		*	*	*	*	*	*	*												
Fuel Economy (FE)									*		*	*	*	*	*	*	*												
Cross Street* (CS*)									*	*	*	*	*	*	*	*	*	*	*	*	*								
Info. Lights (IL)																	*	*	*	*	*	*							
Cassette Tape (CT)																	*	*	*	*	*	*	*	*					
Correct Direct. (CD)																	*	*	*	*	*	*	*	*	*				
Vent (V)																	*	*	*	*	*	*	*	*	*				
Fan (F)																		*	*	*	*	*	*	*	*				
Tone Controls (TC)																			*	*	*	*	*	*	*				
Dest. Dist. (DD)																			*	*	*	*	*	*	*				
Remaining Fuel (RF)																					*	*	*	*	*	*	*	*	*
Dest. Direct. (D^)																									*	*	*	*	*
Following Traffic (FT)																									*	*	*	*	*
Time (T)																									*	*	*	*	*
Speed (SP)																									*	*	*	*	*

Table 32. t-test Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable DISAVE. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	CS*	RN*	RN+	CS+	RD+	RD*	CD	ZL	H	D^	FR	D	FE	TR	F	T°	DD	RF	S	TC	PM	B	CC	T	IL	CT	FT	V	SP
Cross Street* (CS*)	*	*																											
Roadway Name* (RN*)	*	*	*	*	*	*																							
Roadway Name+ (RN+)		*	*	*	*	*																							
Cross Street+ (CS+)		*	*	*	*	*																							
Roadway Dist.+ (RD+)		*	*	*	*	*	*	*																					
Roadway Dist.* (RD*)		*	*	*	*	*	*	*																					
Correct Direct. (CD)						*	*	*																					
Zoom Level (ZL)						*	*	*	*																				
Heading (H)								*	*	*	*																		
Dest. Direct. (D^)									*	*	*	*	*	*	*	*													
Fuel Range (FR)									*	*	*	*	*	*	*	*													
Defrost (D)										*	*	*	*	*	*	*	*	*											
Fuel Economy (FE)										*	*	*	*	*	*	*	*	*											
Tune Radio (TR)										*	*	*	*	*	*	*	*	*	*										
Fan (F)										*	*	*	*	*	*	*	*	*	*										
Temperature (T°)										*	*	*	*	*	*	*	*	*	*										
Dest. Dist. (DD)												*	*	*	*	*	*	*	*										
Remaining Fuel (RF)												*	*	*	*	*	*	*	*	*									
Sentinal (S)														*	*	*	*	*	*	*									
Tone Controls (TC)																		*	*	*	*	*	*	*	*				
Power Mirror (PM)																				*	*	*	*	*	*	*	*		
Balance (B)																				*	*	*	*	*	*	*	*		
Cruise Control (CC)																			*	*	*	*	*	*	*	*	*		
Time (T)																				*	*	*	*	*	*	*	*		
Info. Lights (IL)																				*	*	*	*	*	*	*	*		
Cassette Tape (CT)																					*	*	*	*	*	*	*		
Following Traffic (FT)																					*	*	*	*	*	*	*	*	
Vent (V)																											*	*	*
Speed (SP)																												*	*

Table 33. t-test Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable STPZVAR. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	RD+	TR	CS+	PM	RD*	RN*	T°	CT	ZL	FR	H	CD	FE	D	B	CS*	CC	V	IL	TC	S	DD	F	D^	RF	FT	SP	T
Roadway Name+ (RN+)	*	*	*	*	*	*	*																						
Roadway Dist.+ (RD+)	*	*	*	*	*	*	*																						
Tune Radio (TR)	*	*	*	*	*	*	*	*																					
Cross Street+ (CS+)	*	*	*	*	*	*	*	*																					
Power Mirror (PM)	*	*	*	*	*	*	*	*																					
Roadway Dist.* (RD*)	*	*	*	*	*	*	*	*	*																				
Roadway Name* (RN*)	*	*	*	*	*	*	*	*	*	*	*																		
Temperature (T°)			*	*	*	*	*	*	*	*																			
Cassette Tape (CT)						*	*	*	*	*	*	*																	
Zoom Level (ZL)							*	*	*	*	*	*	*	*			*												
Fuel Range (FR)							*		*	*	*	*	*	*	*	*	*	*											
Heading (H)									*	*	*	*	*	*	*	*	*	*	*										
Correct Direct. (CD)										*	*	*	*	*	*	*	*	*	*										
Fuel Economy (FE)										*	*	*	*	*	*	*	*	*	*										
Defrost (D)											*	*	*	*	*	*	*	*	*	*									
Balance (B)											*	*	*	*	*	*	*	*	*	*									
Cross Street* (CS*)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Cruise Control (CC)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Vent (V)												*	*	*	*	*	*	*	*	*	*	*	*	*					
Info. Lights (IL)															*	*	*	*	*	*	*	*	*	*	*	*			
Tone Controls (TC)																	*	*	*	*	*	*	*	*	*	*	*		
Sentinal (S)																	*	*	*	*	*	*	*	*	*	*	*		
Dest. Dist. (DD)																	*	*	*	*	*	*	*	*	*	*	*		
Fan (F)																	*	*	*	*	*	*	*	*	*	*	*		
Dest. Direct. (D^)																	*	*		*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)																	*	*		*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																					*	*	*	*	*	*	*	*	*
Speed (SP)																									*	*	*	*	*
Time (T)																									*	*	*	*	*

Table 34. Bonferroni Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable TIMEGLANCE. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	RD+	CS+	TR	PM	CC	RD*	RN*	ZL	H	CS*	T°	FR	S	B	FE	CD	D	CT	F	TC	DD	IL	V	RF	D^	FT	T	SP
Roadway Name+ (RN+)	*																												
Roadway Dist.+ (RD+)		*																											
Cross Street+ (CS+)			*	*																									
Tune Radio (TR)			*	*																									
Power Mirror (PM)					*	*	*																						
Cruise Control (CC)					*	*	*																						
Roadway Dist.* (RD*)					*	*	*	*																					
Roadway Name* (RN*)							*	*	*	*	*	*																	
Zoom Level (ZL)								*	*	*	*	*	*	*	*	*	*												
Heading (H)								*	*	*	*	*	*	*	*	*	*	*											
Cross Street* (CS*)								*	*	*	*	*	*	*	*	*	*	*	*	*									
Temperature (T°)								*	*	*	*	*	*	*	*	*	*	*	*										
Fuel Range (FR)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Sentinal (S)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Balance (B)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Fuel Economy (FE)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Correct Direct. (CD)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Defrost (D)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Cassette Tape (CT)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Fan (F)											*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tone Controls (TC)													*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest Dist. (DD)													*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IL)													*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Vent (V)															*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)																			*	*	*	*	*	*	*	*	*	*	*
Dest. Direct. (D^)																			*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																				*	*	*	*	*	*	*	*	*	*
Time (T)																				*	*	*	*	*	*	*	*	*	*
Speed (SP)																				*	*	*	*	*	*	*	*	*	*

Table 35. Bonferroni Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable DISTOT. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	RD+	CS+	TR	RD*	PM	CC	RN*	CS*	ZL	H	T°	FR	CD	FE	D	S	B	F	DD	IL	CT	TC	RF	D^	V	T	FT	SP
Roadway Name+ (RN+)	*																												
Roadway Dist.+ (RD+)		*	*																										
Cross Street+ (CS+)		*	*																										
Tune Radio (TR)				*	*																								
Roadway Dist.* (RD*)				*	*	*																							
Power Mirror (PM)					*	*	*	*																					
Cruise Control (CC)						*	*	*	*																				
Roadway Name* (RN*)						*	*	*	*	*	*	*																	
Cross Street* (CS*)							*	*	*	*	*	*	*	*	*	*													
Zoom Level (ZL)								*	*	*	*	*	*																
Heading (H)								*	*	*	*	*	*	*	*	*													
Temperature (T°)								*	*	*	*	*	*	*	*	*	*	*											
Fuel Range (FR)									*	*	*	*	*	*	*	*	*	*											
Correct Direct. (CD)									*		*	*	*	*	*	*	*	*	*										
Fuel Economy (FE)									*		*	*	*	*	*	*	*	*	*	*									
Defrost (D)									*		*	*	*	*	*	*	*	*	*	*	*								
Sentinal (S)												*	*	*	*	*	*	*	*	*	*	*	*	*					
Balance (B)												*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Fan (F)														*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Dest. Dist. (DD)															*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IF)																*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cassette Tape (CT)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Tone Controls (TC)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Direct. (D^)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Vent (V)																			*	*	*	*	*	*	*	*	*	*	*
Time (T)																			*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																			*	*	*	*	*	*	*	*	*	*	*
Speed (SP)																				*	*	*	*	*	*	*	*	*	*

Table 36. Bonferroni Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable DGLANCE. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	TR	RD+	PM	CS+	CC	RD*	T^{o}	RN*	ZL	H	B	FR	S	D	FE	CS*	IL	CT	CD	V	F	TC	DD	RF	D^	FT	T	SP
Roadway Name+ (RN+)	*																												
Tune Radio TR		*	*	*	*	*																							
Roadway Dist.+ (RD+)		*	*	*	*	*																							
Power Mirror (PM)		*	*	*	*	*																							
Cross Street+ (CS+)		*	*	*	*	*																							
Cruise Control (CC)		*	*	*	*	*																							
Roadway Dist.* (RD*)							*																						
Temperature (T^{o})								*	*	*	*	*	*	*	*	*	*												
Roadway Name* (RN*)								*	*	*	*	*	*	*	*	*	*	*	*	*									
Zoom Level (ZL)								*	*	*	*	*	*	*	*	*	*												
Heading (H)								*	*	*	*	*	*	*	*	*	*	*	*										
Balance (B)								*	*	*	*	*	*	*	*	*	*	*	*	*									
Fuel Range (FR)								*	*	*	*	*	*	*	*	*	*	*	*	*									
Sentinal (S)								*	*	*	*	*	*	*	*	*	*	*	*	*	*								
Defrost (D)								*	*	*	*	*	*	*	*	*	*	*	*	*	*								
Fuel Economy (FE)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*							
Cross Street* (CS*)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Info. Lights (IL)									*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Cassette Tape (CT)									*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Correct Direct. (CD)									*			*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Vent (V)														*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Fan (F)																*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tone Controls (TC)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Dist. (DD)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Direct. (D^)																	*				*	*	*	*	*	*	*	*	*
Following Traffic (FT)																	*				*	*	*	*	*	*	*	*	*
Time (T)																					*	*	*	*	*	*	*	*	*
Speed (SP)																					*	*	*	*	*	*	*	*	*

Table 37. Bonferroni Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable DISTAVE. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	CS*	RN*	RN+	CS+	RD+	RD*	CD	ZL	H	D^	FR	D	FE	TR	F	T°	DD	RF	S	TC	PM	B	CC	T	IL	CT	FT	V	SP
Cross Street* (CS*)	*	*	*	*	*	*	*																						
Roadway Name* (RN*)	*	*	*	*	*	*	*	*																					
Roadway Name+ (RN+)	*	*	*	*	*	*	*	*																					
Cross Street+ (CS+)	*	*	*	*	*	*	*	*																					
Roadway Dist.+ (RD+)	*	*	*	*	*	*	*	*	*																				
Roadway Dist.* (RD*)	*	*	*	*	*	*	*	*	*																				
Correct Direct. (CD)	*	*	*	*	*	*	*	*	*																				
Zoom Level (ZL)		*	*	*	*	*	*	*	*	*	*	*	*																
Heading (H)					*	*	*	*	*	*	*	*	*	*	*	*	*												
Dest. Direct. (D^)								*	*	*	*	*	*	*	*	*	*	*	*										
Fuel Range (FR)								*	*	*	*	*	*	*	*	*	*	*	*										
Defrost (D)								*	*	*	*	*	*	*	*	*	*	*	*	*			*						
Fuel Economy (FE)								*	*	*	*	*	*	*	*	*	*	*	*	*			*						
Tune Radio (TR)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Fan (F)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Temperature (T°)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
Dest. Dist. (DD)									*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Remaining Fuel (RF)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
Sentinal (S)										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Tone Controls (TC)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		
Power Mirror (PM)														*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Balance (B)														*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cruise Control (CC)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Time (T)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IL)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Cassette Tape (CT)																			*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																				*	*	*	*	*	*	*	*	*	*
Vent (V)																				*	*	*	*	*	*	*	*	*	*
Speed (SP)																					*	*	*	*	*	*	*	*	*

Table 38. t-test Multiple Comparisons by Task Including Navigational tasks Divided by Information Availability and Cruise Control. 95% Simultaneous Confidence Limits for the Dependent Variable STPZVAR. (* = information immediately available on navigation display. + = information not immediately available on navigation display.)

	RN+	RD+	TR	CS+	PM	RD*	RN*	T°	CT	ZL	FR	H	CD	FE	D	B	CS*	CC	V	IL	TC	S	DD	F	D^	RF	FT	SP	T
Roadway Name+ (RN+)	*	*	*	*	*	*	*	*	*																				
Roadway Dist.+ (RD+)	*	*	*	*	*	*	*	*	*	*																			
Tune Radio (TR)	*	*	*	*	*	*	*	*	*	*																			
Cross Street+ (CS+)	*	*	*	*	*	*	*	*	*	*	*						*												
Power Mirror (PM)	*	*	*	*	*	*	*	*	*	*							*												
Roadway Dist.* (RD*)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*											
Roadway Name* (RN*)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*										
Temperature (T°)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*											
Cassette Tape (CT)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*										
Zoom Level (ZL)		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*										
Fuel Range (FR)				*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*							
Heading (H)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Correct Direct. (CD)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
Fuel Economy (FE)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Defrost (D)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Balance (B)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			
Cross Street* (CS*)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cruise Control (CC)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Vent (V)							*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Info. Lights (IL)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tone Controls (TC)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sentinal (S)											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Dist. (DD)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Fan (F)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dest. Direct. (D^)														*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Remaining Fuel (RF)														*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Following Traffic (FT)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Speed (SP)																	*	*	*	*	*	*	*	*	*	*	*	*	*
Time (T)																	*	*	*	*	*	*	*	*	*	*	*	*	*

variables TIMEGLANCE and DISTOT, the navigator tasks roadway name, roadway distance, and cross street (zoom required) had the longest task-completion times and total-display-glance times. These tasks are different from all other tasks (as indicated by the confidence limits), with the exception of cross street and tune radio for the dependent variable TIMEGLANCE. For the dependent variable DGLANCE (Table 31), the multiple comparisons show that roadway name (zoom required) had the largest number of display glances (greater than all other tasks). The remaining navigator tasks requiring a zoom-in or zoom-out function to retrieve information are interspersed with several of the conventional tasks for the variable DGLANCE.

The multiple comparisons with divided/additional tasks for the variable DISAVE (Table 32) show that the navigator tasks roadway name, roadway distance, and cross street, have longer single display-glance times than the conventional tasks regardless of information availability. This result is probably due to the complexity of the information that the subject is required to extract from the navigation display for these tasks.

The t-test multiple comparisons for the variable STPZVAR (Table 33) show a greater degree of overlap than the dependent variables previously discussed. Note that with the exception of the navigator task cross street, no difference is present (as indicated by the confidence limits) between the information categories of navigator tasks.

The attentional demand for the cruise-control task appears relatively high (in general) based on the t-test multiple comparisons. Cruise control is grouped with the conventional task power mirror for the variables TIMEGLANCE and DISTOT (Tables 29 and 30), and is grouped with tasks indicating high attentional demand in terms of the number of required display glances (DGLANCE, Table 31). However, as was the case with the other high attentional demand conventional tasks, tune radio and power mirror, the average-display-glance time (DISAVE, Table 32) is lower for the cruise-control task than the high attentional demand navigator tasks.

