

AUDITORY-BASED SUPPLEMENTAL INFORMATION PROCESSING
DEMAND EFFECTS ON DRIVING PERFORMANCE

by

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ABSTRACT

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By Wayne J. Biever

Thirty-six drivers of both genders from three different age groups performed auditory cognitive tasks while driving an instrumented vehicle. The tasks were of two types. The first type of task was the selection of a driving route from a list presented as a recorded sound. These tasks represented the use of In-Vehicle Information Systems (IVIS). The second type of task consisted of a conversation like series of questions designed to replicate the use of a cellular telephone while driving. The IVIS tasks consisted of two levels of information density (short-term memory load) and four element types (complexity levels) including listening, interpretation, planning, and computation. The effects of age, information density, and element type on driving performance were assessed using a composite set of performance measures. Primary measures of driving performance included lateral tracking, longitudinal control and eye glances. Secondary task performance was assessed by task completion time, skipped tasks and task errors. Additionally, subjective assessment was done using a situational awareness probe question and a modified NASA-TLX question set.

Results showed that drivers demonstrated a general decrease in their ability to maintain their lateral position with increased task complexity. Additionally, speed and following distance were less stable during tasks. During tasks, drivers glanced less at their mirrors and instruments and left their lane more often than during baseline driving periods. Even during difficult tasks, drivers had high self-confidence in their awareness of surroundings.

One result of particular interest was an increase in lane deviations and headway variance coupled with increased forward eye glance durations. It is believed that this is evidence of a condition called "Cognitive Capture" in which a driver, though looking more extensively at the forward roadway, is having difficulty tracking the lead vehicle and lane position. High cognitive load is causing the driver to disregard or shed visual information to allow processing of auditory task-related information.

Another result of concern is the inability of drivers to assess their own impairment while performing in vehicle tasks. During tasks drivers demonstrated reduced scanning of mirrors and vehicle instrumentation. This clearly demonstrates reduced situational awareness. Additionally, during tasks lane tracking and headway maintenance performance decreased as well. However, during all tasks drivers assessed their workload higher than baseline driving even though they rated it near the bottom of the scale. Also, drivers perceived no decrease in their situational awareness.

The results of this study show that driving performance can be negatively impacted by even fairly simple cognitive tasks while a driver is looking at the road with their hands on the wheel. Even while viewing the road, a driver may perform an auditory task and be cognitively overloaded to the point of safety concerns. An additional concern is that drivers underestimate the degree of their cognitive load and its impact on their driving performance.

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INTRODUCTION

The ongoing technological revolution in sensors, computers, data presentation, and communications technologies promises significant improvements in driver performance and vehicle safety. However, the negative driving performance implications of increased cognitive load due to increased information processing while driving from in-vehicle information systems (IVIS) are largely unknown. The information processing aspects of IVIS technologies, even just for the data directly related to the primary task of driving, pose an enormous human engineering and design challenge.

Cellular telephones and other information technologies are introducing additional complex non-driving secondary tasks that compete for the driver's attention. Some of these tasks are well known like the operation of switches and other manual controls. Other tasks involve high cognitive load associated with information processing and decision-making. The safety and driver performance implications of these cognitively demanding and sometimes emotionally charged personal and job-related secondary activities are potentially more detrimental and are even less well understood.

This investigation focuses on evaluating the impact of secondary task information processing loads on drivers' ability to safely perform primary driving tasks. The research was funded by the Federal Highway Administration as part of a larger study contracted to the Virginia Tech Transportation Institute at the Virginia Polytechnic Institute and State University to gather data for the generation of a human behavioral model for in-vehicle information systems (IVIS). The goal is to determine the best format in which to present information to drivers while they are driving. This information will form the basis for designs or regulatory actions that take advantage of evolving in-vehicle information systems to enhance driver safety and improve performance, as they become available. This work includes studies to minimize the detrimental effects of IVIS for secondary tasks.

LITERATURE REVIEW

Driving is a visually and cognitively demanding task that inherently includes serious and sometimes critical financial and health consequences for poor performance. “In 1996 in the U.S., there were an estimated 6,842,000 police-reported traffic crashes, in which 41,907 people were killed and 3,511,000 people were injured.” Furthermore, the cost of traffic accidents (death, injuries, and lost time) in the U.S. in 1994 was more than \$150.5 billion (NHTSA, 1996). Driving is the single largest killer of people from ages 6-27 years (NHTSA, 1996).

The Federal Highway Administration, recognizing the potential long-term safety, efficiency, and cost benefits, has identified Intelligent Transportation Systems (ITS) as a major focus of research efforts. The current focus of that research effort is divided into two areas, Commercial Vehicle Operations (CVO) and passenger vehicle research. In-vehicle information systems (IVIS) form the basis of the largest and most important area of study in passenger vehicle research.

IVIS RESEARCH

IVIS systems are technologies that present information to vehicle operators while they are driving. In the broadest sense, that includes primary task information, meaning information integral to driving performance, and secondary task information, meaning information not related to the driving task. Primary task information includes things like vehicle operating status indicators such as speed, temperature, fuel level, brake failure warning, road conditions, and vehicle proximity indicators and warnings. Secondary task information includes information from radios, tape decks, CB radios, passengers, cellular telephones, and in the near future fax, e-mail, and the Internet. Some travel-related information and tasks such as route selection or weather information may normally be a secondary task that could be completed safely during stops or at any time when it does not conflict with safe driving. However, IVIS information for route selection or weather in the case of re-routing around an accident or warnings about road conditions (e.g. black ice on bridges) may become critical primary task information.

IVIS devices have been classified and described in a previous paper. Perez and Mast (1992) described four IVIS subsystems. The subsystems are (1) In-vehicle Routing and Navigation Systems (IRANS), (2) In-vehicle Motorist Services Information Systems (IM SIS), (3) In-vehicle Signing Information Systems (ISIS), and (4) In-vehicle Safety Advisory and Warning Systems (IVSAWS). This characterization includes devices that provide both primary and secondary task information.

In-vehicle routing and navigation systems (IRANS): IRANS are those IVIS subsystems that provide drivers with information about how to get from one place to another, as well as information on traffic operations and recurrent and non-recurrent traffic congestion. These systems may be either passive or active; that is, merely transmitting information, or capable of calculating, selecting, and displaying optimum routes based on reception of real-time information from traffic control centers (Perez & Mast, 1992). IRANS devices may provide either primary or secondary task information depending on the timing and nature of the information being presented.

In-vehicle motorist services information systems (IM SIS): IM SIS are those IVIS subsystems that provide motorists with commercial logos and signing for motels, eating facilities, and service stations, and other similar signing directing motorists to recreational areas,

historical sites, etc. (Perez and Mast, 1992). IMSIS devices normally provide secondary task information.

In-vehicle signing information systems (ISIS): ISIS are those IVIS subsystems that provide non-commercial routing, warning, regulatory and advisory information, which are currently depicted on external roadway signs (Perez & Mast, 1992). ISIS devices may provide either primary or secondary task information depending on the timing and nature of the information being presented.

In-vehicle safety advisory and warning systems (IVSAWS): IVSAWS are those IVIS subsystems that provide warnings of unsafe conditions and situations affecting the roadway ahead of the driver. They provide sufficient advanced warning to permit the driver to take remedial action (e.g. to slow down) (Perez & Mast, 1992). IVSAWS devices normally provide primary task information.

The frantic pace of information and communication technology development is providing a continuous stream of increasingly sophisticated equipment, processes, and methods that are potentially useful for IVIS. Automotive manufacturers and supply companies are rapidly incorporating these advances into prototype and production passenger vehicle systems. Many of the leading edge technologies in this revolution have already been implemented and have shown clear safety improvements (Collins, Biever, Dingus, and Neale, 1997; Hanowski, Gallagher, Kieliszewski, Dingus, Biever, and Neale, 1997). Examples of this include advanced vehicle monitoring systems, high contrast displays, lighting and mirrors that adjust to ambient conditions, and vehicle safety interlocks and indicators to prevent operation in hazardous conditions.

Even more advanced technologies now being added to vehicles have the potential to provide useful navigation, warning, communications, and other information that may reduce the risks associated with driving. However, IVIS devices, by their nature, generate cognitive, visual, auditory, manual, and speech demands. These demands, in many cases, are in direct competition with the demands of driving and can reduce driving performance. For example, moving map displays require drivers to process complex visual information that may require significant periods of time when the driver is not looking at the road (Dingus, Antin, Hulse, and Wierwille, 1988). The effects from the addition of these information-processing loads to the driving environment are not yet well known. There is a strong possibility that if not properly implemented, these systems may create sources of distraction from the driving task that could have detrimental effects on driving safety (Hulse, Dingus, and Barfield, 1998). Research on the safety implications of IVIS devices lags a transportation industry-wide development and implementation effort that is being driven by competition to include IVIS devices that are expected to enhance vehicle marketability. This effort may be driven by the perceived desirability of these devices and not their actual benefits.

The Perez and Mast (1992) characterization does not include those information systems that primarily provide secondary task information not related to the driving task (e.g. radios, tape decks, CB radios, and cellular telephones). Cellular telephones are of particular concern because they have a frightening potential to decrease safety and driver performance as they provide information that competes for the driver's attention. Additionally, they are rapidly becoming commonplace in passenger vehicles. Therefore, cellular telephones are treated here as a separate sub-category of IVIS.

Cellular telephones are the first in a developing series of secondary task information systems that include a level of complexity that is not implicit in the Perez and Mast (1992) characterization of passive or active information systems. The cellular telephone, e-mail, fax, and the Internet known as "the mobile office" are truly interactive systems. These devices

provide communication, which enable drivers to carry out personal and job-related secondary tasks that contain emotional, time-critical, and imperative content. It is possible that such information and urgency may at least partially divert attention from driving. Even when they do not totally divert attention, these tasks are likely to consume some cognitive resources normally reserved for driving. Although the cellular telephone has not been included in the description of IVIS given in previous research, there have been numerous studies directed at these devices.

Epidemiological studies generally search databases of accidents and attempt to statistically correlate the occurrences of cellular telephone use directly with accidents. These studies, although done after the fact using existing databases, have been useful in providing a historical basis for the evaluation of cellular telephone impacts on driving safety. Additionally, these studies describe the magnitude and characteristics of the problems. However, there is little control of data quality from accident reports and consequently there are significant limitations to the types of information that are provided.

All of the epidemiological studies done on cellular telephones have come to a similar conclusion: cellular telephone tasks concurrent with driving dramatically increase the risk of accidents. Redelmeier and Tibshirani (1997) found a 4.3-fold increase in the risk of being involved in an accident within five minutes of using a cellular telephone. This corresponds to a driving performance decrement associated with having a blood alcohol level at the legal limit. Furthermore, Violanti and Marshall (1996) showed that talking on the phone 50 minutes per month increases the driving risk 5.58 times. They also described “younger” or “less experienced” drivers as being at higher risk. Violanti and Marshall (1996) specifically mention the “intense” nature of business calls as being a causative factor. The risk was compounded by combination activities such as cellular telephone conversation and radio tuning simultaneously. These conclusions highlight significant cognitive aspects of IVIS and cellular telephones in the driving environment. From this and the evidence provided by other studies, many countries and some U.S. states have enacted legislation or policies controlling cellular telephone use (Petica, 1993).

While epidemiological studies show a correlation between cell phone use and accidents the actual causes of these accidents are needed in order to address a solution to the problem. On-road and simulator studies can provide this information. By collecting driver performance data devices can be assessed in actual driving conditions. However, these studies still have their own limitations and problems that must be considered. In these studies, drivers are not in their own vehicle, they are not in a hurry to get somewhere, and an experimenter is present. Additionally, in the case of simulators there is no risk of an accident. Each of these conditions may cause drivers to perform differently than they would during normal driving.

Several on-road and simulator studies have addressed the issues of the use of cellular telephones in vehicles. These studies have focused on dialing, receiving, and placing calls on cellular telephones (Serefin, Wen, Paelke, and Green, 1993b; Stein, Parseghian and Allen, 1987). Although these aspects of phone use have been shown to have significant effects on driving performance, the effects of secondary tasks and information processing loads are not shown in the literature.

Past research efforts in the transportation literature do not address the impact of increased cognitive load from secondary tasks. In particular, they do not model the interactive communications generated by cellular telephones.

COGNITIVE MODELS

Much of the research in other non-driving-related disciplines regarding the impact of a secondary cognitive load on a primary task has been designed and interpreted using the dual task model (see Figure 1). In this model, the workload of a secondary task is added to an ongoing primary task until the primary task, the secondary task, or a combination of the two shows a measurable decrease in performance. In this model, the cognitive activities for primary tasks take precedence over the information processing requirements of secondary tasks. These studies suggest that when drivers experience increasing levels of secondary task demands, their performance of the primary task will be relatively stable until they reach their threshold capacity, at which point the secondary task will be shed or the driving performance will abruptly degrade. This model of cognitive resource usage has been paired with a model of driver interactions with the IVIS system. These two models in combination were used as the basis for this study.

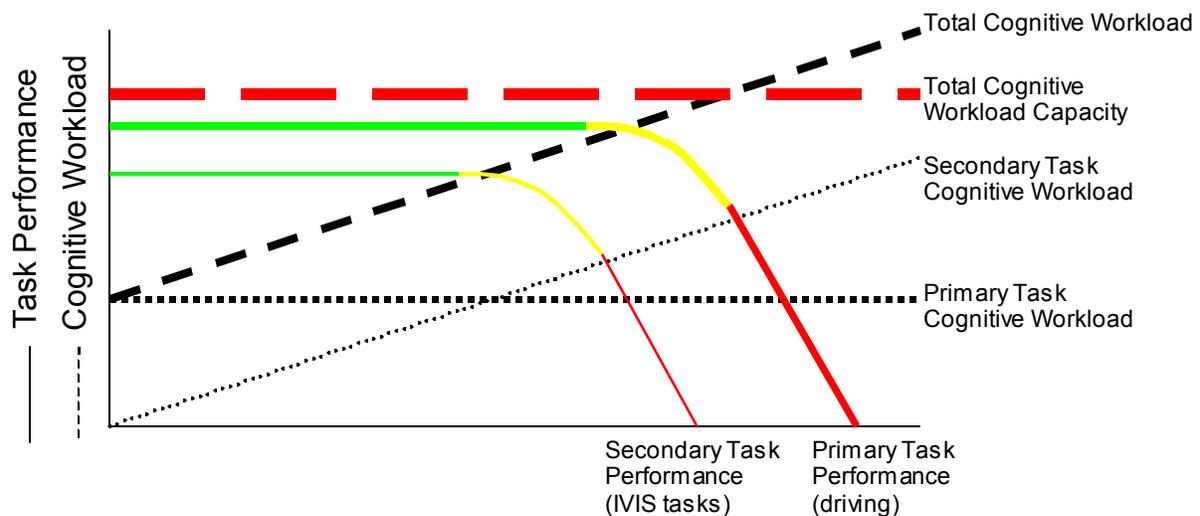


Figure 1 Dual Task Model

The following is a model of cognitive activities that are performed in the driving environment while interacting with an IVIS. All of the cognitive activities involved in the operation of a vehicle and the simultaneous use of an IVIS can be thought of as information processing. Human information processing is defined as the intrinsic capacity of a human to attend, perceive, remember, decide, and act (Wickens, 1992). The cognitive abilities of a driver to process information can be modeled as a finite pool or multiple pools of resources that must be allocated to various information processing activities (Wickens, 1992). The multiple resources cognitive model is shown in Figure 2. It is drawn from the IVIS behavioral model and is used for this research to define the relationships between the information processing tasks and the five resource pools.

In this model, each of the sensory modalities has its own finite capacity or pool of resources. For this research, the model is restricted to the two most important sensory inputs visual and auditory, and the two most important outputs, manual and speech. The input portion of the model includes attention to, and perception of, visual and auditory information. The output portion of the model includes speech and manual actions resulting from the cognitive activities of the driver.

Driver Multiple Resources Model

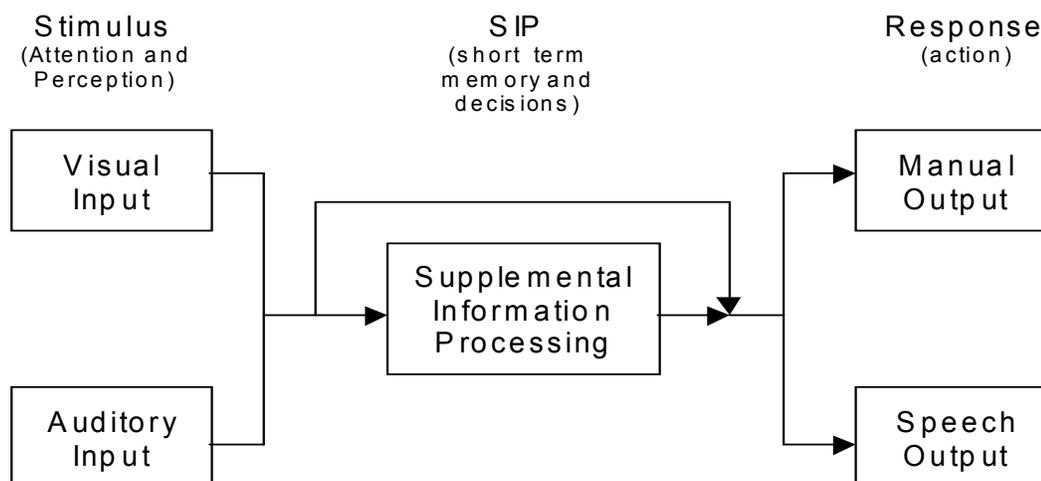


Figure 2 Driver Multiple Resources Model

In addition to the input and output portions of the model, there is a pool of resources associated with supplementary information processing (SIP). SIP includes the memory and decision making portions of information processing. For this research, SIP can be thought of as all those higher order mental activities associated with a task due to its complicated nature. It is assumed that there are information-processing components associated with information retrieval and responses in each of the sensory modalities as well as in primary task performance. However, for the purposes of this research, SIP includes only the memory required for searching or processing and the decision-making elements associated with secondary tasks.

This research controls the levels of SIP demand from secondary tasks and measures the impact on primary driving task performance. Like the dual task model, this model suggests that the cognitive activities for primary tasks take precedence over the information-processing requirements of SIP. Increasing SIP requirements will first consume excess resource capacity and will then compete for primary task information processing resources. When SIP loads require competition with the primary task, there will be degradation in the various measures of primary task performance. It is the degradation of these primary task performance measures that will indicate the impact of SIP. In cases of extreme SIP loads, the driver will shed the secondary task or have a critical safety failure on the primary task. From a driving safety perspective, it would be preferable that the driver shed the secondary task. However, this may not always be the case. Drivers may become so engrossed in the secondary task that they neglect their driving for short periods of time.

Like increasing cognitive workload, decreases in cognitive capacity can result in a situation where SIP demands interfere with driving performance. Factors such as age, health, fatigue, and training may significantly affect the supplementary information-processing capacity of the driver. Both reductions in available capacity and increased demands on information-processing resources contribute to exceeding resource limitations. Exceeding human cognitive limitations can degrade the performance of tasks associated with IVIS displays and cellular telephones (Wickens, 1992). More importantly, these conditions characterized by excessive workload can degrade the performance of driving itself.

INDEPENDENT VARIABLES

The results from past studies of IVIS displays (Collins et al., 1997; Hanowski et al., 1997) are promising in terms of potential benefits to driving performance. However, this past research does not address the impact of increased SIP levels, although the conclusions did identify concerns associated with reduced information-processing capacities of older drivers. The transportation research literature does not directly address the impact of increased cognitive loads on individual or composite measures of driving performance. In particular, these studies do not model the interactive communications generated by cellular telephones.

The availability of SIP resources for secondary tasks is dependent on the cognitive capacity of drivers and the level of cognitive demand needed to safely complete the primary driving task and other non-cell phone cognitive tasks. In-vehicle research includes a high degree of inherent variability. Differences between humans are compounded by operating vehicles on public roads where many conditions are beyond the control of researchers. These factors can dramatically affect both the cognitive capacity of the driver and the non-task workload. Therefore, to reduce variability not due to the experimental tasks and to ensure the safety of participants, many factors were either eliminated or standardized. Almost all of these controls reduced the amount of mental workload and risk to drivers. These experimental conditions have the secondary effect of increasing the cognitive resources available for the secondary task. Thereby, all results are likely to underestimate the impact of IVIS and cell phones on driver safety. The following is a list of variable conditions that were, to the largest extent possible, mitigated.

All driving was conducted in a relatively benign driving environment. There was no bad weather, darkness, traffic, tight curves, detours or other navigation including stops or turns. All driving was conducted in 55 or 65 MPH zones. There was no time pressure associated with the travel. Drivers were aware of the duration of the study and were paid for their time. Drivers had little fatigue or hunger as they were given rest breaks and snacks. Drivers were in good health and had no known impairments or disabilities that would affect their ability to perform as all other drivers. Drivers were given explicit training and tasks were simple to perform. The tasks required no visual input or manual control for output. The only physical component of the task was a button on the steering wheel that subjects could press to repeat task information. It was rarely used. All other information including tasks, probe questions, responses and test related dialogue was conveyed verbally. There was no competing auditory information from other people, radio or other in-vehicle devices. There were no competing manual tasks such as food or beverages, dialing, or manipulation of devices in the vehicle. Personal items such as purses, sunglasses, or papers were not accessible to the driver during task presentations. There were no competing information sources such as vehicle warnings, unusual traffic controls or mechanical idiosyncrasies of the vehicle and drivers could have task information repeated or could skip tasks whenever they wanted to. Tasks included no time pressure except to a small degree in paced conversation tasks. Drivers were observed and tasks were not completed if the researcher felt the driver was distracted or any of these preceding conditions was present. Overall the driver's primary (driving) task workload was very low.

Supplemental Information Processing (Cognitive Workload)

Interactive cell phone communications include personal and job-related activities that can be emotionally charged, urgent, and highly complex. They can involve extremely important information that could potentially take precedence over the more immediate task of safe driving. The relative urgency of message content is situational and contingent on factors specific to

individuals and the situation. Replication of emotionally intense content of the type found in cellular telephone conversations with fidelity across age and gender would be extremely difficult and dangerous. The pre-testing showed that tasks as complicated as these realistic cell phone tasks would be skipped by drivers in the test environment due to lack of motivation even when they did not include emotionally charged information. Even if drivers could be forced to do these tasks it is likely the risk of running the test would be unacceptable. Therefore the tasks contained no emotional, important, engrossing, or confusing content.

Although difficult, it is possible to generate in-vehicle tasks with increasing information content and cognitive complexity while minimizing between subject variations. In this research information content levels were manipulated in an attempt to measure their impact on driving performance. Two independent variables were used to generate increasing levels of SIP. They are information density and a series of information processing elements of increasing difficulty.

Information Density (short term memory levels)

Auditory IVIS tasks included two levels of short-term memory or task density. Task density refers to the number of options in a decision, as well as the number of information items in each option. The low-density condition included tasks that had three different answer options, each with three units of information (3 X 3). The high-density condition included tasks that had four different answer options, each with five units of information (5 X 4). The density levels correspond to both a low and a high level of SIP demand.

Decision Making Elements (information processing complexity levels)

Auditory IVIS tasks were generated that included several different cognitive processes or decision-making elements. The IVIS tasks consisted of listening and responding to a route selection question and an auditory presentation of IVIS route information.

The level of supplemental information-processing demand was determined by characterizing the driver interaction with IVIS (Lee, Morgan, Wheeler, Hulse, and Dingus 1997b, modified). The decision-making elements used were selected from the Lee et al. (1997b) full driver interaction model to be the key elements associated with the supplementary information-processing demand measures of interest. Four decision elements characterize the tasks performed: Search (Listen), Compute, Interpret and Plan. Below are the measures that were selected, along with their operational definitions.

Table 1 Decision-Making Element Descriptions

Decision-Making Element	Description
Search (Listen)	Involves the searching and filtering associated with the extraction of information from the environment that meets pre-defined parameters.
Compute	Involves calculating numerically or logically the answer to a problem.
Plan	Involves the matching of resources to the current objective when making a decision from definitive information, requiring no interpretation of meaning to accomplish an objective.
Interpret	Involves extracting the meaning from a set of cues and/or the decoding of iconic information in order to make a decision.

Listen (Auditory Search)

The driver is listening for a specific information item. The driving environment is scanned for information that meets predefined parameters determined by the driver. No further processing of the information is necessary; the decision simply involves locating information that meets the predefined parameters. To categorize IVIS design characteristics for the Listen element, the number of predefined parameters for which the driver is scanning the environment must be specified. The primary constraints on the driver are focused attention and working memory limitations. Working memory is theorized to be a combination of information items or chunks stored in short-term memory, and the site where information processing takes place. Working memory limitations include the 7 ± 2 items or chunks of information that can be retained by humans in this memory resource (Anderson, 1990).

Compute

The driver must perform mathematical data manipulations to answer a problem. The primary driver constraint is his/her computational ability. Three types of computations were defined for pilot testing and are listed below:

- Compute a sum of two different times
- Compute a quotient of two numbers
- Compute a quotient and then a sum

None of the computation elements appeared to be different during pilot testing. Tasks were therefore only differentiated on a basis of whether there was a calculation involved.

Plan or Interpret

The driver matches available resources in order to achieve objectives. The Plan element and the Listen element are similar. The difference between them is that the Listen element only requires the driver to identify information in the presentation, while the Plan element requires the driver to process the presented information and assimilate it in order to accomplish the desired objective. The primary constraint of the Plan element is the ability of the driver to appropriately prioritize tasks, estimate time availability, and schedule tasks.

The Interpret element is similar to the Plan element in that the Interpret element involves matching the available resources to achieve objectives. However, in the Interpret element, the information chunks that are used are ambiguous. For example, instead of using a delay of 15 minutes as an information item, the item would be “deer carcass in road.” This forces the driver to do additional processing to evaluate the meaning of the information given. The Plan and Interpret elements showed no differences in pilot testing and were combined into a single Plan element.

Conversation

Conversational tasks were included because conversations are the major component of cellular telephone use. Additionally, past research (Redelmeier and Tibshirani, 1997) indicates that there are safety risks associated with cellular phone conversations during driving. Conversational tasks were designed to test the impact of cognitive load in the absence of visual and physical input and output components of cell phone use. Pilot testing indicated that low intensity levels should be selected because at high levels, subjects shed the tasks. It is likely that drivers may not shed even the much more difficult tasks in a real world driving situation.

However, for the purposes of this study, it was assumed that levels of SIP that cause discomfort to the extent that drivers consistently shed a task are unsafe or would not provide the desired driver performance data.

To control the content and duration of the tasks, they were designed as a series of consecutive questions that required only short answers. This method had the added benefit of minimizing the information processing components of extraction and short-term memory. The conversational tasks were presented in two ways. In the paced format, the computer presented the task as a recording. This format forced the subject to answer the questions with a limited response time. In the non-paced format, the questions were asked by the front-seat experimenter, who waited for a verbal response to each question before continuing.

The conversational tasks were intended to simulate the use of a cellular telephone. In addition, during the pilot tests, they suggested the possibility that even very simple conversations with a passenger resulted in measurable driving performance effects.

Age

Other than workload level or capacity utilization rate, the other major factor that affects SIP is the overall capacity of an individual. Age has been found, in a number of studies, to be a significant factor in driving behavior. Both younger and older drivers have strengths and weakness when driving. While younger drivers have faster reaction times, they tend to take more risks and are not as skilled at situational assessment. Older drivers, on the other hand, have excellent situational assessment, but they have decreased reaction times.

Previous studies have shown that older drivers must dedicate a higher percentage of visual attention to the roadway than younger drivers. Older drivers have also shown reduced performance, with respect to younger drivers, during the operation of secondary automotive tasks (Monty, 1984; Dingus, Antin, Hulse, and Wierwille, 1988). Older drivers also may have greater limitations in their sensory, cognitive, and psychomotor skills. Ponds, Brouwer, and Van Wolfelaar (1988) found a decline in dual task performance for older subjects, suggesting that aging impairs the ability to divide attention. Their data suggested that this impairment was restricted to old age (above 60 years).

When one considers that, in the United States, elderly drivers constitute the fastest growing segment of the driving population (Transportation Research Board, 1988), the need to consider age in driving performance measures becomes clear.

DEPENDENT VARIABLES

The safety risk associated with in-vehicle cell phones and IVIS is a function of three factors: 1) The level of mental workload required to tend to the cell phone; 2) The drivers' awareness of the mental workload and any detrimental effect on driving performance, i.e. situational awareness, and thereby, their compensation for or sloughing of the secondary task; 3) The degree to which the primary task is degraded.

Mental Workload

The mental workload construct is the conceptual basis for measuring the amount of workload imposed on the operator. The idea of mental workload comes from the resource theory of cognition introduced in Figure 1. According to Wickens (1992), supplementary information processing can be thought of as use of resources from a pool of available resources. Each task requires the use of some resources (i.e. imposes a mental workload), and therefore, the capacity

of this pool is critical. If there are insufficient resources for the task or tasks being conducted (i.e. excessive mental workload), performance on one or more of the tasks will be degraded.

In order to make judgments about the supplemental information-processing effects of IVIS or cell phones one must evaluate the amount of mental workload imposed on the operator. In the IVIS component of this study the two levels of Information Density and four levels of Decision Making Element impose increasing mental workload. Likewise, the two levels of conversation simulate increased mental workload from cell phone use. Unfortunately, mental workload cannot be measured directly and cannot be precisely quantified.

Wierwille and Eggemeier (1993) give recommendations for the use of multiple measures. A general workload level can be assessed from the composite of these various measures, and the specific measures may highlight certain types of tasks associated with high resource demands. Salvendy (1997) gives an extensive list of mental workload assessment techniques and a method for their selection. The Salvendy (1997) method was used to select measurement variables to be included in the study from the four types of mental workload assessment techniques. The four technique types include: 1) primary task performance measurement, 2) secondary task performance measurement, 3) subjective workload assessment techniques, and 4) physiological measures.

Since none of these four techniques provide a direct measurement of mental workload, a selected set of tests was used to obtain an accurate picture of the supplemental information-processing demands associated with each task. Measures of primary task performance include lateral control, speed maintenance, headway tracking, and eye glance patterns. Errors, completion times and the number of skipped or repeated secondary tasks indicated secondary task performance. Subjective assessment techniques include the NASA-TLX (Task Load Index; Hart and Staveland, 1988) measurement of mental workload, and situational awareness probe questions. Physiological measures were not a part of this experimental design due in part to additional complexity and cost of data collection and in part to the intrusiveness of some measures. Additionally, physiological measures increase the stress level for many subjects and were not compatible with the companion study.

The general construct of mental workload includes psychological attributes such as motivation, anticipation, skill, and fatigue (Jex, 1988), as well as all other factors involved in decision-making. As discussed earlier, this experimental design minimized these factors and standardized their impact on mental workload.

Situational Awareness

Situational awareness is a construct that measures the driver's knowledge of the system's state, operational goals, and expected future outcomes. Endsley (1995a) states that driver situational awareness is a crucial construct on which decision making performance in complex systems will hinge.

Situational awareness was assessed through a combination of measures. First the situational awareness probe question was used to find the driver's perception of their level of awareness. Additional information from the eye glance data were used to evaluate patterns of mirror and instrument checking behavior. Direct driving performance measures were included in order to show any impairment. The combination of these measures gave an estimate of the relative difference between how familiar drivers were with their instruments, other cars, and the driving environment as a whole during tasks compared to baseline driving. Finally, if there was a difference, an estimate could be made about how aware the driver was of that difference.

Subjective Measures

Direct objective measures of performance may not be sensitive to SIP (Eggemeier, 1988). Consequently, two subjective measures of driving performance were included. The subjective assessment included the NASA-TLX used to evaluate mental workload, and a situational awareness probe question.

NASA-TLX

Subjective workload assessment techniques are structured methods of eliciting opinions regarding the amount of mental workload that a driver believes he/she is experiencing. In the simplest terms, we are asking the driver how much mental effort is being required of him/her by the task or tasks he/she is doing. Many subjective assessment techniques have been developed, including the Subjective Workload Assessment Technique (SWAT) (Reid, Shingledecker, and Eggemeier, 1981; Reid and Nygren, 1988), The National Aeronautics and Space Administration's Task Load Index (NASA-TLX) (Hart and Staveland, 1988), and the Cooper-Harper scale (Cooper and Harper, 1969). Each of these scales presents the driver with various dimensions of task difficulty to rate. The resulting data are combined into an overall rating scale of mental workload. The NASA-TLX subjective measurement technique was selected for this study in order to complement other research that is being included in the IVIS behavioral model.

The NASA-TLX includes six sub-scale dimensions that are used to compose an overall rating of workload. The six sub-scales include "physical demand," "mental demand," "time pressure," "operator performance," "operator pressure," and "frustration level." NASA-TLX has been utilized in past studies to measure the cognitive load of drivers (Alm and Nilsson, 1990; Fairclough, Ashby, Ross and Parkes, 1991). For the purposes of this study, only the measures of "mental demand," "time pressure," and "frustration level" were used. This decision follows the results of these three measures as those that were significant for mental tasks in the Fairclough et al. (1991) study of cellular telephone use in automobiles. Further, collection of the other sub-scales would require excessive time and would add additional fatiguing mental workload to the experiment.

