DEVELOPMENT OF GUIDELINES FOR IN-VEHICLE INFORMATION PRESENTATION: TEXT VS. SPEECH

María C. Fumero Aguiló

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
In
Industrial and Systems Engineering

Suzanne E. Lee, Ph.D., Co-Chair
Tonya L. Smith-Jackson, Ph.D., Co-Chair
Brian M. Kleiner, Ph.D., Member

May 12, 2004
Blacksburg, Virginia

Keywords: In-Vehicle Information Systems, Driving Performance, Transportation Safety, Information Displays

Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

María C. Fumero Aguiló

ABSTRACT

The demand for in-vehicle information systems (IVIS) has been increasing through the years. There are numerous systems that can be incorporated into vehicles and various ways in which the information can and should be presented to the driver. The way the information is presented to the drivers is extremely important in terms of increasing safety and decreasing driver distraction. The expected outcomes of this research included the development of human factors guidelines for the design and use of in-vehicle information systems. It was a desirable goal to identify the most suitable information presentation formats for certain tasks, since this may influence the drivers' attention and driving performance. This study focused on how the factors of interest may affect drivers' attention and driving performance while performing IVIS secondary tasks related to specific applications. This was accomplished through an on-road within-factors experiment. Sixteen participants performed secondary tasks related to three IVIS applications at two levels of difficulty. The tasks were presented using five types of displays. Data collected from video and in-vehicle sensors were statistically analyzed to determine significant effects between the factors. Driving performance, external reaction time, and perceived mental workload results were compiled into general guidelines for the design and use of IVIS. The findings of this study strongly suggest that visual displays should not be used for the presentation of IVIS. Auditory and multi-modal (i.e. both visual and auditory interface) displays are the most appropriate ways to present IVIS information. A normal speech rate is preferred over a fast speech rate. IVIS tasks should be kept as simple as possible in terms of the number of steps. From the three manipulated factors (type of display, IVIS application, and task level of difficulty), the type of display had the largest number of significant results across the dependent variables measurements. The visual display led to the worst driver performance, while auditory and multi-modal displays yielded significantly better driving performance.

DEDICATION

To my family, because you are the strength in my life.

To my parents, who have always trusted and respected my decisions and have supported me unconditionally. Remember that the distance makes us closer in our hearts.

Miguel, you are my husband, my friend, my everything. Your patience, love, and understanding have never let me down. I love you.

Miguel Antonio, we started this journey together even before you were born. It is amazing how with just a smile you can lighten up my world. Even without knowing, your hugs and kisses have kept me going even at the hardest times.

Without you all and God blessings, it would not have been the same…

ACKNOWLEDGEMENTS

I would like to express my appreciation to my advisory committee: Dr. Suzanne E. Lee, Dr. Tonya Smith-Jackson, and Dr. Brian Kleiner. Thanks for giving me the opportunity to be part of the transportation safety research. I want to thank Dr. Smith-Jackson for her understanding and attentions to me. To Dr. Kleiner, whose feedback always helped to improve my research. Special thanks to Dr. Lee who was unconditionally available at all times and who showed and guided me through the amazing world of transportation. Suzie, thanks for your patience and support. Thanks to Ford Motor Company and the Ford University Research Program for making this study possible by providing its funding to the Virginia Tech Transportation Institute (VTTI).

Thanks for all the people that directly or indirectly helped me during this study. I want to thank the Hardware and Electronics Lab for setting up the vehicle and all the instrumentation, especially to Rena Wilson. Rena thanks for your kindness and assistance. Thanks to Craig Bucher for adapting the eye glance software to my research needs.

Julie Barker, thanks for providing the interface software, information, and unconditional help without hesitation. It would have been a much harder road without your input. Thanks to Erik Olsen for your help with the data reduction. Your help cut the time in half.

I want to thank my fellow students and co-workers that rode with me in this rollercoaster of study and work. To those who helped me in all possible ways and did not let me stay behind during my last pregnancy stages and motherhood. You all know who you are and I will be forever grateful for being my friends. Myra and Miguel, I cannot describe how important you have been to me. Thanks for all your support.