The Bonferroni multiple comparisons for the navigator tasks, separated by information availability and including the cruise-control task, appear in Tables 34 through 38. Not surprisingly, the Bonferroni multiple comparisons show more confidence limit overlap among tasks than do the t-test comparisons (since the Bonferroni is a more conservative test). Despite these confidence limit overlaps, the navigator tasks that require a zoom-in or zoom-out function show the highest required attentional demand and are largely separate from the other tasks for the variables TIMEGLANCE and DISTOT (Tables 34 and 35). The navigator task roadway name (zoom required) also is separated, as indicated by the confidence limits, from all other tasks for the variable DGLANCE (Table 36). The Bonferroni multiple comparison results for the dependent variables DISAVE and STPZVAR (Tables 37 and 38) are similar to those presented for the t-test multiple comparisons, with the exception of somewhat greater task overlap.

Univariate ANOVAs Testing Gender, Age, Driving Experience and Road Type

The ANOVA summary tables for the independent variables gender, age, driving experience, and road type appear in Appendix B. As shown by the ANOVA summary tables in Appendix B, only the main effects of age and roadway type showed signs of level differences among the dependent variables. In no instance did the main effects of gender or driving experience approach significance. The main effect of road type indicated level differences for the following dependent variables:

TIMEST (p = 0.0227)	STPZVAR (p = 0.0001)
TIMEGLANCE (p = 0.0043)	ACCVAR (p = 0.0008)
DGLANCE (p = 0.0045)	ACCPOS (p = 0.0101)
RGLANCE (p = 0.0038)	STEXT (p = 0.0141)
DISAVE (p = 0.0001)	STPZAV (p = 0.0001)
DISTOT (p = 0.0012)	BRNUM (p = 0.0001)

DISPER (p = 0.0224) STVRMS (p = 0.0001)

RDPER (p = 0.0018) BRTIME (p = 0.0001)

STVELVAR (p = 0.0001)

The main effect of age indicated level differences for the following dependent variables:

TIMEST (p = 0.0089)

TIMEGLANCE (p = 0.0128)

DISAVE (p = 0.0127)

DISTOT (p = 0.0007)

BRTIME (p = 0.0064)

Fortunately, despite the fact that no MANOVAs could be run for these main effects, the results are relatively easy to interpret. Given that no dependent measure approached "standard" levels of significance (i.e., $p = .05$) for the independent variables gender or driving experience, it is reasonable to accept the null hypothesis that no differences do in fact exist based on these measures. These variables will therefore be eliminated from subsequent discussion (see Appendix B for the ANOVA results for all of the dependent measures). The variables road type and age, however, show that level differences are indeed present. Even with the multiple independent ANOVA Type I error inflation problem, it is difficult to deny that differences are present for these variables given the small p-values and relatively large number of measures indicating differences.

Very few interactions for the independent variables gender, experience, age, and roadway approached "standard" levels of significance. The following interactions indicated that differences were present:

RDTOT Road x Gender x Age (p = 0.0171)

RDTOT Road x Age x Experience (p = 0.0146)

RDPER Gender x Age (p = 0.0493)

RDPER Gender x Age x Experience (p = 0.0024)

RDPER Road x Gender x Age x Experience (p = 0.0361)

STVRMS Road x Gender x Age (p = 0.0069)

STVRMS Road x Gender x Age x Experience (p = 0.0053)

Further investigation into the above interactions did not reveal any results which were systematic or easily interpretable. One of the interactions that appeared as though it might provide interpretable results was Roadtype x Gender x Age. An illustration of this interaction for the dependent variable STVRMS sppears in Figure 11. As shown, the Roadtype main effect can be seen, however no logical interpretation of the Roadtype x Gender x Age interaction is apparent.

Selected Differences Due to the Main Effects Age and Road Type

To understand better the differences due to age and road type, means were plotted in bar graph form for those dependent variables indicating differences. These bar

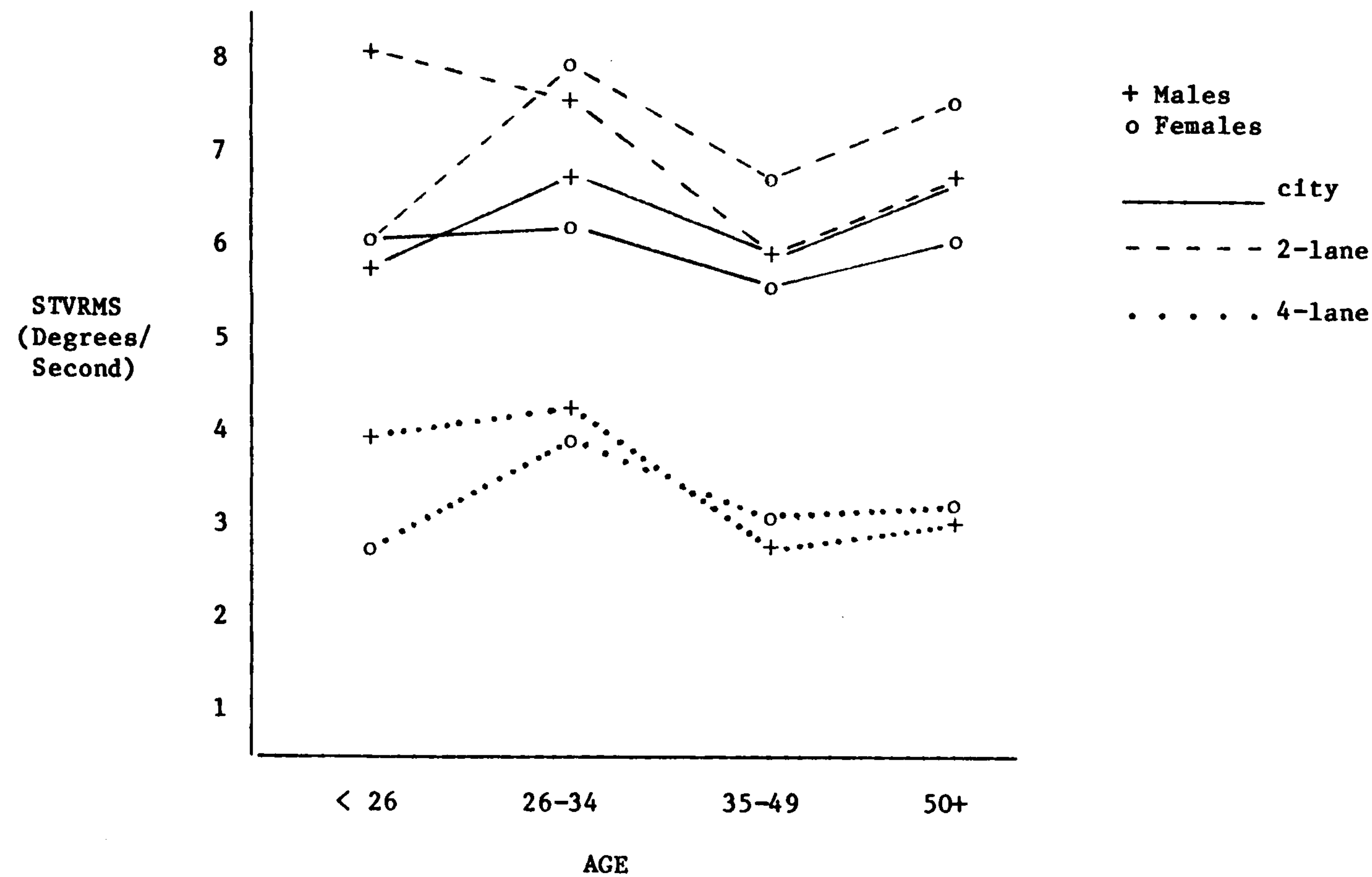
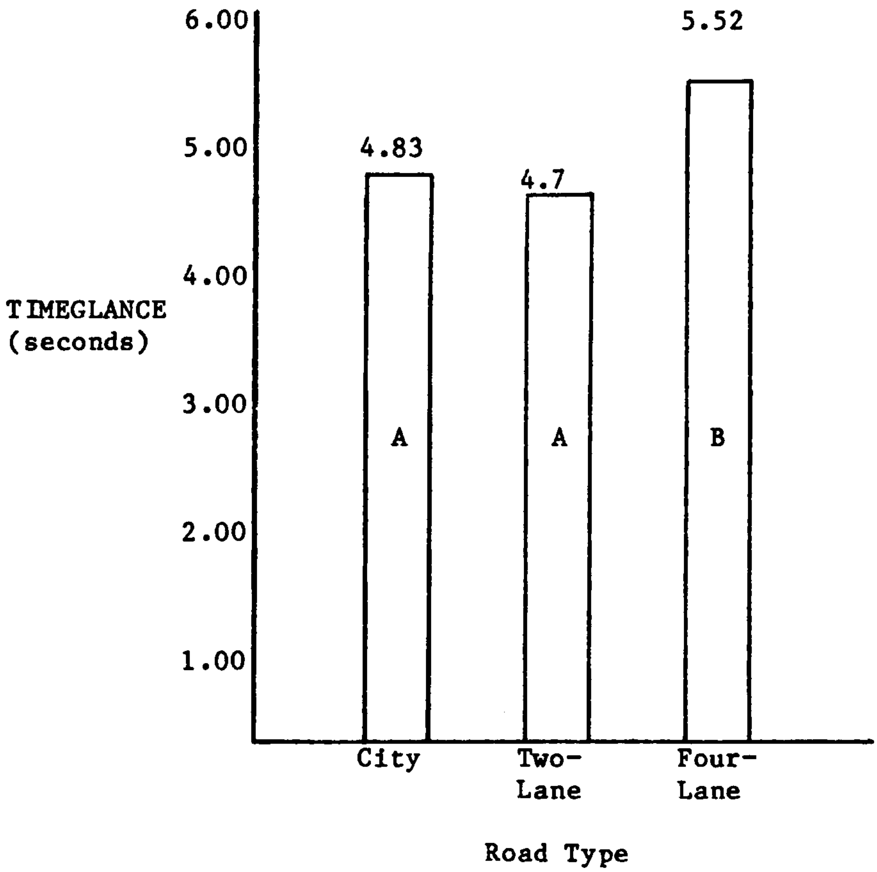


Figure 11. Interaction of Roadtype x Age x Gender for RMS Steering Velocity.

graphs are grouped by main-effect and are described below. Note that level differences based on Bonferroni multiple-comparison tests (95-percent confidence limits) for each main effect are shown in each graph.

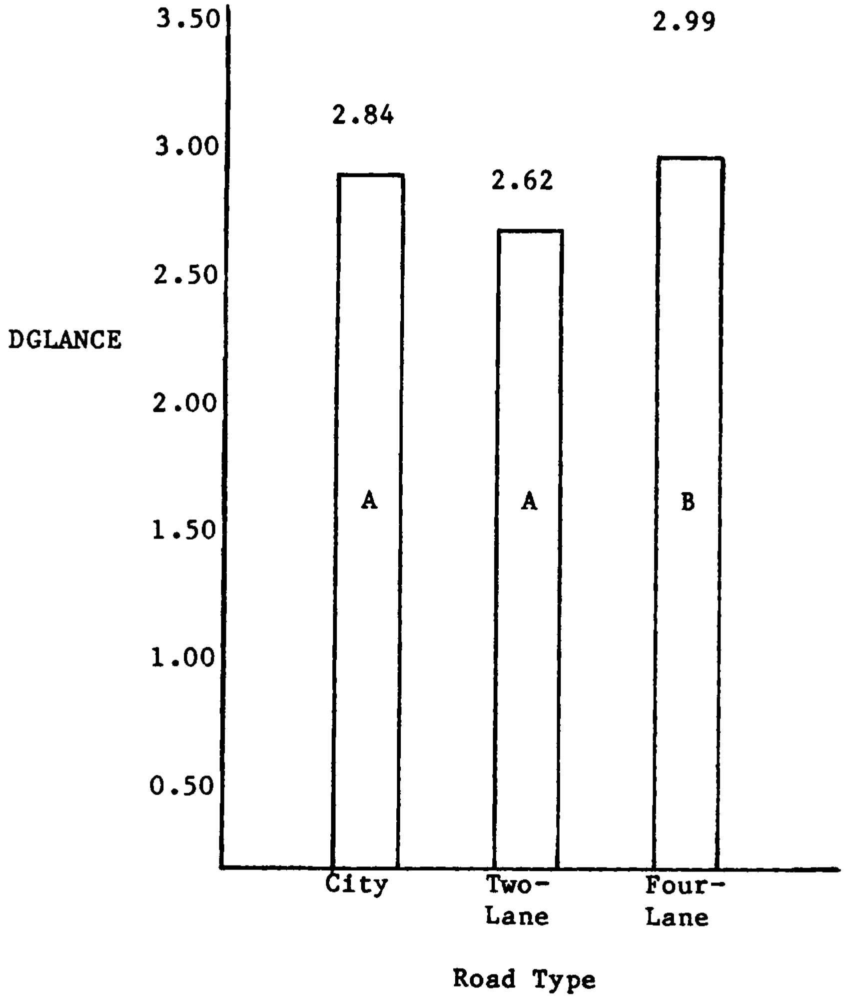
Illustration of road-type differences - TIMEGLANCE. The illustration of road-type differences for the variable TIMEGLANCE (task-completion time from first display glance) appears in Figure 12. As shown, the longest task-completion time occurred for the four-lane road type, and the shortest task-completion times occurred for the two-lane and city-road types. This finding is somewhat counter intuitive. Since it is generally agreed that attentional demand is lowest on a four-lane road, one might expect the task time to be the least because theoretically the subject would have more "spare" time to complete the task. There is, however, a reasonable explanation for this result. Subjects may have performed the tasks at a quickened pace on the two-lane roadway so that greater attention could be devoted to the somewhat more difficult driving task (Senders et al., 1966).

Illustration of road-type differences - DGLANCE. The illustration of road-type differences for the variable DGLANCE (number of display glances) appears in Figure 13. As shown, the four-lane roadway had the largest number of display glances while the two-lane and city roadways had the fewest. As with the TIMEGLANCE graph, this result



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 12. TIMEGLANCE (Task time from first display glance) by road type.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

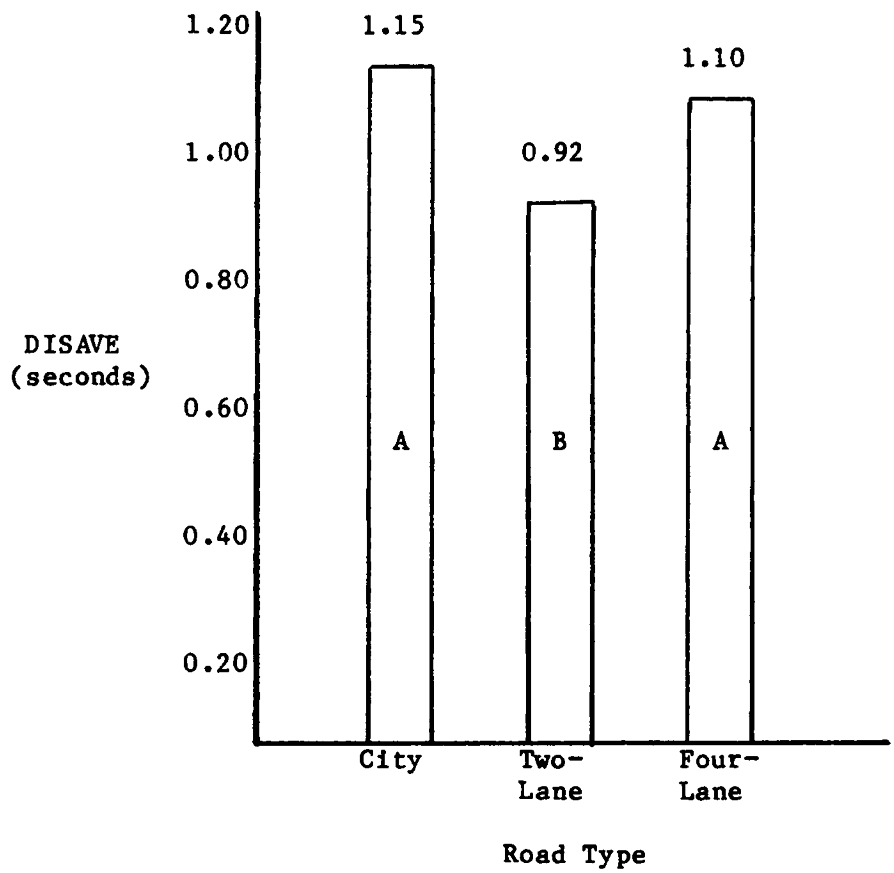
Figure 13. DGLANCE (average number of display glances) by road type.

could be interpreted as being somewhat counter intuitive. A reasonable explanation for this result may be that the subject had a greater number of opportunities to look at a given display given that a four-lane road type requires less attentional demand.