Directly following each task, drivers were asked to rate the "mental demand," "time pressure," and "frustration level" that were associated with driving while performing that task. These subjective measures of workload were recorded and analyzed separately rather than combining them, since the schema provided in the Hart and Staveland (1988) NASA-TLX technique is designed for six or nine sub-scales.

Several difficulties exist with properly implementing this technique. First, the driver's self-assessment is subject to some variability. Zeitlin (1995) described the Chuck Yeager effect as a situation in which drivers, especially younger males, were unwilling to admit to workload levels near their maximum capacities. This effect tends to constrict rating variability. Another concern is that the process of making the subjective assessments of the cognitive task will likely generate additional mental workload that may interfere with the ratings.

Situational Awareness Probe Question

In order to make an assessment of situational awareness impact on driving performance eye glances and driving performance measures were used. In addition to these measures a probe question was asked to estimate the drivers' ability to recognize their own awareness of surroundings. If drivers are unable to recognize reductions in their situational awareness the safety implications are much more severe.

Directly following each task, drivers were asked to rate their “situational awareness” associated with driving while performing that task. In their training they were told this was to include things like their speed, awareness of road signs, the position of other cars, and the distance to lane lines. Drivers gave each task a situational awareness rating on a scale from 1 to 100. The situational awareness measure was recorded and analyzed as a separate subjective measure.

Eye Scanning Behavior

Past research has shown a strong correlation between eye fixation patterns and workload levels in driving (Hulse, Dingus, Fischer, and Wierwille, 1989). The time that each subject spends looking at various parts of the visual scene was recorded from the videotaped footage. Patterns during tasks were compared to scanning behaviors during normal driving. The videotape analysis compared the number of glances to three visual locations and the total number of glances for each task to comparable length baseline driving periods. The visual scene was divided into roadway, mirrors and all other locations.

The number of glances was used as a measure of situational awareness. As the amount of workload increased, the amount of mirror and instrument checking was expected to decrease, along with the situational awareness of the driver. The driver was also expected to have longer and fewer glances, particularly toward the forward roadway. This behavior would indicate visual fixation that is a possible result of high mental workload. The forward roadway is the default viewing location for the driving task since the risk of forward collision is paramount and can only be avoided by lateral and longitudinal vehicle control inputs based on forward view information. Thus, the driver will generally return to or maintain forward viewing during tasks. During high workload situations, however, the driver may experience a narrowing of focus, reduced scanning, or a complete disregard for visual information due to mental workload-related distraction.

Objective Measures

This experiment was designed to evaluate the effects of supplemental information processing (SIP) load from secondary tasks such as using a cell phone on primary task performance. The impact of varying SIP was measured using a suite of objective driving performance measures. These included three measures of secondary task performance, four measures of longitudinal tracking, three measures of lateral tracking, and four measures of eye glance direction.

Longitudinal Tracking

Speed

Both minimum speed and speed variance were recorded as measures of driving performance. It was expected that the driver would reduce his/her speed during high workload periods for two reasons. First, a reduction in speed reduces the amount of visual information that must be processed by the driver. Secondly, the driver has more reaction time and less resulting concern about objects in the vehicle path such as the confederate vehicle. Minimum speed was an indication of the driver’s tolerance for visual information rate and reaction time. The speed variance was a measure of the driver’s ability to maintain his/her speed at a given level.

Headway Variance

Headway variances have been found to indicate high levels of workload or distraction. Headway is a measure of the time-distance between vehicles on the roadway. Short headway distances are closely related to reduced reaction time. Vehicle headway was recorded during each of the task events using a Doppler radar system installed in the experimental vehicle. Headway data were analyzed to compare the variances in headway during normal driving with variances during tasks. This was used as another measure to assess the distraction that the driver was experiencing.

Minimum headway and headway variance were the two headway measures used to assess headway tracking behavior. Minimum headway indicates the level of collision risk that occurred for each condition. Smaller minimum headway distances indicating higher risks were expected for higher workload conditions. In addition, higher workload levels are expected to cause increased headway variances.

Lateral Tracking

Steering

Two steering variables were included as measures of driving performance: maximum steering position and steering position variance. It was expected that drivers who were under large amounts of mental workload would have different steering behavior than normal drivers. If a driver neglects steering for a period of time, the vehicle will continue on its current path. Thus, a smaller variance in steering position would result. The car will also drift, causing a need for larger inputs to make corrections back to the lane center.

Lane Deviations

Another measure of lateral tracking is lane deviation. Anytime the vehicle wheel crossed either of the lane lines the driver was said to have deviated from their lane. Drivers under higher workload levels are expected to drift out of their lane more often. While crossing a lane line rarely causes an accident it is a good measure of the level of distraction of the driver.

RESEARCH QUESTIONS

This research was designed to provide input for the generation of guidelines for SIP levels that will minimize the additional risks and increase the benefits associated with driving while using IVIS devices. This was achieved by evaluating performance measures including IVIS task errors, objective performance measures, and subjective ratings of mental workload and situational awareness for each in-vehicle task. These performance measures were then used to assess the mental workload and situational awareness of drivers under varying SIP loads. Five research questions were used to guide the investigation:

- How do simple conversations impact driving performance?
- How does task element impact driving performance?
- How does task density impact driving performance?
- How does driver age impact their driving performance?
- Are the results of increased secondary cognitive load consistent with a model that either 1) the drivers are losing focus on the secondary task or 2) the drivers are shedding the primary task, or 3) the drivers are persisting with both and degrading both?

METHODS

EXPERIMENTAL DESIGN

The experimental design was a 3 X 2 X 4 mixed factor design. Age (3 levels) was a between-subject variable. Gender was not included as a between-subject variable, but was controlled by counter balancing. Task density (2 levels) and task element (4 levels) were within-subject variables. Data were also recorded during baseline or normal driving conditions for each subject throughout his/her drive. Since the number of baseline data points was not the same as the number of tasks, a one-way analysis of variance was completed for each significant variable to check for differences between baseline and task conditions. All of the tasks were presented to each subject in a random order. The task density variable (2 levels) was a result of two contributing factors; number of possible routes and information items for each route possibility. Information items included items like the speed limit, the route name, the number of miles, and whether there was a gas station present. Each task was classified as low density (3X3), meaning it had three possible routes, each with three information items, or high density (5X4), meaning it had four possible routes, each with five information items. The decision-making element variable (4 levels) was a combination of four primary decision making elements: Listen, Plan, Interpret, and Compute (Lee et al., 1997b). The levels were: 1) Listen only; 2) Listen and Plan or Interpret; 3) Listen and Compute, and 4) Listen, Plan or Interpret, and Compute.

An additional analysis was run for conversational task types (2 levels). Subjects were presented with both a paced and a non-paced conversation task, and additional baseline data were also recorded. Each subject received two replications of the conversational tasks.

Task combinations and the resulting task presentations with their replications are listed in Tables 2 - 3.

INDEPENDENT VARIABLES

Decision Making Elements (4 Levels) and Information Density (2 Levels)

Pilot Testing

A pilot study was conducted to assess the number of levels of decision-making elements and the density of information included in the tasks to be used. The pilot test data for each age group were used to determine the difficulty levels at which performance began to deteriorate or subjects began to skip tasks. These criteria define areas at which driver mental workload becomes an issue.

The full experiment was then used to gather data on driver performance associated with SIP while doing auditory tasks in the range that surrounded the levels selected in the pilot study. The combinations of decision-making elements (Lee et al., 1997b) and task densities that were selected in the pilot study and performed by the subjects are included in Table 2. In addition, Table 3 shows the task densities, elements, and replications that were used in the full study. An expanded description of the pilot and regular study tasks can be found in Appendix C.

Table 2 Density and Element Levels

3 x 3 Density Conditions
(0) Baseline Driving
(1) Listen
(2) Listen + *Plan
(3) Listen + Compute

5 x 4 Density Conditions
(0) Baseline Driving
(1) Listen
(2) Listen + *Plan
(3) Listen + Compute
(4) Listen + *Plan + Compute

Conversational Conditions
(0) Baseline Driving
(5) Paced Conversation (2 replications)
(6) Non-Paced Conversation (2 replications)

* The Plan element includes both the plan and interpretation elements.

Table 3 Tasks Presented and Number of Replications

			Task Density	
			1	2
			3 X 3 (low)	5 X 4 High
Task Element		Base line	5*	5*
		L	1	1
		L, P	2	2
		L, C	2	2
		L, C, P	0**	4

* 5 total baselines for each subject were used for all task comparisons.

** It was not possible to present this type of task without increasing the information density.

Conversation Conditions (2 Levels)

Subjects were presented with both paced and non-paced conversation tasks as given in Table 2. Full task descriptions are given in Appendix C.

Age (3 Levels)

Subject Population

Thirty-six subjects participated in this on-road study (see Table 4): six males and six females who were between 18 and 25 years of age; six males and six females who were between 35 and 45 years of age; six males and six females who were 65 or older.

Young participants were recruited from Virginia Tech University by posted flyers. Middle age and older participants were recruited by advertisements in newspapers, flyers, and visits to retirement communities. Each subject attended one experimental session that lasted approximately four hours. Subjects who did not present a valid driver's license, did not drive at least four times per week, or revealed health conditions that made operating the research vehicle a risk (see Appendix B-3) were dismissed from the experiment. Each participant received \$10.00/hour for his or her participation.

Table 4 Age and Gender Participants

GENDER	AGE		
	Young (18-24 years)	Middle (35-45 years)	Old (65+ years)
Male	6	6	6
Female	6	6	6

DEPENDENT VARIABLES

The dependent variables measure the impact of the various tasks and conditions on the driver's performance and the subsequent safety of those tasks. The data included were of two distinct types: objective performance measures, which included direct measurements of driver activities or induced physical effects, and subjective performance data, which were the drivers' assessments of various psychological measures. The specific measures collected were as follows.

Objective Measures

Primary Task Performance (Driving)

Lateral Tracking Measures

- Steering wheel maximum position in degrees
- Steering wheel position variance
- Lane Deviation

Longitudinal Tracking Measures

- Minimum speed
- Speed variance
- Minimum headway
- Headway variance

Eye Glance Measures

- Total number of glances
- Number of glances to the road
- Number of glances to mirrors
- Number of glances to other locations

Secondary Task Performance (IVIS Tasks)

Task Completion Time

The period of time between the assignment of a task and when that task is correctly completed was recorded for each task. Task completion times were averaged. If a task had an error, that time was not included in the mean task time. The analysis of task completion times was used to assess the duration of tasks and as a possible measure of task difficulty.

Correct Completions

The mean proportion of correct task completions to attempted tasks was computed for each task and subject. The total number of correct completed tasks was recorded for each driver. Errors were analyzed to assess task difficulty.

Subjective Measures

NASA-TLX

A subset of the NASA-TLX (Task Load Index) was used in this study to evaluate the amount of perceived workload of the user. As described by Eggemeier (1988), the subjective scales of mental workload are sensitive to performance variances at a lower level than objective performance that may not catch variations until overload conditions are present. Hart and Staveland (1988) developed and validated the commonly used NASA-TLX rating scale for mental workload. The mental demand, temporal demand, and frustration level indicators were selected from the six original indicators. This was done because the other three measures (physical effort, performance, and effort) do not apply directly to supplementary information-processing load levels.

The three selected NASA-TLX scales of mental demand, temporal demand, and frustration levels were administered to the subject after each task. Analyzing this data provided information on the subject's opinion of the amount of total "mental work" being done during each task they performed. See appendix B-13 for details on NASA-TLX measurement.

Situational Awareness

The primary means of assessing the situational awareness of the driver was to study the eye glance pattern information. Increased focus on the central view and reduced mirror-checking behavior indicated a reduced awareness of the surrounding environment of the vehicle. In addition to these measures of situational awareness, a probe question was used to determine the driver's opinion of their situational awareness during tasks.

DRIVING CONDITIONS

Route

Data were collected on U.S. Highway 460 between Blacksburg, Virginia and Princeton, West Virginia. Tasks were performed and data collected while driving in both directions between Blacksburg and Princeton. Route 460 is a four-lane route with good visibility (see Appendix B-15).

Traffic Density

There was a vehicle following situation for the duration of the drive. A confederate vehicle was driven in front of the test vehicle. Tasks were limited to low traffic density (two or fewer vehicles in the immediate vicinity of the test vehicle), and general traffic density was low.

Environmental Conditions

- Daytime hours
- Clear weather (no rain, snow, or ice)

EQUIPMENT

Driver behavior was investigated on-road using an instrumented 1995 Oldsmobile Aurora four-door sedan (Figure 3.) The primary apparatus that were used in the study included: (1) the automobile, (2) cameras and sensors, (3) software and hardware interfaces for information portrayal and data collection, (4) the IVIS, (5) the information portrayed, and (6) the confederate vehicle.

Automobiles

The experimental vehicle used in the study was a 1995 Oldsmobile Aurora especially equipped for on-road data collection (Figures 3 and 4.) The instrumentation in this vehicle provided the means to collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants. The system included video cameras to record pertinent events and eye movement data. An experimenter control panel recorded task duration and responses. Information from a set of sensors was used for the detection of variations in driving performance and behavior. A computer was used to log the data in the format required for analysis. The vehicle's data collection system allowed for the collection and storage of two forms of data. First, the system provided the capability to store data on a computer in the form of one line of numerical data every tenth of a second during a data run. Secondly, the videotape record was time-stamped and synchronized with the computer data stream so that post-test data reduction and data set merging could occur in the laboratory.



Figure 3 Instrumented Vehicle

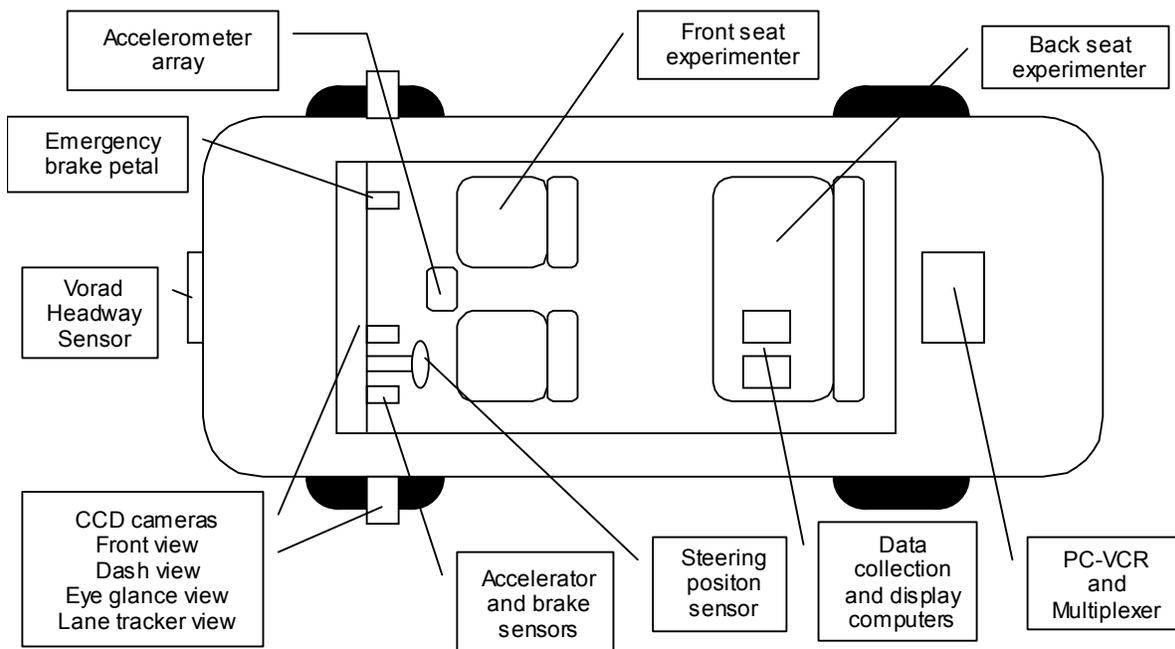


Figure 4 Diagram of the Instrumented Vehicle

The confederate vehicle was not instrumented. However, the confederate experimenter had access to portable safety equipment similar to the items used in the experimental vehicle. An open line of communication between vehicles was maintained to provide the confederate vehicle with knowledge of the task presentations.

Safety Equipment

The following safety equipment was provided as part of the instrumented vehicle system. Such accommodations helped to minimize risks to participants during the experiment:

- All data collection equipment was mounted such that, to the greatest extent possible, it did not pose a hazard to the driver in any foreseeable instance.
- Driver-side and passenger-side air bags were provided.
- Two trained in-vehicle experimenters were in the vehicle at all times. An emergency protocol was established prior to testing.
- A fire extinguisher, first aid kit, and cellular phone were located in the experimental and confederate vehicles.
- An experimenter's brake pedal was mounted in the front passenger-side.
- None of the data collection equipment interfered with any part of the driver's normal field-of-view (FOV).

PC-VCR

A PC-VCR using S-VHS tape recorded the eye glance camera view and included a time stamp onto the videotape. The camera view had 200 horizontal lines of resolution. The VCR received a time stamp from the data collection computer and displayed it continuously on the videotaped record. This allowed for data synchronization during the data analysis phase. An example captured screen image from the vehicle is shown in Figure 5.



Figure 5 Screen Image from Data Collection Video

Eye Glance Camera

The eye glance camera allowed monitoring of eye movements, and its FOV accommodated drivers of various heights and in various seating positions. The view of the subject's eyes was clear and in focus, allowing eye movement classification in the laboratory. The eye glance camera was located in the center rear-view mirror and did not obscure the driver's view or impair his/her use of the mirror. This camera's view was analyzed to assess eye-scanning behaviors.

Lane Tracker

The car was equipped with a device that measures the position of the vehicle with respect to the centerline or the boundary line of the lane of travel. The data were used to monitor lane position variance and number of lane busts or serious lane deviations.

Headway Tracker

The headway tracking system is a device that uses Doppler radar to provide distance information with respect to the lead vehicle. Headway distance data were used to evaluate headway variance during task segments. The lead vehicle varied its rate of travel during task segments, thus creating a situation where the subject had to attend to headway maintenance.

Video/Sensor/Experimenter Control Panel Interface

A custom interface was constructed to integrate the data from the experimenter control panel, driving performance sensors, and speedometer with the data collection computer. In addition, the interface provided a means to accurately read and log the time stamp from the PC-VCR to an accuracy of +/- 0.1-second. The time stamp was coded such that a precise location could be synchronized from any of the videotaped records to the computer data record for post-test laboratory reduction and file integration.

Audio Data Collection System

The audio track of the videotape record of the experiment contained the commentary of the experimenter, driver communication, and the system-generated auditory displays. This was used to clarify display onset times and other verbal commentaries made during the experiment.

Display Information

The displays of various types included notifications and other information that were used in the experimental tasks. These displays were scripted, recorded, and stored in the car's computer to be recalled during the course of the experiment.

Steering Wheel Buttons

Two buttons were located on the steering wheel to the right and left sides of the horn (Figure 6). When the driver depressed either one of these buttons they were able to repeat the presentation of the task that they were working on. Any time a driver repeated a task the data file recorded the incident.



Figure 6 Image of Vehicle Showing Steering Wheel Buttons

Communications Equipment

A small FM band transmitter/receiver unit was used to communicate to the confederate vehicle that a task was being presented to the driver. When a key was depressed on the keyboard to activate the slide presentation, the transmitter sent a signal that instantaneously activated a buzzer in the confederate vehicle.

PROTOCOLS

Participant Screening and Training

Participants were initially screened over the telephone regarding age, gender, driving experience, and health (see Appendix B-1). When a participant was qualified for this experiment, a time was scheduled for testing. Participants were instructed to meet experimenters at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, Virginia. After arriving at the VTTI, the participant was given an overview of the study and he/she was asked to complete an informed consent form (see Appendices B-2 and B-4). Next, the participant was asked to answer a health-screening questionnaire and was given a simple vision test (see Appendix B-3). After these items were completed, the participant was escorted to the test vehicle.

The participant was then familiarized with the vehicle and the controls. With the car in park, the experimenter reviewed general information concerning the operation of the test vehicle (e.g., lights, seat adjustment, mirrors, windshield wipers, etc; see Appendix B-9). The participant was then asked to operate each control and set the seat and mirrors for his/her driving comfort. When the participant announced that he/she felt comfortable with the controls, the experimenter administered a hearing test (see Appendix B-9). This test determined the participant's ability to understand verbal navigational commands and hear the auditory displays. Next, the experimenter explained the IVIS displays and the auditory tasks that the participant

would be required to perform during the drive. As a pre-test to familiarize drivers with the IVIS, the auditory displays, and the car, a short distance drive involving some sample tasks was performed (see Appendix C). The vehicle was then stopped and the driver was encouraged to ask questions or to ask for clarification or explanation if necessary. Once the participant was comfortable with the vehicle, the IVIS, and the auditory tasks, final instructions (see Appendix B-9) were given. The driver then proceeded to the normal drive and data collection segment.

On-Road Data Collection

Two experimenters were in the vehicle with the driver. An experimenter in the front seat gave navigational information and instructions, flagged incident data points, and served as a safety monitor by using the second emergency brake pedal if needed (see Appendix B-10). The experimenter in the rear seat controlled the presentation of tasks and maintained the data collection equipment (see Appendix B-11). IVIS and auditory display information was stored as slides and sound files on a computer located in the vehicle. The rear seat experimenter triggered the presentation of task information for the IVIS and auditory displays according to a previously determined presentation order. Tasks were presented during points in the route considered comparable to each other and safe according to prior analysis of the route. After each task presentation, the subject performed the given task. Immediately following the task, NASA-TLX responses for workload assessment, as well as probe questions, were asked.

The experimental route took approximately three hours to drive. The route began at the intersection of Rte. 460 and Southgate Drive, made a circuit to the West Virginia Welcome Center on Rte. 460 and then returned to the Southgate Drive intersection. This route consisted of a wide four-lane highway for its entire duration. Traffic density on this road was moderate to low, and the subject followed a confederate vehicle for the duration of the drive (see Appendix B-12).

Post Test Data Collection

At the conclusion of the test run, drivers were returned to the research building at the Virginia Tech Transportation Institute and completed an exit debriefing. They were then paid and dismissed.

STATISTICAL ANALYSIS

The analysis included two primary statistical methods, Paired T-Tests and Analysis of Variance (ANOVA).

Paired T-tests were used to analyze the eye glances and lane deviations. Each task condition was compared to a matched duration segment of baseline data collected during normal driving.

The remaining dependent variables in the study were analyzed using a general linear model analysis of variance (ANOVA). Two models were used to accommodate the two types of tasks that were presented. For IVIS auditory tasks, a fully crossed Age x Density x Element model was run. For the conversational tasks, density was not a variable, so an Age x Element model was used.

The IVIS auditory tasks experimental design was a 3 x 2 x 4 mixed factor design. Age (3 levels) was a between-subject variable. Gender was not included as a between-subject variable but was included as a matching variable. Task density (2 levels) and task element (4 levels) were within-subject variables. Task density represents the number of information items present in a

task and the subsequent amount of short-term memory required during the task. Task element represents the type of information processing and is structured in order of complexity. The combination of these two variables provided the various levels of Supplemental Information Processing (SIP) demand. Although both of these variables are set up in an increasing order of difficulty the levels are not equivalent increments.

Due to unequal numbers of baseline conditions as compared to task presentations, a separate one-way analysis was run on variables found significant to compare baseline conditions to task conditions.

The second analysis was run on conversational tasks (2 levels). Subjects were each presented with two replications of the paced and non-paced conversation tasks. Baseline conditions were included in this analysis, and no separate one-way analysis was run.

For each of the analyses of variance and the Student-Newman-Keuls post hoc tests, the test level for significance was set at $\alpha = 0.05$. The data from on-road research contains a high degree of variability that results from individual differences as well as lack of environmental control. The measures in this study are measures of driving performance decrements resulting from very low levels of secondary cognitive workload, which simulate the least distracting real world secondary task. These low levels were chosen due to safety concerns from previous research (Redelmeier and Tibshirani, 1997) and a high rate of skipping of more difficult tasks during the pilot test.

RESULTS

The results of these investigations will be discussed from three perspectives. Here in the RESULTS section they will be presented from the perspective of each measure of driver performance (dependent variable) across all treatments (independent variables). Secondly, in the subsequent DISCUSSION section the results will be discussed as a summary of the overall impact of each treatment across all measures. Finally the IMPLICATIONS FOR DESIGN AND REGULATION section addresses potential changes to enhance the safety of IVIS and cell phone use in vehicles.

Data collected from the drivers included their primary task performance, their eye glance behavior, their secondary task performance and their subjective ratings. The data and statistical analysis are given in Appendix A. Throughout the results section, graphs depicting means for various variables will be included. In these bar graphs, the letters above the bars indicate the Student-Newman-Keuls post hoc analysis groups. Bars with different letters above them are significantly different using the Student-Newman-Keuls post hoc test at an alpha level of $\alpha = 0.05$. Only those data that result in statistically significant findings will be discussed in this section.

PRIMARY TASK PERFORMANCE

LATERAL TRACKING

Lateral tracking measures include three variables that are used to examine lane position and vehicle steering control: maximum steering position, steering position variance, and lane deviations.

Maximum Steering Position

Element Effect

Drivers that are distracted from their driving by high workload tend to monitor the road less frequently or less intently and will tend to drift further before a steering input correction is made. Large steering inputs are associated with cases where the vehicle has drifted further from the normal central location in the lane, and therefore larger steering corrections are required. The maximum steering position is a measure of the largest steering input made during a task. The analysis takes the mean value across a group of tasks associated with the independent variable being tested. The term “mean peak value” refers to this average of the largest steering positions recorded during a given task condition. The full model ANOVA of maximum steering position indicated that the Listen Only task had significantly smaller mean peak steering values than the other element levels ($p = 0.0059$). However, the one-way analysis by element that includes the baseline condition indicated that the Listen Only condition was not significantly different from the other conditions. Although none of the tasks were significantly different from each other, the mean peak steering position was higher during tasks than during normal driving ($p = 0.0017$ one-way ANOVA) (see Figure 7).

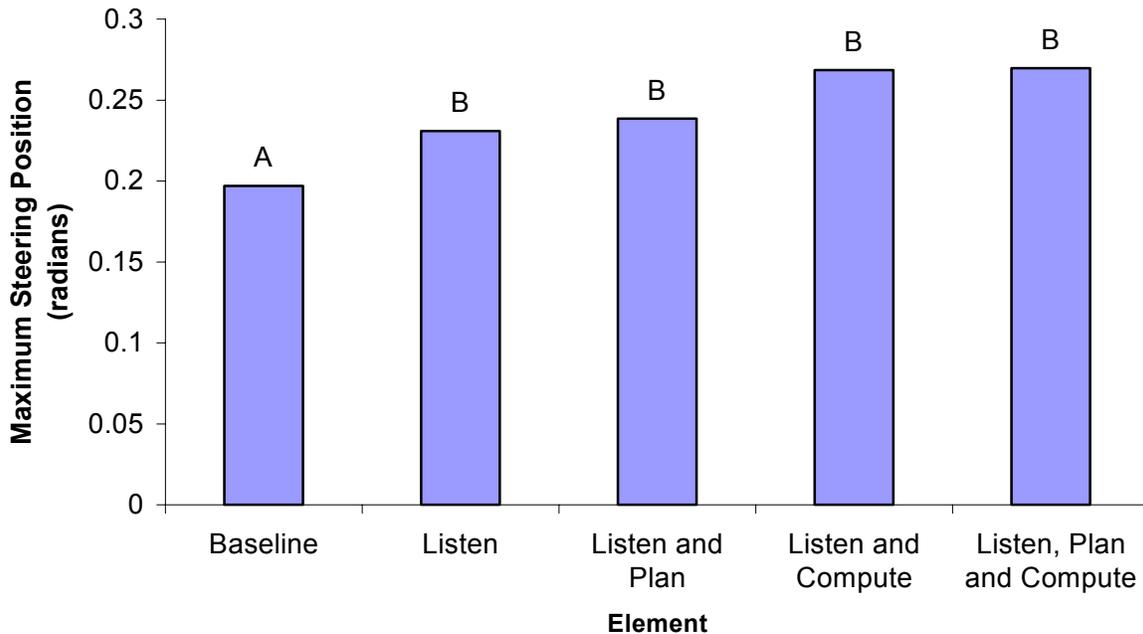


Figure 7 Maximum Steering Position for Elements

Steering Position Variance

Age Effect

The steering variance is an indication of the total amount of steering input that was made to the vehicle. In high workload situations, the driver makes more and larger total steering corrections due to distraction and therefore will have a larger resulting steering variance. Additionally, if the vehicle is traveling faster, larger steering inputs will be required and the variance will also increase. Older drivers showed a smaller steering variance than both of the other age groups ($p = 0.0390$). The older, middle, and younger age groups had steering variance values of 0.0051, 0.0075, and 0.0088 radians, respectively. It would appear that older drivers exerted more precise control of the vehicle; however, it is difficult to conclude a performance improvement for older drivers since their speed was significantly lower than other age groups. The lower minimum speeds (see minimum speed analysis below) maintained by older drivers make steering control less difficult, and there is no other evidence in the data to show a trend of older driver increased performance. However, this result is interesting for another reason. This behavior highlights an important quality of older drivers. This age group tends to exhibit more conservative driving behaviors that can minimize the effects of their reduced abilities.

Lane Deviations

Lane deviations were analyzed using paired t-tests (see appendix A-4).

Overall Effect

In the total 304 tasks including all participants, there were significantly more lane deviations while completing tasks than during comparable normal driving periods ($p = 0.0025$). There were 101 deviations during tasks and 70 during the matching baseline driving.

Density Effect

Of 157 tasks in the high-density condition there were 56 deviations during tasks and 40 during the matched baseline driving. There were significantly more deviations during high-density tasks over baseline ($p = 0.0278$).

Element Effect

The Listen and Compute element showed significantly more lane deviations than the baseline ($p = 0.0255$). There were 79 Listen and Compute tasks and during those there were 32 lane deviations. During the baselines of the same length there were 20 lane deviations.

During Listen, Plan and Compute tasks there were also a significant number of lane deviations ($p = 0.0237$). There were 69 instances of these difficult tasks and they resulted in 27 lane deviations compared to 16 deviations in the matched baseline driving.

Conversation Task Effect

Conversational tasks overall showed a significant increase in lane deviations compared to the baseline condition ($p = 0.0082$). In the course of 39 conversation tasks there were 15 deviations while there were only 5 during matched baseline driving. Additionally, the Paced Conversational tasks showed an increase in lane deviations with 9 occurring in 22 tasks. Since baseline driving resulted in only three lane deviations in the same period this result was also significant ($p = 0.0414$). Non-paced tasks were not significantly different from baseline driving.

Age Effect

Older drivers showed significantly more lane deviations during tasks than during the baseline ($p = 0.0056$). Older drivers completed a total of 60 tasks and during those there were 25 lane deviations. During the baselines of the same length there were 12 lane deviations.

LONGITUDINAL CONTROL

Longitudinal vehicle control measures include four variables that are used to examine speed and vehicle separation: minimum speed, speed variance, minimum headway, and headway variance.

Minimum Speed

Age Effect

Older drivers had lower minimum speeds during tasks than other age groups ($p = 0.0488$). The mean minimum speed for older drivers was 46.0 mph. For middle and younger age groups, the means were 48.3 and 49.5 mph, respectively. This result indicates that older drivers have a preference for lower speeds. This reduced speed may be a compensatory behavior intended to reduce their workload. While all drivers tended to slow down during higher density tasks it was more pronounced for the older age group.

Conversation Age Effect

Older drivers exhibited the same speed behavior by age group during conversational tasks as they did during IVIS auditory tasks. Older drivers had lower minimum speeds during tasks than other age groups ($p = 0.0299$). The mean minimum speed for older drivers was 46.2 mph. For younger and middle age groups, the means were 48.4 and 49.6 mph, respectively. This result supports the observed preference older drivers have for lower speeds.

Speed Variance

Density Effect

The one-way analysis showed that speed variances were longer during higher density tasks than in the baseline or low-density condition ($p = 0.0001$). Variances were also shown to be considerably larger for the high-density condition than for the low-density condition in the full model analysis ($p = 0.0022$). High-density tasks had a mean speed variance of 6.02 mph. For baseline and low-density conditions, the means were 3.93 and 3.51 mph, respectively. This result indicates that drivers have more difficulty controlling their speed during higher density tasks. Headway data suggests that the changes in speed are mostly due to reductions in speed and increasing headway distances during tasks.