The most special thanks go to my husband Miguel. You have helped me the most by believing in me and never letting me fall. Thanks for your patience, comprehension and love.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. REVIEW OF LITERATURE

1.1 Introduction

In-vehicle information systems (IVIS) technologies have been increasing in availability and use, increasing driver's attention and cognitive functioning demands (Ceci, Högman, and Patten, 2001). There are numerous systems that can be incorporated into vehicles and various ways in which the information can and should be presented to the driver. The way the information is presented to the drivers is extremely important in terms of increasing safety and decreasing driver distraction.

Intelligent Transportation Systems (ITS) are in-vehicle systems that can be used for different purposes, including the presentation of warnings to the driver, trip navigation information, and work related uses as phones, computers, etc. Three modalities of presentation of information systems that have been and still are being studied and compared are visual displays, auditory displays, and multi-modal displays. The effects of these display modes on information systems have being investigated for numerous applications, including warning systems, navigation systems, in-vehicle internet, and mobile phones. In addition to the information presentation modes, there are other factors, such as workload and situational awareness, which affect the design of IVIS. These factors are usually considered in research. Human factors guidelines for the design of information systems displays have resulted from previous studies, although the development of guidelines is an on-going process in the search of safety on the roads.

1.2 Visual Displays

Belz, Robinson, and Casali (1999) tested auditory and visual displays designed to alert drivers to potential collisions. Visual displays used alone produced a longer reaction time. It was concluded that a possible cause for this was the fact that the visual display was not positioned in the direct field of view of the driver. Because of this, the driver was distracted from the primary task (driving) to look at the display. This required a higher level of mental processing, resulting in longer response times. Since driving is primarily a visual task, adding visual displays to present warning signals can overload the driver's visual effort, therefore they recommended not to use visual displays alone.

One way to keep the driver's visual attention on the roadway and still use visual displays is to use a Heads-Up Display (HUD), in which the information is projected onto the windshield in front of the driver. HUDs have been introduced recently on commercial vehicles, even though they have been used for years for other purposes (such as aviation and the military). Studies involving HUDs have shown some benefits, although its implementation has not been completely successful. In a study conducted by Gish, Staplin, Stewart, and Perel (1999), the results did not show that HUDs are unsafe, but did not show extreme benefits either. The purpose of the experiment was to evaluate HUD safety by studying the effects of age (three groups), ambient lighting (day or night), display (HUD, Heads-Down Display-HDD, or Auditory Display-AD), tasks (navigation, speed monitoring, collision avoidance), in-vehicle stimulus conditions (no stimulus, false alarm, target), and external stimulus conditions (no stimulus, grating, naturalistic) on the percentage of correct responses to in-vehicle and external stimuli. The experiment was primarily focused on main effects of age and display.

The results showed a small, although not statistically significant, response time advantage of HUD over HDD, although the performance was generally the same during the same parameter conditions (display content, angular display size, angular letter size, and brightness). The slight difference may have been caused by parameters such as spatial location or collimation. A high mental workload was observed among younger participants while using HUD. It is possible that HUD usage experience may reduce this mental workload. Overall, the best response times were observed during the use of ADs. The AD interfered the least with external detections. An inverse relation was observed between age and detection performance (the older the person, the less detection performance). The results suggest that HUDs are not an effective aid for older people. The HUD's presentation may be a factor affecting driver's performance. Further research has been suggested to improve HUD design by manipulating parameters such as resolution, brightness, and field of view. This should be done in a way that will not then create too much distraction for the driver.

Since visual displays are definitely needed for in-vehicle information and tasks, their design must provide the driver a good access and view of information. Sakaguchi, Higuchi, Nakano, and Yamamoto (1998) performed an objective and subjective evaluation of enhanced parameters for visual displays. In both cases it was confirmed that luminance and saturation of the on-board display image may be modified to provide a better view, even on high luminance environments.

1.3 Auditory Displays

Due to the increase of in-vehicle displays developed for ITS, an alternative had to be found to complement visual displays. As more systems are incorporated into a vehicle, the driver will have more load on his visual attention. For this reason, auditory displays have recently been studied and developed extensively.

Auditory displays can be classified into two major categories. These are verbal displays and non-verbal displays. Speech is a verbal auditory display. Examples of non-verbal auditory displays are tones and earcons (also referred as conventional non-verbal auditory displays), and auditory icons. Mynatt (1994) discussed these auditory displays with emphasis on the auditory icons. She highlighted simple advantages and disadvantages of these. For speech (e.g., voice presenting a message) it could be said that the messages tend to be unambiguous and efficient, but may be confused with other messages. This is why it is important to listen to the complete message before responding, leading to slower reaction times.