Illustration of road-type differences - DISAVE. The illustration of road-type differences for the variable DISAVE (average-display-glance length) appears in Figure 14. Notice that the DISAVE means for the city and four-lane road types were approximately equal, while the DISAVE mean for the two-lane road type was less. This finding supports previous findings indicating that the two-lane road type requires the greatest attentional demand (since there was less time between roadway glances).

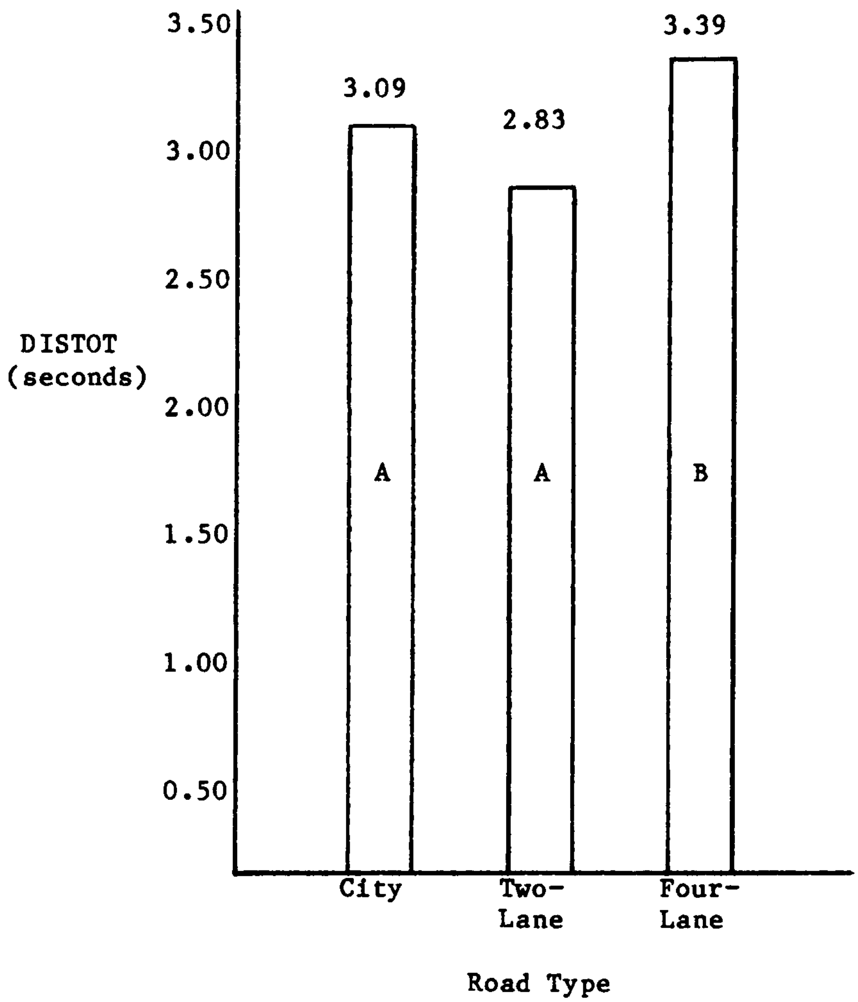
Illustration of road-type differences - DISTOT. The illustration of road-type differences for the variable DISTOT (total-display-glance time) appears in Figure 15. As shown, the DISTOT mean for the four-lane road type was the greatest, and the DISTOT mean for the two-lane road type was the least. This result supports the hypothesis that drivers were unable to observe the display as much on the two-lane roadway as on the four-lane roadway due to the greater attentional demand required by the primary driving task.

Illustration of road-type differences - STVRMS. The illustration of road-type differences for the dependent



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 14. DISAVE (average display single glance time) by road type.



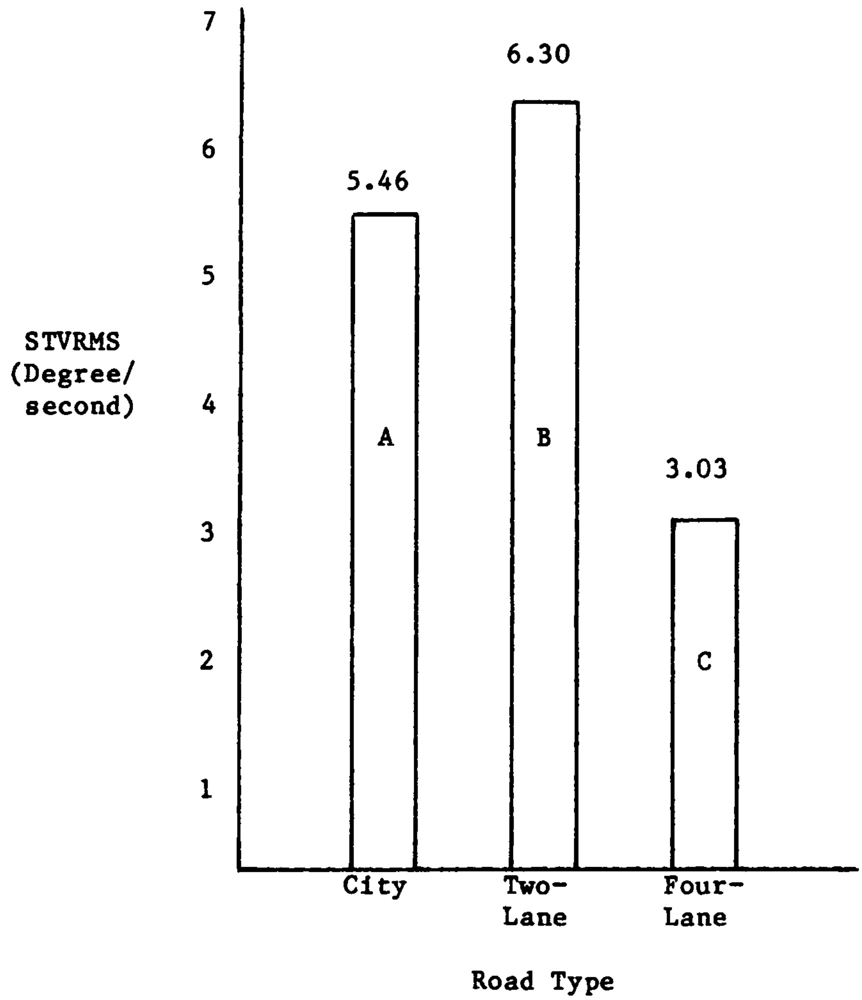
* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 15. DISTOT (average display total glance time) by road type.

variable STVRMS (RMS steering velocity) appears in Figure 16. The figure illustrates the intuitive result that steering-wheel movement is greatest on two-lane roadways and least on four-lane roadways.

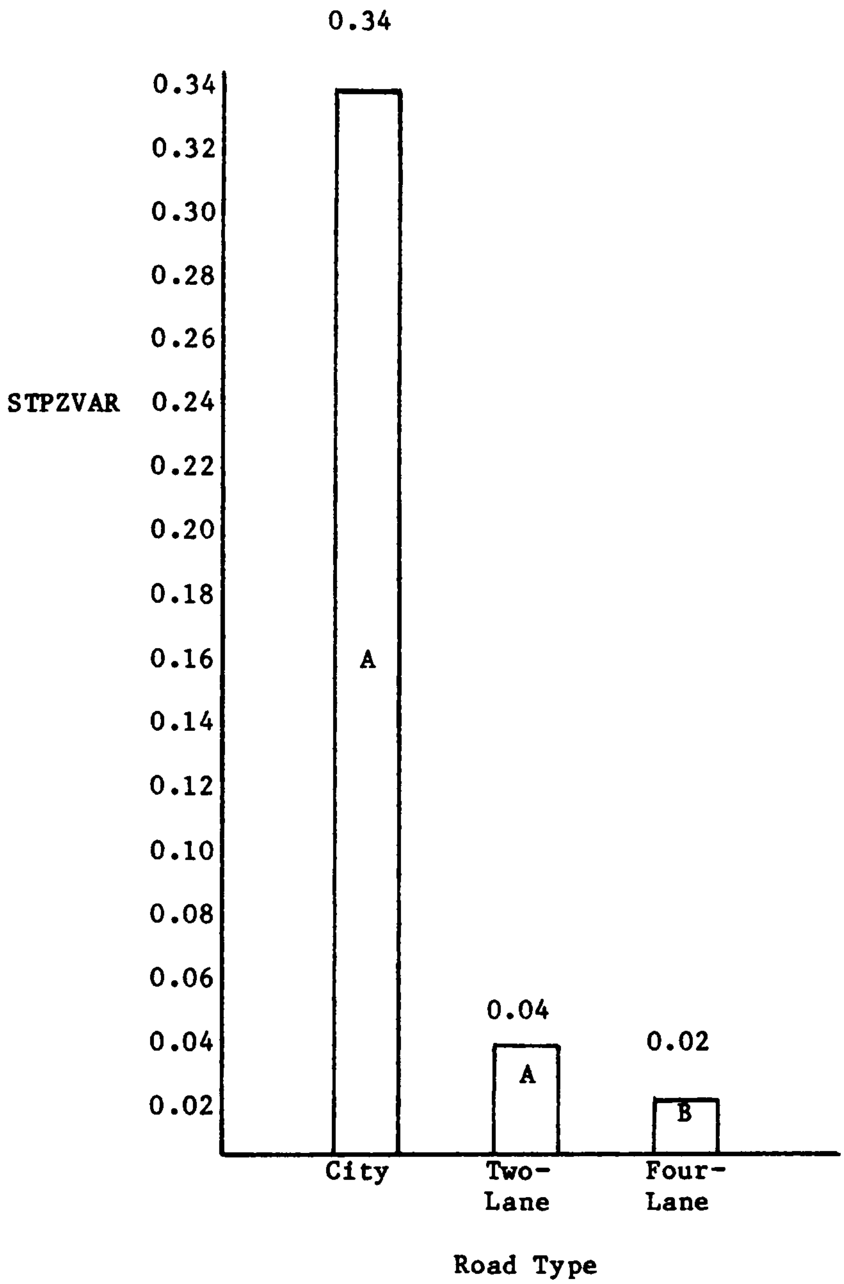
Illustration of road-type differences - STPZVAR. The illustration of road-type differences for the dependent variable STPZVAR (steering-velocity percent zero variance) appears in Figure 17. As shown, a wide margin of difference is indicated by the means between the city road type and both the two-lane and four-lane road types. As indicated by the Bonferroni multiple comparisons, however, actual differences apparently were between the four-lane road type and the two-lane and city road types. This result indicates that a greater number of steering wheel "holds" followed by a correction were present for the two-lane and city road types. One explanation for the large mean (and variance) result for the city road type is that since the speeds on the residential streets were generally much lower than for four-lane roadways, the number of constant corrections or changes in steering would be reduced. Correspondingly, the number and length of steering wheel "holds" would be increased.

Illustration of road-type differences - ACCPOS. The illustration of road-type differences for the dependent variable ACCPOS (accelerator high-pass position variance) appears in Figure 18. As shown, accelerator-pedal position



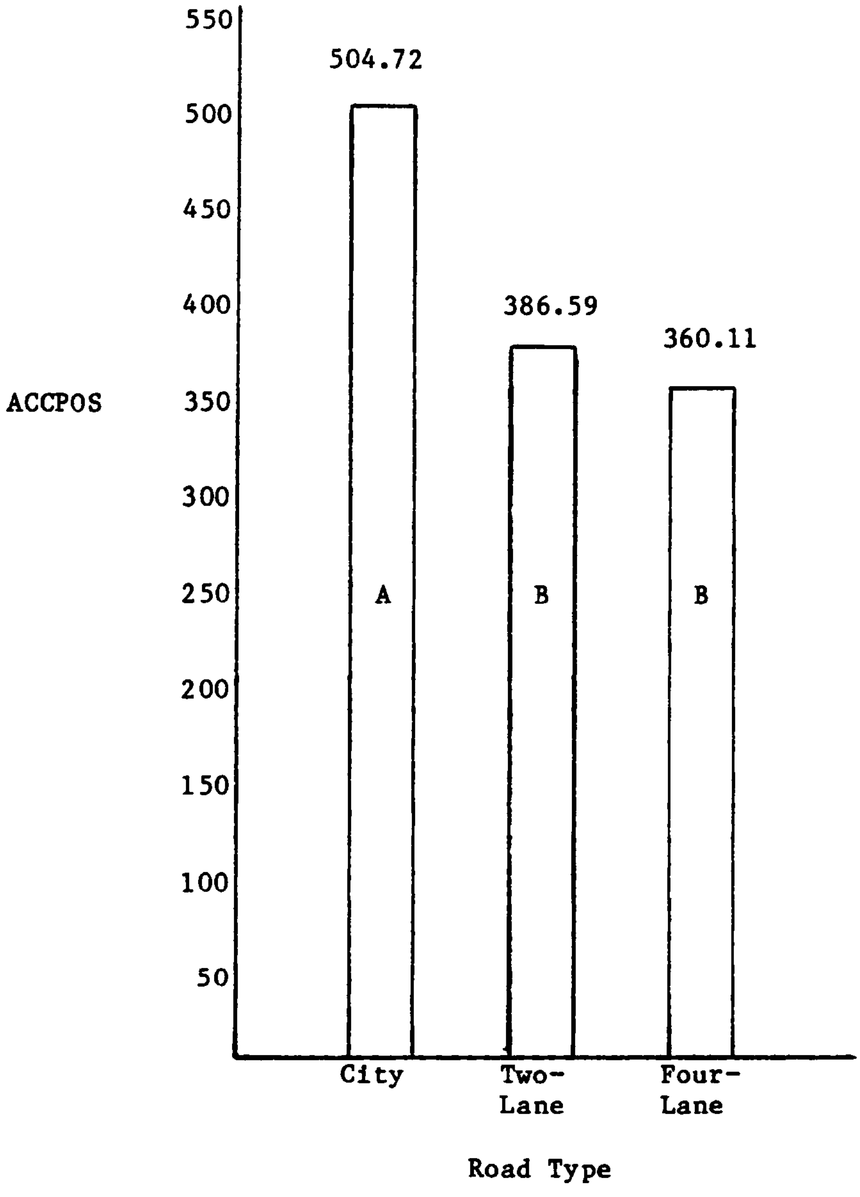
* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 16. STVRMS (RMS lower case steering velocity) by road type.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 17. STPZVAR (steering velocity percent zero variance) by road type.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