Minimum Headway

Age Effect

Older drivers had significantly longer headway distances than other age groups ($p = 0.0009$). Older drivers followed at a mean minimum separation distance of 1.50 seconds. Younger and middle age drivers had mean minimum separations of 1.01 and 0.89 seconds, respectively. Older drivers have more conservative following behavior than the younger populations. However, the average time separation for all drivers was less than the three seconds

of separation recommended by the Virginia Department of Motor Vehicles () for a normal driver remain safe.

Density Effect

Analyses showed a difference between the low and high-density conditions in the full ANOVA model ($p = 0.0005$). However, there was no such effect in the one-way analysis when baseline was included.

Conversation Age Effect

The results of the conversational tasks were very similar to the IVIS task results. Older drivers had significantly longer headway distances than other age groups ($p = 0.0076$). Older drivers followed at a mean minimum separation distance of 1.39 seconds. Middle age and younger drivers had mean minimum separations of 0.96 and 0.94 seconds respectively. Older drivers have again demonstrated more conservative following behavior than the younger populations. All drivers compensated for the higher density tasks by increasing their headway distance. Older drivers compensated significantly more than other age groups for high densities by increases in headway.

Headway Variance

Age Effect

The older driver age group had a larger variance than other age groups ($p = 0.001$). Older drivers had a variance of 0.19 seconds. Middle and younger age groups had variances of 0.081 and 0.065 seconds, respectively. The variance of headway is likely due to the larger headway distances that are maintained by older age groups which increases their variance. Increased distance from a target has the effect of reducing the ability to resolve the separation distance. Similar closure rates and distances would not be as apparent at longer separation distances. Older drivers often chose speeds sufficiently low to cause them to become uncoupled from the lead vehicle. This is a form of task shedding since there is a lower workload associated with driving on an open road than when following a vehicle.

Density Effect

In the full ANOVA model higher density tasks had the effect of causing larger variances in headway for all ages of drivers than the lower density tasks ($p = 0.0041$). However, in the one-way model high and low density tasks were not significantly different. High-density tasks were found to have significantly larger headway separations than baseline driving ($p = 0.0035$). High-density tasks had a headway variance of 0.121 seconds. Low-density tasks showed a headway variance of 0.085 seconds. Finally, the baseline condition was found to have a headway variance of 0.066 seconds. The result is shown in the graph in Figure 8.

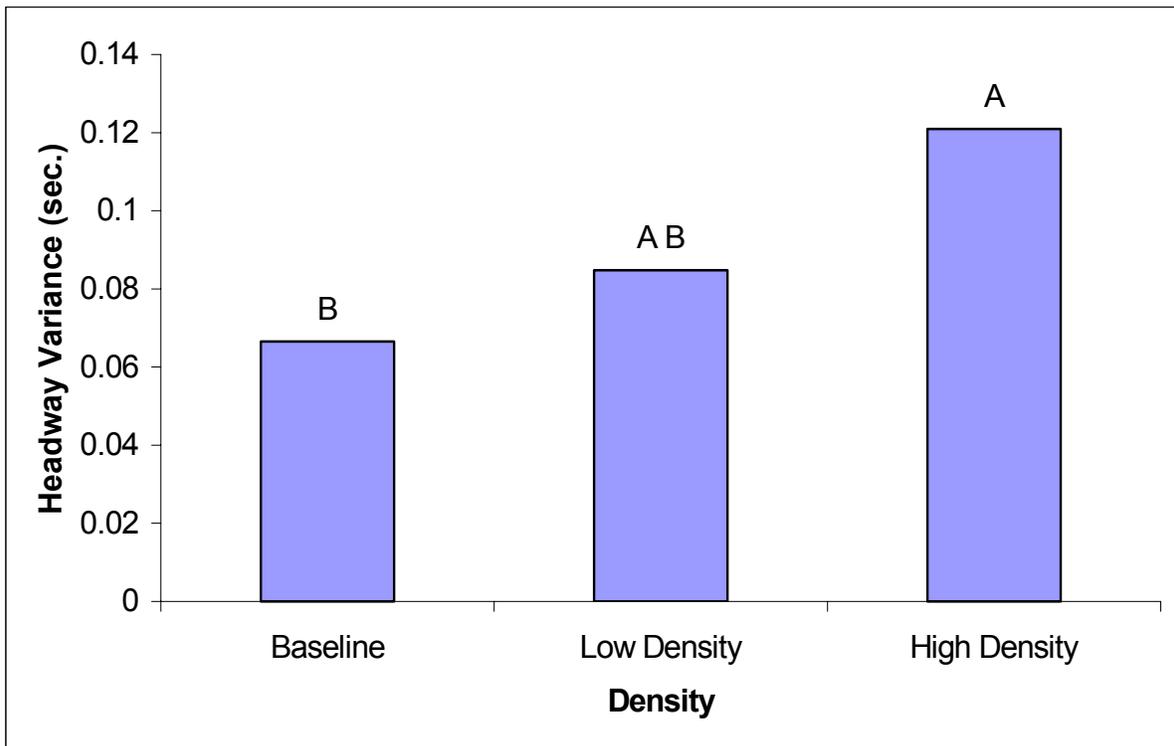


Figure 8 Headway Variance for Density levels

EYE GLANCE

Eye glance behavior is one of the more powerful tools for assessing driving safety based on how drivers focus their attention (Dingus, Antin, Hulse, and Wierwille, 1988). Visual information from the forward roadway is the only way to maintain lateral position, headway distance and to avoid obstacles while driving. Additionally, situational awareness information (including the location of other cars, road signs, and car warning indicators) is gathered from the surrounding environment from mirrors and glances to other locations.

Four separate measures of eye glances were used to assess differences in the visual patterns of drivers during tasks compared to periods of baseline driving. These four variables were the number of total eye glances, roadway eye glances, mirror eye glances, and other eye glances. Total eye glance results (Table 5) indicated that the tasks caused drivers to change their viewing location much less often than during normal driving. Drivers made fewer and longer

glances to the front roadway during tasks. Glances to other locations including mirrors and instruments occurred less often during tasks. The majority of task time was spent watching the forward roadway with very little scanning of the environment.

Table 5 Eye Glance Results (Paired T-tests)

Category		Total Glances	Road	Mirror	Other	N
OVERALL	p-value	0.00000	0.00000	0.00000	0.00000	304
	observed	4680	3562	676	443	
	base	8419	6163	1288	968	
AGE						
	Young	p-value	0.00000	0.00000	0.00000	133
		observed	1915	1570	174	
	base	3292	2480	347	465	
Old	p-value	0.00000	0.00000	0.00003	0.02433	60
	observed	565	411	85	69	
	base	1266	900	252	114	
Middle	p-value	0.00000	0.00000	0.00000	0.00000	111
	observed	2200	1581	417	202	
	base	3861	2783	689	389	
DENSITY						
	3 x 3	p-value	0.00000	0.00000	0.00000	108
		observed	1261	955	173	
	base	2408	1769	363	276	
5 x 4	p-value	0.00000	0.00000	0.00000	0.00000	157
	observed	3082	2338	460	285	
	base	5186	3756	806	624	
Conversation	p-value	0.00000	0.00000	0.00309	0.00508	39
	observed	341	272	43	26	
	base	841	649	120	72	
ELEMENT						
	Listen	p-value	0.00008	0.00068	0.01751	43
		observed	643	498	92	
	base	1015	753	133	129	
LP	p-value	0.00000	0.00000	0.00040	0.00000	74
	observed	1010	750	160	100	
	base	1783	1297	266	220	
LC	p-value	0.00000	0.00000	0.00000	0.00000	79
	observed	1241	929	196	116	
	base	2414	1745	390	279	
LPC	p-value	0.00000	0.00000	0.00001	0.00007	69
	observed	1536	1173	212	152	
	base	2463	1788	398	277	
Paced	p-value	0.00012	0.00002	0.04666	0.03240	22
	observed	210	162	33	15	
	base	487	372	77	38	
Non-Paced	p-value	0.00001	0.00002	0.00185	0.04259	17
	observed	131	110	10	11	
	base	354	277	43	34	

Eye glance results were similar for all task elements, densities and age groups. In each case, the task resulted in significantly fewer eye glances. In many cases, the baseline showed as many as three times the number of glances as the task condition.

The eye glance results demonstrate a narrowing of visual focus that is a clear indicator of reduced situational awareness. Drivers gathered and processed less information about other vehicles to the sides and in their rear and checked speed and other vehicle status indicators less often. Some drivers spent the entire duration of an IVIS task or conversational task (simulated cell phone call) without checking their mirrors or their speed. The reduction in situational awareness occurs for the entire duration of the task.

Eye glance data shows a clear reduction in situational awareness during tasks while subjective questions indicate that drivers did not perceive any reduction in their awareness. This is a major concern for driving safety since drivers cannot change their behavior when they do not perceive a reduction in their awareness.

Drivers spent longer periods of time viewing the forward roadway during tasks while the number of lane deviations and variances in headway distance increased. Review of eye glance data might suggest that the driver was focusing more attention on the forward roadway and should subsequently drive more safely. However, the fact that drivers were crossing lane lines more often and suffering other performance decrements suggests that driver attention may have been on the SIP task to the point that their driving performance suffered even while they were looking forward with their hands on the wheel.

SECONDARY TASK PERFORMANCE

Completion Time

A secondary task can cause a driving safety incident in two important ways. The first is through direct interference with the driving task which occurs when the instantaneous task difficulty is too great. When secondary task demands exceed resource capacity there will be a significant degradation in driving performance. This critical overloading type incident can occur when the SIP demands from a task, which the driver cannot or will not avoid, exceed the available cognitive resources of the driver causing serious degradation in one or more aspects of driving performance resulting in an accident. The second type of safety incident is concerned with the increased probability of having an accident over long periods of slightly impaired driving. A non-critical level of SIP load over longer periods of time will increase the probability of a safety incident.

The completion time of a task will affect both of these types of safety incidents. In the case of critical overloading risk extending the duration of a task can reduce the urgency, intensity and resulting intrusion of SIP tasks on safe driving. Therefore, for SIP tasks at or near the cognitive capacity of the driver, extending task duration may reduce the difficulty and the subsequent immediate risk. However, for all non-critical levels of task difficulty the duration of exposure is proportional to the risk and should be minimized. Higher SIP load (including both complexity and short term memory load) is also proportional to risk for non-critical levels of SIP and should also be minimized. The overall measure of safety includes both the critical incidences caused by overloading cognitive resources and in total exposure to reduced resource capacity over time. Time spent completing in-vehicle tasks should generally be minimized to the greatest extent possible. However, in critical loading cases elongation of tasks may reduce critical incidences.

Element Effect

Completion time analysis (figure 9) showed that increasing levels of element difficulty were associated with increases in task duration ($p < 0.0001$). Post hoc analysis indicated that

each level was significantly different from each of the others. As expected, the Listen Only tasks took the least time at 35.1 seconds. Listen and Plan tasks took a significantly longer average time of 40.0 seconds. Listen and Compute tasks were longer at an average of 47.2 seconds. The hardest tasks, Listen, Plan and Compute, took the longest time at an average of 63.3 seconds.

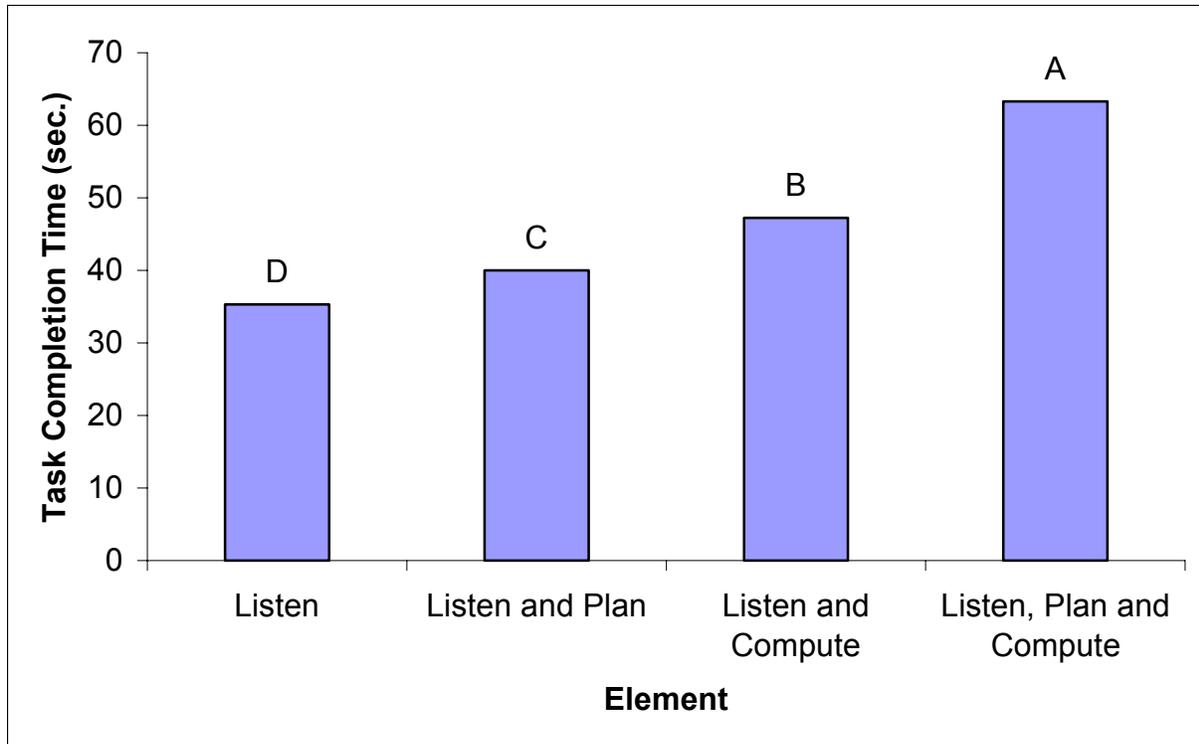


Figure 9 Completion Time for Elements

Density Effect

The completion time variable showed longer mean times for higher density tasks. The low-density condition had a mean of 31.2 seconds. The higher density condition had significantly longer ($p < 0.0001$) completion times. Tasks in the high-density condition were almost twice as long as the low density condition, with a mean time of 59.3 seconds.

Conversation Task Effect

The type of conversation showed a significant difference in task completion time ($p = 0.009$). Paced conversation tasks took a mean time of 48.5 seconds to complete. Non-paced conversation tasks were longer, with a mean completion time of 56.0 seconds. As expected, without the computer to pace drivers in their response, it took them longer to complete the tasks.

Task Errors

Element Effect

Only the two elements which had unambiguous answers were analyzed for errors. The analysis showed that the Listen and Compute element had a significantly higher error rate ($p = 0.0046$) than the Listen Only element. The Listen Only element had an error rate of 4%. The Listen and Compute element had an almost five-fold higher error rate of 19%. Errors on secondary tasks are an indication of increased driver workload. As a driver becomes overloaded by the combination of tasks he/she is doing, his/her performance on secondary tasks will usually drop off before the primary task performance.

Although this study focused on driving performance tasks, errors are an interesting and important issue to examine. Increases in errors are an indication that driving performance is suffering. The IVIS tasks are secondary to the driving task and are shed as the combination of tasks being processed by the driver increases his/her workload to a sufficiently high level. This can be seen in the increases in the number of errors while completing the computational tasks.

Skipped Tasks

During the study drivers were permitted to skip any task that they felt was too difficult or that they felt uncomfortable doing while driving. Additionally, the driver was provided with the ability to repeat the presentation of task information. Skipping or repeating the task information is a way of shedding the secondary task when the combined load of information and driving is too high. Skipped tasks were not statistically analyzed however the raw data for the skipped and repeated tasks is included in Appendix A-5. The majority of tasks skipped and repeated were the more difficult tasks.

SUBJECTIVE MEASURES

Perception of Situational Awareness

Element and Density Effects

Drivers were unable to detect differences in their situational awareness as a result of increased complexity or short term memory demands. It is important to note that this occurs despite the clear degradation in driving performance discussed in other measures.

Age Effect

Older drivers rated their situational awareness significantly higher than other age groups ($p = 0.0198$). Older drivers had a mean perceived situational awareness of 95.5. Younger and middle age groups had more conservative ratings of 87.2 and 82.6, respectively. Older drivers felt very confident of their awareness of their surroundings.

Conversation Age Effect

Conversational tasks showed an identical age result to the IVIS auditory-type tasks. Older drivers rated their situational awareness significantly higher than other age groups ($p = 0.0213$). Older drivers had a mean perceived situational awareness of 95.4. Younger and middle age groups had more conservative ratings of 90.5 and 87.4 respectively.

Older drivers consistently rated their situational awareness higher than other age groups. The increase in lane deviations for older drivers, as well as other decreases in performance measures conflict with these high ratings of situational awareness. These results may indicate that drivers are unaware of or unable to accurately assess the level of degradation of their situational awareness during SIP tasks.

Perception of Workload

Element Effect

Drivers rated their workload levels on the modified NASA-TLX scale. The resulting ratings showed a significant increase in workload corresponding to task element difficulty increases ($p = 0.0001$). Driver rankings are the mean of the three selected workload sub-scales and have values on a scale from 0 (easy) to 100 (difficult). Listen (search) tasks had the lowest rating for workload, with a mean value of 14.4. Listen and Plan tasks were rated significantly harder, with a mean value of 23.7. The elements including computation were rated with the highest workload. They were significantly harder than Listen and Plan elements and had mean values of 27.7 and 27.8 for Listen, Plan and Compute, and Listen and Plan, respectively. The relationship of the element means is shown in Figure 10.

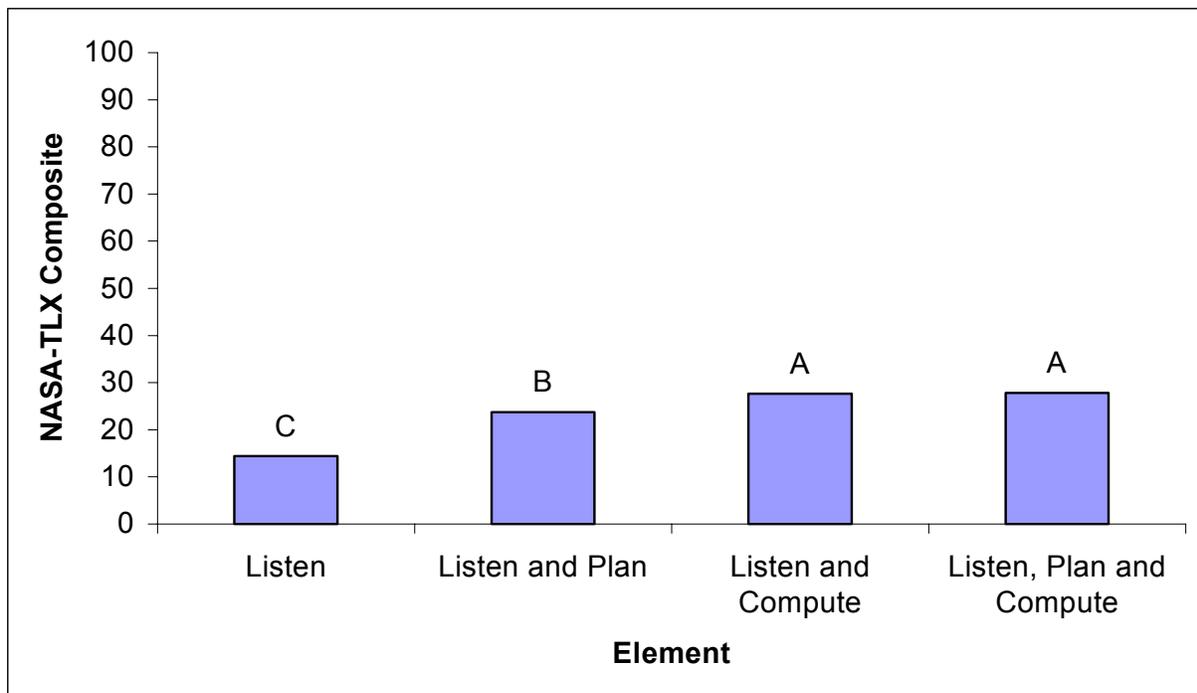


Figure 10 NASA-TLX Subjective Workload for Elements

Density Effect

Drivers perceived significantly more difficulty in high-density task conditions than low density ($p = 0.0001$). Low-density tasks had a mean value of 22.7, whereas high-density tasks had a mean of 25.6.

The NASA-TLX workload measure indicated that drivers were able to assess their task workload and differentiate between differing levels of workload. Ratings of task difficulty ranked element levels in the order expected. In addition, the density levels were ranked in increasing order. The interesting result with the workload evaluation was that all subjects ranked their workload levels very low in relation to the extremes of the scale. This leads one to believe that the tasks were not considered difficult by the subjects, even though they were clearly causing a negative impact on driving performance.

DISCUSSION AND CONCLUSIONS

Past studies of IVIS displays (Collins et al., 1997; Hanowski et al., 1997) do not address the impact of increased cognitive demand on driving performance. However, they do identify concerns associated with reduced information-processing capacities of older drivers. The transportation research literature does not directly address the impact of increased cognitive loads on individual or composite measures of driving performance.

Epidemiological studies of cell phone use by Redelmeier and Tibshirani (1997) and Violanti and Marshal (1996) have shown associated increases in the risk of accidents which are comparable to blood alcohol levels above the legal limit. Simulator and on-road studies by (Serefin, Wen, Paelke, and Green, 1993b; Stein, Parseghian and Allen, 1987) which focus on dialing, receiving and placing calls on cellular phones have shown significant effects on driving performance. These past studies did not model the interactive communications generated by cellular telephones. They did not include the intrusion of personal and job related information content and interactive tasks which are likely to consume cognitive resources normally reserved for driving. The results below detail the driving performance effects of auditory IVIS and conversational tasks, which model the cognitive component of cell phone use.

Because studies involving human cognitive processes are particularly sensitive to experimental conditions, a synopsis of the constraints this protocol imposed on drivers, road conditions and tasks is given here as a basis for interpretation of the study results that follow. This synopsis is also intended to provide a context for projecting the results into the unconstrained, cognitively demanding driving environment faced by automotive designers and regulators entrusted with public driving safety.

The magnitude of the safety risk associated with in-vehicle cell phones and IVIS is a function of: 1) The availability of information processing resources not required for the primary driving task; 2) The level of mental workload required to tend to the cell phone or IVIS display; 3) The driver's awareness of the mental workload and any detrimental effect on driving performance, i.e. situational awareness, and thereby, their compensation for or sloughing of the secondary task; 4) The severity and duration of any resulting degradation in primary driving task performance.

The availability of SIP resources for secondary tasks is dependent on the cognitive capacity of drivers and the level of resources needed to safely complete the primary driving task and other cognitive activities not required for driving. In-vehicle research includes the inherent variability between humans compounded by operating vehicles on public roads. These factors can dramatically affect both the cognitive capacity of the driver and the non-task workload. In order to reduce variability in driver performance not due to the experimental tasks and to ensure the safety of participants the experimental design eliminated or standardized these variables whenever possible.

In order to eliminate fatigue or hunger which might diminish cognitive capacity, drivers were given rest breaks and snacks. Drivers were given a questionnaire prior to driving to insure they were in good health and had no impairments or disabilities.

Training and motivational issues were addressed by giving explicit training and by using simple tasks. Drivers were aware of the duration of the study and were paid for their time.

To the maximum degree possible, non-driving activities normally found in passenger vehicles that impose mental workload were eliminated. There were no competing information sources such as vehicle warnings, unusual traffic controls or mechanical idiosyncrasies of the vehicle. There was no competing auditory information from other people, radio or other in-

vehicle devices. There were no competing manual tasks such as food or beverages, dialing, or manipulation of devices in the vehicle. Personal items such as purses, sunglasses, or papers were not accessible to the driver during task presentations.

All driving was conducted in a relatively benign driving environment. There was no bad weather, darkness, traffic, tight curves, detours or other navigation including stops or turns. All driving was conducted in 55 or 65 MPH zones. There was no time pressure associated with the travel. Tasks included no time pressure except to a small degree in paced conversation tasks. Drivers could have task information repeated or could skip tasks whenever they wanted to. Tasks were not completed if the passenger seat researcher felt the driver was distracted or any of these preceding conditions were present. Overall the driver's primary (driving) task workload was very low.

Almost all of these controls reduced the amount of mental workload and risk to drivers. These experimental conditions have the secondary effect of increasing the availability of cognitive resources for the experimental tasks. Thereby, all results are likely to underestimate the impact of IVIS and cell phones on driver safety in the unconstrained driving environment.

The level of mental workload required to tend to cell phones or IVIS displays is highly variable. Interactive cell phone communications include personal and job-related activities that can be emotionally charged, urgent, and highly complex. Relative urgency is contingent on factors specific to individuals and situations, and extremely important information could potentially take precedence over safe driving. Replication of emotionally intense content of the type found in cellular telephone conversations would be extremely difficult and dangerous. Pre-testing showed that tasks as complicated as realistic cell phone tasks would be skipped by drivers in the test environment even when they did not include emotionally charged information. Therefore the conversational tasks were very simple and contained no emotional, important, engrossing, or confusing content.

Additionally, in order to focus on the cognitive component of IVIS and cell phone use, the tasks required no visual input or manual control for output. The only physical component of the task was a rarely used button on the steering wheel that subjects could press to repeat task information. All other information including tasks, probe questions, responses and test related dialogue was conveyed verbally.

In this research information content and cognitive complexity levels of tasks were manipulated to measure the impact of increasing cognitive workload on driving performance. Two independent variables were used to generate increasing levels of SIP for the IVIS study. They are two levels of information density which increase the demand for short term memory and four decision making elements with increasing levels of information processing complexity.

This study measured the impact of increasing cognitive workload from conversational and IVIS tasks on situational awareness and on the severity and duration of degradation in primary task performance. Results for the Conversational Task Study, for Age, and the IVIS Study are as follows.

CONVERSATION TASKS

Conversation tasks were designed to test the impact of the cognitive load from cellular phone conversations in the absence of the visual and physical input and output components of cellular phone use. In order to control the content and duration of the conversation tasks, they were simplified as a series of consecutive questions that required only short answers. This simplification of an actual live conversation affects the results in several important ways. Because questions were designed to be short answers, the processing that a driver must do in

order to respond to complex information in an intelligent way was not present. The duration of the tasks was less than one minute which is considerably less than the average duration of cellular telephone calls. There was no emotionally charged content, and little of the increased urgency that is associated with the expectation of a response by other parties involved in a phone call. Statistically, the results were less likely to show any significant effects since the most detrimental aspects of conversations were excluded from the study.

The conversational tasks were presented in two ways. In the paced format, the computer presented the task as a recording. This format forced the subject to answer the questions with a limited response time. In the non-paced format, the questions were asked by the front-seat experimenter, who waited for a verbal response to each question before continuing. The pacing of conversations was an attempt to replicate the urgency of response that results from the expectation of the other party in a phone call. The mean completion time of 48.5 seconds for paced tasks was statistically shorter than the 56.0 seconds for non-paced tasks. The time pressure difference was not sufficient to impact the vast majority of performance measures. However, there was a statistical increase in lane deviations between baseline and the paced conversational task treatments.

Drivers showed decreased ability to control their headway, speed and steering during all conversational tasks. There was also a clear reduction in scanning behavior. Fewer glances were counted for all conversational tasks as compared to baseline conditions. Drivers reduced their mirror checking and began taking fewer and longer glances at the forward roadway. These results for conversational cognitive workloads are consistent with the findings of Hulse, Dingus, Fischer and Wierwille (1989), who showed a narrowing of scanning patterns were associated with in-vehicle tasks. These results suggest that a significant portion of the results they observed may come from the cognitive component of their tasks. Long glance duration coupled with the reduced ability to track and control for objects in the front roadway is a serious concern. It appears that the drivers, without being aware of it, are shedding visual information from the primary task in favor of processing secondary task information.

The potential danger from cellular phone use is apparent in two critical measures of driver performance - lane deviations and minimum headway. During conversation tasks, which each lasted less than 1 minute, drivers strayed out of their lanes a statistically significant number of times. While older drivers maintain longer headway distances, their time separation was only 1.39 seconds as compared to 0.95 and 0.96 seconds for younger and middle aged drivers. Driver safety courses generally recommend a time separation of 2 seconds. These results from simplified simulated conversations, which have no consequence for the driver, suggest negative impacts for real cell phone conversations in modern urban or freeway traffic. The changes in driver behavior observed here may help explain the known correlation between accidents and cellular telephone calls documented in epidemiological studies such as Redelmeier & Tibshirani (1997). There is little doubt that on-road and simulator studies focusing on equipment and the activities of placing and receiving calls have identified activities which have unacceptable driving safety consequences. In light of the results reported here, it also seems unlikely that efforts to design and mandate hands free cellular phone use will result in systems that are safe to use while driving.

One of the most important results of this study is that drivers do not realize their own impairment during high workload. Therefore, they are less likely to make a conscious decision to avoid safety problems by eliminating or modifying their cell phone conversations. Although drivers can recognize different levels of workload they don't perceive any as having a major influence on their driving performance. Even during the most complicated tasks in this study drivers rated their workload at most 27 on a scale from 1 to 100. Drivers in the study did not

acknowledge any difference in their own situational awareness even while their visual scanning and driving performance was suffering. Driver mental resources which are already partially consumed by the task may be insufficient for self-appraisal of performance.

The observed deficiencies in driver awareness may seriously limit the options for reducing the risk. Because driver performance is impacted at such low levels of conversation, elimination of cellular phone use while driving may be the only prudent course of action. If, as these results indicate, drivers cannot perceive a change in performance while using phones and therefore, do not perceive additional risk of personal harm, then, it is unlikely that they will voluntarily eliminate or even restrict their own on-the-road use. To the contrary, decreasing costs, miniaturization, expanding geographic coverage, and rapidly improving clarity and range are increasing their popularity. The devices and on going conversations move seamlessly from home to car to office blurring the distinctions in drivers' minds. Unfortunately, from a transportation safety perspective, phone manufacturers and phone companies are continually adding internal functions and external communications capabilities such as E-mail and internet access. They are dramatically increasing the ability to deliver cognitive workload to drivers. Cellular phones provide unprecedented flexibility and freedom. Efforts to restrict on-road use will not be popular. A well designed, factually based, nation wide campaign to inform drivers, could reduce on-road use and lead to a more positive public attitude regarding regulation.

The deficiencies in driver awareness also limit the options for reducing the risk when they do chose to use cellular phones on the road. Since drivers have difficulty monitoring their own performance, they are less likely to modify or terminate conversations. Therefore, much of the responsibility for improving safety falls on the design and manufacture of the devices, and on regulation of their inclusion and use in vehicles.

It will probably prove impossible to reduce risks to an acceptable level by eliminating or reducing the cognitive content of conversations even if privacy issues could be resolved. Even the low levels of additional auditory-based information in simple questions and answers caused a reduction in visual scanning, diminished processing and awareness of visual information necessary for safe driving, and decreased ability to control headway, speed, and steering. It is hard to imagine a real conversation with less content or a more benign driving environment.

The results do suggest that equipment and techniques like those used here could be used to alert drivers when conversations are causing unsafe driving performance; thus, overcoming the perceptual deficiency, and thereby enabling drivers so that they can modify their own behavior to reduce the risk of accidents. While the results clearly demonstrate the impact of Supplementary Information Processing (SIP) workload on driving performance, no single measure is sufficient to indicate dangerous losses in situational awareness or unacceptable cognitive workload levels. Variation of SIP loads impacted drivers and the individual driving performance measures differently. These results suggest a complex interaction between variations in the difficulty of driving tasks, the complexity and perceived importance of secondary tasks, and the ability and preferences of drivers. Even in the simplified test environment, the interactions determine when, which and how primary driving tasks will be interrupted and thereby define the unique risk from each different conversation.

Drivers often process visual, auditory, manual, and speech, information from the primary driving task and a wide variety of supplemental tasks. There is an enormous variability in complexity, emotional content and urgency of this information. How individuals respond to a particular call depends on their relationship to second parties, age, social training, motivation and a host of other factors. All of these factors can affect which measures of performance will be affected at any given time. It is not possible to predict from these studies which measures will be most impacted by variations in phone conversations. However, a composite of common driving

performance measures will clearly indicate the effects of SIP on driving performance. These results suggest using headway, lane deviation, and speed to monitor driving performance and eye glance data to monitor situational awareness. These measures were clearly sensitive to the conversation tasks as presented in this study and can be performed in many cases with off the shelf hardware. The four measures of vehicle control are simple, the connections to driving safety are direct, and the consequences of reduced capabilities are intuitively understandable by the driving public. Eye glance results and the concept of situational awareness may not be familiar to drivers, but they will easily understand the relationships. The data from this study is not sufficient to suggest an algorithm for relating cognitive load, to eye glance behavior to relative risk. Eye glance behavior might provide a means for preventing extended “cognitive capture”.