Conventional non-verbal auditory displays are defined by their acoustic parameters (e.g., amplitude, frequency, and temporal characteristics). When discussing non-verbal auditory interfaces, it should be said that tones (e.g., sharp tone of certain frequency) and earcons (e.g., music sound from an instrument) are easy to produce, but they may be difficult to associate with the desired meaning. Tones are heard quickly, but may be confused with other tones.

Auditory icons are a form of non-verbal auditory displays that provide a more intuitive meaning, making it easier to discriminate between sounds. Mynatt (1994) defines auditory icons as sounds that are related to a source. The icons are a representation of the actual events using stereotypical meanings of objects or actions (e.g., sound of thunder when it is going to rain). Auditory icons have been shown to be more recognizable than conventional displays, although their implementation in complex systems has not been completely successful. This may be caused by misassociation of the icons to actual events (Belz et al., 1999).

Auditory displays have shown performance benefits for in-vehicle tasks, such as speed monitoring and navigation tasks, as compared to visual displays such as HUDs and HDDs (Gish et al., 1999), as was discussed previously in the Visual Displays section.

Llaneras, Lerner, Dingus, and Moyer (2000) studied how auditory format (prose vs. list-form) and speech rate (normal-125 wpm vs. time-compressed-225 wpm) affect driving performance. Driving performance parameters included headway and speed maintenance, steering, and lateral acceleration. Task related measures included task completion time and number of repetitions requested by the driver of each task. Both auditory format and speech rate affected driving performance. It was found that the list-form auditory format resulted in less variability of maintenance tasks than did the prose format. In terms of speech rate, it was found that the time-compressed rate led to less driving performance variability, as well as faster task response times. The time to complete the tasks was not affected by the display formats, and neither the displays nor the speech rates affected the number of repetitions needed by the drivers. They concluded that the list-form format and time-compressed rate resulted in better performance with less variance in driving tasks and less driver distraction.

Robinson, Base, and Eberts (1985) compared display modalities in aviation to determine the most effective way of presenting information to pilots in high visual task environments. The four modalities compared were visual spatial (bar graphs), visual verbal (numbers), auditory spatial (tones), and auditory verbal (synthesized speech). These displays provided the pilot a distance range from which he chose a certain weapon to attack the enemy. It was found that the presentation of information via auditory verbal for secondary tasks resulted in better pilot performance over the other modalities. The use of synthesized speech resulted in more enemy kills and less errors in weapon selection. Robinson et al. (1985) concluded that auditory displays consisting of synthesized speech are appropriate for presenting secondary task information in high visual and spatial demand environments.

Although auditory displays have been tested and demonstrated as an alternative to visual displays, they have not been shown to be completely safe. Because auditory displays have little or no physical demands, it has been wrongly believed that these systems do not distract the driver. In fact, there is a potential mental workload that can affect driving performance as well.

Lee, Caven, Haake, and Brown (2001) investigated how speech-based interfaces can affect driving performance with the purpose of assessing and minimizing the safety hazards caused by the mental distraction associated with in-vehicle information systems. The experiment was performed with the use of a driving simulator. The study measured driving performance, situation awareness, subjective workload, and perceived distraction. These independent variables were the use of an e-mail system (system used or not), its complexity (simple or complex), and driving environment (simple or complex). Driving performance was measured by the reaction time to the braking of a lead vehicle. Situation awareness was tested with questions regarding the e-mail contents and road environment. Workload and perceived distraction were measured with the use of rating scales.

The results for driving performance showed longer reaction times when the e-mail system was used and for the complex roadway environment. These factors seem to increase the mental workload resulting in slower responses to critical events. In this case there was no significant difference between the simple and complex systems. The driver's situational awareness was expected to be affected by the system complexity, resulting in better comprehension of e-mail contents when the simple system was used. Instead, the comprehension of e-mail contents was not affected by the complexity of the environment. The awareness of the road was affected by the complexity of the environment but not by the use of the system or its complexity. The subjective ratings for workload and distraction showed that the workload depended on the use of the e-mail system and its complexity. The environment did not have a significant effect. The perceived distraction had similar results. The environment may not have been perceived as a significant source of workload and distraction because the drivers are used to driving in similar situations, taking for granted dangers and hazards to which they are exposed to.