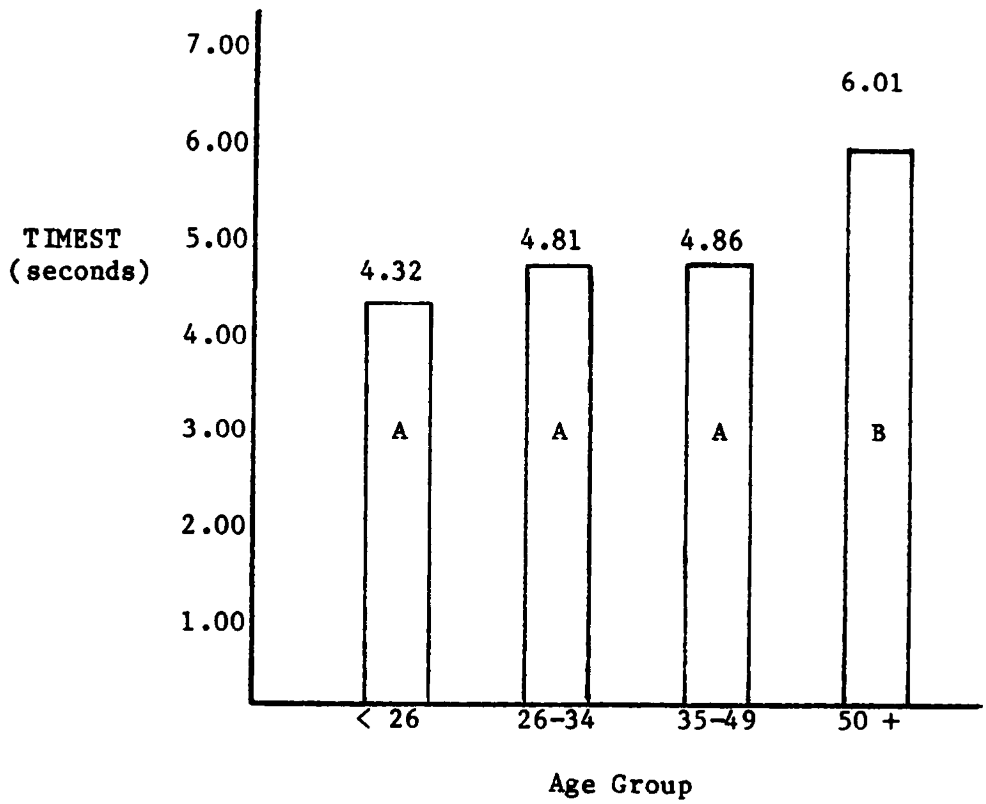
Figure 18. ACCPOS (accelerator high pass position variance) by road type.

variance was greatest for the city road type and least for the two-lane and four-lane road types. This result is probably due to city (residential) driving aspects such as stop-and-go (accelerate and decelerate) driving.

Illustration of age differences - TIMEST. The illustration of age differences for the dependent variable TIMEST (task-completion time from button press) appears in Figure 19. As shown, the task-completion time (on the average) was relatively constant for the three under-fifty age groups. The over-fifty age group, however, required a greater amount of time to complete the tasks. One hypothesis that would explain this difference might be a speed/accuracy tradeoff. That is, the older subjects showed "greater care" by taking more time to perform the tasks accurately.

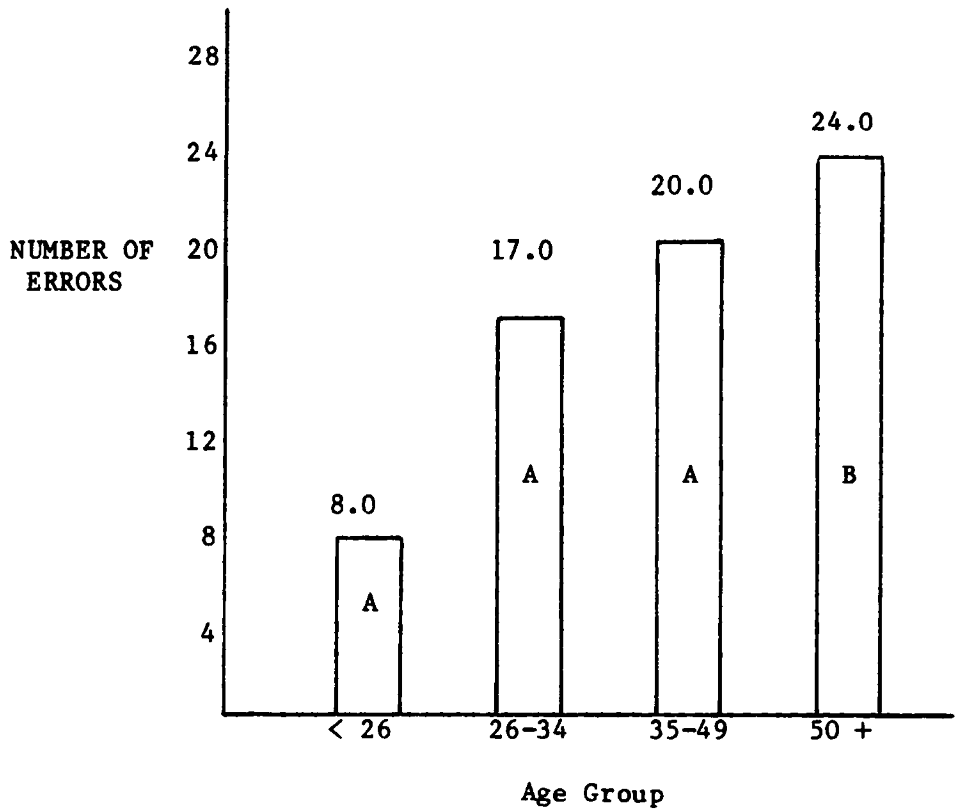
To check this hypothesis, the number of errors performed by each age group was calculated and is shown in Figure 20. As shown by the table, the speed/accuracy tradeoff hypothesis is not supported since the over-fifty age group committed the greatest number of errors during task performance.

Illustration of age differences - DISTOT. The graph illustrating age differences for the dependent variable DISTOT (total-display-glance time) appears in Figure 21. As shown, the three under-fifty age groups had approximately equal mean total-display-glance times. On the



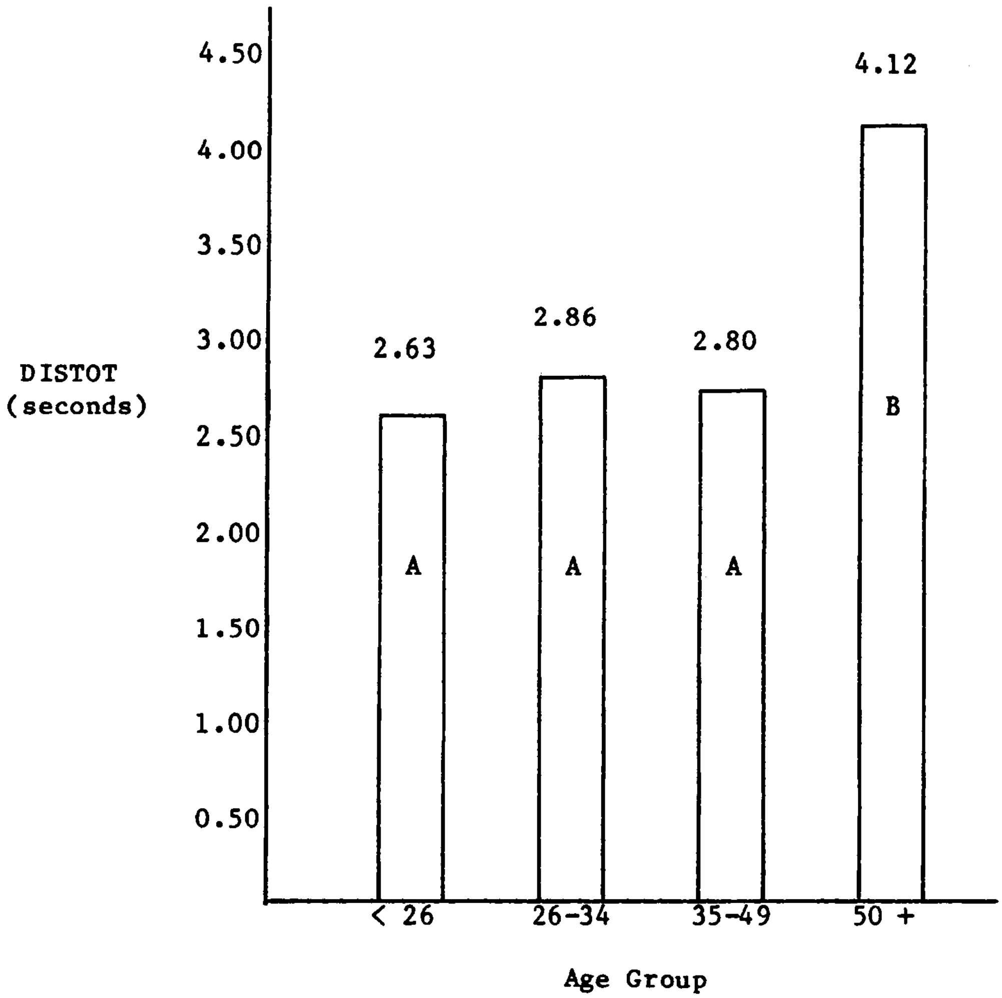
* Groupings based on Bonferroni multiple comparisons (different letters indicate age group differences at the 95% confidence level)

Figure 19. TIMEST (task completion time from button press) by age group.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 20. Number of task errors by age group.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 21. DISTOT (average display total glance time) by age group.

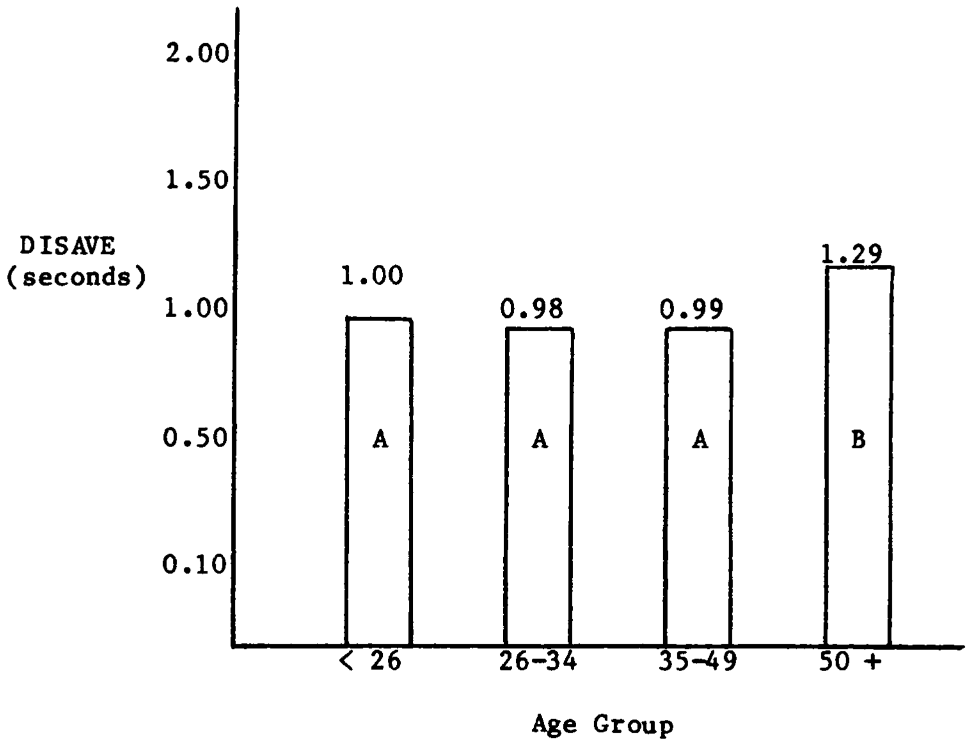
average, however, the over-fifty age group spent a greater amount of time observing the various displays.

Illustration of age differences - DISAVE. The illustration of age differences for the dependent variable DISAVE (average-display-glance time) appears in Figure 22. As shown, the three under-fifty age groups were essentially equal in terms of average-display-glance length. The over-fifty age group, however, had a higher average-display-glance time than the other three age groups. This result indicates that, as a group, the older drivers required more time to extract information from a given display.

Illustration of age differences - BRTIME. The illustration of age differences for the dependent variable BRTIME (brake-pedal dwell time) appears in Figure 23. As shown, the average brake dwell times for the three under-fifty age groups were approximately equal. The average brake dwell time for the over-fifty group, however, was greater than for the other three groups. One might hypothesize that, based on these results, the older age group was more cautious or conservative while driving than the other three groups.

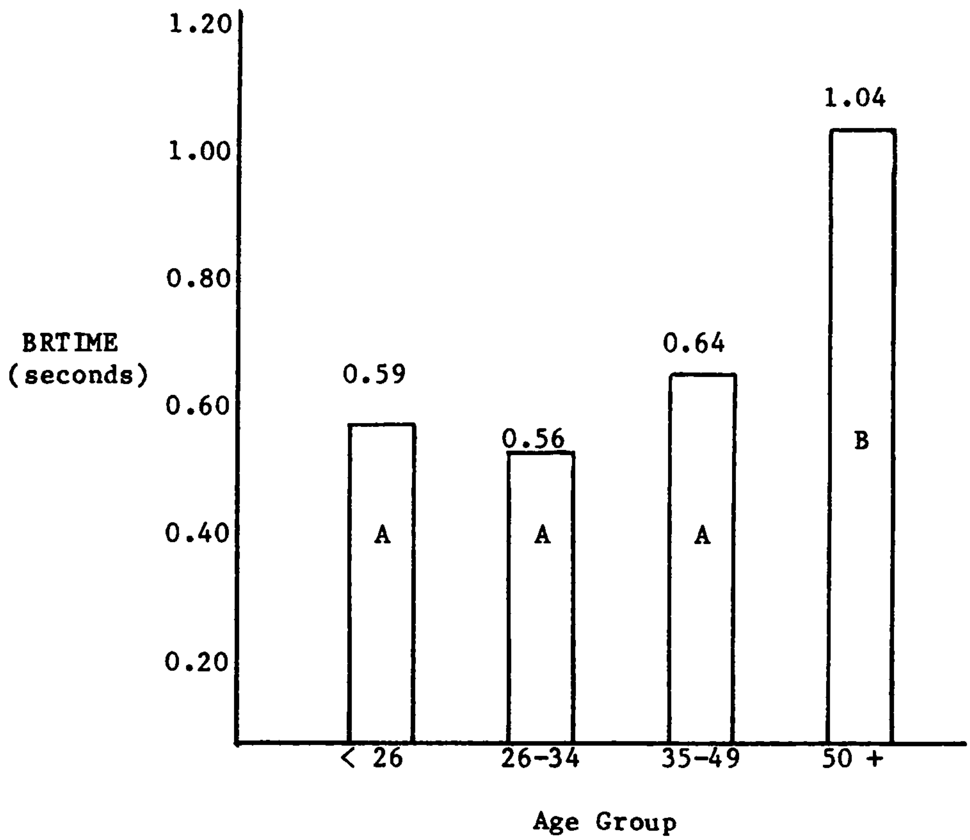
Analysis of Traffic Density

A statistical procedure testing differences between the two levels of traffic density, could not be performed.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

Figure 22. DISAVE (average display single glance time) by age group.