AGE

Drivers over 65 years old have reduced eyesight and decreased short-term memory abilities, as well as slower reaction times (Transportation Research Board, 1988). This would seem to indicate that older drivers are at more risk while driving. In fact, older drivers (65 plus years) were shown to have less degradation in performance than the two younger age groups (18-24 years and 34-45 years) on several of the driving measures. This could be due to behavior that tends to compensate for their diminished abilities. Older drivers followed at longer distances and at slower speeds than other age groups. This gave them the advantage of having a longer period of time for reaction which mitigated the negative effect on headway and speed maintenance. The older age group had less steering variance which is an apparent reduction in control input to the vehicle. This could indicate more precise control of the vehicle which could result from the slower speeds maintained by older drivers. However, the number of lane deviations was significantly higher for older drivers. This suggests that older drivers may have been waiting longer between steering control inputs. Older drivers spent longer periods of time doing the tasks they were presented. This is likely to be the result of two different factors. First, the older drivers may have more difficulty in doing the tasks because of short-term memory requirements. The second is that older drivers may compensate for the increased workload by spreading the task out over time, when as in this experiment, there is no time pressure to complete the task. This compensatory behavior is a likely reason that only the lane deviation measure showed increased safety risks for the older driver age group.

While all drivers could identify differences between workload levels, their assessments of workload were consistently low across all age groups. They all consistently suffered significant degradation in driving performance while perceiving workload levels in the bottom quarter of the scale.

Older drivers were particularly confident in their situational awareness with statistically higher ratings than the other two age groups. There are two possible reasons for this high situational awareness rating. The first is that they actually had better awareness because their longer headway and reduced speed coupled with longer task completion times allowed for more scanning of the environment. However, the eye glance data combined with headway data support a different conclusion. The second possibility is that older drivers’ reduced capability contributes to a condition where secondary tasks and driving impact their ability to accurately assess situational awareness. It is also consistent with the observation that drivers were unable to maintain headway distances during tasks despite increasing the amount of time they spent looking forward. It fits with the idea that they were suffering “cognitive capture” from the conversation tasks which limited processing of other information.

All three age groups were unaware of their reduced situational awareness despite significant degradation in their driving performance and dramatic detrimental changes in eye-glance surveillance of the driving environment. It appears that their ability to perceive the detrimental impacts of cellular phone use or IVIS, and therefore their ability to compensate for or terminate in-vehicle tasks, is diminished as the cognitive load and safety risk from continuing the tasks increases.

The performance of the older age group suggests a possible approach for reducing safety risks associated with the more difficult IVIS tasks. Secondary task information can cause driving safety incidents when the peak task difficulty is too great. Increases in SIP including both task complexity (element effect) and short term memory demand (density effect) increase the magnitude of the distraction and the resulting safety risk. Just extending the duration, without otherwise modifying the task can reduce the urgency, intensity and resulting intrusion on safe driving. For some types of SIP tasks that exceed the cognitive capacity of the driver, it may be possible to partition the task into a longer duration series of simpler tasks. Extending the duration can reduce both the difficulty and the peak memory demand of IVIS secondary tasks and consequently the safety risks. Care should be taken to avoid the cumulative risk of extended lower levels of exposure to impaired driving, but they may be preferable to the immediate consequences of driving while severely overloaded.

Lengthening tasks to reduce risk applies only to IVIS tasks which contain a fixed amount of information and have a predictable impact on driving and not to cell phone tasks. Increasing the duration of cellular phone calls will most likely increase the safety risk. This is because it is not possible to modulate or predict the intensity, complexity or memory demands of cell phone conversations. Reducing the length of cell phone calls will reduce the risk from exposure and is likely to reduce the intensity, complexity and emotional content. Although it may be possible to control the length of cell phone calls, it would be difficult to regulate. These results suggest it may be useful to provide cellular phone training to drivers in an effort to convince them to totally eliminate use of cell phones while driving. More realistically, a campaign that encourages drivers to shorten conversations, or better yet, to ask other parties to accept a return call from a stop could have a tremendous positive effect.

Safety risk includes both the critical incidences caused by overloading cognitive resources and chronic exposure to lower level resource demands over time. Time spent completing in-vehicle tasks should generally be minimized to the greatest extent possible. However, in some cases, extending the duration of IVIS tasks may help reduce the risk of critical safety incidences.

IVIS TASKS

Element (Task Complexity)

Increasing information processing element difficulty negatively affected driver performance on the measures of speed, headway variance, maximum steering position, eye glances and lane deviations. Task completion time increased with task complexity. The Listen and Compute, and the Listen, Plan and Compute elements resulted in a higher error rate than the Listen Only element level. Drivers correctly perceived relative difficulty in the task elements on the subjective workload evaluations. Forward eye glance duration increased with task complexity. Drivers did not perceive any change in situational awareness.

Density (Short-term memory levels)

The results of this study suggest that overloading the short-term memory represents a much larger intrusion into the primary task of driving than the type of decision-making element. This is the reason such clear effects were shown in almost every variable by density. Degraded driving performance measures included lane deviations, speed variance, minimum headway, headway variance and eye glances. The completion time for the tasks was longer. Eye glance analysis showed a narrowing of focus with longer and fewer glances to all locations except the forward roadway. They did not observe any change in situational awareness. Drivers perceived higher workload levels as density increased. Their perception of increasing workload is supported by the driving performance measures, but this makes their very low appraisal of even the highest density workload an alarming misperception.

Summary of IVIS Tasks

Both the increases in task difficulty and the increases in task density resulted in increased duration of forward eye glances. As with the conversation tasks, drivers gathered and processed less information about other vehicles to the sides and in their rear and checked speed and other vehicle status indicators less often. Some drivers spent the entire duration of an IVIS task without checking their mirrors or their speed. Additionally, as during the conversation tasks, drivers showed decreased ability to control their headway, speed, and steering. Although the increases in the duration of each glance might be expected to indicate increased forward roadway attention, this conclusion is inconsistent with the observed degradation in driver performance. The reason for this discrepancy is that although drivers are viewing the forward roadway they are not processing the information they receive from it to the degree that they do in baseline driving conditions. This result is believed to be an indication of “cognitive capture” a situation where secondary task information processing causes a failure to process primary task visual information. The auditory tasks are in fact significantly interfering with, and consequently negatively impacting, driving performance. During both auditory IVIS and conversation tasks, driving performance suffered even while they were looking forward with their hands on the wheel.

The results of the study indicate significant impacts of auditory IVIS route selection tasks on driving performance which were similar to the conversation task results. Increased cognitive load from IVIS secondary tasks resulted in reductions in performance on each of the driving measures. This included speed variance, minimum headway and headway variance, maximum steering position, lane deviations, and eye-glance behavior. Concurrently, they took longer to complete secondary tasks and committed more task errors on more demanding tasks. Subjective analysis showed that while drivers correctly perceived a difference in mental workload for task elements and densities, they consistently rated the most difficult task in the bottom quarter of the absolute scale even while driving performance measures suffered. Furthermore, eye glance data shows a clear reduction in situational awareness during tasks. Surveillance of instruments and mirrors decreased as density and complexity increased. At the same time, subjective questions indicate that drivers did not perceive any reduction in their awareness. This is a major concern for driving safety since drivers cannot change their behavior when they do not perceive a reduction in their awareness.

The driving performance, workload perception and situational awareness results from IVIS tasks parallel the results from conversational tasks. As with the cellular phone type tasks, these results support restriction of secondary IVIS use by drivers while operating the vehicle. This is to say, limiting IVIS use to parked or non-driving situations. This approach would be very unpopular because drivers are rapidly becoming familiar with IVIS technology which is

desirable and useful. However, IVIS is clearly a part of the vehicle and cannot be transported as freely as cell phones which will facilitate their control.

As with the cell phone, because drivers cannot detect the degradation in driving performance, the burden for alleviating the safety problems with IVIS rests on automotive regulators and designers. As discussed in the conversation section, the methods used to measure headway, lane deviations, speed and eye-glance changes can be used to assist drivers when they choose to use IVIS while driving. As previously discussed, it is possible to alert drivers when increased cognitive workload from secondary tasks is interfering with safe driving. This would enable drivers to modify their own behavior allowing them to reduce the risk of accidents.

Unlike the situation with cellular phones, IVIS designers have the ability to intervene in the density, complexity, timing and pace of the tasks. The measures used in this study can be applied to improving the safety of drivers using IVIS systems in two important ways. First, new IVIS tasks or whole systems can be tested using a number of the measures from this study. This would allow the most difficult tasks to be avoided, simplified or spread over more time to reduce the safety risk. These and other studies suggest that managing the density component of IVIS will greatly reduce safety risk. Here, even the memory required to listen to three information items and choose between three routes with no need to interpret, compute or plan was sufficient to impair driving performance and reduce situational awareness. By managing complexity, and probably more importantly, density designers can reduce the age effect observed here and by Monty (1984), Dingus, Antin, Hulse, and Wierwille (1988), Ponds, Brouwer, and Van Wolffelaar (1988). In addition, it is possible to estimate the exposure rate and evaluate long term risks of systems prior to putting them on the road.

The second approach to reducing risk would be to develop systems that adapt real-time, to driving conditions, driver workload and ongoing measures of driving performance. In these adaptive systems, IVIS could delay presentations or modify content, duration, complexity and short term memory requirements based on the driving situation, driver preferences and driver performance. It could also include the ability to alert drivers when their performance or situational awareness becomes marginal allowing them to disregard or pause IVIS activities. This adaptive type of system would allow more information processing than would be possible for a more static type system designed to restrict cognitive workload below levels which might result in unacceptable safety risks across all driving conditions. However, adaptive systems would be much more complex and expensive.

IMPLICATIONS FOR DESIGN AND REGULATION

Past studies do not address the impact of increased cognitive demand from cellular phones or IVIS displays on driving performance. In these studies small increases in cognitive workload from these non-driving tasks caused significant degradation in drivers' ability to maintain headway, speed, and lateral control, disrupted the acquisition and processing of critical driving information, and reduced their situational awareness. Drivers were unaware that their driving was impaired. The results, and the implications for design and regulation are especially striking because:

1) The cognitive workloads were at the lower margins of cellular phone or IVIS use. The tasks were very simple and contained no emotional, important, engrossing, or confusing content. They did not include content characteristic of interactive personal and job-related communications that can be emotionally charged, urgent, and highly complex, and which have even more dangerous potential to consume cognitive resources normally reserved for driving. Tasks were shorter than one minute. Additionally, in order to focus on the cognitive component of IVIS and cell phone use, the tasks required no visual input or manual control for output. Information, including tasks, probe questions, responses and test related dialogue was conveyed verbally.

Time pressure to complete tasks was not a significant factor in driving performance. Drivers could have task information repeated or could skip tasks at will. Tasks were not completed when the passenger seat researcher detected distraction or any unplanned influence on cognitive workload.

2) Drivers were not subject to health problems, fatigue, or hunger which can diminish cognitive capacity. They were given rest breaks and snacks.

3) To the degree possible, motivational and training variability were reduced by specific training in the research vehicle and subjects were informed of the task duration and that they would be paid for the session with out regard to their performance.

4) Cognitive demands from other non-driving activities, which are part of normal driving conditions, were eliminated. There were no competing information sources such as vehicle warnings, unusual traffic controls or mechanical idiosyncrasies. There was no competing auditory information from other people, radio or other in-vehicle devices. There were no competing manual tasks such as food or beverages, dialing, or manipulation of devices in the vehicle. Personal items such as purses, sunglasses, or papers were not accessible during tasks.

5) The cognitive resources required for safe conduct of the primary driving task were extremely low. There was no bad weather, darkness, traffic, tight curves, detours or other navigation including stops or turns. All driving was conducted in 55 or 65 MPH zones on four lane interstate highway in excellent repair. There was no time pressure associated with the travel.

6) In-vehicle research includes the inherent variability between humans, compounded by operating vehicles on public roads, which can dramatically affect both the cognitive capacity of the driver and the non-task workload. The experimental conditions reduced but did not eliminate variability in driver performance not due to the experimental tasks. Almost all of these controls reduced the amount of mental workload and risk to drivers. This had the secondary effect of increasing the availability of cognitive resources for the experimental tasks. Thereby, all results are likely to underestimate the impact of IVIS and cell phones on driver safety in the unconstrained driving environment.

SITUATIONAL AWARENESS

Drivers' Perception of Workload

Do not expect drivers to detect and manage cognitive workloads of even trivial secondary tasks at levels which do not significantly degrade performance of the primary driving task. Drivers were able to accurately distinguish increasing levels of cognitive workload due to increasing information density or task complexity or conversations. However, despite consistent degradation in ability to maintain headway, speed, and lateral control, they did not perceive any level as having an impact on their driving performance. Drivers' highest workload rating was 27 on a 1 to 100 scale.

Surveillance

Small increases in cognitive workload from non-driving tasks while driving will significantly hamper drivers' acquisition and processing of critical driving information. Even small increases in cognitive workload due to task density, complexity or conversations resulted in fewer mirror and internal vehicle glances, and longer duration forward eye glances. Some drivers spent the entire duration of an IVIS task without checking their mirrors or their speed. This behavior has two separate but related consequences and associated implications for design and regulation:

First, drivers gathered and processed less information about other vehicles to the sides and in their rear. They checked speed and other vehicle status indicators less often. They were less aware of road signs and other features of the roadway. The impacts of this decrease were not a part of this study, but some driving instruction courses recommend checking mirrors every 10 to 15 seconds.

Second, drivers may be having more difficulty mentally processing what they do see. Despite increasing the amount of time spent looking forward, drivers' ability to maintain headway decreased as cognitive workload increased. These results for more purely cognitive workloads are consistent with the narrowing of scanning patterns observed by Hulse, Dingus, Fischer and Wierwille (1989), during in-vehicle tasks. Long forward glance duration coupled with the reduced ability to track and control for forward objects is thought to be an indication of "cognitive capture", where by, secondary task information processing causes a failure to process primary task visual information. The auditory tasks are in fact significantly interfering with, and consequently negatively impacting, driving performance.

During both auditory IVIS and conversation tasks, driving performance suffered even while they were looking forward with their hands on the wheel.

Situational Awareness

Drivers do experience significant degradation in situational awareness as a result of small increases in cognitive workloads, but are unaware of the change. This impairment is apparent in the degraded driving performance and eye glance surveillance which occurred during tasks. However, they are not aware of the changes in performance or the reduced situational awareness. Even though they correctly ranked the workload levels on NASA TLX tests given after each task, they did not report a change in their situational awareness in response to probe questions given at the same time.

It is possible that drivers are not capable of detecting situational awareness changes while secondary tasks and driving are consuming the majority of available cognitive resources. This hypothesis is supported by the decrease in eye glance scanning and the associated indication that

drivers experience “cognitive capture” from the conversation tasks which limits the processing of other information. It also fits with a possible explanation of older drivers statistically higher ratings of their own situational awareness. Possibly, older drivers’ reduced capability (Monty (1984), Dingus, Antin, Hulse, and Wierwille (1988), Ponds, Brouwer, and Van Wolffelaar (1988)) contributes to a condition where there are no cognitive resources available to perceive situational awareness.

Driver Impairment

One of the most important and alarming results of this study is that drivers underestimate their own impairment during increased workload. It appears that their ability to perceive the detrimental impacts of cellular phone use or IVIS, and therefore their ability to compensate for or terminate in-vehicle tasks, is diminished as the cognitive load and safety risk from continuing the tasks increases. It appears that simultaneously, drivers, without being aware of it, are shedding visual information from the primary task in favor of processing secondary task information, and are losing their ability to perceive their own loss of situational awareness.

One consequence is that drivers are not able to make a conscious decision to avoid safety problems by eliminating or modifying their cell phone conversations or IVIS use.

Since drivers are unable to recognize their own decreases in performance and continue to maintain their default risk levels, they put themselves at risk unknowingly. It becomes the responsibility of device manufacturers and regulatory agencies to provide controls on the amount of mental processing required of drivers. The responsibility for the safety of both the drivers choosing to use these devices and everyone else on the road, falls on the designers and regulators of information systems who are entrusted with public driving safety.

CELLULAR PHONES

Risk

The potential danger from cellular phone use is apparent in the two most critical measures of driver performance - lane deviations and minimum headway. During 39 conversation tasks, which each lasted less than 1 minute, drivers strayed out of their lanes a statistically significant and functionally risky 15 times. While older drivers were statistically better at maintaining headway distances, their time separation was only 1.39 seconds as compared to 0.95 and 0.96 seconds for younger and middle aged drivers. Driver safety courses generally recommend a minimum time separation of 2 to 3 seconds.

Drivers suffered a clear reduction in scanning behavior and diminished situational awareness. They were unable to maintain headway despite spending more time looking forward. It appears that the drivers without being aware of it, are shedding visual information from the primary task in favor of processing secondary task information. They don’t perceive the impact on their driving performance and don’t acknowledge any difference in their own situational awareness. They may not even be capable of detecting their performance failures because mental resources that would be required to assess their performance are already consumed by driving and the task itself.

Conversations were simplified as a series of short answer questions with no complex or emotionally charged content, and little of the increased urgency that is associated with the expectation of a response by other parties involved in a phone call. They excluded the visual and physical input and output components of cellular phone use. Statistically, the results were less

likely to show any significant effects since the most detrimental aspects of conversations were excluded from the study.

These results in a vehicle devoid of distractions, conducted in a totally benign driving environment, suggest potentially dire consequences from real cell phone conversations in modern urban or freeway traffic. The changes in driver behavior observed here may help explain the known correlation between accidents and cellular telephone calls documented in epidemiological studies such as Redelmeier & Tibshirani (1997). In light of the results reported here, it seems unlikely that hands free cellular phones will solve the safety issues associated with cell phone use while driving.

Unfortunately, from a transportation safety perspective, phone manufacturers and phone companies are continually adding internal functions and external communications capabilities such as E-mail and internet access. They are dramatically increasing the ability to deliver cognitive workload to drivers.

Cognitive overloading of drivers, especially in the auditory format, is an insidious detriment to safety.

Driver self regulation

It is likely most drivers who own cellular phones will not restrict their own use. Results from this study indicate that drivers often do not perceive changes in their performance while using phones and therefore, do not perceive any additional risk in their use. It is unlikely that drivers will voluntarily eliminate or even restrict their own on-the-road use. To the contrary, decreasing costs, miniaturization, expanding geographic coverage, and rapidly improving clarity and range are increasing their popularity. The devices and on going conversations move seamlessly from home to car to office blurring the distinctions in drivers' minds.

Regulatory action

The risks observed from cellular phone tasks identified in this study support restriction of cellular phone use while driving. Other on-road and simulator studies leave little doubt as to the danger associated with their use. They have been cited as the cause of traffic fatalities. Epidemiological studies leave little doubt that cellular phone use while driving is a significant risk factor. As previously discussed, there is little likelihood of non-regulatory control and the following discussion provides little hope for training or technology to reduce the risk after a driver decides to engage in a conversation.

Cellular phones provide unprecedented flexibility and freedom. Efforts to restrict on-road use will not be popular.

Public information campaign

A well designed, factually based, nation wide campaign to inform drivers, similar to the seat belt campaign, could reduce on road use and lead to a more positive public attitude regarding regulation.

This study suggests that driving safety may benefit from cellular phone training in cases when drivers are not convinced to totally eliminate use of cell phones while driving. Reducing the length of cell phone calls will reduce the risk from exposure and is likely to reduce the intensity, complexity and emotional content. A campaign that encourages drivers to shorten conversations, or better yet, convinces them to ask other parties to accept a return call later, "because they are driving" could have a positive effect. Although this study did not include urgent or emotionally charged content, convincing drivers to delay such conversations until they find the first place to park would be to everyone's benefit.

An effort which convinces the general public that cellular phone use while driving is dangerous might have even broader safety consequences if it reduces the willingness to talk to someone who is driving. Something similar to “friends don’t let friends drink and drive” might be particularly appropriate, given the comparability between the risk from using a phone and driving with high blood alcohol.

Future Designs

Reducing Cognitive Workload

It will probably prove impossible to reduce risks to an acceptable level by eliminating or reducing the cognitive content of conversations. First, even if privacy issues could be resolved, it may not be technologically feasible to predict the intensity, complexity or memory demands of cell phone conversations and it is not practical to intervene to modulate the cognitive demand.

Second, even the low levels of additional auditory-based information in simple questions and answers caused a reduction in visual scanning, diminished the processing and awareness of visual information necessary for safe driving, and decreased the ability to control headway, speed, and steering. It is hard to imagine a real conversation with less content or a more benign driving environment.

Reducing Exposure

Reducing the length of cell phone calls will reduce the risk from exposure and is likely to reduce the intensity, complexity and emotional content. It will be difficult to design a system to control the length of cell phone calls because the devices are transportable. It will be even harder to limit the restriction to only the drivers, and even more difficult to regulate.

Driving Performance Feedback

Equipment and techniques like those used here could be used to alert drivers when ongoing conversations are causing unsafe driving performance. This could alleviate the problems of cognitive capture and diminished situational awareness, thereby enabling drivers’ ability to modify their own behavior.

No single measure is sufficient because, even in the simplified test environment, the complexity and perceived importance of secondary tasks and the ability and preferences of drivers caused variation in both the kind and degree of impact tasks had on driving performance. In the unconstrained real world environment, drivers process visual, auditory, manual, and speech information from the primary driving task and a wide variety of supplemental tasks. There is enormous variability in complexity, emotional content and urgency of information. How individuals respond to a particular call depends on their relationship to second parties, age, social training, motivation and a host of other factors. Because all of these factors can affect performance, a composite of common driving performance measures will be needed to gauge the effects of cellular phone conversations.

These results suggest using headway, lane deviation, and speed to monitor driving performance and eye glance data to monitor situational awareness. These measures were clearly sensitive to SIP levels and can be performed with off the shelf hardware. The four measures of vehicle control are simple, the connections to driving safety are direct, and the consequences of reduced capabilities are intuitively understandable by the driving public. Eye glance results and the concept of situational awareness may not be familiar to drivers, but they will easily

understand the relationships between when and where they are looking and what they know. The data from this study is not sufficient to suggest an algorithm for relating cognitive load to eye glance behavior to relative risk.

Additionally, eye glance behavior measures and feedback might provide a means for preventing extended “cognitive capture”.

AGE

Older drivers (65 plus years) may compensate for increasing cognitive workload by extending task duration. Older drivers demonstrated statistically smaller, although still significant as compared to baseline, degradation in several performance measures than the two younger age groups (18-24 years and 34-45 years). These results conflict with studies showing that drivers over 65 years old have reduced eyesight and decreased short-term memory abilities, as well as slower reaction times (Monty, 1984; Dingus, Antin, Hulse, and Wierwille, 1988; Ponds, Brouwer, and Van Wolffelaar, 1988; Transportation Research Board, 1988) putting them at more risk while driving.

This may be due to behavior that compensates for some of the diminished capabilities. Older drivers spent longer periods of time doing the tasks, maintained lower minimum speeds, and followed at longer distances than other age groups. This may be, at least in part, because older drivers’ diminished cognitive capabilities, such as lowered short-term memory, make it more difficult to complete the tasks. Extending task duration also affords them more response time, potentially explaining why the older age group suffered less degradation in steering variance. Older drivers had significantly higher lane deviations than younger groups, which makes it quite likely that the better than expected lane deviation observations are the result of spreading the task out and are not due to more precise control.

Older drivers may be less aware of the impact on their performance. Older drivers’ excellent ability to identify differences between workload levels was similar to the younger groups. They also consistently assessed task workload levels in the bottom quarter of the scale while demonstrating significant degradation in driving performance. However, older drivers’ self appraisals of situational awareness showed statistically higher ratings than both younger age groups. One possible explanation for this result is that they actually have better awareness because their longer headway and reduced speed coupled with longer task completion times allowed for more scanning of the environment. Eye glance data, which clearly demonstrates decreased situational awareness, does not support this conclusion. The second possibility is that older drivers’ reduced cognitive capabilities contribute to a condition where secondary tasks and driving consume all available resources leaving none to assess situational awareness. This interpretation is supported by the eye glance data. It is also consistent with the observation that drivers were unable to maintain headway distances during tasks, despite increasing the amount of time they spent looking forward. It fits with the idea that they were suffering “cognitive capture” from conversation and IVIS tasks which limited processing of other information.

All three age groups were unaware of their reduced situational awareness despite significant degradation in their driving performance and dramatic detrimental changes in eye-glance surveillance of the driving environment. It is possible that diminished capabilities due to aging aggravate this problem. They all share an inability to perceive detrimental impacts from cognitive workloads characteristic of cellular phones and IVIS. They lack the ability to compensate for or terminate in-vehicle tasks and the deficiency worsens as cognitive workload increases and driving performance degrades in a frightening positive feedback loop headed

towards an accident. Drivers themselves are not capable of solving these performance problems. This situation demands the intervention of designers, manufacturers and regulators.

IVIS

Risk

The impact of IVIS tasks on driving performance and situational awareness are similar to those found in the cellular phone tasks. Both the increases in task difficulty and the increases in task density resulted in increased duration of forward eye glances. As with the conversation tasks, drivers gathered and processed less information about other vehicles to the sides and in their rear and checked speed and other vehicle status indicators less often. Some drivers spent the entire duration of an IVIS task without checking their mirrors or their speed. Additionally, as during the conversation tasks, drivers showed decreased ability to control their headway, speed, and steering. The auditory tasks are in fact significantly interfering with, and consequently negatively impacting, driving performance. During auditory IVIS tasks, driving performance suffered even while drivers were looking forward with their hands on the wheel.

Increased cognitive load from IVIS secondary tasks resulted in reductions in performance on each of the driving measures. This included speed variance, minimum headway and headway variance, maximum steering position, lane deviations, and eye-glance behavior. Concurrently, they took longer to complete secondary tasks and committed more task errors on more demanding tasks. Subjective analysis showed that while drivers correctly perceived a difference in mental workload for task elements and densities, they consistently rated even the most difficult task in the bottom quarter of the absolute scale even while driving performance measures suffered. Furthermore, eye glance data shows a clear reduction in situational awareness during tasks. Surveillance of the mirrors, side view windows and instruments decreased as density and complexity increased. At the same time, subjective questions indicate that drivers did not perceive any reduction in their awareness. This is a major concern for driving safety since drivers cannot change their behavior when they do not perceive a reduction in their awareness.

Regulation

As with the cell phone, because drivers cannot detect the degradation in driving performance, the burden for alleviating the safety problems with IVIS rests on automotive regulators and designers. Results of the IVIS tasks support elimination, modification and / or severe restriction of secondary IVIS use by drivers while operating the vehicle. This is to say, limiting IVIS use to non-driving or low workload periods as well as simplifying tasks. This approach would be very unpopular because drivers are rapidly becoming familiar with IVIS technology which is desirable, useful and rapidly expanding in both complexity and range of application. In fact basic components needed to produce a large array of IVIS such as General Motors "On-Star"® already include global positioning, road maps, and many other information sources. IVIS is clearly a part of the vehicle and since it cannot be transported as freely as cell phones it will be easier to design and regulate its control. Additionally, there are ways of controlling the content, duration and timing of task presentations to further facilitate the control of IVIS safety risks that are not available for the regulation of cell phones. As discussed for cellular phones, the methods used to measure headway, lane deviations, speed and eye-glance changes can be used to assist drivers when they choose to use IVIS while driving.

Design Considerations

This study has shown four important factors that define the level of intrusion IVIS tasks will have on driving performance and the subsequent safety risks. They are: 1) Task density (short-term memory requirements), 2) Task element type (task complexity), 3) Task duration (amount of time drivers are exposed to impairment) and 4) Task timing (interaction between IVIS, driving and other in-vehicle activities). Additionally, there are three factors that affect the timing and subsequent safety risk of IVIS. They are: 1) Driver limitations, 2) Driving environment, and 3) Task differentiation. These factors combine to define the overall cumulative risk of IVIS use.

Density (Short-term memory levels)

The results of this study suggest that overloading the short-term memory represents a much larger intrusion into the primary task of driving than the type of decision-making element. To some degree, short-term memory effects obscured the element effects. This is the reason such clear effects were shown in almost every variable by density. Degraded driving performance measures included lane deviations, speed variance, minimum headway, headway variance and eye glances. The completion time for the tasks was longer. Eye glance analysis showed a narrowing of focus with longer and fewer glances to all locations except the forward roadway. They did not observe any change in situational awareness. Drivers perceived higher workload levels as density increased.

Decreasing information density or short-term memory load is the most important factor in reducing the impact of SIP tasks on driving performance. This can be accomplished by narrowing the number of decision options and the number of information items in each option. In this study even selection from three routes with three information items each (low density IVIS) or a simple series of non-critical questions (conversation tasks) had an impact on driving performance. The number of skipped tasks and other performance decrements were much worse for high density tasks containing five routes with four information items each. Therefore, a reasonable limit is probably three options with three simple pieces of information per option.

Element (Task Complexity)

Increasing information processing element difficulty negatively affected driver performance on the measures of speed, headway variance, maximum steering position, eye glances and lane deviations. Task completion time increased with task complexity. The Listen and Compute, and the Listen, Plan and Compute elements resulted in a higher error rate on secondary tasks than the Listen Only element level. Drivers correctly perceived relative difficulty in the task elements workload levels. Forward eye glance duration increased with task complexity and drivers did not perceive any change in situational awareness.

Content complexity should be kept to a minimum since any excess information processing has a dramatic impact on driving performance. If possible, drivers should be presented with simple yes / no type decisions. Calculations are difficult for many people even while not driving and can easily be handled by processing information before it is presented to a driver.

Designs should reduce complexity to the greatest extent possible. In particular, avoid computation related tasks for drivers. Driver preferences for route types can be used in pre-processing information to be included in route options in order to reduce complexity. This reduction of the information presented will have the added benefit of reducing the duration of

time that is required for each task that is conducted. This is desirable because of driver preference and more importantly because it will reduce exposure to the performance impacts of doing these tasks.

Duration (exposure)

The performance of the older age group suggests a possible approach for reducing safety risks associated with the duration of more difficult IVIS tasks. Secondary task information can cause driving safety incidents when the peak task difficulty is too great. Increases in SIP including both task complexity (element effect) and short term memory demand (density effect) increase the magnitude of the distraction and the resulting safety risk. Just extending the duration, without otherwise modifying the task can reduce the urgency, intensity and resulting intrusion on safe driving. For some types of SIP tasks that exceed the cognitive capacity of the driver, it may be possible to partition the task into a longer duration series of simpler tasks. Extending the duration can reduce both the difficulty and the peak memory demand of IVIS secondary tasks and consequently the safety risks. Care should be taken to avoid the cumulative risk of extended lower levels of exposure to impaired driving, but they may be preferable to the immediate consequences of driving while severely overloaded.

Safety risk includes both the critical incidences caused by overloading cognitive resources and chronic exposure to lower level resource demands over time. Time spent completing in-vehicle tasks should generally be minimized to the greatest extent possible. However, in some cases extending the duration of IVIS tasks may help reduce the risk of critical safety incidences.

Timing

In real world driving environment there are large variations in the amount of information, complexity of tasks and cognitive capacity of drivers. These factors all impact the available cognitive resources a driver has to complete IVIS tasks. Many of these factors are predictable, such as traffic densities near large intersections and diminished short-term memory capacity of older drivers. The timing of presentation of IVIS tasks can greatly affect the ability of the driver to handle the task and reduce the impact on their driving performance and situational awareness.

IVIS safety can be greatly enhanced by accounting for other information inputs and cognitive loads on the driver. These factors can then be modeled and applied to present tasks at a time when these other loads will have the least negative effect on the driving. Three of the most important of these other factors for which timing may be beneficial are: 1) Driver limitations (cognitive capacity), 2) Driving environment (traffic, road conditions, and weather), 3) Data criticality (urgency or relevance of tasks).

Driver limitations

As discussed earlier there are large variations in the cognitive capacity and information processing behaviors of drivers. Some of these are fairly well known, like the reduced short-term memory processing abilities of older drivers. Others, such as preferences between information needed for primary tasks and other information, are more nebulous. However, designers should understand that it is not predictable whether a driver will disregard or process a given piece of information based on its importance for driving safety. A driver's immediate personal relationships, professional responsibilities and social training, like respect for elders,

may have more impact on driver choices than current safe driving consequences. Furthermore, drivers may not even be consistent with their own past behavior on the same tasks.

Driving environment

Driving environment is a significant factor as well. Drivers on open interstate highways may have little difficulty processing information and driving simultaneously. Unfortunately, in urban environments where driving complexity is much higher, there is also significantly more information to be processed and displayed. Additional information from the driving environment may increase short-term memory requirements. Therefore, different limits on information in auditory displays may be required for different driving environments. The results from this study suggest that the limits for memory, duration, and complexity should be fairly restrictive, since drivers seem unable to assess their own ability to handle this type of tasks.

Task Differentiation

Systems should unambiguously differentiate between time critical or safety related information and other task or status information. Task content is an important factor in when and how a task should be presented. Presentation of critical information should interrupt or modify other IVIS tasks or divert the driver's attention back to safe driving.

Suggested Design Solutions

The measures used in this study can be applied to improving the safety of drivers using IVIS systems in two important ways.