This study shows that speech-based systems may indeed increase mental workload, thus degrading driving performance. This indicates that verbal auditory systems are not the perfect means to eliminate distractions in the use of in-vehicle information systems. They are a source of distraction as well, not particularly in terms of operation but for the attention they require.

Ranney, Harbluk, and Noy (2002) conducted a test track experiment to compare the effects of speech and visual interfaces on driver distraction. The objectives of this study were to compare the two interfaces while performing tasks besides driving and to determine how driving performance is affected when performing tasks of various complexities. The independent variables were driver group (test drivers and engineers), secondary task complexity (none, baseline, simple, and complex), and interface modality (auditory/speech and visual). The dependent variables were vehicle control measures, peripheral detection task performance measures, and secondary task performance measures. The participants were instructed to drive maintaining a constant distance from a leading vehicle while performing tasks of different complexities. This was done using each of the interface modalities.

The vehicle control measures consisted of car following measures and steering reversals and holds. For the car following measures, the secondary task complexity and the interaction of secondary tasks and interface were significant. This means that when secondary tasks were performed, the participants had a longer following distance. The same tendency of longer distances was observed when the visual interface was used, no matter the complexity of the task, than with the auditory interface. For steering reversals and holds there was no significant difference between the interfaces, but there was a significant relationship between interface and secondary task interaction. The visual interface resulted in more holds (no steering activity) than the speech interface, resulting from the reduced attention to the driving task due the secondary tasks.

The peripheral detection tasks consisted of detecting visual stimuli while performing secondary tasks. For these measurements there was significance in the interface factor, the secondary task factor, and the interaction between interface and secondary task. These significant results indicate that drivers detected more targets while performing secondary tasks (no matter the complexity) with the speech interface than with the visual interface. Even more targets were detected when no secondary tasks were performed. The response times to these targets were significantly faster when the speech interface was used than with the visual interface.

The secondary task performance resulted in shorter completion times when simple tasks were performed than complex tasks. There was no significant difference between the interface modalities.

The peripheral detection task performance results suggest that there could be a potential benefit for hazard detection when the speech (auditory) interface is used. However, due to the distraction associated with secondary tasks, the auditory interface may not be enough to avoid this distraction for high visual demand situations such as driving.

1.4 Multi-Modal Displays

Multi-modal displays are modes of presenting the same information, in different ways, at the same time (e.g., the combination of visual and auditory displays). In the Belz et al. (1999) experiment, the drivers' preferences were for multi-modal displays. For front-to-rear collisions the drivers preferred the combination of auditory (either conventional or icons) and visual displays. For the side collisions they preferred the combination of auditory and visual displays and mirrors. The drivers' performance usually improves with the use of multi-modal displays, but the effect of workload should be included in this analysis. The use of combined displays may increase information processing times due to visual and auditory redundancy as compared to single modalities (i.e. visual alone and auditory alone) (Stephens, 1990). The simultaneous presentation of information may produce higher workload levels on the driver since the information has to be extracted from different sources and interpreted or associated with the same message in different ways. This may require a high mental effort, resulting in slower response times. However, there seems to be a preference for these systems among drivers (Belz et. al., 1999).

Liu, Schreiner, and Dingus (2000) performed a simulator research to study the effects of different forms of displays (visual, auditory, and multi-modal) on the driver's performance related to workload, navigation performance, and emergency response. The visual display consisted of a programmable and adjustable liquid crystal display (LCD) in heads-up position. The information was displayed using both text and icons, depending on the information that was presented and the availability of icons to represent it. The auditory information was presented using a verbal (speech) auditory display mode. A female voice with a speech rate of 150 wmp was used. The auditory information was presented using three speakers. It was found that the use of multi-modal displays, combining both modes presented above, provided the best performance for all the factors studied.