* Groupings based on Bonferroni multiple comparisons (different letters indicate road type differences at the 95% confidence level)

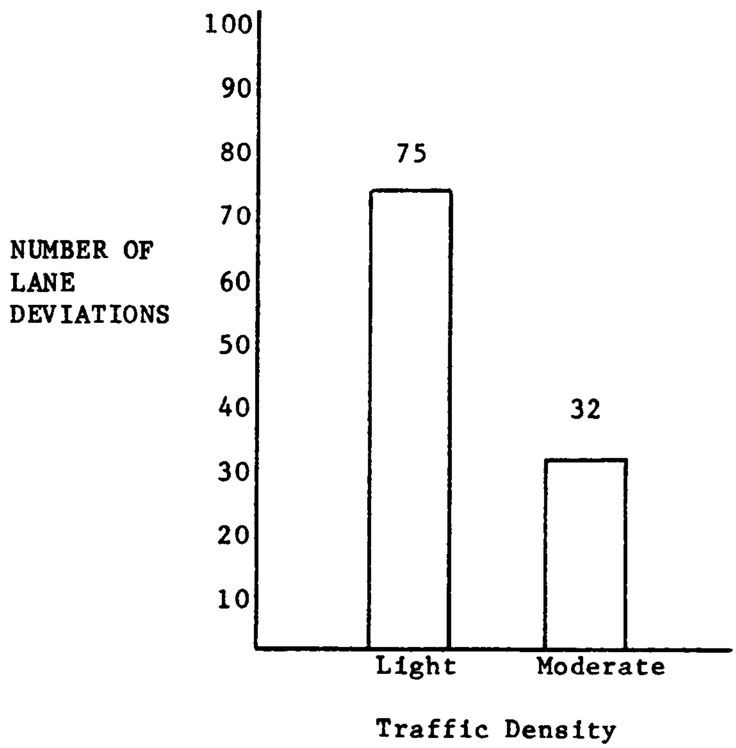
Figure 23. BRTIME (average brake dwell time per activation) by age group.

Since traffic was characterized by the experimenter on a run-by-run basis, the data were neither within nor between subjects (i.e., one run classified differently than the other two runs for the same subject).

To gain an understanding of traffic density effects on driver behavior, the sum of the number of lane deviations for each level of traffic density was calculated and appears in Figure 24. As shown, the number of lane deviations was more than twice as large for the low-traffic-density condition. Even when considering the difference in the number of occurrences for the low and moderate traffic conditions, this result lends support to the hypothesis that drivers exercise greater care and attention when other traffic is in close proximity.

Cluster Analysis

A cluster analysis was performed to aid in the grouping of tasks based on attentional demand. A cluster analysis is a multivariate technique that uses the information contained in two or more dependent measures to form groups suggested by the data. The SAS Cluster procedure was used to perform the cluster analysis using the average squared Euclidean distance to form the clusters (SAS Institute, 1985). With this method the average distance of all the points between clusters is used as the cluster distance. The clustering method starts with _n_ clusters (where



Note: Number of occurrences: Light - 52
Moderate - 44

Figure 24. Number of Lane Deviations by Traffic Density.

n is the number of points specified), finds the closest cluster, merges that pair together, forms a new distance matrix, and continues the same steps until all clusters are merged. The dependent measures used in the analysis were those that showed the greatest sensitivity in the univariate multiple-comparisons analysis: TIMEGLANCE, DISTOT, DGLANCE, DISAVE, and STPZVAR. (It should be noted that, to the best of the author's knowledge, no validation of the clustering technique has been accomplished for a mixed-factor experimental design of this complexity. However, Scott and Knott (1974) tested a similar analysis on a randomized block ANOVA design with encouraging results.)

A cluster analysis was performed for both the undivided set of tasks and the set of tasks including the navigator tasks divided by information availability and the cruise-control task. The output of each of these analyses was printed in the form of a dendrogram with the number of clusters formed between tasks during the merging process used as the width of the graph.

Cluster analysis - undivided task data set. The cluster analysis dendrogram for the undivided task data set appears in Figure 25. To interpret the dendrogram, lay a straight edge vertically over the table. By moving the straight edge back and forth horizontally, and noting where the breaks occur in the lines of Xs, various clusters can be seen. Two vertical locations appear noteworthy.

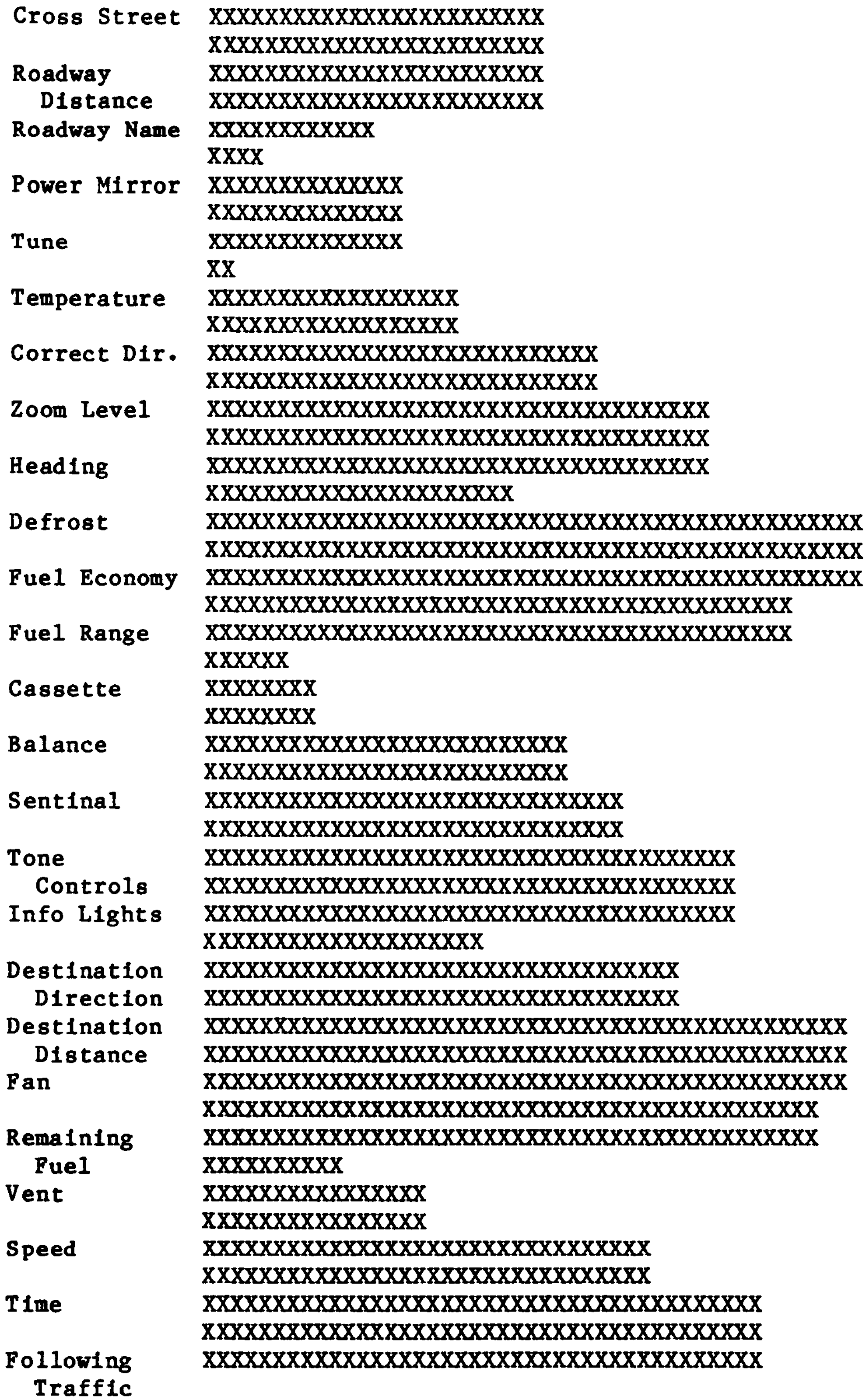


Figure 25. Cluster analysis dendrogram by task.

Leaving the first 8 columns of Xs uncovered, the clusters are as follows:

1. roadway name, roadway distance, cross street
2. tune radio, power mirror
3. temperature, correct direction, zoom level, heading, defrost fuel economy, fuel range
4. cassette tape, balance, sentinal, tone controls, info lights, destination direction, destination distance, fan, remaining fuel, vent, speed time, following traffic.

Leaving the first 12 rows of Xs uncovered, the clusters are as follows:

1. cross street, roadway distance, roadway name
2. power mirror, tune radio
3. temperature, correct direction, zoom level, heading, defrost, fuel economy, fuel range
4. cassette tape
5. balance, sentinal, tone controls, info lights, destination direction, destination distance, fan, remaining fuel
6. vent, speed, time, following traffic.