First, new IVIS tasks or whole systems can be tested using a number of the measures from this study. This would allow the most difficult tasks to be avoided, simplified, spread over more time or applied during safe periods to reduce the safety risk. This study suggests that managing the density, complexity, duration and timing of IVIS tasks will greatly reduce the safety risk. In addition, testing systems and tasks will make it possible to estimate the exposure and evaluate the long term risks of systems and tasks prior to providing them on the road.

The second approach to reducing risk would be to develop systems that adapt real-time, to driving conditions, driver workload and ongoing measures of driving performance. In these adaptive systems, IVIS could delay presentations or modify content, duration, complexity and short-term memory requirements based on the driving situation, driver preferences and past and current driver performance. Systems could also include the ability to alert drivers when their performance or situational awareness becomes marginal allowing them to disregard or pause IVIS activities. This adaptive type of system would allow more information processing than would be possible using the more static type systems available now. Systems limited to levels safe in the most challenging real world driving situations will provide little if any capability to drivers. However, these adaptive systems will be much more complex and expensive.

FUTURE RESEARCH ISSUES

- An in-depth study focused on conversational tasks of various types may explain more accurately the known effects of cellular telephone use on accident rates. A study of this type should include issues such as urgency, signal clarity, and emotional reaction to content that are not present in other auditory information, such as the radio.
- The interaction effects of driving complexity and information processing tasks created by different driving environments should be reviewed.
- The IVIS tasks could be tested in such a way as to further distinguish the effects of short-term memory from those caused by the elements of higher mental processes such as computation, interpretation, and planning.
- An analysis of physiological measures should be completed in an attempt to find measures that are sensitive to emotional distress or other urgency factors. It is likely that emotional content and time pressure will intensify driving performance problems.
- Future experimentation should address which measures are the most informative when assessing driver distraction. Which variables were affected was not consistent with respect to task combinations. This means that drivers may have different behaviors for dealing with high workload depending on personal preference and / or other conditions.

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APPENDIX A

Analysis of Variance with Student-Newman-Keuls post hoc analysis and Paired T-tests.

APPENDIX A-1: ANOVA TABLES FOR IVIS TASKS

ANOVA Table for: Completion Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	3710.81953156	1855.40976578	3.10	0.0586
DENSITY	1	38521.57155058	38521.57155058	148.82	0.0001*
DENSITY*AGE	2	11.07492815	5.53746407	0.02	0.9788
ELEMENT	3	10035.47436654	3345.15812218	10.26	0.0001*
ELEMENT*AGE	6	981.55465399	163.59244233	0.50	0.8056
ELEMENT*DENSITY	2	913.06414204	456.53207102	1.41	0.2541
ELEMENT*DENSITY*AGE	4	330.49464163	82.62366041	0.26	0.9049

Student-Newman-Keuls test for variable: COMPTIME

Alpha= 0.05 df= 33 MSE= 599.3683

SNK Grouping	Mean	N	AGE
A	48.276	131	35-45 years
A	47.937	110	65+ years
B	45.760	153	18-25 years

Alpha= 0.05 df= 95 MSE= 326.0322

SNK Grouping	Mean	N	ELEMENT
A	63.311	101	Listen, Plan and Compute
B	47.216	113	Listen and Compute
C	40.021	112	Listen and Plan
D	35.092	68	Listen

Alpha= 0.05 df= 31 MSE= 258.8455

SNK Grouping	Mean	N	DENSITY
A	59.257	225	High
B	31.158	169	Low

ANOVA Table for: Errors

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	0.44889632	0.22444816	1.68	0.1972
DENSITY	1	0.02470722	0.02470722	0.19	0.6689
DENSITY*AGE	2	0.00667894	0.00333947	0.03	0.9753
ELEMENT	1	1.18591483	1.18591483	8.89	0.0046*
ELEMENT*AGE	2	0.42850063	0.21425032	1.61	0.2118
ELEMENT*DENSITY	1	0.30385794	0.30385794	2.28	0.1381
ELEMENT*DENSITY*AGE	2	0.28202219	0.14101110	1.06	0.3558

Student-Newman-Keuls test for variable: ERRORS

Alpha= 0.05 df= 31 MSE= 0.076608

SNK Grouping	Mean	N	ELEMENT
A	0.19626	107	Listen, Plan and Compute
B	0.04688	64	Listen and Compute

ANOVA Table for: Maximum Steering Position

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	0.04264346	0.02132173	2.10	0.1382
DENSITY	1	0.03103052	0.03103052	3.04	0.0909
DENSITY*AGE	2	0.00991275	0.00495637	0.49	0.6195
ELEMENT	3	0.20270039	0.06756680	4.43	0.0059*
ELEMENT*AGE	6	0.05551758	0.00925293	0.61	0.7249
ELEMENT*DENSITY	2	0.00018527	0.00009264	0.01	0.9892
ELEMENT*DENSITY*AGE	4	0.04316020	0.01079005	1.26	0.2975

Student-Newman-Keuls test for variable: MXSTEER

Alpha= 0.05 df= 95 MSE= 0.015267

SNK Grouping	Mean	N	ELEMENT
A	0.26963	101	Listen, Plan and Compute
A	0.26837	113	Listen and Compute
A	0.23850	112	Listen and Plan
B	0.19696	68	Listen

Alpha= 0.05 df= 31 MSE= 0.010191

SNK Grouping	Mean	N	DENSITY
A	0.26120	225	High
B	0.23013	169	Low

ANOVA Table for: Steering Position Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	0.00047063	0.00023531	3.59	0.0390*
DENSITY	1	0.00017157	0.00017157	3.25	0.0813
DENSITY*AGE	2	0.00012912	0.00006456	1.22	0.3086
ELEMENT	3	0.00068198	0.00022733	2.07	0.1093
ELEMENT*AGE	6	0.00078965	0.00013161	1.20	0.3139
ELEMENT*DENSITY	2	0.00007975	0.00003987	0.60	0.5527
ELEMENT*DENSITY*AGE	4	0.00030046	0.00007512	1.13	0.3534

Student-Newman-Keuls test for variable: VSTEER

Alpha= 0.05 df= 33 MSE= 0.000066

SNK Grouping	Mean	N	AGE
A	0.008796	131	35-45 years
A	0.007457	153	18-25 years
B	0.005072	110	65+ years

Alpha= 0.05 df= 31 MSE= 0.000053

SNK Grouping	Mean	N	DENSITY
A	0.0082156	225	High
B	0.0059325	169	Low

ANOVA Table for: Minimum Speed

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	503.23924539	251.61962270	3.31	0.0488*
DENSITY	1	23.27963214	23.27963214	2.05	0.1623
DENSITY*AGE	2	23.90226802	11.95113401	1.05	0.3613
ELEMENT	3	17.58561336	5.86187112	0.40	0.7512
ELEMENT*AGE	6	54.70364064	9.11727344	0.63	0.7086
ELEMENT*DENSITY	2	1.46709703	0.73354851	0.05	0.9472
ELEMENT*DENSITY*AGE	4	37.65622405	9.41405601	0.70	0.5976

Student-Newman-Keuls test for variable: MNSPEED

Alpha= 0.05 df= 33 MSE= 75.94026

SNK Grouping	Mean	N	AGE
A	49.482	153	18-25 years
A	48.270	130	35-45 years
B	46.045	109	65+ years

ANOVA Table for: Speed Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	142.28101347	71.14050673	1.09	0.3475
DENSITY	1	767.82889746	767.82889746	11.20	0.0022*
DENSITY*AGE	2	214.23602688	107.11801344	1.56	0.2257
ELEMENT	3	127.85235585	42.61745195	0.78	0.5084
ELEMENT*AGE	6	237.61709120	39.60284853	0.72	0.6312
ELEMENT*DENSITY	2	37.60703375	18.80351688	1.00	0.3749
ELEMENT*DENSITY*AGE	4	57.57271197	14.39317799	0.77	0.5519

Student-Newman-Keuls test for variable: VSPEED

Alpha= 0.05 df= 31 MSE= 68.55629

SNK Grouping	Mean	N	DENSITY
A	6.0256	225	High
B	3.5148	167	Low

ANOVA Table for: Minimum Headway

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	16.21534735	8.10767367	8.79	0.0009*
DENSITY	1	1.80489362	1.80489362	15.16	0.0005*
DENSITY*AGE	2	0.77145217	0.38572609	3.24	0.0528
ELEMENT	3	1.49136741	0.49712247	2.07	0.1089
ELEMENT*AGE	6	1.68718200	0.28119700	1.17	0.3275
ELEMENT*DENSITY	2	0.65163286	0.32581643	1.39	0.2586
ELEMENT*DENSITY*AGE	4	0.70236034	0.17559008	0.75	0.5625

Student-Newman-Keuls test for variable: MNHEAD

Alpha= 0.05 df= 33 MSE= 0.922701

SNK Grouping	Mean	N	AGE
A	1.4959	109	65+ years
B	1.0111	153	18-25 years
B	0.8918	130	35-45 years

Alpha= 0.05 df= 31 MSE= 0.119073

SNK Grouping	Mean	N	DENSITY
A	1.18627	167	Low
B	1.04700	225	High

ANOVA Table for: Headway Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	1.16077174	0.58038587	13.02	0.0001*
DENSITY	1	0.23978551	0.23978551	9.62	0.0041*
DENSITY*AGE	2	0.06807758	0.03403879	1.37	0.2701
ELEMENT	3	0.10413323	0.03471108	1.27	0.2878
ELEMENT*AGE	6	0.07025186	0.01170864	0.43	0.8575
ELEMENT*DENSITY	2	0.03501716	0.01750858	1.06	0.3554
ELEMENT*DENSITY*AGE	4	0.01455473	0.00363868	0.22	0.9259

Student-Newman-Keuls test for variable: VHEAD

Alpha= 0.05 df= 33 MSE= 0.044571

SNK Grouping	Mean	N	AGE
A	0.19237	109	65+ years
B	0.08077	130	35-45 years
B	0.06470	153	18-25 years

Alpha= 0.05 df= 31 MSE= 0.024918

SNK Grouping	Mean	N	DENSITY
A	0.12094	225	High
B	0.08476	167	Low

ANOVA Table for: NASA-TLX

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	1882.51810894	941.25905447	0.38	0.6858
DENSITY	1	1533.83586273	1533.83586273	26.19	0.0001*
DENSITY*AGE	2	184.65989529	92.32994764	1.58	0.2234
ELEMENT	3	10182.24777027	3394.08259009	26.76	0.0001*
ELEMENT*AGE	6	374.68666983	62.44777830	0.49	0.8126
ELEMENT*DENSITY	2	102.63079206	51.31539603	1.05	0.3575
ELEMENT*DENSITY*AGE	4	23.67444634	5.91861158	0.12	0.9741

Student-Newman-Keuls test for variable: NASATLX

Alpha= 0.05 df= 92 MSE= 126.8354

SNK Grouping	Mean	N	ELEMENT
A	27.818	112	Listen and Compute
A	27.653	101	Listen, Plan and Compute
B	23.743	109	Listen and Plan
C	14.395	65	Listen

Alpha= 0.05 df= 30 MSE= 58.57461

SNK Grouping	Mean	N	DENSITY
A	25.6323	223	High
B	22.6606	164	Low

ANOVA Table for: Situational Awareness

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	6123.12080146	3061.56040073	4.44	0.0198*
DENSITY	1	0.49565313	0.49565313	0.01	0.9294
DENSITY*AGE	2	2.10000509	1.05000254	0.02	0.9832
ELEMENT	3	415.65724308	138.55241436	2.42	0.0708*
ELEMENT*AGE	6	556.56265596	92.76044266	1.62	0.1497
ELEMENT*DENSITY	2	101.72588093	50.86294046	0.51	0.6064
ELEMENT*DENSITY*AGE	4	294.12933857	73.53233464	0.73	0.5755

Student-Newman-Keuls test for variable: SITUAWAR

Alpha= 0.05 df= 32 MSE= 689.0548

SNK Grouping	Mean	N	AGE
A	95.515	103	65+ years
B	87.190	153	18-25 years
B	82.557	131	35-45 years

Alpha= 0.05 df= 92 MSE= 57.16647

SNK Grouping	Mean	N	ELEMENT
A	89.462	65	Listen
B	88.010	101	Listen, Plan and Compute
B	87.862	109	Listen and Plan
B	86.714	112	Listen and Compute

APPENDIX A-2: ONE WAY ANOVA TABLES INCLUDING BASELINES

ANOVA Table for: Maximum Steering Position

Source	DF	Type III SS	Mean Square	F Value	Pr > F
ELEMENT	4	0.23010304	0.05752576	4.53	0.0017*

Student-Newman-Keuls test for variable: MXSTEER

Alpha= 0.05 df= 167 MSE= 0.012708

SNK Grouping	Mean	N	ELEMENT
A	0.26963	101	Listen, Plan and Compute
A	0.26837	113	Listen and Compute
A	0.23850	112	Listen and Plan
A	0.23083	62	Listen
B	0.19696	68	Baseline

ANOVA Table for: Speed Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DENSITY	2	815.17972173	407.58986086	10.34	0.0001*

Student-Newman-Keuls test for variable: VSPEED

Alpha= 0.05 df= 99 MSE= 39.40611

SNK Grouping	Mean	N	DENSITY
A	6.0256	225	High
B	3.9392	93	Baseline
B	3.5148	167	Low

ANOVA Table for: Minimum Headway

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DENSITY	2	1.52769848	0.76384924	0.87	0.4209

ANOVA Table for: Headway Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
DENSITY	2	0.50431072	0.25215536	6.00	0.0035*

Student-Newman-Keuls test for variable: VHEAD

Alpha= 0.05 df= 99 MSE= 0.042026

SNK Grouping	Mean	N	DENSITY
A	0.12094	225	High
B	0.08476	167	Low
B	0.06654	93	Baseline

APPENDIX A-3: ANOVA TABLES FOR CONVERSATIONAL TASKS

ANOVA Table for: Completion Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	1186.96826925	593.48413462	1.64	0.2089
TASKTYP	2	4859.19576339	2429.59788170	7.86	0.0009*
TASKTYP*AGE	4	683.36489633	170.84122408	0.55	0.6978

Student-Newman-Keuls test for variable: COMPTIME

Alpha= 0.05 df= 61 MSE= 309.1488

SNK Grouping	Mean	N	TASKTYP
A	56.037	68	Non-Paced Conversation
B	48.548	71	Paced Conversation
C	40.971	31	Baseline

ANOVA Table for: Maximum Steering Position

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	0.01055282	0.00527641	0.60	0.5547
TASKTYP	2	0.01189373	0.00594686	0.97	0.3863
TASKTYP*AGE	4	0.04388375	0.01097094	1.78	0.1439

ANOVA Table for: Steering Position Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	0.00013809	0.00006905	1.43	0.2548
TASKTYP	2	0.00015401	0.00007701	2.96	0.0595*
TASKTYP*AGE	4	0.00008940	0.00002235	0.86	0.4944

Student-Newman-Keuls test for variable: VSTEER

Alpha= 0.05 df= 61 MSE= 0.000026

SNK Grouping	Mean	N	TASKTYP
A	0.007846	71	Paced Conversation
A	0.006193	68	Non-Paced Conversation
B	0.005857	31	Baseline

ANOVA Table for: Minimum Speed

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	268.70665009	134.35332504	3.91	0.0299*
TASKTYP	2	12.59249975	6.29624988	0.93	0.3985
TASKTYP*AGE	4	10.34653183	2.58663296	0.38	0.8194

Student-Newman-Keuls test for variable: MNSPEED

Alpha= 0.05 df= 33 MSE= 34.36506

SNK Grouping	Mean	N	AGE
A	49.630	57	18-25 years
A	48.386	57	35-45 years
B	46.151	55	65+ years

ANOVA Table for: Speed Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	77.65307439	38.82653720	2.22	0.1242
TASKTYP	2	83.91344308	41.95672154	2.54	0.0874*
TASKTYP*AGE	4	38.21140320	9.55285080	0.58	0.6800

Student-Newman-Keuls test for variable: VSPEED

Alpha= 0.05 df= 61 MSE= 16.53995

SNK Grouping	Mean	N	TASKTYP
A	5.5414	70	Paced Conversation
A	4.8641	68	Non-Paced Conversation
B	3.9392	31	Baseline

ANOVA Table for: Minimum Headway

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	5.25812280	2.62906140	5.68	0.0076*
TASKTYP	2	0.19227559	0.09613779	0.85	0.4323
TASKTYP*AGE	4	0.06694653	0.01673663	0.15	0.9632

Student-Newman-Keuls test for variable: MNHEAD

Alpha= 0.05 df= 33 MSE= 0.462483

SNK Grouping	Mean	N	AGE
A	1.3920	55	65+ years
B	0.9626	57	35-45 years
B	0.9385	57	18-25 years

ANOVA Table for: Headway Variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	0.11704963	0.05852481	2.81	0.0746*
TASKTYP	2	0.04695938	0.02347969	2.44	0.0958*
TASKTYP*AGE	4	0.00624427	0.00156107	0.16	0.9567

Student-Newman-Keuls test for variable: VHEAD

Alpha= 0.05 df= 33 MSE= 0.020823

SNK Grouping	Mean	N	AGE
A	0.14855	55	65+ years
B	0.08762	57	18-25 years
B	0.08192	57	35-45 years

Alpha= 0.05 df= 61 MSE= 0.00963

SNK Grouping	Mean	N	TASKTYP
A	0.11809	70	Paced Conversation
A	0.11037	68	Non-Paced Conversation
B	0.06654	31	Baseline

ANOVA Table for: NASA-TLX

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	335.44847780	167.72423890	0.30	0.7403
TASKTYP	1	11.19344903	11.19344903	0.23	0.6340
TASKTYP*AGE	2	7.62129548	3.81064774	0.08	0.9245

ANOVA Table for: Situational Awareness

Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE	2	1150.65016210	575.32508105	4.35	0.0213*
TASKTYP	1	29.53414469	29.53414469	1.11	0.2994
TASKTYP*AGE	2	47.33844189	23.66922095	0.89	0.4199

Student-Newman-Keuls test for variable: SITUAWAR

Alpha= 0.05 df= 32 MSE= 132.3018

SNK Grouping	Mean	N	AGE
A	95.381	42	65+ years
B	90.511	45	18-25 years
B	87.444	45	35-45 years

APPENDIX A-4: PAIRED T-TEST TABLES

Category		Total Glances	Road	Mirror	Other	Lane busts	N	
OVERALL	p-value	0.00000	0.00000	0.00000	0.00000	0.0025	304	
	observed	4680	3562	676	443	101		
	base	8419	6163	1288	968	70		
AGE								
	Young	p-value	0.00000	0.00000	0.00000	0.00000	0.1131	133
		observed	1915	1570	174	172	41	
base		3292	2480	347	465	32		
Old	p-value	0.00000	0.00000	0.00003	0.02433	0.0056	60	
	observed	565	411	85	69	25		
	base	1266	900	252	114	12		
Middle	p-value	0.00000	0.00000	0.00000	0.00000	0.0804	111	
	observed	2200	1581	417	202	35		
	base	3861	2783	689	389	26		
DENSITY								
	3 x 3	p-value	0.00000	0.00000	0.00000	0.00001	0.1598	108
		observed	1261	955	173	133	31	
base		2408	1769	363	276	25		
5 x 4	p-value	0.00000	0.00000	0.00000	0.00000	0.0278	157	
	observed	3082	2338	460	285	56		
	base	5186	3756	806	624	40		
Conversation	p-value	0.00000	0.00000	0.00309	0.00508	0.0082	39	
	observed	341	272	43	26	15		
	base	841	649	120	72	5		

Category ELEMENT	Total Glances	Road	Mirror	Other	Lane busts	N	
Listen	p-value	0.00008	0.00068	0.01751	0.00007	0.2667	43
	observed	643	498	92	53	7	
	base	1015	753	133	129	9	
LP	p-value	0.00000	0.00000	0.00040	0.00000	0.4245	74
	observed	1010	750	160	100	21	
	base	1783	1297	266	220	20	
LC	p-value	0.00000	0.00000	0.00000	0.00000	0.0255	79
	observed	1241	929	196	116	32	
	base	2414	1745	390	279	20	
LPC	p-value	0.00000	0.00000	0.00001	0.00007	0.0237	69
	observed	1536	1173	212	152	27	
	base	2463	1788	398	277	16	
Paced	p-value	0.00012	0.00002	0.04666	0.03240	0.0414	22
	observed	210	162	33	15	9	
	base	487	372	77	38	3	
Non-Paced	p-value	0.00001	0.00002	0.00185	0.04259	0.0519	17
	observed	131	110	10	11	6	
	base	354	277	43	34	2	

APPENDIX A-5: SKIPPED AND REPEAT TASK TABLE

AGE	TASK	DENSITY	ELEMENT	TOTAL	SKIPPED	% skips	REPEATS	% repeats
All	IVIS	All	All	464	70	15.1%	28	6.0%
All	IVIS	Both	Listen	69	1	1.4%	4	5.8%
All	IVIS	Both	Listen + Plan	132	20	15.2%	4	3.0%
All	IVIS	Both	Listen + Compute	131	18	13.7%	9	6.9%
All	IVIS	Both	Listen + Compute + Plan	132	31	23.5%	11	8.3%
All	Conv		Both	139	0	0.0%	3	2.2%
All	IVIS	Low	Listen	36	0	0.0%	1	2.8%
All	IVIS	Low	Listen + Plan	69	1	1.4%	3	4.3%
All	IVIS	Low	Listen + Compute	69	4	5.8%	3	4.3%
All	IVIS	High	Listen	33	1	3.0%	3	9.1%
All	IVIS	High	Listen + Plan	63	19	30.2%	1	1.6%
All	IVIS	High	Listen + Compute	62	14	22.6%	6	9.7%
All	IVIS	High	Listen + Compute + Plan	132	31	23.5%	11	8.3%
All	Conv		Paced conversation	71	0	0.0%	3	4.2%
All	Conv		Non-Paced conversation	68	0	0.0%	0	0.0%
Young	IVIS	Low	Listen	12	0	0.0%	0	0.0%
Young	IVIS	Low	Listen + Plan	24	0	0.0%	0	0.0%
Young	IVIS	Low	Listen + Compute	22	0	0.0%	0	0.0%
Young	IVIS	High	Listen	11	0	0.0%	1	9.1%
Young	IVIS	High	Listen + Plan	23	3	13.0%	0	0.0%
Young	IVIS	High	Listen + Compute	24	2	8.3%	1	4.2%
Young	IVIS	High	Listen + Compute + Plan	48	6	12.5%	4	8.3%
Young	Conv		Paced conversation	24	0	0.0%	0	0.0%
Young	Conv		Non-Paced conversation	23	0	0.0%	0	0.0%

AGE	TASK	DENSITY	ELEMENT	TOTAL	SKIPPED	% skips	REPEATS	% repeats
Middle	IVIS	Low	Listen	12	0	0.0%	1	8.3%
Middle	IVIS	Low	Listen + Plan	23	0	0.0%	0	0.0%
Middle	IVIS	Low	Listen + Compute	23	0	0.0%	0	0.0%
Middle	IVIS	High	Listen	12	0	0.0%	2	16.7%
Middle	IVIS	High	Listen + Plan	19	6	31.6%	0	0.0%
Middle	IVIS	High	Listen + Compute	21	6	28.6%	1	4.8%
Middle	IVIS	High	Listen + Compute + Plan	42	9	21.4%	4	9.5%
Middle	Conv		Paced conversation	24	0	0.0%	2	8.3%
Middle	Conv		Non-Paced conversation	22	0	0.0%	0	0.0%
Old	IVIS	Low	Listen	12	0	0.0%	0	0.0%
Old	IVIS	Low	Listen + Plan	22	1	4.5%	3	13.6%
Old	IVIS	Low	Listen + Compute	24	4	16.7%	3	12.5%
Old	IVIS	High	Listen	10	1	10.0%	0	0.0%
Old	IVIS	High	Listen + Plan	21	10	47.6%	1	4.8%
Old	IVIS	High	Listen + Compute	17	6	35.3%	4	23.5%
Old	IVIS	High	Listen + Compute + Plan	42	16	38.1%	3	7.1%
Old	Conv		Paced conversation	23	0	0.0%	1	4.3%
Old	Conv		Non-Paced conversation	23	0	0.0%	0	0.0%

APPENDIX B

Protocols, Procedures, Stimulus Materials

APPENDIX B-1: PRELIMINARY TELEPHONE SCREENING QUESTIONNAIRE

Participant's **Age:**
Name: _____
Participant's Phone: _____ **Male / Female:** _____
Pass: _____ **Fail:** _____

ADMINISTERED BY PHONE

NOTE TO INTERVIEWER: Ask the participant the following questions and record his/her responses. Participants are required to have a valid driver's license and drive at least twice a week.

PHONE INTERVIEWER: As part of the study, I need to ask you a few questions. Your answers will determine your eligibility for this study. This data will not be associated with your name, and will be treated confidentially.

1) Do you have a valid driver's license?

_____ Yes _____ No

2) How many times per week do you drive in Blacksburg or the surrounding area?

4 + 2 -3 X 1X <1X

3) Approximately how many miles do you drive per year?

- 1___ Under 2,000
- 2___ 2,000 - 7,999
- 3___ 8,000 - 12,999
- 4___ 13,000 - 19,999
- 5___ 20,000 or more

PHONE INTERVIEWER:

If passes...Now I'd like to schedule a time when you can come to the Center for the study.

If fails...Thanks for your time; unfortunately you do not qualify for this particular study. Would you be interested on being put on a participant list for future studies?

* SCHEDULE A TIME DATE AND TIME _____

PHONE INTERVIEWER: Also, since you will be driving a car, I need to ask you to refrain from drinking any alcohol for the 24 hrs before the experiment. Is this all right with you?

YES _____ NO _____

Thank you, I'll see you? (DATE and TIME). Let me provide you with directions to the Center...

APPENDIX B-2: INFORMED CONSENT INFORMATION

Informed Consent for Participants of Investigative Projects

Title of Project: In-vehicle Task Performance Study

Investigators: John P. Gallagher, Industrial and Systems Engineering graduate student

Dr. Thomas A. Dingus, Industrial and Systems Engineering Professor and Director of the Virginia Tech Center for Transportation Research

Dr. Walter W. Wierwille, Paul T. Norton Professor of Industrial and Systems Engineering and Senior Transportation Research Fellow at the Virginia Tech Center for Transportation Research

I. The Purpose of this Research Project

The purpose of this research experiment is to evaluate driving behavior and performance while drivers concurrently perform in-vehicle tasks. These tasks will include adjusting the audio system; adjusting the climate-control system, using the cellular telephone, reading information from in-vehicle displays, navigating with the aid of an Advanced Traveler Information System (ATIS), and using speech input for controlling in-vehicle tasks. The data obtained will be used to evaluate the attention demand of different in-vehicle information systems. Thirty-six subjects, each tested individually, will participate in this experiment.

II. Procedures

In the study, you will be asked to perform specific in-car tasks as you drive on U.S. Route 460 and other primary and secondary roads in the New River Valley area. Two trained experimenters will ride in the research vehicle with you during the experiment to assist in the data-gathering process and to help ensure the safe operation of the experimental vehicle. It is your responsibility as the driver to obey all traffic regulations and to maintain safe operations of the vehicle at all times. You must treat the driving task as the primary task and perform the other instructed task only when it is safe to do so. You will be required to have the lap/shoulder belt restraint system securely fastened while driving.

The experimental vehicle is a late model American car. The car is equipped with an automatic transmission, analog instrument cluster, cellular phone, entertainment system (audio), climate-control, and driver information systems. The car is also equipped with an advanced traveler information system and a speech recognition system. In this study, you will drive and perform a variety of in-vehicle tasks.

The vehicle is also outfitted with devices designed to monitor various relevant aspects of your driving behavior (for example, video cameras and recorder, microphones, and computers). 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 cellular phone will be carried in the vehicle at all times, in case of an emergency.

The study will consist of four experimental stages. The experiment will proceed as follows.

1. Introductory Stage

This stage consists of preliminaries. You will thoroughly read the informed consent form. Assuming that you sign the informed consent form, we will ask you to fill out a brief medical screening questionnaire. Next, we will give you a simple vision test and we will also ask to see your driver's license. Once you successfully complete all preliminaries, we will begin your training. The first stage is expected to last about 10 minutes.

2. Training Stage

We will take you to the research vehicle where we will train you on the use of the different in-vehicle information systems. Since the instrument panels and controls may differ from the vehicle you normally drive, it is necessary to train you on the in-vehicle tasks you will be performing throughout the experiment. We will then ask you to perform a series of tasks using the different in-vehicle information systems you were just trained on. This stage should take approximately 20 minutes.

3. Driving Stage

After a short rest break, you will begin driving the vehicle on a pre-selected route and will be asked to begin performing a series of instructed in-vehicle tasks. The driving stage will alternate between periods of regular driving and driving while performing the various tasks for which you have been trained. This stage is expected to last approximately 80 minutes depending on the amount of re-training required. At the end of the drive you will return to the Center for Transportation Research (CTR).

4. Debriefing and Payment Stage

On returning to CTR, you will be asked to read an experiment debriefing statement. You will then be paid and dismissed. This stage should take about 10 minutes.

Your total participation time will be approximately two hours, but may be somewhat shorter or longer depending on the length of rest breaks and amount of training needed.

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 the amount of time you participated. This includes the right to withdraw at any time after having read and signed the informed consent form. If you withdraw during the driving stage, the experimenter will take over the driving and return you to CTR.

If you have any questions about the experiment or your rights as a participant after reading the informed consent form, please do not hesitate to ask. We will answer your questions as openly and honestly as possible.

III. Risks

There are some risks and discomforts to which subjects are exposed in volunteering for this research. The risks are:

- (1) The risk of an accident normally associated with driving an automobile in light or moderate traffic, as well as on straight and curved roadways.
- (2) The slight additional risk of an accident while performing instructed in-vehicle tasks. Past research indicates that this risk is minimal.
- (3) Possible fatigue due to the length of the experiment. However, you will be given short rest breaks during the experimental session.
- (4) While you are driving the vehicle, you will be videotaped by cameras. As a result, we will ask you not to wear sunglasses. If this at any time during the course of the experiment impairs your ability to drive the vehicle safely, you should notify the experimenter.

The following precautions will be taken to ensure minimal risk to the subjects:

- (1) The experimenter will monitor your driving, and will ask you to stop if he feels 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.

- (2) You will be required to wear the lap and shoulder belt restraint system anytime the car is on the road. The vehicle is also equipped with a driver's side airbag supplemental restraint system.
- (3) The vehicle is equipped with a fire extinguisher, first-aid kit, cellular phone, and an experimenter's safety brake pedal.
- (4) If an accident does occur, the experimenter will arrange medical transportation to a nearby hospital emergency room. You will be required to undergo examination by medical personnel in the emergency room.

IV. Benefits of this Research Project

While there are no direct benefits to you from this research (other than payment), you may find the experiment interesting. No promise or guarantee of benefits has been made to encourage you to participate. Your participation, along with that of the other volunteers, should make it possible to improve the design of in-vehicle systems. Improvements in the design of automotive in-vehicle systems may have a significant impact on driving safety, system usability, and consumer satisfaction.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after you have participated, your name will be separated from your data. A coding scheme will be employed to identify your data by gender and subject number only (e.g., Male, Subject No. 3).

Eye movement behavior is measured using a video camera and recorder during the experiment. A camera, positioned inside the center rearview mirror, is used to record drivers' eye movements. The video image recorded is of the driver's head with some additional space around the head to accommodate any head movements by the driver during data collection. The videotapes will be stored in a locked filing cabinet at the Virginia Tech Center for Transportation Research. Access to the tapes will be under the supervision of Dr. Thomas Dingus and Dr. Walter Wierwille. John Gallagher will have access to the tapes and will score the eye movement behavior using "frame-by-frame" analysis. The video tapes will be erased one year after the data has been analyzed and the results written-up.

At no time will the researchers release the videotapes from the study to anyone other than individuals working on the project without your written consent.

VI. Compensation

You will be paid \$10 per hour for the time you actually spend in the experiment. Payment will be made immediately after you have finished your participation.

VII. Freedom to Withdraw

You should know that at any time you are free to withdraw from participation in this research program without penalty. No one will try to make you continue if you do not want to continue, and you will be paid for the amount of time you actually participated.

VIII. Approval of Research

This research project has been approved, as required by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University, the Department of Industrial and Systems Engineering, and the Virginia Tech Center for Transportation Research.

IX. Participant’s Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

- (1) I should not volunteer for participation in this research if I am younger than 18 years of age, or if I do not have a valid driver's license, or if I am not in good health, or if I am pregnant.
- (2) I should not take part in the driving task if I have taken any drug, alcoholic beverage, or medication within the previous 24 hours which might affect my ability to safely operate an automobile. It is my responsibility to inform the experimenters of any additional conditions which might interfere with my ability to drive. Such conditions would include inadequate sleep, hangover, headache, cold symptoms, depression, allergies, emotional upset, visual or hearing impairment, seizures (fits), nerve or muscle disease, or other similar conditions.
- (3) As the driver of the research vehicle, I must obey all traffic regulations and maintain safe operation of the vehicles at all times. I will treat the driving task as the primary task and perform the other instructed tasks only when it is safe to do so.