Fussell, Grenville, Kiesler, Forlizzi, and Wichansky (2002) conducted an experiment to test multi-modal displays using a wireless cellular phone. The purpose of the study was to determine when audio is most useful in a multi-modal phone with database applications. The experiment consisted of reading and/or listening to a long list. The participants were asked to choose a hotel from this list given certain specifications. The experimental conditions included text vs. text and audio, stationary (sitting at a desk) vs. driving (car simulator), and low vs. high task difficulty. Questionnaires were given to the participants to obtain demographics and preferences measures. The results obtained show that people chose the audio option in the driving condition while the text option was preferred for the stationary condition. The response times were significantly longer when the audio option was used than with the text option, although the driving performance was not affected. The participants reported a higher workload in the driving condition, considering that two tasks (driving and phone task) had to be performed during this condition. They also reported less visual attention to the phone while driving than in the stationary condition, maintaining the visual attention to the driving task.

Based on this experiment, it was concluded that a multi-modal display is preferred in a driving condition, as compared to a stationary condition where text is preferred over audio enhancement. People chose the audio option only if they were in a visually demanding condition. It is important to note that the audio option did not improve the driving performance and did increase the response times. Overall, the results show that the drivers rather perform tasks while stationary than while driving.

1.5 Warning Systems

One of the uses of ITS is the presentation of warning signals to drivers. These warnings include the presence of obstacles on the road as well as critical information regarding road and traffic conditions. It is important to present this information clearly to the drivers so they can respond with the seriousness and urgency the situation requires. Uno, Hiramatsu, Ito, Atsumi, and Akamatsu (1997) studied the level of understanding of the drivers when critical and urgent warnings were presented via visual and auditory displays. The experiment tested the driver's perception of criticality and urgency. Criticality was defined as the perceived danger of collision or vehicle trouble if the display was ignored. Urgency was the perceived requirement to respond to a situation. This study consisted of combining different factors at different levels. For the visual display, color-luminance characteristics (eleven levels combining colors and luminance), temporal factors (seven levels combining intermittent presentation cycles and display activation rates), and spatial factors (six levels combining visual angles at the subject's eye point and shapes) were considered. For auditory displays, the factors considered were sound pressure (four loudness levels at the subject's head position), frequency characteristics (twelve levels combining fundamental tone and secondary component frequencies), and temporal factors (thirteen levels consisting of different tones and periodic presentations combining intermittent cycles and rates). For the auditory display, a background noise simulating vehicle noise was incorporated to the experiment. This was a laboratory experiment.

The results of this experiment suggest that for visual displays, the color red increases perceived criticality and urgency, which also increased as the display luminance increased. For the temporal characteristics, perceived criticality and urgency increase at 0.5 second or shorter intermittent cycle and when the blinking rate becomes slower in shorter cycle displays. For the spatial characteristics it was found that larger visual angle displays increased perceived criticality and urgency, but they were not affected by the various shapes used.

The resulting characteristics for auditory displays indicate that to increase perceived criticality and urgency, sound pressure levels should be greater. For the frequency characteristics, perceived criticality and urgency increased as the frequency of the fundamental tone became higher and with composite rather than pure tones. For the temporal characteristics, perceived criticality and urgency were greatly increased for tones with cycles of 0.2 second, and at higher intermittent rates.

The results of the experiment suggest that for visual displays, the most significant factors are color-luminance and temporal characteristics. For auditory displays, sound pressures and frequency characteristics are the most significant. The manipulation of these factors as described should lead to increased perception for critical and urgent responses.

An experiment was conducted by Graham, Hirst, and Carter (1995) to compare reaction times when auditory warnings were presented using traditional warnings and auditory icons. The traditional warnings used were a synthetic 600 Hz tone and a speech warning. The speech warning was the word “ahead” presented by a female voice. The auditory icons were the sound of a car horn and the sound of skidding tires. These warnings were presented for three situations: vehicle emerging from side roads (left and right) and a stationary vehicle in the road ahead. As a result of this study, it was found that auditory icons produced faster reaction times than did the traditional warnings. This could have been caused by the perceived urgency of the warning due to factors such as frequency, amplitude envelope shape, and melodic structure. Speech warnings may result in slower reaction times due to the time it takes to process them. Although auditory icons resulted in faster reaction times, they also resulted in a higher number of wrong responses, reacting to the warning when there were no imminent collisions. Again, this could have been caused by the perceived urgency. In this case, parameters may be manipulated to produce a less or more urgent sound depending on the situation encountered. It was concluded that overall, auditory icons are a better way to present collision warnings over traditional warnings such as speech and tones.