Cluster analysis - navigator tasks divided by information availability and cruise control. The cluster analysis dendrogram for the data set including the navigator tasks divided by navigator information availability and the cruise-control task appears in Figure 26. Note that only the top portion of the dendrogram is shown in Figure 26 due to space limitations. Refer to Figure 25 to determine task groupings for the remaining tasks. As

```
Cross Street+        XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Roadway Distance+    XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXX
Roadway Name+        XXXXXXXXXXXXXXXX
                     XXXXXX
Cruise Control       XXXXXXXXXX
                     XXXXXXXXXX
Power Mirror         XXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXXXX
Tune Radio           XXXXXXXXXXXXXXXXXXXXXXXXXX
                     XX
Cross Street*        XXXXXXXX
                     XXXXXXXX
Roadway Distance*    XXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXX
Roadway Name*        XXXXXXXXXXXXXXXXXX
                     XXXX
Temperature          XXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXX
Correct Direction    XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Zoom Level           XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Heading              XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Defrost              XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

+ Info. not immediately available on display

* Info. immediately available on display

Note: Only the top section of the dendrogram showing the clusters of the divided tasks and the cruise control task is shown. See Figure 25 for the remaining task clusters.

Figure 26. Cluster analysis dendrogram by task including navigational tasks divided by information availability.

shown, the vertical location leaving 8 lines of Xs uncovered forms the following clusters:

1. cross street (zoom required), roadway distance (zoom required), roadway name (zoom required)
2. cruise control, power mirror, tune radio
3. cross street (information available), roadway distance (information available), roadway name (information available)
4. all remaining tasks shown.

Moving the vertical location so that 12 lines of Xs are uncovered forms the following clusters:

1. cross street (zoom required), roadway distance (zoom required), roadway name (zoom required)
2. cruise control
3. power mirror, tune radio
4. cross street (information available)
5. roadway distance (information available), roadway name (information available)
6. all remaining tasks shown

Note that interpretation of the dendrograms is subjective to some degree. The groups of tasks shown above, therefore, should be interpreted with caution.

DISCUSSION

Task Grouping Based on Attentional Demand

One of the primary goals of this study was to develop task groupings for functionally equivalent tasks in terms of required driver attentional demand. Through these task groupings, it was hoped that the navigator tasks could be functionally equated with the familiar conventional tasks.

Task Grouping Based on A Priori Criteria

Based on the literature reviewed for this research, a priori criteria were selected for classification of tasks into low, medium, and high attentional demand. These criteria were based solely on the required-display-glance time (the dependent variable DISTOT for this research).

Based on these a priori criteria and the DISTOT data, the tasks were classified into the low, medium, and high attentional-demand categories. In doing so, however, it became apparent that a number of tasks required much greater display-glance time than the highest criterion level. Therefore, a fourth category -- very high attentional demand -- was added to describe more effectively the task groups. The criterion for the fourth category was selected in part due to a wide gap in the data and in part to create equal intervals between medium and high, and between high and very high attentional-demand categories.

The categorization of the tasks based on the a priori visual attentional demand criteria (and the fourth a posteriori criterion) is shown in Table 39. The task classification in Table 39 is closely aligned with what would be expected from a driver task analysis. For the low attentional-demand tasks, the driver is required to retrieve simple information (in the case of speed and following traffic) that is in the normal scan pattern, or to operate a control (in the case of turn signal) that does not require (generally) visual contact to find and activate.

For the medium attentional-demand tasks, the driver is required to retrieve simple information that is not in the normal scan pattern (remaining fuel, time, info lights, destination distance, destination direction) or to manipulate a simple control that requires visual contact to find and manipulate (tone controls, balance controls, sentinal, fan, and vent).

For the high attentional-demand tasks, the task-analytic classifications become somewhat less clear and more difficult to describe. The tasks fuel range and fuel economy require the driver to locate and activate a control, and to retrieve simple information. The tasks

TABLE 39

Grouping of Tasks Based on A Priori Classification of Visual Attentional Demand

Criteria	Conventional	Navigator
Low Attentional Demand (DISTOT < 1.0)	Following Traffic Turn Signal Speed	
Medium Attentional Demand ($1.0 \leq$ DISTOT < 2.5)	Remaining Fuel Info Lights Tone Controls Balance Controls Sentinal Fan Vent Time	Destination Distance Destination Direction
High Attentional Demand ($2.5 \leq$ DISTOT < 4.0)	Fuel Range Fuel Economy Defrost Temperature Cassette Tape	Heading Zoom Level Appropriate Direction
Very High Attentional Deman (DISTOT $\geq$ 4.0)	Power Mirror Tune Radio Cruise Control	Roadway Name Roadway Distance Cross Street

defrost and temperature require the manipulation of one control several times, or the manipulation of several controls. The task cassette tape requires the driver to locate a loose object and insert it in a specific location in a specific orientation. The tasks heading and appropriate direction require the driver to retrieve information and make a judgement. The task zoom-level requires the driver to retrieve information, make a judgement on that information, and perform a control manipulation. Although it appears reasonable that the aforementioned tasks are classified as requiring high visual attentional demand based on the criteria defined, logically it is impossible to equate them in terms of required driver functions.

The very high attentional-demand category can be broken down into fewer functional groups than the high attentional-demand tasks, although the groups are no easier to equate. The power-mirror, tune-radio, and cruise-control tasks require rather complex control adjustment. (The cruise-control task, however, requires a foot control for adjustment.) The roadway name, roadway distance, and cross street tasks require judgement and complex information retrieval, as well as control manipulations in many instances.

It is apparent that while the a priori classification criteria provide logical and informative classifications based on the data collected for the low and medium attentional-demand categories, they are inadequate for classification of the tasks requiring greater attentional demand.

Task Groupings Based on Post-Hoc Multiple Comparisons

The t-test and Bonferroni multiple comparisons provided valuable information for equating tasks in terms of required driver attentional demand. Five of the dependent measures, TIMEGLANCE (task time from first display glance), DISTOT (total-display-glance time), DGLANCE (number of display glances), DISAVE (average-display-glance time), and STPZVAR (steering-velocity percent zero variance), proved to be particularly sensitive to task differences.

The results of the multiple comparisons show that the navigator tasks roadway name, roadway distance, and cross street require a long time to complete, require long single-display glances, and require a large number of glances in comparison to the other tasks. Based on a broad perspective across the five dependent measures, it is apparent that these tasks stand out as requiring the highest attentional demand.

These three navigator tasks require the retrieval of complex information. The information to be retrieved, however, is not always available on the display; rather, the driver must search for it using the zoom-in or zoom-out performed functions. Two of these tasks, roadway name and roadway distance, are performed each time navigation to an unknown location is accomplished. The third task, cross street, would probably only be performed occasionally to check the navigator accuracy or to determine a turn-around point if a street were missed. Therefore, the improvement of these navigation tasks is considered a key issue, particularly in the case of roadway name and roadway distance.

To determine differences in these three tasks due to information availability (information immediately available on the display vs. zoom-in or zoom-out required), the information conditions were separated as part of a second multiple-comparisons analysis. The second analysis provided two important results with regard to the three tasks. First, when the driver was required to search for the information, these tasks required the greatest attentional demand compared to all other tasks. However, when the information was immediately available on the display, these tasks appeared to equate (for the most part) with the conventional tasks power mirror, tune radio, and cruise control.

The second important piece of information gained from the division of the navigator tasks by information availability was that the single-display-glance length (DISAVE) was very high compared to the other tasks in either case. Therefore, it is apparent that extracting information from the navigation display -- even when the information is readily available -- is a more complex task than for the other displays.

The multiple-comparison analyses were less valuable for grouping the remaining tasks due to large overlaps between tasks, especially in the case of the more conservative Bonferroni comparisons. The fact that this large overlap was present, however, especially when considering the relative attentional demand of the remaining five navigator tasks, indicates that differences were not as great between some of the tasks requiring moderate to low attentional demand compared to those tasks requiring higher attentional demand.

Despite the large overlaps present in the multiple-comparison data for many of the tasks, it is apparent that three to four groups could be formed for each of the dependent measures, especially for the t-test comparisons. It is also apparent that many of the task groupings are similar when comparing dependent measures. However, rather than discuss groupings based on multiple-dependent measures from univariate analyses, it is more appropriate to consider groupings based on the multivariate cluster analyses.

Task Grouping Based on Cluster Analyses

The multivariate cluster analysis described in the

Results section provides perhaps the best overall view of the task groupings. The task groupings formed by the cluster analysis are consistent with the findings of the a priori logical groupings based on driver-task requirements and the multiple-comparison analyses.

For the undivided set of tasks (with no separation of navigation tasks and no cruise-control task) the optimal task groupings as indicated by the cluster analysis are:

- cross street, roadway distance, roadway name
- power mirror, tune radio
- temperature, correct direction, zoom level, heading, defrost, fuel economy, fuel range
- cassette tape
- balance, sentinal, tone controls, info lights, destination direction, destination distance, fan, remaining fuel
- vent, speed, time, following traffic.

Two of the tasks appear slightly out of place. One might expect the cassette tape and vent tasks to be grouped with higher attentional demand tasks. For both of these tasks, the experimenters noted that much of the task was accomplished by "feel" without looking at the "displays" immediately. In the case of the vent task, several subjects performed the task with only one short glance after the hand was near the vent. In the case of the cassette tape, many subjects found the tape, picked it up and began orienting it before they looked at it the first time.

Therefore, these tasks are probably correctly grouped based on attentional demand as defined for this research.

The cluster analysis for the tasks, including the cruise-control task and the navigator tasks divided according to information availability, provided interesting results. The clusters of tasks affected by the task addition/division are shown below:

- cross street, roadway distance, roadway name (information not immediately available)
- cruise control
- power mirror, tune radio
- cross-street (information available)
- roadway name, roadway distance (information available).

These cluster analysis results indicate that the information availability for the navigator is important and that improvements are likely needed. The results also suggest that if information availability could be substantially improved, use of the navigator would not require as much attentional demand on a moment-to-moment (short-term) basis as some conventional tasks. If one assumes that none of the conventional tasks require too much attentional demand, an improved navigation system could be considered safe and practical for the automotive environment.

The issue of how much attentional demand is too much, for both navigator and conventional secondary driving tasks, is addressed in the next section.

Secondary Task Attentional Demand -- How Much is Too Much?

Thus far, the results of this study have consisted of the ranking of a number of tasks in terms of required attentional demand and the functional grouping equating similar tasks in terms of attentional demand. However, the question of maximum safe secondary task attentional demand needs to be addressed to assess properly both the navigator and conventional tasks. It might be assumed that since the conventional tasks are performed thousands of times daily, they do not require too much attentional demand. However, even though conventional tasks such as tuning the radio are accomplished daily, how many rear-end or other collisions have occurred during a secondary task such as this?

The key issue here, as with any safety-related human factors problem, is to optimize the design. The radio scan and seek functions are good examples. These convenience features in all likelihood significantly reduce the attentional demand of the radio-tuning task, thereby reducing the number of accidents through an improved design.

Given that drivers time-share between the roadway and display at relatively constant intervals, it seems apparent that conscientious drivers could perform very complex tasks for long periods of time while maintaining lane position and speed, as long as progressive information toward the task end could be gathered with each display glance.

However, if an emergency situation were to arise, it is less likely that the driver would detect the situation immediately.

Therefore, for tasks that require a reasonable control manipulation (i.e., convenient, do not require too much force, etc.) or simple information retrieval (where the single-glance time is not too long), it appears that task duration is the key element in assessing attentional demand due to:

1. The increasing probability of encountering an emergency situation during task performance with increasing task time, and
2. The interruption of normal scan patterns for lengths of time where traffic dynamics can change substantially.

Three conventional tasks that were performed during this study have questionably high attentional demand requirements. These tasks are cruise control, power mirror, and tune radio. The cruise control task is generally performed on four-lane limited-access roads in situations of light traffic. Under these circumstances, the attentional demand requirement of the cruise-control task is probably not too great. The tune-radio task, as previously mentioned, has design features (scan and seek) that probably reduce the required attentional demand to a safe level.

The power mirror task, however, probably should not be accomplished while the automobile is moving. The level of attentional demand required and the large number of lane deviations (as discussed in the Results section) indicate that this task should be accomplished during a pre-drive situation only. It is therefore recommended that the power mirror function be locked-out while the vehicle is moving.

A logical criterion for maximum safe attentional demand associated with the navigator tasks is somewhat more difficult to address. The primary reason for this difficulty is that complex information must be extracted from the display. This was reflected in the average-single-display glance time results. The seven tasks with the longest mean-glance times were navigator tasks. Therefore, unlike the conventional tasks described above, the attentional demand assessment of the navigator tasks probably cannot be characterized in terms of task time alone.

One factor that needs to be considered at this point is the navigation task itself. Any means of navigation requires the extraction of relatively complex information. Therefore, the fact that the average-display-glance time is comparable to (at least some of) the conventional tasks should be viewed as encouraging.

Considering both the single-display-glance length and the task-completion time results, the design associated with the navigator tasks roadway name, roadway distance, and cross street needs to be improved. Although somewhat less critical, the design associated with several of the other navigator tasks (e.g., heading and zoom level) could also be improved in an attempt to reduce the required display single-glance time. Suggested navigator design improvements are discussed in the Conclusions and Recommendations section.

Summary Discussion of Subject and Roadway Factors

Of the subject factors investigated (gender, age, and driving experience), only the age results indicated that differences were present based on the dependent measures collected. The fact that no gender differences were present is not surprising, since the results of the majority of driving studies have not indicated the presence of measurable differences due to gender.

The result that driving experience indicated no differences is also not of great surprise. Although several studies were found indicating experience differences in driving, the low-experience group in these studies generally drove less than 2,000 miles per year. For the groups selected for this study (2,000-10,000 miles per year, and greater than 10,000 miles per year), the drivers were sufficiently experienced so that no differences could be measured.

The age differences that were found in this study were consistent with the findings of previous studies. The over-fifty age group appeared to be generally more cautious while driving than the other three age groups, as indicated by several of the results (e.g., task time, brake dwell time). Despite this apparent caution, however, the older age group made more task errors than the other age groups. This result is consistent with several studies indicating that certain aspects of central-processing capabilities associated with driving are reduced with age.

The results of the roadway analyses were also consistent with the findings of previous research. Road type level differences were present for a large number of the dependent variables. The results generally indicated that attentional demand requirements were the least on a four-lane limited-access roadway, and the greatest on a two-lane rural roadway.