X. Participant’s Permission

I have read and understand the Informed Consent and conditions of this research project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this research project.

Signature	Date
-----------	------

Should I have any questions about this research or its conduct, I may contact:

- | | |
|---|----------|
| Dr. Thomas A. Dingus
Principal Investigator | 231-8831 |
| Dr. Walter W. Wierwille
Principal Investigator | 231-7740 |
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APPENDIX B-3: HEALTH SCREENING QUESTIONNAIRE

1. Are you in good general health? Yes No

If no, list any health-related conditions you are experiencing or have experienced in the recent past.

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep Yes No

Hangover Yes No

Headache Yes No

Cold symptoms Yes No

Depression Yes No

Allergies Yes No

Emotional upset Yes No

3. Do you have a history of any of the following?

Visual Impairment Yes No

(If yes, please describe.) _____

Hearing Impairment Yes No

(If yes, please describe.) _____

Seizures or other lapses of consciousness Yes No

(If yes, please describe.) _____

Any disorders similar to the above or that would impair
your driving ability Yes No

(If yes, please describe.) _____

4. List any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours. _____

5. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours. _____

6. Are you taking any drugs of any kind other than those listed in 4 or 5 above?

Yes No

7. If you are female, are you pregnant? Yes No

Signature Date

APPENDIX B-4: INFORMATION SHEET FOR PARTICIPANTS

Thanks for offering to help with this study. Information about the procedures for the study are explained below. Please feel free to ask any questions you may have.

Tasks to be Completed During the Drive

Your primary task is to safely drive the automobile; you should allow nothing to interfere with this. To simulate medium traffic density, there will be an automobile driven in front of you by personnel from the Center for Transportation Research. As you are driving, you will be provided information on a visual display or auditorily and will be asked to make decisions from this information. These are secondary tasks and you should NOT allow them to interfere with safely driving the vehicle.

Periodically along the route you will hear a tone; following the tone, you will hear instructions provided by the computer on how to complete the task, i.e. select a hotel. After the instructions are completed, information will either be presented on the visual display or will be presented auditorily.

Visual Tasks

Visual information will remain on the screen until you state your decision, i.e. selecting a hotel based on the information provided. You may repeat the instructions at any time and as many times as you would like by pressing the button on the left side of the steering wheel.

There is no time limit, take as much time as you want.

Auditory Tasks

Auditory information will be presented once and will stop. If you wish to replay the information, simply press the button on the right side of the steering wheel. You may repeat the information as many times as you like.

If you would like to replay the instructions at any time, simply press the button on the left side of the steering wheel. You may interrupt the presentation of information to hear the instructions. If you should interrupt the presentation of information, after the instructions are repeated, the information presentation will start at the beginning.

You may provide an answer at any time. If you choose to replay the information, you do not have to wait until the information repeats in its entirety to state your answer.

Task Description

You will be asked to perform a variety of tasks. Some tasks will ask you to choose a hotel or to choose a route; with these tasks, it is desired that you search the information and identify and use the information you find useful in making your decision. We realize that not everyone will choose to use the same criteria when making a decision. It doesn't matter to us which criteria you use or how many you use. However, it is important that we know which information you used to arrive at your decision (i.e. If five items of information were presented, it is important for us to know that you used 1, 2, 3, 4 or 5 items, and which items you used). Therefore, at the conclusion of each task, the experimenter will ask why you selected your answer. At this time, indicate which criteria you used (for example, you might have considered distance, cost, and quality when selecting a hotel).

When given the task of selecting a route to the hospital or airport, you are not in a rush to get to the hospital or airport. Imagine you are going to visit someone in the hospital, or that you are going to meet someone at the airport.

Some tasks will require that you perform calculations, while other tasks will provide you with the option of doing calculation(s). It is important that we know if you performed a calculation and what type of calculation you performed.

When you are asked to determine the cheapest route or the quickest route, we would like you to perform a calculation with the information provided. We will prompt you for a numeric answer after you have stated your selected route. As with any task, you can always say “skip” if you do not wish to perform the task while driving.

If you are asked to select a route and toll costs, speed limit, distance, and/or time delays are provided, you have the option of performing one or more calculations. When asked to select a route, use the information as you normally would while driving. After you provide your route selection, we will ask you if you performed a calculation and if so, what type.

- If at any time you feel a task requires too much attention to ensure safe driving, simply say “skip” and the task will end.
- If at any time you wish to stop and take a break, indicate your desire to the experimenters.
- If at any time you wish to end your participation in the study, simply state your desire to the experimenters and we will return to the Center for Transportation Research.

Rating of Task Difficulty

After each task is completed, we will ask you to rate the mental demand, frustration level, and time sharing demand of the task. You will also be asked to rate how aware of your surroundings you were while completing the task.

Rating scales have been developed for you to use in evaluating your experiences during the different tasks. Please read the descriptions of the scales carefully. It is extremely important that they be clear to you; please ask if you have any questions. You may request a description of the scales at any time during the experiment.

After performing each task, you will be asked to evaluate the task by selecting a value from 1 to 100 for each of the scales. Each line has two endpoint descriptors that describe the scale. For example, Frustration Level goes from 1 (not frustrating) to 100 (extremely frustrating). The experimenter will say the name of each scale, at which point you will respond with your evaluation of the task you just completed on a scale from 1 to 100. Please consider your responses carefully in distinguishing among the task conditions. Consider each scale individually. Your ratings will play an important role in the evaluation being conducted; thus, your active participation is essential to the success of this experiment, and is greatly appreciated.

See Appendix B-14 for a full description of subjective Rating Scales.

Sequence of Events

Prior to going outside to the vehicle, you will be shown examples of each type of task.

After going outside to the vehicle but prior to driving, sample information will be presented on the display.

You will be shown the controls of the vehicle you will drive.

Once any questions you have are answered, we will drive around the block so that you can familiarize yourself with the handling of the vehicle.

When you feel comfortable with driving the vehicle, another short drive will be taken to allow you to practice performing tasks with the information presented by the computer (controlled by the experimenters).

When you feel comfortable performing the tasks, we will then drive to Route 460.

List of Tasks to be Completed on the Drive

Listed below is a complete list of tasks you will be asked to perform. Information to complete these tasks will be provided on the visual display and auditorily, in different formats, on the drive today.

- Select a route to the hospital
- Select a route to the airport
- Select the cheapest route to the airport
- Select the quickest route to the airport
- Select a hotel
- Which hotel has a vacancy?
- Which hotel is ____ miles away?
- Which roadway has no tolls?
- Which roadway has _____ delay?
- Which roadway has a speed limit of _____ miles per hour?
- Is _____ roadway located on the map?
- Which route has a gas station?
- Which option has no monetary cost?

APPENDIX B-5: INSTRUCTIONS AND SUITABILITY ASSESSMENT

Experimenter Instructions

Welcome Subject

Experimenter

The research you will be helping with is funded by the Federal Highway Administration. The purpose is to gather information that will be made free to the public, including car manufacturers.

The goal is to determine the best format in which to present information to drivers while driving. In the near future, when in-vehicle information systems are readily available in all vehicles, we want to ensure that the information is presented in a format and complexity level that doesn't create a safety hazard.

The study will consist of driving on US Route 460 into West Virginia and back. I will be riding in the front passenger seat and will be asking you questions after you complete each task. There will be an individual riding in the back who will be monitoring the computers and equipment. There will also be another person driving a car in front of us. Do not worry about him, ignore him; if other cars come in between us, don't worry about it. His purpose is to be traffic for us if there are no other vehicles around. We have him there because we didn't want some participants to have a lot of traffic and others to have no traffic. This way everyone will have at least one car in front of him or her.

Along the drive, we will present information to you and ask you to perform a task with it, such as select a hotel or select a route. Today, we will be presenting information in different formats, both visually and auditorily, to determine which formats are preferred. If at anytime you feel that the information is too complex to read or listen to while driving, simply say skip. We aren't testing your ability to perform a task; rather, we are trying to determine your preference. Saying "skip" is good data for us so that we know not to present information in that complexity or format to individuals when the vehicle is moving.

I have prepared some paperwork that will provide you with more information about the study. Before we begin, do you have any questions?

(Answer any questions participants may have)

The first thing I'd like for you to do is read and fill out two forms. The first form tells you about the study, your responsibilities, safety concerns, compensation, etc. The second form is a questionnaire about your general health. The purpose is to determine that you don't have any visual, hearing, or other condition that would interfere with safely driving the vehicle. After you read and complete both forms, please sign and date them both. You will be given a copy of the informed consent to keep. Feel free to ask any questions you may have.

Suitability Assessment

Paperwork

- Informed consent
- Health questionnaire

License

- Check to see that it is a current valid driving license

Distance Vision Test

- Administer vision test. 40/20 distance vision is required to proceed.

Instruction Handout

- Ask participant to read instruction handout, and then answer any question.

Subjective question training

- Explain Mental Demand, Frustration Level, Time-sharing Demand, and Situation Awareness

APPENDIX B-6: SUBJECT TRAINING

Note: Since the training was joint between a set of visual tasks and the auditory tasks of interest, much of the training protocol has been modified from what was actually presented to subjects. What is included here is in a format that represents only the portion of the training necessary for completion of auditory tasks. Example tasks are visual, but the content of tasks and methods for response are identical.

Information Items

Experimenter

For your drive today, pretend you are in the near future, sensors will be built into the roadway that will transmit information to vehicles describing current roadway conditions. Assume the information that is presented to you accurately describes the current roadway conditions. For example, if the information states that the road is slippery or the bridge is icy, then assume this is true. This information, which will be provided to you, is different from the information simply warning you that these conditions may occur, as is the case with roadway signs posted on roadways. Also, if a train crossing delay or drawbridge delay is presented, assume that the computer has calculated when you will be arriving at these locations. Based on your current position and speed, the computer has determined that a train will be crossing the tracks or the drawbridge will be up; you can't cross when you arrive at the location.

Delays

The following types of delays may be present on roadways:

- Traffic signal ahead
- Heavy truck traffic (18 wheelers)
- Fire truck (moving or stationary, but has its lights on and wants you to know it's there)
- Construction flagman
- Construction work
- Farm machinery
- Accident

Hazards

The following hazards may be present on the roadways:

- Pedestrian crossing
- Children playing
- School area
- Icy bridge
- Deer crossing
- Slippery road

More Delay Icons

The following are lengths of time for delays which are simply the time in minutes you will be delayed.

- 20 – minute delay

- 40 – minute delay
- 55 – minute delay

Lanes Closed

The following cases indicate the number of lanes of travel in your direction and how many of them are blocked/closed due to the delay:

- Two lanes, two lanes blocked
- One lane, one lane blocked
- Two lanes, one lane blocked

Information may state that all lanes are blocked, but this does not necessarily mean all traffic is stopped. It may be possible to drive on the shoulder, or there may be police or construction workers on scene directing traffic (stop traffic in opposing lanes and have you drive in those lanes).

Roadways

The type of roadway will be one of the following three types:

- Interstate 17 – Four lanes, limited access, with a median. Two lanes of travel in each direction. Think of Interstate 81.
- US Route 37 – Four lanes, may or may not have a median. Two lanes of travel in each direction. Think of US Route 460.
- VA State Highway 42. Two lanes, one lane in each direction. Think of the road out in front of this building.

Hotels

The following icons indicate various hotels:

- Marriott
- Double-Tree
- Hilton
- Comfort Inn
- Best Western
- Sheraton
- Embassy Suites

Additional Hotel Information

Hotels may include the following information:

- Vacancies
- Dollar cost of hotel
- Whether there is a restaurant present
- Hotel quality rated from a low of one to a high of five stars

Traffic Density

Traffic density will be rated at three different levels:

- Low traffic density
- Medium traffic density
- High traffic density

This indicates the amount of traffic elsewhere on the route, unassociated with any delays.

Other Icons

Other pieces of information that may be presented to you include the following:

- Hospital
- Airport
- Toll costs
- Gas stations

Testing of Understanding

Experimenter

We will now review a few sample cases of tasks and how to answer the questions. These slides will be read to you and you will have no display for reference during auditory tasks.

Note: A Training slide showing all the icons to be used in visual tasks was included with an explanation of each.

Presentation of Sample Tasks

Training Slide #1: Table, Search.

(Display training slide #1 on computer)

Option	Hotel Cost	Food Cost	Parking Cost	Admission Cost	Toll Cost
1	\$93.00	\$6.00	High	\$2.50	High
2	\$0.00	\$0.00	No Cost	\$0.00	No cost
3	\$0.00	\$4.10	No cost	\$54.00	Low
4	\$0.00	\$3.00	Low	\$0.00	High
5	\$0.00	\$11.00	High	\$8.50	No cost

Figure 11 Training Slide #1

Instructions: Identify the option with no monetary cost.

Experimenter

Complete the task and state your answer.

Participant states answer.

Experimenter

(Verify that the correct selection was chosen. If it was not, explain how to do the task and ask the participant to choose again.)

Training Slide #2: Paragraph, Search and Compute.

(Display training slide #2 on computer)

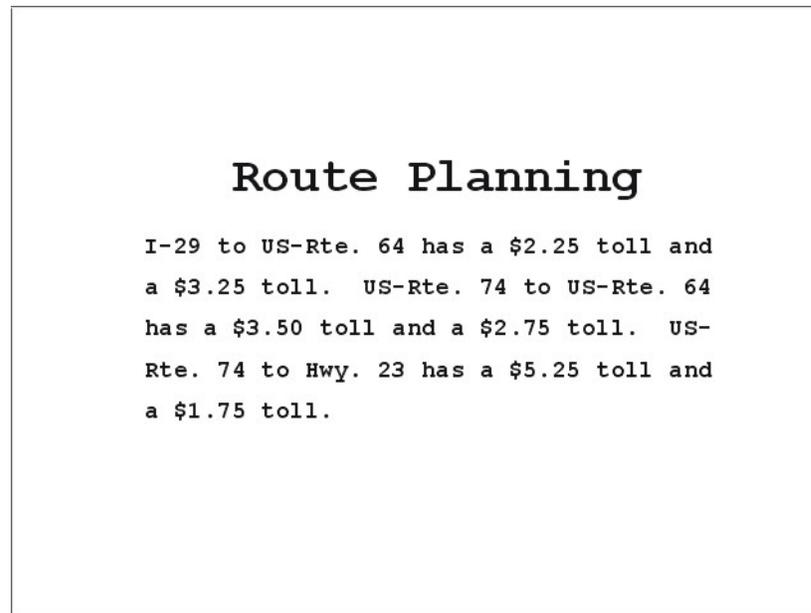


Figure 12 Training Slide #2

Instructions: Determine the cheapest route to take to the airport.

Experimenter

When you state your answer, simply state the route numbers. You don't need to state what type of road it is (interstate, U.S. route, or highway). For example, if you want to take I-38 to Highway 24, simply state as your answer "38 to 24."

Whenever your instructions state to determine the cheapest route or the quickest route, I will ask you if you performed a calculation, rough calculation, or a comparison with no calculation. If you feel comfortable performing a calculation, I would like you to perform one to determine the cheapest or quickest route. If you say that you performed a calculation or rough calculation, I will then ask for the numeric answer you calculated or roughly approximated. I will then state each category of information that was displayed and ask if you considered it in making a decision. I would like for you to follow the instructions stated by the computer, but it is not imperative that you do. However, it is important that I know what information you used in making your decision. When I compile all the data, I will categorize the data by the number of categories of information you used and whether you did any type of calculation. This is why I will ask you if you used categories of information that there was no need to use in order to

complete the task as instructed. I'm simply checking to make sure that I understand how you used the presented information.

As with any task, if you feel the task is too difficult to perform, simply say "skip" and the task will end.

Go ahead and complete this task, determine the cheapest route to the airport, and then state your answer; if you feel the task is too difficult to perform, you may say "skip" and the task will end.

Participant states answer.

Experimenter

Did you perform a calculation, rough calculation, or did you do a simple comparison with no calculation?

(If a calculation was performed, ask subject to state how much the cheapest route would cost).

(Ask if each category of information was considered: type of road and tolls. Participant will answer yes/no for each category of information.)

(Discuss what constitutes using a category of information – ex. Comparing the type of roadways on one route with the roadways on another route vs. simply looking at one option and determining that the roadways met some criteria.)

Training Slide #3: Tables, Search and Compute.

(Display training slide #3 on computer)

Route Planning			
Route	Distance	Speed Limit	Toll Cost
I-34, Hwy. 54	120 miles	50 mph	\$6.25
US-Rte. 68, US-Rte. 15	145 miles	40 mph	\$1.25
US-Rte. 68, Hwy. 16	162 miles	55 mph	\$3.25
I-34, US-Rte. 71	310 miles	65 mph	\$2.75
US-Rte. 68, Hwy. 54	195 miles	35 mph	\$6.50

Figure 13 Training Slide #3

Instructions: Determine the quickest route to the airport.

Experimenter

With this task, we are looking for you to use the distance and speed limits to determine the quickest route. As with the previous task, perform a calculation and then state your answer.

After you state your answer, I will again ask you if you performed a calculation, rough calculation, or a simple comparison. If you performed a calculation or rough calculation, I will ask you for a numeric answer or approximation you calculated for the selected route. Remember, you may say skip if you would not choose to perform this task while driving.

When information about speed limit is provided to you in paragraph and table format, the average speed limit has been determined and provided to you.

If you use a speed limit that is different from the one that is provided on the display for a route, let me know what value you used in determining the quickest route. For example, if a roadway has a speed limit of 55mph but you normally drive 50mph or 60mph, then make your decision and/or calculations as you normally would. However, let me know what values you used if they are different than those provided.

Go ahead and determine the quickest route to the airport. Remember that you may say “skip” at anytime.

Participant states answer.

Experimenter

Did you perform a calculation, rough calculation, or did you do a simple comparison with no calculation?

(If a calculation was performed, ask subject to state how long the quickest route would take).

(Ask if each category of information was considered: type of road, speed limit, distance, and toll cost. Participant will answer yes/no for each category of information.)

Training Slide #4: Table, Search and Compute.

(Display training slide #4 on computer).

Route Planning			
Route	Distance	Speed Limit	Delays
US-Rte. 68, Hwy. 54	170 miles	40 mph	22 min
US-Rte. 68, Hwy. 16	225 miles	65 mph	21 min
I-34, US-Rte. 33	195 miles	50 mph	8 min
I-34, Hwy. 28	170 miles	35 mph	42 min
I-34, US-Rte. 71	210 miles	45 mph	10 min

Figure 14 Training Slide #4

Instructions: Determine the quickest route to the airport.

Experimenter

This task is similar to the last task; with this slide, you are also presented information on length of delays in addition to the distance and speed limit. Use the information as you feel comfortable.

Go ahead and determine the quickest route to the airport.

Participant states answer.

Experimenter

Did you perform a calculation, rough calculation, or did you do a simple comparison with no calculation?

(If a calculation was performed, ask subject to state how long the quickest route would take.)

(Ask if each category of information was considered: type of road, speed limit, distance, and delays. Participant will answer yes/no for each category of information.)

Training Slide #5: Table; Search, Compute, and Plan.

(Display training slide #5 on computer).

Route Planning			
Route	Distance	Speed Limit	Toll Cost
I-34, Hwy. 54	120 miles	50 mph	\$6.25
US-Rte. 68, US-Rte. 15	145 miles	40 mph	\$1.25
US-Rte. 68, Hwy. 16	162 miles	55 mph	\$3.25
I-34, US-Rte. 71	310 miles	65 mph	\$2.75
US-Rte. 68, Hwy. 54	195 miles	35 mph	\$6.50

Figure 15 Training Slide #5

Instructions: Select a route to the airport.

Experimenter

This slide presents the same information as a previous slide. However, the instructions were different. These instructions asked you to select a route, whereas the previous instructions asked you to select the quickest route. When the instructions ask you to select a route, feel free to use the information in the manner you normally would when making a decision. You may choose to do a calculation or you may choose not to; you may choose to perform comparisons between the different categories of information, or you may simply perform a calculation. It is up to you how you use the information.

However, please remember that when we ask for the quickest route or the cheapest route, we would like for you to perform a calculation.

Go ahead and select a route to the hospital, using the information as you choose.

Participant states answer.

Experimenter

Did you perform a calculation, rough calculation, or did you do a simple comparison with no calculation?

(If a calculation was performed, ask subject to state how long the route they selected would take.)

(Ask if each category of information was considered: type of road distance, speed limit, and toll costs. Participant will answer yes/no for each category of information.)

Auditory, Training Task #1
(Play audio-tape for auditory, training task #1)

Instructions: Select a route to the hospital.

Experimenter

The next example will be an auditory task. You will hear the instructions, there will be a brief pause, and then the information necessary to complete the task will be presented. You may have the instructions and information repeated as many times as you would like.

With auditory tasks, 3 or 5 options will be presented; listen to all options before giving an answer when the task instructions are select a hotel or route, or to select the cheapest or quickest route.

When you state an answer for route questions, you may answer with either option 1, 2, 3, 4, or 5, or by saying the route numbers as you did with the visual tasks. Do whichever is easiest.

(Show illustration of the location of buttons and explain how information is presented and how/when information can be repeated.)

- Push left button to replay instructions and information
- Push right button to replay only the information
- May choose to replay instructions and/or information as many times as desired
- Listen to all options before stating selection
- When you choose to replay information, you may state your selection at anytime after the information has been presented once. It is not necessary to repeat all the information.
- You may say “skip” at anytime and the task will end.

(Present Slide 252)

Participant listens to information.

(Replay information as many times as necessary)

Participant states answer.

(Ask participant if each of the different categories of information was considered: type of road, distance, speed limit, delays, hazards, and gas station. Participant answers yes/no for each category of information.)

Auditory, Training Task #2.
(Play audio-tape for auditory training task #2)

Instructions: Select a route to the hospital.

Experimenter

The next example will be an auditory task. You will hear the instruction, there will be a brief pause, and then the information necessary to complete the task will be presented. Remember, you may have the instructions and information repeated as many times as you would like.

Participant listens to information.

(Replay information as many times as necessary)

Participant states selection.

Experimenter

(Ask participant if each of the different categories of information was considered: type of road, distance, delay, weather, lanes closed, and congestion. Participant answers yes/no for each category of information.)

Summary of desk-top training

Experimenter

You've now seen an example of each type of task that you will be shown in the vehicle. These slides had the highest complexity of information that you would be shown while you are driving. There are slides that have significantly less information; we will present these slides with less information to you first during the drive.

I just want to remind you that it is all right to skip a task that is presented. This is good data for us. Say "skip" if you feel that performing the task takes too much attention away from driving, or if you really had to make this decision in real life, you would want to pull over to the side of the road to look at the display more closely or to take notes while listening to the auditory information. We are not evaluating how much information you can make yourself process, but rather how much you feel comfortable processing and would choose to process based on the attention demand required and your confidence in selecting the correct option.

One last thing, when making decisions, remain stubborn-do not modify the way you make decisions. The same categories of information will be repeatedly used, and I will ask if you used each category of information, after each task. Don't feel like you should change the way you make decisions because I keep asking if you used a category of information. I don't want you to change the way you normally would make decisions. But, I must ask every time to determine which categories of information were used.

Do you have any questions before we go out to the car?

(Answer any final questions)

APPENDIX B-7: PILOT TEST PROTOCOL FOR IVIS TASKS

Tasks

General Task Characteristics

Coding

Coding of information will be constant: type of input device; type of menu system used including hierarchical structure; utilization of legends; type of input request (manual/speech); type of response (manual/speech).

Information Portrayal

Information portrayal will be constant: auditory beep to indicate start of task, constant auditory presentation of information.

Presentation Order

Presentation order will be balanced using random assignment of treatment combinations.

Presentation Formats

The complexity of the IVIS information refers to the number of information units present (Campbell, 1997). In this study, units of information will be in text and iconic format. A unit of information can describe roadway (e.g. traffic delay), type of roadway (e.g. interstate), weather (e.g. thunderstorms), etc.

The IVIS tasks are written in a tabular format. The display will include 3, 4, or 6 columns of text; each column contains one unit of information for each option. The number of options will be 3, 5, or 7. The combination of these gives us 3 x 3, 4 x 5, 6 x 5, and 6 x 7, corresponding to 9, 20, 30, and 42 information units for the different display densities, respectively.

Pilot Testing Tasks

Changing the similarity of the options presented may vary the number of criteria used for decision making. Options that differ significantly will likely be selected on only a few or a single primary criteria. Options highly similar may be excessively difficult to differentiate and drivers may default to random selection or some other simplified selection method. In the pilot test, the similarity of options will be traded off with the number of criteria used in decision making. Once this relationship is known, it will be possible to roughly control how many decision criteria are used.

Listed in Appendix C-1 are sample tasks that will be used in the pilot-testing phase. The task length in terms of time and sentence complexity will be varied to determine the difficulty levels that should be used in the full study for each of the age groups. Some pilot task information is given below (see Table 5.)

Table 6 Pilot Task Matrix

Condition	IVIS Tabular	Conversational
Listen	1	8
Listen + Compute	2	9
Listen + Interpret	3	10
Listen + Plan	4	11
Listen + Plan + Compute	5	12
Listen + Plan + Interpret	6	13
Listen + Plan + Interpret + Compute	7	14

- Task instructions will be presented verbally by the experimenter.
- Task displays will be recorded messages.
- Responses will be verbal and will be recorded by an experimenter in the vehicle.
- Tasks will be designed to keep responses to a minimum to prevent extraneous conversations.
- After each response, the subject will receive a probe question to determine how many decision criteria were used, as well as the subjective workload assessment questions.
- Displays will not cycle automatically. Drivers will be required to request a repetition of the display. If requested, the entire display of information will be presented again.
- The number of repetitions requested will be recorded and analyzed as a measure of information retrieval difficulty or short-term memory intrusion.
- For tasks in the Listen Only condition (1 and 8), the correct answer will be the last information item given. This is so that the driver is required to listen to the entire display before making a response. This will provide similarity to other tasks, thereby facilitating analysis across the visual and auditory modalities.
- In all mixed conditions (2-6 and 8-12), the correct response will occur at random places in the display. Since these conditions require additional information processing the driver will need to listen to the whole message to obtain all of the criteria that he/she uses for his/her decision.

In-vehicle Tasks

Four elements (Listen, Compute, Plan, and Interpret) will characterize the IVIS tasks performed. Each of the elements will be presented to the driver in two levels of difficulty.

Listen (Auditory Search)

Definition: The auditory demand associated with performing a task. “Search involves scanning the environment for information that meets predefined parameters” (Lee et al., 1997). This definition has been modified to include all the listening and filtering associated with the extraction of the information from the visual field.

Output: Identification of an item that matches the listen parameter (Lee et al., 1997).

No further processing of the information is necessary; it simply involves locating information that meets predefined parameters.

Constraints: The primary constraints on the driver are focused attention and working memory limitations.

Levels of Difficulty: The number of categories of information that have relevant information for the given task.

Example: The information in Table 6 is displayed and the driver is instructed to select the four-star hotel.

Table 7 Listen Task

Hotels Available					
Name	Distance	Cost	Quality	Child Care	Restaurant
Marriott	15 miles	\$95.00	****	Yes	Yes
Howard Johnson	25 miles	\$50.00	**	No	Yes
Holiday Inn	45 miles	\$55.00	***	No	Yes
Comfort Inn	50 miles	\$75.00	***	Yes	No
Sleep Inn	90 miles	\$45.00	**	No	No

Compute

Definition: “Compute involves calculating, either numerically or logically, the answer to a problem. This process involves both short- and long-term memory” (Lee et al., 1997).

Output: “The output is the answer to a problem or question” (Lee et al., 1997).

Constraints: The primary driver constraint is his/her computational abilities.

Levels of Difficulty: There will be three categories of computations: determining the total number of miles provided miles driven each day; determining the quickest route provided the distance and mph; and determining the quickest route provided the distance, mph, and delays (in minutes).

Example: The information in Table 7 is displayed and the driver is asked to determine the quickest route. The driver must use the distance and mph provided to determine the quickest route.

Table 8 Listen and Compute Task.

Route Planning					
Route	Distance	Speed Limit	Gas Station Present	Estimated Delays	Toll Cost
I-77	135 miles	55 mph	Yes	33 min.	\$0.00
US-15	110 miles	45 mph	No	17 min.	\$1.50
US-27	105 miles	50 mph	No	45 min.	\$4.00
US-356	145 miles	65 mph	No	5 min.	\$10.00
US-39	120 miles	45 mph	Yes	None	\$3.00

Plan

Definition: “Plan involves matching resources to the current objectives” (Lee et al., 1997). This definition has been expanded to define the Plan element as making a decision from definitive information, requiring no interpretation of meaning to accomplish an objective (i.e., the specification of the quality ratings of hotels or the specification of the amount of delay to expect on a given route). The difference between the Listen Only tasks and the Listen and Plan tasks is that the Listen tasks only require the driver to scan and locate information on the display, whereas the Listen and Plan tasks require the driver to scan and locate information on the display, and then further process the information to determine how best to accomplish an objective(s).

Output: “Output is a coordinated set of actions that meet the goals of the driver within the constraints of the situation” (Lee et al., 1997).

Constraints: The primary constraint of the Plan element is the ability of the driver to appropriately prioritize, schedule, and estimate.

Levels of Difficulty: The number of criteria the driver considers when making a decision. For example, the driver may be provided 6 different criteria when choosing a route (distance, toll costs, delays, gas station present, rest areas on route, and speed limit); however, the driver may consider all 6 when making a decision or perhaps only 3.

Example: The information in Table 8 is displayed and the driver is asked to select the best route.

Table 9 Listen and Plan Task

Route Planning					
Route	Distance	Rest Areas	Gas Station Present	Estimated Delays	Toll Cost
I-77	135 miles	Yes	Yes	33 min.	\$0.00
US-15	110 miles	No	No	17 min.	\$1.50
US-27	105 miles	Yes	No	45 min.	\$4.00
US-356	145 miles	Yes	No	5 min.	\$10.00
US-39	120 miles	Yes	Yes	None	\$3.00

Interpret

Definition: “The process of interpret involves extracting the meaning of a set of cues” (Lee et al., 1997). This definition has been expanded to define the Interpret element as making a decision from information that requires interpretation to determine the significance of it in order to accomplish an objective (i.e. determine the significance of a car accident, train crossing, or construction on a route). Interpret has also been expanded to include the decoding which is required when icons are presented which represent hotels, gas stations, construction areas, accidents, etc. An example: a driver is presented two icons and must determine that they represent a Sheraton hotel and a Shell gas station. The difference between a Listen and Plan task vs. a Listen, Plan, and Interpret task is that the Listen and Plan task is characterized by a driver using definitive information to determine how to best accomplish an objective, whereas the Listen, Plan, and Interpret task also involves the driver using information to determine how best to accomplish an objective, but the driver must first interpret the information presented.

Output: The output is an understanding of the current situation in the context of the goals of the driver (Lee et al., 1997).

Constraints: The primary constraint on the driver is the ability to interpret the available information (e.g., spatial information or iconic information) and to develop appropriate mental models (Lee et al., 1997).

Levels of Difficulty: The number of criteria the driver considers when making a decision. For example, the driver may be provided 6 different criteria when choosing a route (weather conditions, safety hazards, type of delay, lanes closed, and type of road); however, the driver may consider all 6 when making a decision or perhaps only 2.

Example: The information in Table 9 is displayed and the driver is instructed to select a route. The driver must first interpret the significance of type of road, lanes closed, weather conditions, traffic delays, and safety hazards, and then determine the best route to select.

Table 10 Listen, Plan and Interpret Task

Route Planning					
Route	Type of Road	Lanes Closed	Weather Conditions	Traffic Delays	Safety Hazards
I-81	Interstate	1 lane	Overcast	Accident	None
US-579	2-lane	No lanes	Rain	Construction	None
I-90	Interstate	No lanes	Thunderstorms	None	Rock slide
US-84	4-lane	2 lanes	Heavy Rain	Drawbridge	Flooding
US-17	4-lane	1 lane	Clear	Train Crossing	Icy bridge

Listed in Tables 10 and 11 are examples of a Listen, Plan, and Compute task and a Listen, Plan, Interpret, and Compute task, respectively. The same information is provided in Listen, Plan, and Compute tasks and Listen and Compute tasks. However, the instructions provided the driver differ. In Listen, Plan, and Compute tasks, the driver is asked to select a route, whereas in Listen and Compute tasks, the driver is asked to perform a calculation such as determine the quickest route.