Belz et al. (1999) performed a similar study of common auditory warnings and auditory icons for the prevention of collisions. For front-to-rear collisions, it was found that auditory icons result in faster response times than conventional auditory warnings and visual displays. This may be due to less mental demand being required to respond to the warning. It is believed that the auditory icons require less mental processing because they are identified by their distal stimulus, as compared to conventional auditory warnings, which may require more mental processing since their meanings have to be recalled before a response is initiated. Both auditory warning methods produced the same response times as the auditory icons when they were combined with the visual display. For side collision avoidance it was also found that auditory icons produced better response times than conventional auditory warnings, and even better when combined with visual displays. The research results indicate that when both auditory warnings are compared, the icons are more easily remembered and less likely to be forgotten than the conventional warnings. This study concluded that, in fact, auditory icons may be useful as warning devices.

Almén (2002) conducted a simulator experiment to compare how drivers react to warnings to get the attention back onto the driving task. The objective of the experiment was to investigate how driver attention was affected by auditory and tactile alerting devices. The study consisted of a driver distracted by a secondary task and calling his/her attention back to the primary task of driving by an alerting method. The independent variables were four experimental conditions: audio alerting, tactile alerting, audio and tactile alerting, and no alerting. The auditory warning consisted of a male voice calling the driver's name and the tactile warning was the vibration of the whole car. The secondary task was to read numbers from a computer screen placed at the passenger front seat. Stimuli along the road were presented to measure driver's performance while reacting to these. Driver's performance was determined by measures of reaction time, time to collision, distance to stimuli, lateral position, lateral deviation, and speed. The experiment resulted in no significant difference between the test conditions, although it could be observed that the two alerting modalities used together produced slighter better results. However, due to the results obtained, it cannot be concluded that a warning system is better than another.

1.6 Advanced Traveler Information Systems

Advanced Traveler Information Systems (ATIS), such as navigation systems, provide drivers with a large amount of information. Liu et al. (2000) performed a simulator experiment to identify which display modality produces the best performance (displaying multi-function ATIS information). The experiment studied the effects of driver age (younger and older), display modality (visual, auditory and multi-modal), driving load (low and high), and information complexity (simple and complex) on driving performance, navigation performance, and emergency response performance. The information displayed, either visually or auditorially, included standard vehicle information, route guidance information, signing information, vehicle condition monitoring information, and road condition and immediate hazard warning information.

Driving performance under the high driving load condition showed that the multi-modal display option is most effective in helping drivers maintain a constant speed under simple and complex information conditions. The auditory display resulted in better performance for the complex information condition than the simple information condition. The auditory display resulted in similar or worse performance as compared to the multi-modal display. Driving performance was worst when the visual display alone was used. It was concluded that complex information should be limited when using visual displays to avoid driver overload.

Results for driving performance under the low driving load condition showed that driving behavior was degraded with the complex information condition using the visual display, as well as when multi-modal displays were used with the simple information condition. For the auditory display, the simple information condition resulted in better performance than the complex information condition.

Navigation and emergency response performance were best when multi-modal displays were used. The use of visual displays for navigation performance resulted in more navigation related errors under the high load, simple information condition, although there were more correct turns in the complex information condition than when auditory displays were used. Visual displays resulted in the worst performance for emergency response. Auditory displays enhanced performance, but not as much as multi-modal displays. Overall, it was found that the best performance was obtained when the information was presented via multi-modal displays, combining both visual and auditory displays.

Since many tasks involved in the use of in-vehicle ITS are more complex than common driving tasks, a standard has been proposed to control the length of time these tasks should take. This standard is being studied by the Society of Automotive Engineers (SAE) ITS Safety and Human Factors Committee. The standard is titled *Navigation and Route Guidance Function Accessibility While Driving* (SAE J2364), also known as the 15-second rule. This recommended practice has been defined as a design limit for the time it takes to perform navigation functions tasks using visual and manual control devices, used while the vehicle is in motion (ITS America, 1999). The recommended maximum time for achieving navigation related tasks is fifteen seconds (Green, 1999).

This time limit is still under discussion. This may seem like a short time to perform an in-vehicle navigation related task, but may be a long time when safety is a primary issue. A new proposed 20-second limit is being considered, but there is currently no word on when this limit might be approved.