The results for the traffic-density analysis indicated that drivers exercised greater caution with other traffic in close proximity. It should be noted, however, that the face-valid eye-scanning measures were not among the variables indicating differences for the traffic density factor.

The Effect of Subject Training

As previously described in the Procedure section, novice subjects were trained to use the navigation system and conventional automotive controls and displays until they were able to demonstrate mistake-free proficient performance of all required tasks. This training process required from two to four hours of time, depending on the subject.

It is anticipated that highly experienced users of the navigation system would be able to perform the navigation tasks with some greater degree of proficiency than the novice users who participated in this study. The amount of increase in proficiency that would result from experience is unknown. However, with design improvements, all of the navigator tasks could likely be performed safely and efficiently (especially in certain low-risk traffic and roadway situations). Therefore, even a small increase in proficiency could potentially make a meaningful difference in required attentional demand.

Specific recommended navigation system design improvements and suggestions for additional test and evaluation research with experienced users are discussed in the next section.

CONCLUSIONS AND RECOMMENDATIONS

The navigation system evaluated for this research is an effective device for the most part. The fact that many of the navigator tasks are comparable to the conventional tasks indicates that the navigation task can probably be accomplished reasonably safely and efficiently with some design improvements. These design improvements can be categorized in two basic ways: improvements that would reduce total-task time and total-display-glance time, and improvements that would reduce single-display-glance time. Although these categories of improvements are not totally independent of one another, they stem from somewhat different considerations.

Through design improvements which could be implemented into the current system with current technology, it seems apparent that the total-task time and total-display-glance time can be reduced to a level that is safe for many traffic and roadway situations. These improvements are discussed in detail in the next section. The reduction in the required single-display-glance time, however, is perhaps not as easily accomplished. The required single-display-glance time was longer (in general) for the navigation tasks than for the conventional tasks. This single-glance time difference was, in all likelihood, due to the greater complexity of navigation display information as compared to information provided by any other automotive display. This complexity apparently forces the driver to spend a greater amount of time searching for and interpreting information for a number of navigator tasks.

It should be noted, however, that the differences between the single-glance times for the conventional and navigation tasks were not large in magnitude, especially considering the variance present due to other factors such as subject differences, road type, and traffic density. Nevertheless, differences were present. It is difficult to assess whether the navigation task single-glance time was too great in terms of a potential safety hazard. For example, despite the differences in single-glance times noted above, none of the navigation tasks had the largest number of lane deviations. In fact, the conventional tasks, cassette tape and power mirror, had the largest number of lane deviations.

Despite the fact that it cannot be shown conclusively that the information displayed by the navigation system is too complex for the automotive environment, the method of information presentation is probably not optimal in terms of safety and efficiency. Other methods of information presentation such as auditory or visual-verbal instead of visual-graphic might be safer, but are not practical for incorporation into the current system. Incorporation of another method of information presentation would be impractical since the current navigation provides only a starting point, a destination point, and area roadways. With this configuration, the visual-graphic method of information presentation is probably the only feasible alternative. If, however, the navigation system were configured to automatically select and display a route to a destination, or would allow the driver to select and enter a route via cursor control while stationary, then alternate means of information presentation could be investigated. Design improvements which describe design configuration changes and recommended design improvements appear in the following sections.

Information Availability

The results showed that the navigator tasks for which a zoom-in or zoom-out function was required had substantially greater attentional demand than any of the other tasks. For illustrations of these results, see Table 10 (navigator tasks roadway name, roadway distance, and cross street separated by information availability for total-display-glance time) and Table 30 (t-test multiple comparisons for the total-display-glance time). If all of the required navigation information were available on the display, it is anticipated that the overall navigation task would require substantially less attentional demand. Two potential design modifications that would provide at least a partial solution to this problem are described below.

Auto-zoom. While driving to a destination, a driver must zoom in several times in order to have the optimal amount of information continuously available. If the driver starts out with the destination star on the screen, eventually a zoom in will provide a greater amount of detail with the destination star still appearing on the screen (when the destination distance becomes less than the next lower scale value). As a driver gets close to a destination (e.g., less than one mile), the frequency of required zoom ins increases (depending on whether the destination is on a primary or secondary street).

This zoom-in requirement could be eliminated with the inclusion of an auto-zoom function. This function, when activated by the driver, would automatically maintain the destination star on the screen on the lowest zoom level possible (thus maximizing secondary-street information). This function could be activated manually by the driver and deactivated when a manual zoom in or zoom out was performed. Once the driver extracted the desired information from the manually set zoom level, the auto-zoom function could either be reactivated manually or automatically after a pre-set length of time. It is anticipated that this function would eliminate many of the zoom-in and zoom-out requirements that are necessary to find roadways on the way to a destination.

Optimized route algorithms. Another design improvement to reduce attentional demand by providing constantly available navigation system information would be the display of an entire route for the entire drive to the destination. This would require the navigation system to select a route to the destination, something that it is not currently designed to do. Through the use of algorithms to select the optimal route to a destination where a limited number of choices (four, for example) are calculated at each decision point, such a design improvement seems feasible without the addition of a large amount of computing capacity.

Two algorithms seem worthwhile and implementable with information already available within the current navigation system.

1. Shortest route algorithm. This algorithm would check several different routes based on "moving software" (already contained in the pan and relocate functions). While the vehicle was stationary, the algorithm would check the destination distance for several routes at each decision point (intersection). The directional-arrow information would be utilized to help limit the number of choices (i.e., no road selected that runs greater than 90 degrees away from the destination). The algorithm would continue from intersection to intersection until the short-

est route was determined. The navigation system would then display the shortest route between the starting point and the destination.

2. Main roadway algorithm. Using the "moving software" and directional arrow information described above and in addition, using the primary/secondary roadway information available in the navigation system software, this algorithm would select the most major roadways available between the starting point and the destination. The roadway selection process would be similar to the shortest route algorithm described above (i.e., limited selection of roads within 90 degrees of the destination direction) but would consider whether a roadway was primary or secondary during the route selection process.

A number of design features could be implemented to improve the navigation system if algorithms such as the ones described above could be developed. These features include:

1. Highlighting and display of the entire route (highlighting of the route could be accomplished with brighter lines currently used by the system to differentiate between primary and secondary streets). A highlighted route in conjunction with an auto-zoom type of function would virtually eliminate the need for manual zoom in or zoom out.

2. Warning of an approaching intersection. Since the exact route would be programmed into the navigator, available trend information (via wheel sensors and the computerized map) could be used to alert the driver of an approaching intersection along the route. An automatic zoom-in and/or auditory tone could be used to alert/provide information to the driver about an upcoming turn.

It is anticipated that, if implemented, a route algorithm could substantially reduce the attentional demand required by the navigation system. This design improvement contains one potential problem: the current navigation system design does not recognize one-way streets as being one-way. Therefore, the navigation system might conceivably select a route going the wrong way on a one-way street (or a closed road, for that matter). Warning the driver of this potential problem, however, would probably provide an adequate solution, since the driver would have the same information as to whether a one-way street was present for a manually or automatically selected route.

Additional Design Improvements

Several additional improvements were noted that would provide a more optimal navigation system design. These improvements were not directly supported by the formal study results, other than perhaps the task error data.

Rather, these improvements are based, to a large extent, on informal experimenter observations of driver navigation behavior. Each of these design improvements is discussed below.

Compass display. As noted in the Results section discussion describing the large number of mistakes associated with the heading task, the compass display could be greatly improved. A great deal of confusion was encountered when the arrow was pointing away from north or south, especially southwest or southeast. The problem can be illustrated by a southeast heading direction. When the vehicle is heading southeast, the north arrow is pointing toward the left-lower part of the display. For a normal compass, when the arrow is pointing to the left-lower quadrant, it is an indication of a southwest heading. This non-standardization causes confusion. This display should be improved by changing the arrow to a four-point star or eliminating it altogether. Eliminating the compass arrow would also eliminate confusion between the destination arrow and the compass arrow, a mistake that was noted several times during quick display glances. Since the compass arrow is generally not used for navigation, eliminating it would also simplify the display information. An alternate solution to eliminating the compass display would be to give the driver the option of displaying the compass star.

Reallocation of secondary streets. There were a number of instances during the course of this study where a subject inadvertently encountered a dead-end street while navigating on the way to a destination. This dead-end problem occurred in situations where a very low zoom-level had to be used to extract required navigation information (e.g., display of the roadway being traveled) while the destination was still a considerable distance away. When the lowest zoom-levels (one-fourth or one-eighth) are displayed under the circumstances described above, the driver must rely on the destination direction arrow and a very short portion of displayed roadway to navigate. Often this reliance leads to a street which appears continuous (for the short distance displayed), but in fact is not. Especially for zoom-levels under two miles, the roadway being traveled should appear on the display regardless of whether it is classified as a primary or secondary street.

Another secondary-street allocation improvement that could be implemented would be to selectively show roadways based on area density. When the roads are few and far between, secondary roads should appear on the display at higher zoom-levels than the one-eighth or one-quarter mile scale (e.g., one-half or one mile). The goal should be to optimize the amount of navigation information presented without cluttering the display and without strict adherence to a pre-determined roadway classification scheme.

<u>Quicker update of position</u>. The position-update rate for the display is often too slow, especially when zooming in to a low zoom level. When the navigator has been set on a zoom level for a period of time, the driver adapts to the display distance-time lag. Once the display map is zoomed in, the distance-time lag shown on the map is greater. This lag causes drivers to occasionally miss turns. The lack of adaptation appears to be due to the fact that the trend of the delay cannot be constantly watched due to the attention required by the driving task, and therefore requires time for driver adjustment. One solution that could alleviate this problem would be to use trend information provided by the wheel sensors regarding speed to update position in a more timely manner. Even if the trend information caused the arrow to lead slightly, it is better when navigating to be slightly ahead (looking for the intersection when it is not quite there) than to be slightly behind (looking for the intersection when you are on top of it or already past it).

<u>Interchanges</u>. For interstate highways, the navigator does not show which roadways crossing the interstate have interchanges and which do not (at higher zoom-levels). This occasionally causes an error when the driver plans a route with the assumption that an interchange is present, when in fact it is not. One solution would be to break the crossing roadway lines that do not have interchanges or to place

an asterisk where crossing roadways do have interchanges on higher zoom-levels.

Scale and distance to destination numbers. When the distance to the destination is an even integer, the decimal indication disappears. This can cause confusion between the displayed zoom-level and the destination distance numbers (e.g., 5 miles to the destination on the 10-mile scale). The solution to this problem is to have the decimal point and zero remain for the destination-distance number when the destination is an even integer value.

Summary

The navigation system evaluated as part of this research is a relatively effective device, useful for its intended purpose. A number of design improvements are required, however, to optimize the efficiency of the device. These improvements center on two specific problems: the reduction of task-completion time and total display-glance time, and the reduction of single-display-glance time. The improvement of the task-completion time and the total-display-glance time appears possible with practically implementable changes. The single-display-glance time, however, may be difficult to improve unless substantial changes to the graphic presentation of information can be accomplished, or a different type of information presentation (visual verbal or auditory) can be incorporated.

Implementation of the improvements outlined in this section and additional testing to determine the impact of the design changes on required driver attentional demand is recommended. Research into the presentation of required navigation information should also be undertaken once the practical state of the art has been determined with regard to improved navigation system design. In addition, research using highly experienced navigation system users is recommended so that the relationship between experience and attentional demand can be established for the moving-map-navigation task.

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APPENDICES

APPENDIX A

Subject's Introduction and Informed Consent Form

Instructions Given to Subject Prior to Obtaining Informed Consent

Introduction to the Navigation Study

The purpose of the study is to evaluate driver performance using various methods of navigation. This study is being conducted by the Human Factors Laboratory, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, telephone number: (703) 961-7962. The research team consists of Jon Antin, Tom Dingus, and Melissa Hulse, who are graduate students in Industrial Engineering and Operations Research under the direction of Dr. Walter W. Wierwille, principal investigator and Professor of Industrial Engineering and Operations Research.

In the study you will at times be asked to navigate unfamiliar routes in the local area; at other times you will be asked to perform various tasks commonly done while driving. Two trained experimenters will ride in the car with you through the experiment to participate in the data gathering process and to help ensure the safe operation of the experimental vehicle. <u>It is your responsibility as the driver to obey all traffic regulations and to maintain safe operation of the vehicle at all times</u>. You will, at all times, be required to have the lap and shoulder restraints securely fastened.

The experimental vehicle, a late model American car will be outfitted with instrumentation designed to gather relevant data.

This instrumentation will not appreciably affect the driving task, and your primary goal at all times must be to ensure the safety of yourself, your passengers (the experimental team), and the experimental vehicle.

The vehicle will be outfitted with devices designed to monitor various relevant aspects of driver behavior. These measurement devices do not require that your attention be diverted from the driving task. All equipment will be placed in the vehicle and secured such that it will not present a hazard. Also, a fire extinguisher, a first-aid kit, and a CB radio will be carried in the vehicle at all times, in case an emergency occurs.

The study basically consists of two sessions:

Session I

This will be a practice session in which you will learn how to use the ETAK Navigator, an in-car moving-map navigation display. You will also be familiarized with the vehicle's regular dash instrumentation. While the vehicle is parked, you will be shown how the navigator works and you will practice with it. Similarly, you will practice with the dash instrumentation. Thereafter, you will drive with the navigator and continue to learn how to use it and the other dash instrumentation. The driving will continue until you are thoroughly familiar with the use of the navigation system and the dash instrumentation.