Table 11 Listen, Plan, and Compute Task

Route Planning					
Route Option	Distance	Speed Limit	Rest Areas	Gas Station On-route	Toll Cost
I-95	165 miles	65 mph	Yes	Yes	\$1.00
US-7	95 miles	45 mph	No	Yes	\$1.50
US-542	125 miles	55 mph	No	No	\$4.00
US-68	135 miles	65 mph	Yes	Yes	\$10.00
US-421	105 miles	50 mph	No	No	\$8.50

Table 12 Listen, Plan, Interpret, and Compute Task

Route Selection					
Route Option	Distance	Speed Limit	Traffic Delays	Weather Conditions	Safety Hazards
I-70	115 miles	65 mph	Accident	Overcast	None
US-38	80 miles	45 mph	Construction	Rain	None
US-42	95 miles	55 mph	Train Crossing	Clear	Rock slide
US-54	150 miles	50 mph	Construction	Thunderstorms	Flooding
US-98	125 miles	65 mph	Detour	Heavy Rain	Icy bridge

Refer to Appendix C for a complete listing of all in-vehicle tasks.

APPENDIX B-8: IN-VEHICLE TRAINING AND PRACTICE DRIVE

Have Participant Adjust Seat

Have Participant Adjust Mirrors

Verify Eyes in View of Camera

Have rear seat experimenter verify that both of the participant's eyes can be seen clearly in the camera. *(If both eyes are not in clear view, adjust the mirror and/or seat such that the participant feels comfortable with the mirror position and his/her eyes are in view of the camera.)*

Vehicle Controls

Have the participant locate and become comfortable with wiper, signal, and headlight controls.

Point out the instruments on the display:

- Speedometer
- Temperature gauge (really the gas gauge). When the red area is reached, it means we are low on gas.
- Display to right of speedometer will remain blank for the duration of the drive.

Vision Test and Hearing Test

(Display training slide #6)

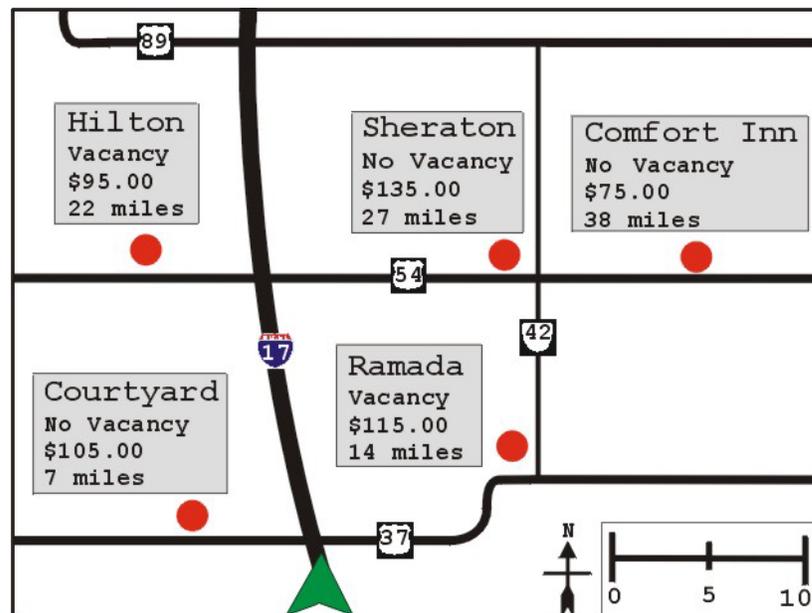


Figure 16 Training Slide #6

Instructions: Select a hotel.

Adjust display position for the participant's comfort.

Ask the participant to read the information displayed on the screen. If the participant is unable to read the information displayed, thank him/her for offering to help and *end the study*.

Ask the participant to repeat the instructions he/she heard. Ask if they would like the volume increased. Repeat until the participant states the desired level has been obtained. If the participant is unable to understand the information presented auditorily, thank him/her for coming and *end the study*.

Ask the subject to go ahead and select a hotel.

Participant states selection

Experimenter

(Ask participant if each category of information was considered: hotel name, vacancy, cost, and distance in making his/her decision. Participant answers yes/no for each category of information.)

Practice Drive

(Ask participant if he/she is ready. If he/she is ready, drive around the practice route to allow the participant to become familiar with the vehicle.)

Experimenter

Do not worry about keeping up with the lead vehicle or worry if a vehicle comes between you and him. Remember, the purpose of the lead vehicle is to simulate traffic; if other vehicles come between you and him, then they will take his place as traffic.

If I see that you have become overly distracted by the display and are starting to go off the road, I will simply say ROAD. When you hear this, stop looking at the display and put your full attention to the roadway.

I have an emergency brake pedal on my side. If I push it this is what it will feel like. (*Check to make sure vehicles aren't behind the Aurora, and gently press brake*)

(After driving around the practice route once, ask the subject if he/she feels comfortable with the handling of the vehicle. If he/she would like more practice, allow him/her to drive around the route as many times as needed.)

Practice Slides

(*Have subject drive around practice route.*)

(*Present Training Slides #7, 8, 9, 10, and 11*)

These slides are increasingly difficult and should provide a good warm up.

(*If no problems exist, begin data collection with regular tasks*)

APPENDIX B-9: FRONT SEAT EXPERIMENTER'S PROTOCOL

The front seat experimenter is the safety officer. His primary task is to maintain a safe driving condition for the participant by monitoring the driving environment. His secondary task is to control data collection by selecting tasks to be presented.

DATA COLLECTION PROCEDURES

Task Presentation Timeline

1. Present task (do not present tasks during sharp curves or while driving through towns)
2. Allow the participant time to complete each task. If unsafe driving behavior is exhibited, end task.
3. Ask participant probe questions to determine what information was used and if any calculation(s) were performed.
4. Ask participant subjective evaluation questions for workload and situation awareness.
5. Record answers on data collection sheet.

Procedures

Prior to starting data collection, place task sheets, in a prearranged order, in a binder. Each task sheet has a unique combination of type of task and presentation format. The different slides for this unique combination, each with a different level of complexity, are listed on the sheet.

1. During data collection, present one task per page in the notebook.
2. Select a complexity level that is suspected to be slightly under red-line.
3. State the task to be presented. The rear seat experimenter will type in the slide number and slide will be presented.
4. After the participant provides his/her answer:
 - Ask the participant which categories of information he/she used,
 - Ask the participant for subjective measures, and
 - Ask rear experimenter for number of eye glances.
5. Once one task per page has been presented, start on the first page again, and present a second complexity level. If, during the first task presentation the complexity level resulted in a measure under red-line, then present a more difficult complexity level. For safety reasons, progress upward in difficulty toward the red-line. Avoid giving a task that is significantly over red-line. If during the first task presentation the complexity level resulted in a measure over the red-line then present a less difficult complexity level.
6. After a second complexity level has been presented for each category of task, start at the first page and present a third task if the two previous complexity levels did not yield measures below and above red-line. The goal is to have one task below and one task slightly above red-line. Use 9 eye glances to the IVIS display as a rough estimate that a red-line has been reached if driving behavior does not indicate that a red-line has been reached.
7. When a task is presented, the computer automatically sends a signal to the confederate driver: one beep at the beginning of a task, and two beeps at the end of a task.

Baseline Measures

1. For every 4-5 visual tasks, there will be a page in the notebook that states that a baseline reading is to be collected for either 5, 10, 20, or 30 seconds.
2. To flag data as baseline data:
3. Inconspicuously raise right hand to side of head, put one finger up. This informs the rear seat experimenter to signal the confederate vehicle that a baseline condition is being performed. Note: the confederate driver receives the same signals for the starting and ending of baseline conditions. He/she does not know which is being recorded in the data set. Press and hold in the data flagger button for a preset number of seconds. Inconspicuously raise right hand to side of head, put two fingers up. This informs the rear-seat experimenter to signal the confederate vehicle that a baseline condition has ended.
4. If during baseline data collection an event occurs (i.e. participant sneezes, vehicle merges into traffic in between confederate vehicle and test vehicle, etc.) that creates non-baseline conditions, depress the data flagger and signal rear-seat experimenter that the baseline condition has ended. When a baseline condition is present again, repeat steps 1-3.

Breaks

Periodically ask the participant how he/she is feeling and if he/she would like to take a break. Take breaks approximately every 45 minutes, or more often, as needed by the participant.

APPENDIX B-10: BACK SEAT EXPERIMENTER'S PROTOCOL

The back seat experimenter was tasked with monitoring the equipment and presenting the tasks that were assigned by the front seat experimenter. During tasks, the back seat experimenter counted the approximate number of glances to the display as a measure of task difficulty. The number of glances was used as a criterion for presentation difficulty level for visual-based tasks.

APPENDIX B-11: CONFEDERATE VEHICLE DRIVER'S PROTOCOL

Procedures

General

- Drive along the predetermined route on U.S. Route 460.
- Maintain a speed, when possible, of ± 5 mph of the posted speed limit. The speed limit, on sections of the route that tasks are presented, ranges between 55mph and 65mph
- If the experimental vehicle becomes too distant, (greater than a 5 second separation), slow down until the distance between the experimental vehicle and the confederate vehicle becomes less than 5 seconds.
- If the experimental vehicle becomes too close, (uncomfortable or less than one-second separation), accelerate to allow for a comfortable headway distance.

During Task Presentation

- When a single tone signal is sent via the hand-held radio from the experimental vehicle, indicating the beginning of a task, decelerate approximately 5 mph.
- When decelerating, if possible, do not use the vehicle's brakes. Instead, decelerate by releasing the accelerator pedal when going up a hill or by down shifting when on a flat or down hill section of road.
- When a double tone signal is sent via the hand-held radio from the experimental vehicle, indicating the end of a task, resume driving at the posted speed limit.
- Remain in the right lane for the completion of a task.
- If slow moving traffic prevents driving at the posted speed limit, then follow at a safe distance until the task has been completed, then pass slow moving traffic.

APPENDIX B-12: AUDITORY TASK PRESENTATION DESCRIPTION

Brief explanation of auditory task sequence

- The task sound could be repeated by pressing the task button at any time during the task.
- The instruction sound could be repeated by pressing the instruction button at any time.
- The tasks were selected by a random ordering.
- Tasks that exceeded driving abilities were thrown out of the experiment by category during the pilot study.
- All other tasks were presented unless the task was terminated more than once by the front seat experimenter for safety reasons or unfavorable driving conditions.

Auditory task sequence

- Experimenter initiated the task by pressing a button on the keyboard.
- The subject received the task instruction sound.
- The subject was able to repeat the instruction if necessary by pressing the repeat instruction button at any time.
- If the repeat button was pressed the instruction repeated.
- The instruction sound could be repeated as many times as necessary
- The computer would then begin recording the variables of interest and the task sound would play.
- Data collection for the task ended when the subject responded with the answer to the question.
- At any time the driver decided that the task was too difficult, he/she was instructed to answer “skip,” indicating that he/she was uncomfortable completing the task. In this case, the next task was presented to the driver.

APPENDIX B-13: SUBJECTIVE RATING SCALE INSTRUCTIONS

We are not only interested in assessing your performance, but also the experiences you had during the different task conditions. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another.

Since workload is something that is experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. This set of four rating scales was developed for you to use in evaluating your experiences during different tasks. Please read the descriptions of the scales carefully. If you have a question about any of the scales in the table, please ask me about it. It is extremely important that they be clear to you. You may request a description of the scales if you wish at any time during the experiment.

Frustration Level

This scale is used to assess how frustrated you felt by the task. Low frustration would be if the task made sense and was not tricky or difficult to complete for some other reason. High frustration level would be a situation where the task is confusing or interferes with your driving or comfort.

Mental Demand

This scale is a rating of how much thinking you felt was required to get the correct answer to the task. Low mental demand would be a question where you felt the answer was obvious. High mental demand would be a situation where you felt you had to think extensively or do calculations or were unsure of the answer.

Time Sharing Demand

This rating is to assess how difficult you felt it was to drive and do the task at the same time. An indication of high time sharing demand would be if you were required to switch your attention back and forth in order to keep the vehicle under control and complete the task. Low time sharing demand is indicated by no need to focus at all. High time sharing demand is indicated by difficulty in concentrating on the task or driving and a need to switch back and forth.

Awareness of Surroundings

This is a rating of how well you feel you knew the important features of your surroundings and the relationships between them. This includes things like cars and their positions, intersections and road signs, the distances from the sides of the road and your speed. Low awareness of surroundings is indicated by not checking or not knowing things like where other vehicles are or what your speed is.

High awareness of surroundings is a situation where you know all the relationships associated with the vehicle.

After performing each task, you will be asked to evaluate the task by selecting a value from 1 to 100 for each of the three scales. Each line has two endpoint descriptors that describe the scale. For example, Frustration Level goes from 1 (not frustrating) to 100 (extremely frustrating). The experimenter will say the name of each scale, at which point you will respond with your evaluation of the task you just completed on a scale from one to one hundred. Please consider your responses carefully in distinguishing among the task conditions. Consider each scale individually. Your ratings will play an important role in the evaluation being conducted, thus, your active participation is essential to the success of this experiment, and is greatly appreciated.

Table 13 Subjective Rating Scale Definitions

RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL EFFORT	<i>Low/High 1 / 100</i>	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
TIME PRESSURE	<i>Low/High 1 / 100</i>	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
FRUSTRATION LEVEL	<i>Low/High 1 / 100</i>	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?
AWARENESS OF SURROUNDINGS	<i>Low/High 1 / 100</i>	How comfortable were you with your knowledge of the driving environment and the relationships in it during the task?

APPENDIX C

Pilot and Regular Task scripts.

APPENDIX C-1: TASKS PRESENTED DURING PILOT STUDY

Listen 3x3 Route low.

Select the 124-mile route.

task201.voc

U.S. Route 92 to Highway 61 is a distance of 126 miles and has a speed limit of 65 miles per hour.

Interstate 14 to U.S. Route 27 is a distance of 153 miles and has a speed limit of 45 miles per hour.

Highway 78 to Highway 88 is a distance of 124 miles and has a speed limit of 55 miles per hour.

Listen 3x3 Route low

Select the route with no gas station.

task202.voc

Interstate 67 to Highway 4 is a distance of 165 miles and has a gas station.

Highway 26 to U.S. Route 71 is a distance of 180 miles and has a gas station.

U.S. Route 33 to Highway 63 is a distance of 177 miles and has no gas station.

Listen, Compute 3x3 Route low.

Select the least expensive route to the airport.

task203.voc

Interstate 34 to U.S. Route 47 has a 3-dollar and 75-cent toll and a 2-dollar and 25-cent toll.

U.S. Route 86 to U.S. Route 99 has a 5-dollar and 50-cent toll and a 3-dollar and 75-cent toll.

U.S. Route 56 to Highway 76 has a 6-dollar and 25-cent toll and a 3-dollar and 75-cent toll.

Listen, Compute 3x3 Route medium.

Select the quickest route to the airport.

task204.voc

Interstate 53 to U.S. Route 24 is a distance of 109 miles and has a speed limit of 65 miles per hour.

Interstate 31 to Highway 100 is a distance of 114 miles and has a speed limit of 55 miles per hour.

Highway 21 to Highway 58 is a distance of 100 miles and has a speed limit of 45 miles per hour.

Listen, Plan 3x3 Route low.

Select a route to the hospital.

task205.voc

Interstate 63 to U.S. Route 47 is a distance of 45 miles and has 10 minutes in delays.

U.S. Route 23 to Highway 57 is a distance of 45 miles and has 22 minutes in delays.

Highway 47 to Highway 83 is a distance of 45 miles and has 21 minutes in delays.

Listen, Plan 3x3 Route medium.

Select a route to the hospital.

task206.voc

U.S. Route 41 to Highway 59 is a distance of 247 miles and has 18 minutes in delays.

Interstate 47 to U.S. Route 60 is a distance of 253 miles and has 12 minutes in delays.

U.S. Route 69 to U.S. Route 99 is a distance of 241 miles and has 39 minutes in delays.

Listen, Plan 3x3 Route medium.

Select a route to the hospital.

task207.voc

U.S. Route 26 to Highway 7 is a distance of 80 miles and has 23 minutes in delays.

Interstate 1 to Highway 37 is a distance of 39 miles and has 31 minutes in delays.

Highway 72 to U.S. Route 44 is a distance of 73 miles and has 12 minutes in delays.

Listen, Interpret 3x3 Route low.

Select a route to the hospital.

task208.voc

U.S. Route 51 to Highway 37 is a distance of 48 miles and has an accident delay.

Interstate 77 to U.S. Route 50 is a distance of 48 miles and has a train crossing delay.

U.S. Route 91 to Highway 40 is a distance of 48 miles and has a school crossing delay.

Listen, Interpret 3x3 Route medium.

Select a route to the hospital.

task209.voc

Interstate 21 to Highway 6 is a distance of 85 miles and has a construction delay.

Highway 5 to U.S. Route 55 is a distance of 89 miles and has an accident delay.

U.S. Route 56 to Highway 63 is a distance of 76 miles and has a cattle crossing delay.

Listen, Interpret 3x3 Route medium.

Select a route to the hospital.

task210.voc

Interstate 86 to U.S. Route 44 is a distance of 35 miles and has a train crossing delay.

U.S. Route 77 to Highway 38 is a distance of 84 miles and has a school crossing delay.

Highway 89 to Highway 16 is a distance of 91 miles and has a construction delay.

Listen, Plan 3x3 Hotel low.

Select a hotel.

task211.voc

The Ramada has no vacancy and is a distance of 17 miles away.

The Holiday Inn has a vacancy and is a distance of 17 miles away.

The Marriott has a vacancy and is a distance of 17 miles away.

Listen, Plan 3x3 Hotel medium.

inst06.voc

Select a hotel.

task212.voc

The Comfort Inn has a vacancy and is a distance of 43 miles away.

The Motel 8 has no vacancy and is a distance of 51 miles away.

The Embassy Suites has a vacancy and is a distance of 46 miles away.

Listen, Plan 3x3 Hotel medium.

Select a hotel.

task213.voc

The Ramada has a vacancy and is a distance of 48 miles away.

The Howard Johnson's has no vacancy and is a distance of 40 miles away.

The Motel 8 has a vacancy and is a distance of 52 miles away.

Listen 5x4 Route low.

Select the route with a gas station.

task221.voc

Interstate 86 to U.S. Route 4 has light congestion, has clear weather, and has no gas station.

U.S. Route 92 to U.S. Route 58 has light congestion, has rainy weather, and has no gas station.

U.S. Route 87 to Highway 52 has moderate congestion, has clear weather, and has no gas station.

Highway 75 to U.S. Route 51 has light congestion, has rainy weather, and has no gas station.

U.S. Route 3 to Highway 47 has moderate congestion, has foggy weather, and has a gas station.

Listen 5x4 Route low.

Select the route with moderate congestion.

task222.voc

Highway 3 to Highway 23 has no gas station, has clear weather, and has light congestion.

Interstate 84 to U.S. Route 43 has a gas station, has rainy weather, and has heavy congestion.

U.S. Route 73 to Highway 20 has a gas station, has clear weather, and has heavy congestion.

Interstate 81 to U.S. Route 69 has a gas station, has rainy weather, and has light congestion.

U.S. Route 34 to Highway 63 has no gas station, has foggy weather, and has moderate congestion.

Listen, Compute 5x4 Route low.

Select the least expensive route to the airport.

task223.voc

Highway 28 to Highway 88 has a 6-dollar and 25-cent toll, a 4-dollar and 25-cent toll, and has a gas station.

Interstate 59 to U.S. Route 98 has a 1-dollar and 50-cent toll, a 2-dollar and 50-cent toll, and has a gas station.

U.S. Route 40 to Highway 36 has a 6-dollar and 25-cent toll, a 1-dollar and 75-cent toll, and has a gas station.

Interstate 56 to U.S. Route 26 has a 6-dollar and 50-cent toll, a 2-dollar and 25-cent toll, and has no gas station.

U.S. Route 41 to Highway 54 has a 2-dollar and 75-cent toll, a 3-dollar and 75-cent toll, and has a gas station.

Listen, Compute 5x4 Route medium.

Select the quickest route to the airport.

task224.voc

Highway 5 to Highway 98 is a distance of 135 miles, has a speed limit of 65 miles per hour, and has no gas station.

Interstate 54 to U.S. Route 33 is a distance of 176 miles, has a speed limit of 55 miles per hour, and has a gas station.

U.S. Route 4 to Highway 24 is a distance of 156 miles, has a speed limit of 65 miles per hour, and has a gas station.

Interstate 69 to U.S. Route 89 is a distance of 183 miles, has a speed limit of 45 miles per hour, and has no gas station.

Interstate 18 to U.S. Route 64 is a distance of 129 miles, has a speed limit of 55 miles per hour, and has a gas station.

Listen, Compute 5x4 Route High.

Select the quickest route to the airport.

task225.voc

U.S. Route 46 to Highway 59 is a distance of 46 miles, has a speed limit of 45 miles per hour, and has 19 minutes in delays.

Interstate 70 to U.S. Route 84 is a distance of 77 miles, has a speed limit of 65 miles per hour, and has 23 minutes in delays.

U.S. Route 13 to Highway 77 is a distance of 89 miles, has a speed limit of 75 miles per hour, and has 47 minutes in delays.

Highway 31 to Highway 78 is a distance of 65 miles, has a speed limit of 45 miles per hour, and has 4 minutes in delays.

U.S. Route 44 to Highway 64 is a distance of 36 miles, has a speed limit of 55 miles per hour, and has 25 minutes in delays.

Listen, Plan 5x4 Route low.

Select a route to the hospital.

task226.voc

Interstate 56 to U.S. Route 73 is a distance of 62 miles, has 24 minutes in delays, and has a slippery road hazard.

U.S. Route 2 to Highway 44 is a distance of 62 miles, has 12 minutes in delays, and has a slippery road hazard.

Interstate 91 to U.S. Route 60 is a distance of 62 miles, has 19 minutes in delays, and has a slippery road hazard.

U.S. Route 94 to Highway 72 is a distance of 62 miles, has 15 minutes in delays, and has a slippery road hazard.

Highway 24 to U.S. Route 18 is a distance of 62 miles, has 7 minutes in delays, and has a slippery road hazard.

Listen, Plan 5x4 Route High.

Select a route to the hospital.

task227.voc

U.S. Route 20 to Highway 56 is a distance of 43 miles, has 25 minutes in delays, and has a slippery road hazard.

Highway 52 to Highway 70 is a distance of 64 miles, has 42 minutes in delays, and has a deer-crossing hazard.

Interstate 2 to U.S. Route 72 is a distance of 85 miles, has 15 minutes in delays, and has a fallen rock hazard.

U.S. Route 40 to Highway 35 is a distance of 85 miles, has 25 minutes in delays, and has a slippery road hazard.

Interstate 91 to U.S. Route 56 is a distance of 73 miles, has 37 minutes in delays, and has a low visibility hazard.

Listen, Plan 5x4 Route High.

Select a route to the hospital.

task228.voc

Highway 6 to Highway 43 is a distance of 35 miles, has 9 minutes in delays, and has a slippery road hazard.

Highway 68 to U.S. Route 38 is a distance of 48 miles, has 12 minutes in delays, and has a deer-crossing hazard.

U.S. Route 2 to Highway 72 is a distance of 80 miles, has 41 minutes in delays, and has a fallen rock hazard.

Interstate 58 to U.S. Route 41 is a distance of 15 miles, has 32 minutes in delays, and has a low visibility hazard.

U.S. Route 25 to Highway 90 is a distance of 81 miles, has 19 minutes in delays, and has an icy bridge hazard.

Listen, Plan, Compute 5x4 Route low.

Select a route to the airport.

task229.voc

U.S. Route 1 to Highway 29 has a 4-dollar and 25-cent toll, a 2-dollar and 75-cent toll, and has no gas station.

Interstate 19 to U.S. Route 20 has a 6-dollar and 50-cent toll, a 3-dollar and 50-cent toll, and has a gas station.

U.S. Route 60 to Highway 92 has a 1-dollar and 75-cent toll, a 3-dollar and 75-cent toll, and has no gas station.

Interstate 73 to U.S. Route 87 has a 3-dollar and 25-cent toll, a 6-dollar and 25-cent toll, and has a gas station.

U.S. Route 47 to Highway 3 has a 1-dollar and 75-cent toll, a 5-dollar and 50-cent toll, and has no gas station.

Listen, Plan, Compute 5x4 Route medium.

Select a route to the airport.

task230.voc

Highway 24 to U.S. Route 78 is a distance of 96 miles, has a speed limit of 45 miles per hour, and has a gas station.

U.S. Route 75 to Highway 20 is a distance of 176 miles, has a speed limit of 55 miles per hour, and has no gas station.

Interstate 53 to U.S. Route 75 is a distance of 184 miles, has a speed limit of 50 miles per hour, and has no gas station.

U.S. Route 50 to Highway 12 is a distance of 184 miles, has a speed limit of 65 miles per hour, and has a gas station.

Interstate 24 to U.S. Route 23 is a distance of 192 miles, has a speed limit of 65 miles per hour, and has a gas station.

Listen, Plan, Compute 5x4 Route High.

Select a route to the airport.

task231.voc

Highway 37 to Highway 54 is a distance of 97 miles, has a speed limit of 45 miles per hour, and has 21 minutes in delays.

Interstate 84 to U.S. Route 34 is a distance of 106 miles, has a speed limit of 50 miles per hour, and has 19 minutes in delays.

U.S. Route 79 to Highway 33 is a distance of 138 miles, has a speed limit of 65 miles per hour, and has 31 minutes in delays.

Interstate 62 to U.S. Route 75 is a distance of 120 miles, has a speed limit of 55 miles per hour, and has 10 minutes in delays.

Interstate 21 to U.S. Route 31 is a distance of 143 miles, has a speed limit of 65 miles per hour, and has 48 minutes in delays.

Listen, Plan, Interpret 5x4 Route Low.

Select a route to the hospital.

task232.voc

U.S. Route 85 to Highway 48 is a distance of 22 miles, has an emergency vehicle delay, and U.S. Route 10 has 0 of 2 lanes closed.

Highway 51 to U.S. Route 41 is a distance of 22 miles, has a construction delay, and Highway 48 has 0 of 2 lanes closed.

Interstate 40 to Highway 83 is a distance of 22 miles, has an accident delay, and Interstate 49 has 0 of 2 lanes closed.

Highway 81 to U.S. Route 48 is a distance of 22 miles, has a school crossing delay, and Highway 17 has 0 of 2 lanes closed.

U.S. Route 10 to Highway 79 is a distance of 22 miles, has an accident delay, and U.S. Route 50 has 0 of 2 lanes closed.

Listen, Plan, Interpret 5x4 Route High.

Select a route to the hospital.

task233.voc

Interstate 44 to U.S. Route 36 is a distance of 30 miles, has a drawbridge delay, and Interstate 52 has 0 of 2 lanes closed.

U.S. Route 87 to Highway 16 is a distance of 22 miles, has a funeral procession delay, and U.S. Route 11 has 1 of 2 lane closed.

Interstate 73 to U.S. Route 97 is a distance of 76 miles, has an accident delay, and Interstate 52 has 2 of 2 lanes closed.

U.S. Route 58 to Highway 56 is a distance of 32 miles, has a cattle crossing delay, and U.S. Route 98 has 1 of 2 lane closed.

Interstate 16 to U.S. Route 15 is a distance of 74 miles, has a train crossing delay, and Interstate 77 has 0 of 2 lanes closed.

Listen, Plan, Interpret 5x4 Route High.

Select a route to the hospital.

task234.voc

Highway 98 to Highway 11 is a distance of 29 miles, has an accident delay, and Highway 36 has 2 of 2 lanes closed.

Interstate 74 to U.S. Route 90 is a distance of 28 miles, has a school crossing delay, and Interstate 18 has 1 of 2 lane closed.

U.S. Route 54 to Highway 88 is a distance of 31 miles, has an emergency vehicle delay, and U.S. Route 56 has 0 of 2 lanes closed.

Highway 16 to Highway 95 is a distance of 36 miles, has a train crossing delay, and Highway 62 has 1 of 2 lane closed.

U.S. Route 54 to U.S. Route 5 is a distance of 22 miles, has an accident delay, and U.S. Route 89 has 1 of 2 lane closed.

Listen, Plan, Interpret, Compute 5x4 Route Low.

Select a route to the airport.

task235.voc

Interstate 82 to U.S. Route 61 has a 5-dollar and 75-cent toll, a 1-dollar and 25-cent toll, and has an emergency vehicle delay.

U.S. Route 57 to Highway 92 has a 2-dollar and 50-cent toll, a 2-dollar and 25-cent toll, and has a school crossing delay.

U.S. Route 62 to Highway 19 has a 4-dollar and 75-cent toll, a 3-dollar and 75-cent toll, and has an accident delay.

Interstate 33 to U.S. Route 42 has a 1-dollar and 25-cent toll, a 3-dollar and 75-cent toll, and has a drawbridge delay.

U.S. Route 36 to Highway 49 has a 3-dollar and 50-cent toll, a 2-dollar and 50-cent toll, and has a train crossing delay.

Listen, Plan, Interpret, Compute 5x4 Route Medium.

Select a route to the airport.

task236.voc

Interstate 30 to U.S. Route 12 is a distance of 212 miles, has a speed limit of 65 miles per hour, and has a drawbridge delay.

U.S. Route 11 to U.S. Route 14 is a distance of 151 miles, has a speed limit of 45 miles per hour, and has a construction delay.

Interstate 81 to Highway 90 is a distance of 162 miles, has a speed limit of 50 miles per hour, and has a school crossing delay.

Highway 84 to Highway 11 is a distance of 210 miles, has a speed limit of 65 miles per hour, and has a train crossing delay.

Interstate 31 to U.S. Route 53 is a distance of 172 miles, has a speed limit of 55 miles per hour, and has a funeral procession delay.

Listen, Plan 5x4 Hotel Low.

Select a hotel.

task237.voc

The Howard Johnson has a vacancy, costs 73 dollars, and is a distance of 35 miles away.

The Days Inn has a vacancy, costs 73 dollars, and is a distance of 35 miles away.

The Comfort Inn has a vacancy, costs 73 dollars, and is a distance of 35 miles away.

The Days Inn has no vacancy, costs 73 dollars, and is a distance of 35 miles away.

The Howard Johnson has a vacancy, costs 73 dollars, and is a distance of 35 miles away.

Listen, Plan 5x4 Hotel High.

Select a hotel.

task238.voc

The Motel 8 has a vacancy, costs 52 dollars, and is a distance of 198 miles away.

The Ramada has no vacancy, costs 59 dollars, and is a distance of 200 miles away.

The Holiday Inn has no vacancy, costs 64 dollars, and is a distance of 128 miles away.

The Howard Johnson has a vacancy, costs 75 dollars, and is a distance of 149 miles away.

The Best Western has no vacancy, costs 84 dollars, and is a distance of 201 miles away.

Listen, Plan 5x4 Hotel High.

Select a hotel.

task239.voc

The Best Western has a vacancy, costs 85 dollars, and is a distance of 34 miles away.

The Ramada has a vacancy, costs 61 dollars, and is a distance of 17 miles away.

The Holiday Inn has no vacancy, costs 52 dollars, and is a distance of 13 miles away.

The Comfort Inn has no vacancy, costs 71 dollars, and is a distance of 21 miles away.

The Marriott has a vacancy, costs 82 dollars, and is a distance of 16 miles away.

Listen 5x6 Route Low.

Select the route with a 55-mile per hour speed limit.

task241.voc

U.S. Route 56 to U.S. Route 90 is a distance of 46 miles, has a speed limit of 55 miles per hour, has clear weather, has light congestion, and has no gas station.

U.S. Route 24 to Highway 28 is a distance of 96 miles, has a speed limit of 40 miles per hour, has rainy weather, has moderate congestion, and has a gas station.

Interstate 100 to Highway 81 is a distance of 62 miles, has a speed limit of 50 miles per hour, has clear weather, has moderate congestion, and has no gas station.

Highway 16 to U.S. Route 80 is a distance of 86 miles, has a speed limit of 45 miles per hour, has rainy weather, has moderate congestion, and has a gas station.

Interstate 99 to U.S. Route 90 is a distance of 88 miles, has a speed limit of 65 miles per hour, has foggy weather, has heavy congestion, and has a gas station.

Listen 5x6 Route High.

Select the route with foggy weather.

task242.voc

U.S. Route 96 to U.S. Route 48 is a distance of 64 miles, has a speed limit of 55 miles per hour, has rainy weather, has moderate congestion, and has a gas station.

U.S. Route 59 to Highway 87 is a distance of 42 miles, has a speed limit of 45 miles per hour, has clear weather, has light congestion, and has no gas station.

Highway 40 to Highway 47 is a distance of 64 miles, has a speed limit of 65 miles per hour, has rainy weather, has moderate congestion, and has a gas station.

Interstate 45 to U.S. Route 68 is a distance of 55 miles, has a speed limit of 65 miles per hour, has rainy weather, has heavy congestion, and has no gas station.

U.S. Route 81 to U.S. Route 61 is a distance of 78 miles, has a speed limit of 70 miles per hour, has foggy weather, has light congestion, and has a gas station.

Listen, Compute 5x6 Route Low.

Select the least expensive route to the airport.

task243.voc

U.S. Route 73 to Highway 73 is a distance of 84 miles, has a 6-dollar and 75-cent toll, a 3-dollar and 75-cent toll, has a rest area, and has no gas station.