Session II:

This session will involve the performance of instructed tasks and the gathering of information from in-dash instruments while driving. If you feel at any time that the demands of the driving task are too great, all experimental tasks should be delayed until the driving task is firmly under control.

Upon completion of the sessions, you will be paid at the rate of $5.00/hr. If during the study you feel that you cannot continue for any reason, you have the right to terminate your participation; you will be paid for your participation up to that time. This includes the right to withdraw after having read and signed the attached informed consent form.

If you have any questions about the experiment or your rights as a participant after reading the attached informed consent form, please do not hesitate to ask. We will answer your questions as openly and honestly as possible; however, answers to some of your questions may be delayed until you have completed the experimental sessions in order to avoid biasing the outcome of the study. We ask that you please not discuss the details of this experiment with anyone, especially potential subjects, since prior knowledge of seemingly incidental facts could seriously affect the outcome of the study. It is expected that all data will have been gathered by June 15, 1986; you may feel free to discuss the study with anyone after that date.

It is possible that at times the tasks may seem difficult, and you may feel stressed and frustrated. Your performance and feelings reflect the difficulty of the task, not your personal abilities and talents. Further, your data will be treated with anonymity; that is, shortly after completion of your experimental sessions, your data will no longer be associated with your name.

There are some risks inherent in this study. They are outlined in the following informed consent form.

PARTICIPANT'S INFORMED CONSENT

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the document "Introduction to the Navigation Study," which you have already read.

2. There are some risks and discomforts to which you expose yourself in volunteering for this research.

   The risks are:

   a. The risk of an accident normally associated with driving an automobile in light or moderate traffic,

   b. The slight additional risk of an accident that might possibly occur while reading the ETAK display,

   c. The slight additional risk of an accident that might possibly occur as a result of listening to instructions from one of the experimenters.

   The magnitude of the risks is believed to be minimal for the following reasons:

   People normally drive in moderate traffic with low risk of an accident.

   Approximately 200 people on the west coast of the United States use the ETAK Navigation system to find their way while driving, with what appears to be low risk of an accident.

   Passengers normally talk to a driver without substantially increasing the risk of an accident.

   The following precautions will be taken during your driving:

   a. The experimenters will monitor your driving, and will ask you to stop if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.

b. You will be required to wear the lap and shoulder belt restraint system anytime the car is on the road.

c. The vehicle will be equipped with a fire extinguisher, first-aid kit, and a CB radio.

d. If an accident does occur, the experimenters will arrange medical transportation to a nearby hospital emergency room. You will be required to undergo examination by medical personnel in the emergency room.

A likely discomfort in this experiment is:

a. the length of the experiment, which could be as much as six hours. (There will be rest breaks, however.)

3. The data gathered in this experiment will be treated with anonymity. Shortly after you have participated, your name will be separated from your data.

4. While there are no direct benefits to you from this research (other than payment), you may find the tasks interesting, particularly while using the ETAK system.

   Your participation, along with that of other volunteers, should make it possible to improve in-car navigation displays before they become widely available to the public.

5. You should not volunteer for participation in this research if you are under 18 years old, or if you do not have a valid driver's license, or if you are not in good health, or if you have taken any drug or medication. It is your responsibility to inform the experimenters of any additional condition which you feel might interfere with your ability to drive. Such conditions would include inadequate sleep, hunger, hangover, headache, cold symptoms, depression, allergies, premenstrual syndrome, emotional upset, or other similar conditions.

6. You should know that the principal investigator of the research project and his associates will answer any questions that you may have about this project, and you should not sign this consent form until you are satisfied that you understand all of the previous descriptions and conditions.

   You should further be aware that you may contact Mr. Charles D. Waring, Chairman of the University's Institution Review Board, if you have questions or concerns about this experiment. His phone number is (703) 961-5284.

7. You should know that at any time you are free to withdraw from participation in this research program without penalty.

   You will be paid at a rate of $5.00 per hour for the time you actually spend. Payment will be made shortly after you have finished your participation.

8. Signature of the volunteer and date:

   I have read and understand the scope of this research project and I have no other questions. I hereby give my consent to participate, but I understand that I may stop participation if I choose to do so.

   Signature ______________________

   Date ______________________

9. Signature of a member of the research team and date:

   Signature ______________________

   Date ______________________

10. Signature of witness, not a member of research team and date:

    Signature ______________________

    Date ______________________

APPENDIX B

ANOVA Summary Tables for the

Independent Variables Gender, Age,

Driving Experience, and Road Type

TABLE 40

Initial ANOVA Summary Table for the Dependent Variable TIMEST

	df	SS	F	p
Between Subjects				
Sex (S)	1	86.22	1.49	0.2405
Age (A)	3	950.88	5.46	0.0089
Exp (E)	1	66.93	1.15	0.2888
S x A	3	162.77	0.93	0.4467
S x E	3	1.25	0.02	0.8851
A x E	1	13.28	0.08	0.9719
S x A x E	3	39.76	0.23	0.8752
Subjects (SB/SAE)	16	928.47		
Within Subjects				
Roadway (R)	2	139.65	4.27	0.0227
R x S	2	40.49	1.24	0.3033
R x E	6	40.95	1.25	0.2993
R x A	2	61.62	0.63	0.7063
R x S x A	6	53.01	0.54	0.7734
R x S x E	2	6.69	0.20	0.8160
R x A x E	6	131.66	1.34	0.2676
R x S x A x E	6	36.39	0.37	0.8919
R x SB/SAE	32	523.04		

TABLE 41

Initial ANOVA Summary Table for the Dependent Variable STEXT

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.00012	1.91	0.1860
Age (A)	3	0.00008	0.41	0.7490
Exp (E)	1	0.00000	0.00	0.9747
S x A	3	0.00013	0.70	0.5668
S x E	1	0.00002	0.39	0.5430
A x E	3	0.00008	0.44	0.7285
S x A x E	3	0.00015	0.81	0.5085
Subjects (SB/SAE)	16	0.00102		
Within Subjects				
Roadway (R)	2	0.00051	4.88	0.0141
R x S	2	0.00005	0.55	0.5810
R x E	6	0.00032	1.02	0.4304
R x A	2	0.00011	1.04	0.3639
R x S x A	6	0.00022	0.71	0.6440
R x S x E	2	0.00019	1.80	0.1823
R x A x E	6	0.00025	0.80	0.5750
R x S x A x E	6	0.00069	2.20	0.0684
R x SB/SAE	32	0.00167		

TABLE 42

Initial ANOVA Summary Table for the Dependent Variable TIMEGLANCE

	df	SS	F	p
Between Subjects				
Sex (S)	1	72.33	1.18	0.2933
Age (A)	3	910.15	4.95	0.0128
Exp (E)	1	114.54	1.87	0.1904
S x A	3	252.77	1.38	0.2862
S x E	3	10.50	0.17	0.6844
A x E	1	20.87	0.11	0.9509
S x A x E	3	31.26	0.17	0.9150
Subjects (SB/SAE)	16	980.22		
Within Subjects				
Roadway (R)	2	301.68	6.51	0.0043
R x S	2	31.61	0.68	0.5129
R x E	6	27.50	0.59	0.5585
R x A	2	71.91	0.52	0.7916
R x S x A	6	70.23	0.50	0.7999
R x S x E	2	18.21	0.39	0.6784
R x A x E	6	154.73	1.11	0.3770
R x S x A x E	6	62.13	0.45	0.8418
R x SB/SAE	32	741.79		

TABLE 43

Initial ANOVA Summary Table for the Dependent Variable DGLANCE

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.18	0.01	0.9204
Age (A)	3	76.31	1.48	0.2589
Exp (E)	1	20.21	1.17	0.2950
S x A	3	117.20	2.27	0.1201
S x E	3	52.50	3.04	0.1002
A x E	1	7.75	0.15	0.9283
S x A x E	3	52.90	1.02	0.4088
Subjects (SB/SAE)	16	275.90		
Within Subjects				
Roadway (R)	2	57.03	6.43	0.0045
R x S	2	11.12	1.25	0.2993
R x E	6	2.56	0.29	0.7513
R x A	2	17.63	0.66	0.6806
R x S x A	6	26.37	0.99	0.4484
R x S x E	2	4.16	0.47	0.6302
R x A x E	6	28.98	1.09	0.3904
R x S x A x E	6	18.10	0.68	0.6671
R x SB/SAE	32	142.02		

TABLE 44

Initial ANOVA Summary Table for the Dependent Variable RGLANCE

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.44	0.02	0.8789
Age (A)	3	70.63	1.28	0.3136
Exp (E)	1	4.70	0.26	0.6197
S x A	3	80.27	1.46	0.2629
S x E	3	33.78	1.84	0.1934
A x E	1	12.80	0.23	0.8723
S x A x E	3	39.44	0.72	0.5560
Subjects (SB/SAE)	16	293.28		
Within Subjects				
Roadway (R)	2	43.25	6.65	0.0038
R x S	2	11.67	1.79	0.1825
R x E	6	1.60	0.25	0.7836
R x A	2	21.84	1.12	0.3730
R x S x A	6	22.54	1.16	0.3538
R x S x E	2	2.29	0.35	0.7054
R x A x E	6	24.33	1.25	0.3089
R x S x A x E	6	13.10	0.67	0.6730
R x SB/SAE	32	104.01		

TABLE 45

Initial ANOVA Summary Table for the Dependent Variable DISAVE

	df	SS	F	p
Between Subjects				
Sex (S)	1	4.31	1.51	0.2369
Age (A)	3	42.56	4.97	0.0127
Exp (E)	1	0.07	0.03	0.8743
S x A	3	7.94	0.93	0.4504
S x E	3	8.30	2.91	0.1076
A x E	1	11.04	1.29	0.3125
S x A x E	3	24.49	2.86	0.0699
Subjects (SB/SAE)	16	45.71		
Within Subjects				
Roadway (R)	2	25.22	39.57	0.0001
R x S	2	1.17	1.84	0.1747
R x E	6	0.12	0.19	0.8289
R x A	2	2.98	1.56	0.1910
R x S x A	6	2.43	1.27	0.2988
R x S x E	2	1.13	1.77	0.1872
R x A x E	6	1.69	0.88	0.5173
R x S x A x E	6	1.32	0.69	0.6569
R x SB/SAE	32	10.19		

TABLE 46

Initial ANOVA Summary Table for the Dependent Variable RDAVE

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.10	0.15	0.7017
Age (A)	3	4.67	2.36	0.1095
Exp (E)	1	0.04	0.06	0.8056
S x A	3	0.20	0.10	0.9596
S x E	3	0.05	0.08	0.7802
A x E	1	1.06	0.53	0.6654
S x A x E	3	4.30	2.18	0.1308
Subjects (SB/SAE)	16	10.54		
Within Subjects				
Roadway (R)	2	0.53	0.76	0.4576
R x S	2	0.75	1.08	0.3502
R x E	6	0.85	1.23	0.3065
R x A	2	1.51	0.73	0.6315
R x S x A	6	2.71	1.30	0.2856
R x S x E	2	0.75	1.07	0.3535
R x A x E	6	4.12	1.98	0.0984
R x S x A x E	6	3.51	1.69	0.1565
R x SB/SAE	32	11.11		

TABLE 47

Initial ANOVA Summary Table for the Dependent Variable RDTOT

	df	SS	F	p
Between Subjects				
Sex (S)	1	4.67	0.43	0.5196
Age (A)	3	28.23	0.87	0.4749
Exp (E)	1	16.26	1.51	0.2368
S x A	3	14.48	0.45	0.7218
S x E	1	1.34	0.12	0.7289
A x E	3	22.91	0.71	0.5604
S x A x E	3	15.03	0.47	0.7104
Subjects (SB/SAE)	16	172.21		
Within Subjects				
Roadway (R)	2	10.66	2.81	0.0750
R x S	2	1.39	0.37	0.6956
R x E	6	9.32	0.82	0.5631
R x A	2	9.13	2.41	0.1062
R x S x A	6	35.04	3.08	0.0171
R x S x E	2	4.92	1.30	0.2873
R x A x E	6	32.37	2.85	0.0246
R x S x A x E	6	11.34	1.00	0.4441
R x SB/SAE	32	60.67		

TABLE 48

Initial ANOVA Summary Table for the Dependent Variable DISTOT

	df	SS	F	p
Between Subjects				
Sex (S)	1	41.46	1.39	0.2564
Age (A)	3	870.50	9.69	0.0007
Exp (E)	1	18.81	0.63	0.4395
S x A	3	121.23	1.35	0.2935
S x E	1	3.38	0.11	0.7413
A x E	3	57.12	0.64	0.6025
S x A x E	3	19.96	0.22	0.8795
Subjects (SB/SAE)	16	478.88		
Within Subjects				
Roadway (R)	2	131.84	8.38	0.0012
R x S	2	23.64	1.50	0.2378
R x E	6	20.59	0.44	0.8490
R x A	2	9.03	0.57	0.5690
R x S x A	6	28.98	0.61	0.7173
R x S x E	2	2.13	0.14	0.8740
R x A x E	6	43.36	0.92	0.4943
R x S x A x E	6	39.26	0.83	0.5541
R x SB/SAE	32	251.67		

TABLE 49

Initial ANOVA Summary Table for the Dependent Variable DISPER

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.19	0.54	0.4745
Age (A)	3	2.53	2.45	0.1008
Exp (E)	1	0.12	0.35	0.5597
S x A	3	0.42	0.41	0.7482
S x E	1	0.00	0.01	0.9370
A x E	3	0.98	0.95	0.4408
S x A x E	3	0.87	0.84	0.4915
Subjects (SB/SAE)	16	5.51		
Within Subjects				
Roadway (R)	2	1.03	4.29	0.0224
R x S	2	0.10	0.40	0.6749
R x E	6	0.98	1.36	0.2592
R x A	2	0.08	0.33	0.7239
R x S x A	6	0.77	1.07	0.4036
R x S x E	2	0.00	0.00	0.9984
R x A x E	6	0.48	0.67	0.6753
R x S x A x E	6	0.44	0.62	0.7165
R x SB/SAE	32	3.85		

TABLE 50

Initial ANOVA Summary Table for the Dependent Variable RDPER

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.00	0.06	0.8141
Age (A)	3	0.54	2.32	0.1139
Exp (E)	1	0.01	0.08	0.7781
S x A	3	0.76	3.26	0.0493
S x E	1	0.34	4.41	0.0519
A x E	3	0.74	3.19	0.0521
S x A x E	3	1.74	7.50	0.0024
Subjects (SB/SAE)	16	1.24		
Within Subjects				
Roadway (R)	2	0.82	7.75	0.0018
R x S	2	0.11	1.09	0.3500
R x E	6	0.54	1.72	0.1474
R x A	2	0.14	1.33	0.2795
R x S x A	6	0.73	2.30	0.0588
R x S x E	2	0.26	2.51	0.0974
R x A x E	6	0.33	1.04	0.4171
R x S x A x E	6	0.82	2.60	0.0361
R x SB/SAE	32	1.68		

TABLE 51

Initial ANOVA Summary Table for the Dependent Variable STVELVAR

	df	SS	F	p
Between Subjects				
Sex (S)	1	2319121.77	0.17	0.6869
Age (A)	3	77830284.03	1.88	0.1729
Exp (E)	1	11314953.76	0.82	0.3781
S x A	3	11001362.20	0.27	0.8486
S x E	1	1012979.19	0.07	0.7897
A x E	3	25110486.46	0.61	0.6194
S x A x E	3	21245181.52	0.51	0.6782
Subjects (SB/SAE)	16	220279694.19		
Within Subjects				
Roadway (R)	2	500467367.44	49.24	0.0001
R x S	2	4016560.26	0.40	0.6768
R x E	6	27260344.23	0.89	0.5111
R x A	2	7044814.18	0.69	0.5074
R x S x A	6	29582224.95	0.97	0.4610
R x S x E	2	1126748.13	0.11	0.8954
R x A x E	6	29324503.14	0.96	0.4664
R x S x A x E	6	60800574.43	1.99	0.0958
R x SB/SAE	32	162631133.09		

TABLE 52

Initial ANOVA Summary Table for the Dependent Variable STVRMS

	df	SS	F	p
Between Subjects				
Sex (S)	1	1382.51	0.22	0.6442
Age (A)	3	28110.02	1.50	0.2521
Exp (E)	1	329.69	0.05	0.8211
S x A	3	12837.24	0.69	0.5736
S x E	1	17868.80	2.86	0.1099
A x E	3	6888.28	0.37	0.7770
S x A x E	3	19399.07	1.04	0.4030
Subjects (SB/SAE)	16	99811.27		
Within Subjects				
Roadway (R)	2	589439.89	345.00	0.0001
R x S	2	2669.03	1.56	0.2252
R x E	6	8781.54	1.71	0.1499
R x A	2	4052.39	2.37	0.1095
R x S x A	6	18845.71	3.68	0.0069
R x S x E	2	597.05	0.35	0.7077
R x A x E	6	6090.76	1.19	0.3374
R x S x A x E	6	19744.84	3.85	0.0053
R x SB/SAE	32	27335.97		

TABLE 53

Initial ANOVA Summary Table for the Dependent Variable ACCRMS

	df	SS	F	p
Between Subjects				
Sex (S)	1	2.52	0.01	0.9281
Age (A)	3	509.09	0.57	0.6454
Exp (E)	1	776.59	2.59	0.1271
S x A	3	625.90	0.70	0.5681
S x E	1	638.23	2.13	0.1640
A x E	3	771.47	0.86	0.4831
S x A x E	3	558.29	0.62	0.6118
Subjects (SB/SAE)	16	4798.06		
Within Subjects				
Roadway (R)	2	382.60	3.16	0.0559
R x S	2	51.12	0.42	0.6591
R x E	6	684.92	1.89	0.1138
R x A	2	44.80	0.37	0.6936
R x S x A	6	72.52	0.20	0.9744
R x S x E	2	228.99	1.89	0.1673
R x A x E	6	157.70	0.43	0.8505
R x S x A x E	6	594.68	1.64	0.1691
R x SB/SAE	32	1936.87		

TABLE 54

Initial ANOVA Summary Table for the Dependent Variable ACCVAR

	df	SS	F	p
Between Subjects				
Sex (S)	1	303.49	0.02	0.8891
Age (A)	3	105719.35	2.33	0.1130
Exp (E)	1	6530.04	0.43	0.5205
S x A	3	52014.61	1.15	0.3606
S x E	1	7448.31	0.49	0.4929
A x E	3	61448.05	1.35	0.2923
S x A x E	3	20843.60	0.46	0.7145
Subjects (SB/SAE)	16	241986.56		
Within Subjects				
Roadway (R)	2	126605.21	8.93	0.0008
R x S	2	161.65	0.01	0.9887
R x E	6	57090.08	1.34	0.2679
R x A	2	4916.18	0.35	0.7097
R x S x A	6	28999.97	0.68	0.6656
R x S x E	2	1746.23	0.12	0.8846
R x A x E	6	36404.96	0.86	0.5376
R x S x A x E	6	21940.86	0.52	0.7920
R x SB/SAE	32	226946.89		

TABLE 55

Initial ANOVA Summary Table for the Dependent Variable ACCPOS

	df	SS	F	p
Between Subjects				
Sex (S)	1	129361.32	0.02	0.8849
Age (A)	3	14794911.72	0.82	0.4992
Exp (E)	1	4431230.44	0.74	0.4020
S x A	3	21131775.94	1.18	0.3492
S x E	1	21785273.88	3.64	0.0744
A x E	3	10189425.17	0.57	0.6440
S x A x E	3	18082884.15	1.01	0.4148
Subjects (SB/SAE)	16	95664773.68		
Within Subjects				
Roadway (R)	2	9783843.73	5.33	0.0101
R x S	2	248782.89	0.14	0.8738
R x E	6	7153250.52	1.30	0.2861
R x A	2	733880.05	0.40	0.6738
R x S x A	6	1856646.96	0.34	0.9122
R x S x E	2	963184.87	0.52	0.5968
R x A x E	6	1338319.73	0.24	0.9587
R x S x A x E	6	12861794.34	2.33	0.0554
R x SB/SAE	32	29379316.41		

TABLE 56

Initial ANOVA Summary Table for the Dependent Variable STPZAV

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.06	0.23	0.6416
Age (A)	3	1.32	1.63	0.2224
Exp (E)	1	0.00	0.00	0.9830
S x A	3	1.39	1.72	0.2040
S x E	1	0.81	3.01	0.1022
A x E	3	0.50	0.62	0.6140
S x A x E	3	1.05	1.29	0.3130
Subjects (SB/SAE)	16	4.33		
Within Subjects				
Roadway (R)	2	22.87	316.40	0.0001
R x S	2	0.12	1.66	0.2053
R x E	6	0.17	0.80	0.5799
R x A	2	0.22	2.99	0.0646
R x S x A	6	0.42	1.91	0.1088
R x S x E	2	0.02	0.33	0.7188
R x A x E	6	0.10	0.46	0.8302
R x S x A x E	6	0.41	1.89	0.1134
R x SB/SAE	32	1.16		

TABLE 57

Initial ANOVA Summary Table for the Dependent Variable BRNUM

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.47	0.95	0.3439
Age (A)	3	1.86	1.27	0.3190
Exp (E)	1	0.27	0.55	0.4709
S x A	3	3.43	2.34	0.1125
S x E	1	0.07	0.14	0.7087
A x E	3	0.69	0.47	0.7096
S x A x E	3	1.58	1.07	0.3890
Subjects (SB/SAE)	16	7.84		
Within Subjects				
Roadway (R)	2	100.48	175.68	0.0001
R x S	2	0.18	0.31	0.7352
R x E	6	2.02	1.18	0.3415
R x A	2	1.12	1.96	0.1577
R x S x A	6	1.79	1.04	0.4163
R x S x E	2	1.15	2.01	0.1508
R x A x E	6	0.89	0.52	0.7882
R x S x A x E	6	2.36	1.38	0.2542
R x SB/SAE	32	9.15		

TABLE 58

Initial ANOVA Summary Table for the Dependent Variable BRTIME

	df	SS	F	p
Between Subjects				
Sex (S)	1	4.99	0.93	0.35
Age (A)	3	95.52	5.93	0.0064
Exp (E)	1	12.93	2.41	0.1403
S x A	3	17.49	1.09	0.3836
S x E	1	2.36	0.44	0.5168
A x E	3	21.17	1.31	0.3045
S x A x E	3	4.84	0.30	0.8246
Subjects (SB/SAE)	16	85.95		
Within Subjects				
Roadway (R)	2	603.34	88.94	0.0001
R x S	2	4.10	0.60	0.5522
R x E	6	46.97	2.31	0.0578
R x A	2	13.75	2.03	0.1484
R x S x A	6	18.74	0.92	0.4930
R x S x E	2	1.74	0.26	0.7755
R x A x E	6	20.91	1.03	0.4257
R x S x A x E	6	4.05	0.20	0.9747
R x SB/SAE	32	108.54		

TABLE 59

Initial ANOVA Summary Table for the Dependent Variable LANEX

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.23	0.59	0.4552
Age (A)	3	2.43	2.11	0.1397
Exp (E)	1	0.07	0.18	0.6742
S x A	3	0.28	0.24	0.8662
S x E	1	0.19	0.49	0.4949
A x E	3	0.50	0.43	0.7323
S x A x E	3	0.41	0.36	0.7842
Subjects (SB/SAE)	16	6.14		
Within Subjects				
Roadway (R)	2	0.69	3.72	0.0354
R x S	2	0.22	1.20	0.3147
R x E	6	0.96	1.71	0.1501
R x A	2	0.14	0.74	0.4857
R x S x A	6	0.47	0.83	0.5524
R x S x E	2	0.15	0.80	0.9250
R x A x E	6	0.54	0.97	0.4624
R x S x A x E	6	0.32	0.57	0.7490
R x SB/SAE	32	2.99		

TABLE 60

Initial ANOVA Summary Table for the Dependent Variable STPZVAR

	df	SS	F	p
Between Subjects				
Sex (S)	1	0.0000	0.00	0.9788
Age (A)	3	0.0215	1.39	0.2813
Exp (E)	1	0.0032	0.63	0.4401
S x A	3	0.0206	1.34	0.2971
S x E	1	0.0202	3.92	0.0652
A x E	3	0.0011	0.07	0.9748
S x A x E	3	0.0186	1.20	0.3407
Subjects (SB/SAE)	16	0.0814		
Within Subjects				
Roadway (R)	2	0.0963	34.63	0.0001
R x S	2	0.0014	0.50	0.6095
R x E	6	0.0094	1.13	0.3687
R x A	2	0.0018	0.65	0.5302
R x S x A	6	0.0081	0.97	0.4592
R x S x E	2	0.0075	2.69	0.0835
R x A x E	6	0.0044	0.52	0.7857
R x S x A x E	6	0.0059	0.71	0.6463
R x SB/SAE	32	0.05		

APPENDIX C

Diagram of Task Presentation Order

A -- No Task Data Run	
B -- Low Attentional Demand Task	Task "Group"
C -- Navigator Task	Six Groups
D -- Medium Attentional Demand Task	TOTAL
E -- High Attentional Demand Task	

"Within" Group Presentation Order

Latin Square

A	B	C	D	E	A	B	
B	C	D	E	A	B	C	
C	D	E	A	B	C	D	. . .
D	E	A	B	C	D	E	
E	A	B	C	D	E	A	
S_1	S_2	S_3	S_4	S_5	S_6	S_7	. . .

"Between" Group Presentation Order

Latin Square

Group 1-6

1	2	3	4	5	6	S_1 - S_5	Two Remaining Subjects
2	3	4	5	6	1	S_6 - S_{10}	(S_{31}, S_{32}) randomly
3	4	5	6	1	2	S_{11}-S_{15}	assigned to two additional
4	5	6	1	2	3	S_{16} - S_{20}	presentation orders
5	6	1	2	3	4	S_{21} - S_{25}	
6	1	2	3	4	5	S_{26} - S_{30}	

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