Interstate 91 to U.S. Route 95 is a distance of 148 miles, has a 3-dollar and 50-cent toll, a 4-dollar and 25-cent toll, has no rest area, and has a gas station.

U.S. Route 75 to Highway 72 is a distance of 76 miles, has a 1-dollar and 75-cent toll, a 2-dollar and 75-cent toll, has no rest area, and has no gas station.

Interstate 74 to U.S. Route 1 is a distance of 156 miles, has a 4-dollar and 25-cent toll, a 6-dollar and 50-cent toll, has a rest area, and has no gas station.

U.S. Route 1 to U.S. Route 96 is a distance of 80 miles, has a 4-dollar and 50-cent toll, a 3-dollar and 75-cent toll, has no rest area, and has a gas station.

Listen, Compute 5x6 Route Medium.

Select the quickest route to the airport.

task244.voc

U.S. Route 92 to Highway 47 is a distance of 27 miles, has a speed limit of 45 miles per hour, has a 1-dollar and 50-cent toll, has a rest area, and has a gas station.

Interstate 88 to Highway 99 is a distance of 34 miles, has a speed limit of 55 miles per hour, has a 9-dollar and 25-cent toll, has no rest area, and has no gas station.

Highway 64 to U.S. Route 6 is a distance of 33 miles, has a speed limit of 65 miles per hour, has a 6-dollar and 50-cent toll, has a rest area, and has a gas station.

U.S. Route 39 to Highway 37 is a distance of 25 miles, has a speed limit of 65 miles per hour, has a 5-dollar and 25-cent toll, has no rest area, and has no gas station.

Interstate 14 to U.S. Route 36 is a distance of 15 miles, has a speed limit of 45 miles per hour, has a 1-dollar and 75-cent toll, has no rest area, and has a gas station.

Listen, Compute 5x6 Route High.

Select the quickest route to the airport.

task245.voc

Highway 33 to Highway 94 is a distance of 41 miles, has a speed limit of 45 miles per hour, has 4 minutes in delays, has no rest area, and has a gas station.

Interstate 1 to Highway 94 is a distance of 40 miles, has a speed limit of 65 miles per hour, has 31 minutes in delays, has a rest area, and has no gas station.

Highway 100 to U.S. Route 7 is a distance of 21 miles, has a speed limit of 55 miles per hour, has 17 minutes in delays, has no rest area, and has a gas station.

U.S. Route 52 to Highway 48 is a distance of 44 miles, has a speed limit of 55 miles per hour, has 14 minutes in delays, has a rest area, and has a gas station.

Interstate 91 to U.S. Route 98 is a distance of 26 miles, has a speed limit of 45 miles per hour, has 27 minutes in delays, has no rest area, and has no gas station.

Listen, Plan 5x6 Route Low.

Select a route to the hospital.

task246.voc

U.S. Route 84 to U.S. Route 67 is a distance of 76 miles, has 4 minutes in delays, has a low visibility hazard, has a 3-dollar toll, and has a gas station.

U.S. Route 16 to Highway 77 is a distance of 76 miles, has 6 minutes in delays, has a low visibility hazard, has a 3-dollar toll, and has a gas station.

Interstate 72 to U.S. Route 15 is a distance of 76 miles, has 39 minutes in delays, has a low visibility hazard, has a 3-dollar toll, and has a gas station.

Interstate 84 to Highway 51 is a distance of 76 miles, has 10 minutes in delays, has a low visibility hazard, has a 3-dollar toll, and has a gas station.

Highway 16 to Highway 64 is a distance of 76 miles, has 9 minutes in delays, has a low visibility hazard, has a 3-dollar toll, and has a gas station.

Listen, Plan 5x6 Route Medium.

Select a route to the hospital.

task247.voc

Interstate 3 to U.S. Route 94 is a distance of 52 miles, has 20 minutes in delays, has an icy bridge hazard, has a 1-dollar toll, and has a gas station.

U.S. Route 41 to Highway 46 is a distance of 64 miles, has 33 minutes in delays, has a fallen rock hazard, has a 1-dollar toll, and has a gas station.

Highway 21 to Highway 10 is a distance of 35 miles, has 5 minutes in delays, has a deer crossing hazard, has a 1-dollar toll, and has a gas station.

U.S. Route 39 to Highway 71 is a distance of 80 miles, has 7 minutes in delays, has an icy bridge hazard, has a 1-dollar toll, and has a gas station.

Interstate 4 to U.S. Route 82 is a distance of 43 miles, has 23 minutes in delays, has a low visibility hazard, has a 1-dollar toll, and has a gas station.

Listen, Plan 5x6 Route High.

Select a route to the hospital.

task248.voc

U.S. Route 54 to U.S. Route 6 is a distance of 34 miles, has 14 minutes in delays, has a slippery road hazard, has a 7-dollar toll, and has no gas station.

U.S. Route 13 to Highway 1 is a distance of 78 miles, has 14 minutes in delays, has a low visibility hazard, has a 9-dollar toll, and has a gas station.

Interstate 19 to Highway 5 is a distance of 64 miles, has 18 minutes in delays, has a deer crossing hazard, has a 4-dollar toll, and has no gas station.

Highway 71 to U.S. Route 34 is a distance of 55 miles, has 13 minutes in delays, has a slippery road hazard, has a 3-dollar toll, and has no gas station.

U.S. Route 17 to Highway 43 is a distance of 63 miles, has 35 minutes in delays, has a deer crossing hazard, has a 1-dollar toll, and has a gas station.

Listen, Plan 5x6 Route High.

Select a route to the hospital.

task249.voc

Interstate 97 to U.S. Route 2 is a distance of 73 miles, has 7 minutes in delays, has a deer-crossing hazard, has a 3-dollar toll, and has a gas station.

U.S. Route 13 to Highway 31 is a distance of 91 miles, has 4 minutes in delays, has a slippery road hazard, has a 6-dollar toll, and has a gas station.

Interstate 70 to Highway 59 is a distance of 27 miles, has 16 minutes in delays, has a low visibility hazard, has a 2-dollar toll, and has no gas station.

Highway 30 to U.S. Route 98 is a distance of 83 miles, has 19 minutes in delays, has a deer-crossing hazard, has a 3-dollar toll, and has a gas station.

U.S. Route 37 to Highway 66 is a distance of 87 miles, has 41 minutes in delays, has a fallen rock hazard, has a 6-dollar toll, and has a gas station.

Listen, Plan, Compute 5x6 Route Low.

Select a route to the airport.

task250.voc

Interstate 89 to U.S. Route 55 is a distance of 160 miles, has a 6-dollar and 50-cent toll, a 3-dollar and 25-cent toll, has a fallen rock hazard, and has no gas station.

U.S. Route 36 to Highway 56 is a distance of 196 miles, has a 1-dollar and 25-cent toll, a 6-dollar and 50-cent toll, has a deer crossing hazard, and has a gas station.

Highway 29 to Highway 12 is a distance of 168 miles, has a 3-dollar and 50-cent toll, a 6-dollar and 50-cent toll, has an icy bridge hazard, and has a gas station.

Interstate 56 to U.S. Route 97 is a distance of 132 miles, has a 3-dollar and 25-cent toll, a 2-dollar and 25-cent toll, has a fallen rock hazard, and has a gas station.

U.S. Route 98 to U.S. Route 84 is a distance of 152 miles, has a 4-dollar and 75-cent toll, a 2-dollar and 75-cent toll, has a slippery road hazard, and has no gas station.

Listen, Plan, Compute 5x6 Route Medium.

Select a route to the airport.

task251.voc

U.S. Route 47 to Highway 25 is a distance of 11 miles, has a speed limit of 45 miles per hour, has a 2-dollar and 50-cent toll, has a slippery road hazard, and has a gas station.

Highway 18 to U.S. Route 57 is a distance of 24 miles, has a speed limit of 55 miles per hour, has a 6-dollar and 25-cent toll, has a low visibility hazard, and has no gas station.

U.S. Route 54 to Highway 64 is a distance of 42 miles, has a speed limit of 45 miles per hour, has a 4-dollar and 50-cent toll, has an icy bridge hazard, and has a gas station.

Highway 22 to Highway 60 is a distance of 32 miles, has a speed limit of 65 miles per hour, has a 1-dollar and 25-cent toll, has a deer crossing hazard, and has no gas station.

Interstate 89 to U.S. Route 39 is a distance of 42 miles, has a speed limit of 55 miles per hour, has a 2-dollar and 75-cent toll, has a low visibility hazard, and has a gas station.

Listen, Plan, Compute 5x6 Route High.

Select a route to the airport.

task252.voc

U.S. Route 64 to Highway 57 is a distance of 294 miles, has a speed limit of 50 miles per hour, has 12 minutes in delays, has a low visibility hazard, and has no gas station.

Interstate 50 to U.S. Route 16 is a distance of 222 miles, has a speed limit of 45 miles per hour, has 23 minutes in delays, has an icy bridge hazard, and has a gas station.

U.S. Route 87 to Highway 78 is a distance of 216 miles, has a speed limit of 65 miles per hour, has 13 minutes in delays, has a fallen rock hazard, and has a gas station.

Highway 12 to Highway 4 is a distance of 234 miles, has a speed limit of 55 miles per hour, has 41 minutes in delays, has a deer crossing hazard, and has a gas station.

Interstate 54 to U.S. Route 1 is a distance of 300 miles, has a speed limit of 75 miles per hour, has 32 minutes in delays, has a slippery road hazard, and has no gas station.

Listen, Plan, Interpret 5x6 Route Low.

Select a route to the hospital.

task253.voc

U.S. Route 69 to Highway 75 is a distance of 43 miles, has a construction delay, has clear weather, has no lanes closed, and has low congestion.

Interstate 91 to U.S. Route 43 is a distance of 43 miles, has an accident delay, has clear weather, has no lanes closed, and has low congestion.

U.S. Route 66 to Highway 35 is a distance of 43 miles, has a train crossing delay, has clear weather, has no lanes closed, and has low congestion.

Highway 56 to Highway 51 is a distance of 43 miles, has a school crossing delay, has clear weather, has no lanes closed, and has low congestion.

Interstate 50 to U.S. Route 39 is a distance of 43 miles, has a construction delay, has clear weather, has no lanes closed, and has low congestion.

Listen, Plan, Interpret 5x6 Route Medium.

Select a route to the hospital.

task254.voc

U.S. Route 37 to Highway 73 is a distance of 56 miles, has a cattle crossing delay, has clear weather, has no lanes closed, and has moderate congestion.

Interstate 63 to U.S. Route 45 is a distance of 44 miles, has a drawbridge delay, has foggy weather, has no lanes closed, and has moderate congestion.

Interstate 30 to U.S. Route 42 is a distance of 63 miles, has an accident delay, has rainy weather, has no lanes closed, and has moderate congestion.

U.S. Route 31 to Highway 19 is a distance of 35 miles, has a school crossing delay, has rainy weather, has no lanes closed, and has moderate congestion.

Interstate 48 to U.S. Route 45 is a distance of 68 miles, has an accident delay, has foggy weather, has no lanes closed, and has moderate congestion.

Listen, Plan, Interpret 5x6 Route High.

Select a route to the hospital.

task255.voc

U.S. Route 23 to Highway 7 is a distance of 87 miles, has a drawbridge delay, has foggy weather, has no lanes closed, and has light congestion.

Highway 64 to Highway 23 is a distance of 41 miles, has an accident delay, has rainy weather, has 1 lane closed, and has moderate congestion.

U.S. Route 96 to U.S. Route 35 is a distance of 50 miles, has a train crossing delay, has clear weather, has 2 lanes closed, and has light congestion.

Interstate 77 to U.S. Route 5 is a distance of 65 miles, has a cattle crossing delay, has rainy weather, has 1 lane closed, and has heavy congestion.

U.S. Route 90 to Highway 92 is a distance of 18 miles, has an accident delay, has rainy weather, has no lanes closed, and has moderate congestion.

Listen, Plan, Interpret 5x6 Route High.

Select a route to the hospital.

task256.voc

Interstate 40 to U.S. Route 12 is a distance of 54 miles, has an accident delay, has foggy weather, has no lanes closed, and has heavy congestion.

U.S. Route 13 to Highway 76 is a distance of 28 miles, has a train crossing delay, has clear weather, has 1 lane closed, and has heavy congestion.

Highway 48 to U.S. Route 9 is a distance of 84 miles, has a construction delay, has rainy weather, has no lanes closed, and has light congestion.

U.S. Route 49 to Highway 65 is a distance of 94 miles, has a funeral procession delay, has clear weather, has 1 lane closed, and has light congestion.

Highway 28 to Highway 89 is a distance of 72 miles, has an emergency vehicle delay, has clear weather, has no lanes closed, and has moderate congestion.

Listen, Plan, Interpret, Compute 5x6 Route Low.

Select a route to the airport.

task257.voc

Interstate 84 to U.S. Route 6 has a 4-dollar and 75-cent toll, a 6-dollar and 50-cent toll, has an accident delay, has foggy weather, and has heavy congestion.

U.S. Route 29 to Highway 63 has a 3-dollar and 50-cent toll, a 2-dollar and 75-cent toll, has an emergency vehicle delay, has rainy weather, and has light congestion.

Interstate 98 to U.S. Route 60 has a 1-dollar and 75-cent toll, a 3-dollar and 50-cent toll, has a construction delay, has clear weather, and has moderate congestion.

Highway 34 to Highway 49 has a 2-dollar and 25-cent toll, a 3-dollar and 75-cent toll, has a train crossing delay, has rainy weather, and has heavy congestion.

Highway 55 to U.S. Route 99 has a 1-dollar and 50-cent toll, a 5-dollar and 75-cent toll, has a construction delay, has clear weather, and has light congestion.

Listen, Plan, Interpret, Compute 5x6 Route Medium.

Select a route to the airport.

task258.voc

U.S. Route 47 to Highway 71 is a distance of 270 miles, has a speed limit of 65 miles per hour, has a train crossing delay, has clear weather, and has light congestion.

Interstate 40 to U.S. Route 14 is a distance of 282 miles, has a speed limit of 65 miles per hour, has an accident delay, has rainy weather, and has heavy congestion.

U.S. Route 32 to Highway 0 is a distance of 154 miles, has a speed limit of 45 miles per hour, has a construction delay, has clear weather, and has moderate congestion.

U.S. Route 34 to Highway 85 is a distance of 118 miles, has a speed limit of 55 miles per hour, has an accident delay, has foggy weather, and has moderate congestion.

Interstate 58 to U.S. Route 67 is a distance of 198 miles, has a speed limit of 55 miles per hour, has a train crossing delay, has rainy weather, and has heavy congestion.

Listen, Plan, Interpret, Compute 5x6 Route High.

Select a route to the airport.

task259.voc

U.S. Route 39 to Highway 76 is a distance of 19 miles, has a speed limit of 55 miles per hour, has 33 minutes in delays, has foggy weather, and has moderate congestion.

Interstate 28 to U.S. Route 49 is a distance of 10 miles, has a speed limit of 45 miles per hour, has 12 minutes in delays, has clear weather, and has light congestion.

U.S. Route 40 to Highway 27 is a distance of 47 miles, has a speed limit of 65 miles per hour, has 17 minutes in delays, has rainy weather, and has heavy congestion.

Highway 10 to U.S. Route 91 is a distance of 32 miles, has a speed limit of 55 miles per hour, has 22 minutes in delays, has foggy weather, and has light congestion.

U.S. Route 58 to Highway 88 is a distance of 16 miles, has a speed limit of 55 miles per hour, has 31 minutes in delays, has clear weather, and has heavy congestion.

Listen, Plan 5x6 Hotel Low.

Select a hotel.

task260.voc

The Ramada has a vacancy, costs 73 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 32 miles away.

The Marriott has a vacancy, costs 73 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 32 miles away.

The Howard Johnson has no vacancy, costs 73 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 32 miles away.

The Days Inn has no vacancy, costs 73 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 32 miles away.

The Comfort Inn has a vacancy, costs 73 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 32 miles away.

Listen, Plan 5x6 Hotel Medium.

Select a hotel.

task261.voc

The Days Inn has no vacancy, costs 77 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 51 miles away.

The Howard Johnson has a vacancy, costs 75 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 11 miles away.

The Motel 8 has a vacancy, costs 81 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 47 miles away.

The Ramada has a vacancy, costs 86 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 83 miles away.

The Holiday Inn has no vacancy, costs 85 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 25 miles away.

Listen, Plan 5x6 Hotel High.

Select a hotel.

task262.voc

The Howard Johnson has a vacancy, costs 44 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 39 miles away.

The Motel 8 has a vacancy, costs 39 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 32 miles away.

The Holiday Inn has no vacancy, costs 68 dollars, has a restaurant, has a 2-star quality rating, and is a distance of 73 miles away.

The Marriott has no vacancy, costs 47 dollars, has no restaurant, has a 4-star quality rating, and is a distance of 93 miles away.

The Ramada has a vacancy, costs 68 dollars, has a restaurant, has a 2-star quality rating, and is a distance of 91 miles away.

Listen, Plan 5x6 Hotel High.

Select a hotel.

task263.voc

The Ramada has no vacancy, costs 56 dollars, has no restaurant, has a 4-star quality rating, and is a distance of 56 miles away.

The Holiday Inn has no vacancy, costs 61 dollars, has a restaurant, has a 4-star quality rating, and is a distance of 36 miles away.

The Comfort Inn has a vacancy, costs 82 dollars, has a restaurant, has a 2-star quality rating, and is a distance of 14 miles away.

The Marriott has a vacancy, costs 54 dollars, has no restaurant, has a 3-star quality rating, and is a distance of 29 miles away.

The Motel 8 has no vacancy, costs 79 dollars, has a restaurant, has a 2-star quality rating, and is a distance of 22 miles away.

APPENDIX C-2: TASKS PRESENTED DURING REGULAR STUDY

Task Description Table

Table 14 Task Matrix Showing Number, Elements, Density, and Information Items

Number	Density	Element	Information Items for Each Route or Hotel Selection				
Instruction is task specific selecting for last item in presentation							
201	3x3	L		R	distance	speed limit	
202	3x3	L		R	distance	Gas Station	
221	5x4	L		R	congestion	Weather	Gas Station
298	5x4	L		R	Gas Station	Weather	congestion
Select a hotel							
213	3x3	L	,P	H	vacancy	Distance	
239	5x4	L	,P	H	vacancy	Cost	distance
Select a route to the hospital							
299	3x3	L	,P	R	distance	Delays	
222	5x4	L	,P	R	distance	Delays	hazards
224	3x3	L	,P,I	R	distance	Delays	
225	5x4	L	,P,I	R	distance	Delays	lane closed
Select the least expensive route to the airport							
240	3x3	L	,C	R	toll cost	toll cost	
242	5x4	L	,C	R	toll cost	toll cost	distance
Select the quickest route to the airport							
241	3x3	L	,C	R	distance	speed limit	
243	5x4	L	,C	R	distance	speed limit	toll cost

244	5x4	,C	L	dd + divide	A	oute	R	dista nce	speed limit	delays	
Select a route to the airport											
245	5x4	,C,P	L	dd	a	oute	R	toll cost	toll cost	distance	
246	5x4	,C,P	L	ivide	d	oute	R	dista nce	speed limit	toll cost	
248	5x4	,C,P,I	L	dd	a	oute	R	toll cost	toll cost	delays (description)	
247	5x4	,C,P,I	L	ivide	d	oute	R	dista nce	speed limit	delays (description)	
250	Paced Conversational Task 1										
251	Paced Conversational Task 2										
261	Non-Paced Conversational Task 1										
262	Non-Paced Conversational Task 2										

IVIS Tasks

240

Select the least expensive route to the airport

Interstate 17 to U.S. Route 18 has a \$4.75 toll and a \$3.75 toll.

U.S. Route 29 to U.S. Route 18 has a \$4.25 toll and a \$2.50 toll.

U.S. Route 29 to U.S. Route 46 has a \$5.75 toll and a \$2.50 toll.

241

Select the quickest route to the airport

Interstate 17 to U.S. Route 12 is 109 miles and has a speed limit of 65 mph.

Interstate 17 to Highway 44 is 114 miles and has a speed limit of 55 mph.

U.S. Route 29 to Highway 12 is 100 miles and has a speed limit of 45 mph.

221

Select the route that has a gas station.

Interstate 17 to U.S. Route 18 has light congestion, has clear weather, and has no gas station.

U.S. Route 19 to U.S. Route 18 has light congestion, has rainy weather, and has no gas station.

U.S. Route 29 to U.S. Route 46 has moderate congestion, has clear weather, and has no gas station.

U.S. Route 29 to U.S. Route 12 has light congestion, has rainy weather, and has no gas station.

U.S. Route 29 to Highway 19 has moderate congestion, has foggy weather, and has a gas station.

224

Select a route to the hospital

Interstate 17 to U.S. Route 46 is 25 miles and has a train crossing delay.

U.S. Route 29 to U.S. Route 18 is 54 miles and has a school bus delay.

U.S. Route 29 to U.S. Route 46 is 82 miles and has a construction delay.

242

Select the least expensive route to the airport

U.S. Route 29 to U.S. Route 12 is 35 miles, has a \$5.75 toll, and a \$3.75 toll.

Interstate 17 to U.S. Route 12 is 12 miles, has a \$6.25 toll, and a \$1.25 toll.

U.S. Route 29 to Highway 19 is 47 miles, has a \$5.75 toll, and a \$8.50 toll.

Interstate 17 to Highway 19 is 58 miles, has a \$5.25 toll, and a \$1.75 toll.

U.S. Route 29 to Highway 44 is 62 miles, has a \$2.50 toll, and a \$3.50 toll.

243

Select the quickest route to the airport

U.S. Route 29 to U.S. Route 18 is 135 miles, has a speed limit of 65 mph, and has a \$2.50 toll.
Interstate 17 to Highway 44 is 176 miles, has a speed limit of 55 mph, and has a \$8.25 toll.
U.S. Route 29 to U.S. Route 46 is 156 miles, has a speed limit of 65 mph, and has a \$3.25 toll.
Interstate 17 to U.S. Route 18 is 183 miles, has a speed limit of 45 mph, and has a \$1.75 toll.
Interstate 17 to U.S. Route 46 is 129 miles, has a speed limit of 55 mph, and has a \$5.25 toll.

244

Select the quickest route to the airport

U.S. Route 29 to U.S. Route 12 is 46 miles, has a speed limit of 45 mph, and has a 19-minute delay.
Interstate 17 to U.S. Route 12 is 62 miles, has a speed limit of 65 mph, and has a 23-minute delay.
U.S. Route 29 to Highway 19 is 89 miles, has a speed limit of 75 mph, and has a 47-minute delay.
U.S. Route 29 to Highway 44 is 65 miles, has a speed limit of 45 mph, and has a 4-minute delay.
U.S. Route 29 to U.S. Route 18 is 36 miles, has a speed limit of 55 mph, and has a 25-minute delay.

222

Select a route to the hospital

U.S. Route 29 to U.S. Route 46 is 45 miles, has a 23-minute delay, and has a slippery road hazard.
U.S. Route 29 to U.S. Route 12 is 62 miles, has a 37-minute delay, and has a deer-crossing hazard.
Interstate 17 to Highway 19 is 81 miles, has a 17-minute delay, and has a fallen rock hazard.
U.S. Route 29 to Highway 19 is 87 miles, has a 24-minute delay, and has a slippery road hazard.
Interstate 17 to Highway 44 is 72 miles, has a 46-minute delay, and has a low visibility hazard.

245

Select a route to the airport

U.S. Route 29 to Highway 44 is 67 miles, has a \$3.75 toll, and a \$1.50 toll.
Interstate 17 to U.S. Route 18 is 34 miles, has a \$5.25 toll, and a \$2.25 toll.
U.S. Route 29 to U.S. Route 18 is 82 miles, has a \$1.50 toll, and a \$2.50 toll.
Interstate 17 to U.S. Route 46 is 19 miles, has a \$2.75 toll, and a \$5.75 toll.
U.S. Route 29 to U.S. Route 46 is 49 miles, has a \$8.50 toll, and a \$4.25 toll.

246

Select a route to the airport

U.S. Route 29 to U.S. Route 12 is 97 miles, has a speed limit of 45 mph, and has a \$3.25 toll.
Interstate 17 to U.S. Route 12 is 106 miles, has a speed limit of 50 mph, and has a \$8.50 toll.
U.S. Route 29 to Highway 19 is 138 miles, has a speed limit of 65 mph, and has a \$5.25 toll.
Interstate 17 to Highway 19 is 120 miles, has a speed limit of 55 mph, and has a \$4.25 toll.
Interstate 17 to Highway 44 is 143 miles, has a speed limit of 65 mph, and has a \$2.75 toll.

225

Select a route to the hospital

Interstate 17 to U.S. Route 18 is 30 miles, U.S. Route 96 has a drawbridge delay, 2 of 2 lanes are closed.

U.S. Route 29 to Highway 44 is 22 miles, U.S. Route 11 has a funeral procession delay, 1 of 2 lanes is closed.

Interstate 17 to U.S. Route 46 is 76 miles, Interstate 52 has an accident delay, 2 of 2 lanes are closed.

U.S. Route 29 to U.S. Route 18 is 32 miles, Highway 6 has a school bus delay, 1 of 1 lane is closed.

Interstate 17 to U.S. Route 12 is 74 miles, U.S. Route 44 has a train crossing delay, 2 of 2 lanes are closed.

248

Select a route to the airport

Interstate 17 to Highway 19 has a \$4.50 toll, a \$8.75 toll, and has an emergency vehicle delay.
U.S. Route 29 to U.S. Route 46 has a \$1.25 toll, a \$1.75 toll, and has a school crossing delay.
U.S. Route 29 to U.S. Route 12 has a \$3.50 toll, a \$2.50 toll, and has an accident delay.
Interstate 17 to Highway 44 has a \$8.75 toll, a \$2.50 toll, and has a drawbridge delay.
U.S. Route 29 to Highway 19 has a \$2.25 toll, a \$1.25 toll, and has a train crossing delay.

247

Select a route to the airport

Interstate 17 to U.S. Route 18 is 212 miles, has a speed limit of 65 mph, and has a drawbridge delay.

U.S. Route 29 to Highway 44 is 151 miles, has a speed limit of 45 mph, and has a construction delay.

Interstate 17 to U.S. Route 46 is 162 miles, has a speed limit of 50 mph, and has a school crossing delay.

U.S. Route 29 to U.S. Route 18 is 210 miles, has a speed limit of 65 mph, and has a train crossing delay.

Interstate 17 to U.S. Route 12 is 172 miles, has a speed limit of 55 mph, and has a funeral procession delay.

201

Select the 124-mile route.

U.S. Route 29 to U.S. Route 46 is a distance of 126 miles and has a speed limit of 65 miles per hour.

Interstate 17 to Highway 19 is a distance of 153 miles and has a speed limit of 45 miles per hour.

U.S. Route 29 to U.S. Route 12 is a distance of 124 miles and has a speed limit of 55 miles per hour.

202

Select the route with no gas station.

Interstate 17 to Highway 44 is a distance of 165 miles and has a gas station.

U.S. Route 29 to Highway 19 is a distance of 180 miles and has a gas station.

U.S. Route 29 to Highway 44 is a distance of 177 miles and has no gas station.

298

Select the route that has moderate congestion.

U.S. Route 29 to Highway 44 has no gas station, has clear weather, and has light congestion.

Interstate 17 to U.S. Route 46 has a gas station, has rainy weather, and has heavy congestion.

U.S. Route 29 to U.S. Route 18 has a gas station, has clear weather, and has heavy congestion.

Interstate 17 to U.S. Route 12 has a gas station, has rainy weather, and has light congestion.

U.S. Route 29 to U.S. Route 46 has no gas station, has foggy weather, and has moderate congestion.

299

Select a route to the hospital

U.S. Route 29 to Highway 19 is 65 miles and has a 16-minute delay.

Interstate 17 to U.S. Route 18 is 42 miles and has a 26-minute delay.

U.S. Route 29 to Highway 44 is 56 miles and has a 12-minute delay.

213

Select a hotel

The Ramada has a vacancy and is a distance of 48 miles away.

The Howard Johnson's has no vacancy and is a distance of 40 miles away.

The Motel 8 has a vacancy and is a distance of 52 miles away.

239

Select a hotel

The Best Western has a vacancy, costs 85 dollars, and is a distance of 34 miles away.

The Ramada has a vacancy, costs 61 dollars, and is a distance of 17 miles away.

The Holiday Inn has no vacancy, costs 52 dollars, and is a distance of 13 miles away.

The Comfort Inn has no vacancy, costs 71 dollars, and is a distance of 21 miles away.

The Marriott has a vacancy, costs 82 dollars, and is a distance of 16 miles away.

Conversation Tasks

Paced Conversation Task 1

250

Did you feel safe while doing the auditory tasks?

YES NO

Would you purchase a navigation system for your vehicle, if it were available and affordable?

YES NO

Did you find the visual information displays distracting?

YES NO

Which was more difficult for you, the graphics with icons or the graphics with text?

Graphics with Icons Graphics with Text

Would you feel comfortable reading a one-paragraph length letter while driving?

YES NO

Do you own a cell phone?

YES NO

Would you use a cell phone while driving in heavy traffic?

YES NO

Would you read a simple map while driving?

YES NO

Do you prefer to drive in the daytime or at night?

Daytime Night

Paced Conversation Task 2

251

Did you feel tired after doing the visual tasks?

YES NO

Would you use an electronic mail system for your vehicle, if it were given to you?

YES NO

Did you find the auditory information difficult to hear?

YES NO

Which was more informative to you, the text in table form or the text in paragraph form?

Text in tables Text in paragraphs

Would you feel comfortable listening to a several paragraph length letter while driving?

YES NO

Do you want a car stereo?

YES NO

Would you use a car stereo while driving in light traffic?

YES NO

Would you read complex directions while driving?

YES NO

Do you prefer to drive near other cars or isolated?

Near other cars Isolated

Non-Paced Conversation Task 1

261

Did you feel safe while doing the visual tasks?

YES NO

Would you purchase an electronic mail system for your vehicle, if it were available and affordable?

YES NO

Did you find the auditory information displays distracting?

YES NO

Which was more difficult for you, the text in table form or the text in paragraph form?

Text in tables Text in paragraphs

Would you feel comfortable listening to a one-paragraph length letter while driving?

YES NO

Do you own a car stereo?

YES NO

Would you use a car stereo while driving in heavy traffic?

YES NO

Would you read simple directions while driving?

YES NO

Do you prefer to drive on the highway or in town?

Highway Town

Non-Paced Conversation Task 2

262

Did you feel tired after doing the auditory tasks?

YES NO

Would you use a navigation system for your vehicle, if it were given to you?

YES NO

Did you find the visual information difficult to see?

YES NO

Which was more informative to you, the graphics with icons or the graphics with text?

Graphics with Icons Graphics with Text

Would you feel comfortable reading a several paragraph length letter while driving?

YES NO

Do you want a cell phone?

YES NO

Would you use a cell phone while driving in light traffic?

YES NO

Would you read a complex map while driving?

YES NO

Do you prefer to drive with others in the car or alone?

With others Alone

VITA

WAYNE J. BIEVER

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EDUCATION:

Virginia Polytechnic Institute and State University, Blacksburg, VA
Master of Science, Industrial and Systems Engineering, May 2001.
Human Factors Engineering and Ergonomics Option
Certificate in Safety Engineering

Virginia Polytechnic Institute and State University, Blacksburg, VA
Bachelor of Science, Industrial and Systems Engineering, December 1995.

EXPERIENCE:

Center for Transportation Research, Blacksburg, VA
Researcher, December 1997 – May 1998

Collected performance and subjective data from participants, assisted in the development of hardware and software specifications and protocols, performed data reduction and analysis, researched existing body of knowledge, wrote technical papers and reports.

Projects:

- In-vehicle information systems behavioral model and design support: Auditory based supplemental information processing demand effects on driving performance
- Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): An Examination of Driver Performance under Reduced Visibility Conditions when Using an In-vehicle Signing and Information System (ISIS)
- Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): A Study of Driver Response to Unexpected Situations when Using an Integrated In-Vehicle Information System (IVIS)

MCI, Pentagon City, VA
Intern, May 1996 – October 1996

Worked with programmers to design and create a web based order entry system.

AWARD:

National Institute for Occupational Safety and Health
Stipend recipient, December 1996 – December 1997

SOFTWARE:

SAS, AutoCAD, Fortran, Microsoft Office Pro, HTML 4.0

ACTIVITIES:

- Human Factors and Ergonomics Society – Student member, 1997 – present
- Virginia Tech Student Chapter of the American Society of Safety Engineers – Member, 1995 – present; President, 1996 – 1997
- Virginia Tech Student Chapter of the Human Factors and Ergonomics Society – Member, 1995 – present
- Virginia Tech Student Chapter of the Society of Manufacturing Engineers – Member, 1992 – 1995

Wayne J. Biever