Stephens (1990) studied the interaction of navigational information presentation with preparation modes. The information presentations were maps, text lists, and auditory (speech) displays. The preparation modes were previous trip preparation, on-line retrieval of information (at the moment), and a combination of both modes. A wide range of variables were used to evaluate the driving performance of the subjects. Results obtained from this study include better performance when on-line information was used instead of preparation for long trips. Contrary to this, preparation had better results than on-line systems for short trips. Overall, the best performance was obtained when on-line audio systems were used, resulting in faster response times. The on-line lists were not as effective as the audio systems, but yielded faster response times than the use of maps. It is important to note that this was a simulator study where results were obtained under ideal conditions with no external contributors to the noise.

1.7 In-Vehicle Internet

In-Vehicle Internet (IVI) has been considered as a potential addition to vehicle information systems. It would be designed for either driver or passengers as users. Burns and Lansdown (2002) discuss benefits, considerations, and recommendations for IVI systems.

IVI may provide benefits such as assisting the driver with office tasks and avoiding roadwork delays by providing dynamic digital maps and traffic updates. It has also been suggested that IVI would help to decrease driver fatigue and boredom by providing entertainment and information. Vehicle passengers have been considered as potential users of IVI as well. In this case, all amenities available in a standard internet system may be provided, since driver tasks do not need to be considered. Burns and Lansdown (2002) consider that an acceptable and successful IVI system would be one that supports multiple vehicle users, presents the information in appropriate and various ways, and controls human machine interactions. All of these should be done considering the different needs of the users without jeopardizing their safety.

As with any vehicle information system, safety is a factor that must be considered for IVI design and development. The design must focus on safe systems that do not distract the drivers. The safety issue is something that must be addressed before any of these systems is available to users. The safety risks and problems must be evaluated at the early stages of design and development.

Driver attention may be affected in a negative way with the incorporation of IVI systems. Mental, visual, and manual components could be affected, increasing driver distraction. The mental demands on a driver may increase for various reasons, such as the information feedback delay when an IVI system is used. This delay may cause distraction as well as frustration to the driver. Frustration may be considered as a type of emotional distraction that may have a negative impact on driving safety. Another factor that can increase mental demand is information variability. Information changes continuously due to factors such as time, location, and format. The presentation of information on the World Wide Web (WWW) varies from site to site, making it difficult for the driver to interpret the information in an uniform way. This inconsistency in information presentation increases the driver's mental demands.

As discussed previously, it is known that in-vehicle information systems may overload the visual capacities of the user. The developers of IVI systems present the incorporation of speech interfaces as a possible solution to this problem. In the Auditory Displays section above, it was explained that this can be a solution, although it will not necessarily decrease a driver's level of distraction, since people are accustomed to interacting with the Internet in a visual rather than auditory modality. The system design must accommodate all users, accounting for age, experience, and ability variations among users.

The manual component presents a design challenge to accommodate such systems into the vehicle. Controls and workspaces must facilitate system interaction with the user without interfering with normal driving tasks. Burns and Lansdown (2002) recommend sources for design guidelines such as the BSI Code of Practice, the EC statement of principles, the TRL Checklist, the Green human factors guidelines, and the Campbell guidelines. These sources do not give specifics for IVI systems design, but may provide general guidance.

1.8 Mobile Phones

It is known that one of the most used information systems is the mobile (cellular) phone. The in-vehicle use of this technology is a concern when on-road safety is considered. The exact safety effects are not known, but driver distraction, errors, and vehicle accidents around the world have been linked to the use of phones while driving, and for this reason many countries have already banned their use on the roads.

Direct Line Motor Insurance is a United Kingdom insurance company that has performed research in the use of mobile phones while driving, with the purpose of promoting legal changes that would address this issue. Their research was published as The Mobile Phone Report (2002). To assess the risk of using phones while driving, the research compared the use of hand-held and hands-free mobile phones to driving performance when alcohol is consumed. Since driving with blood alcohol levels over established limits is recognized as risky, this comparison provides a baseline risk level against which cell phone use can be compared. The simulator experiment was performed using four road conditions (motorway with moderate traffic, maintaining safe distance when following another vehicle, attempting to negotiate a bend in the road, and driving on a two way road with traffic lights). Participants were talking on the phone after having or not having consumed alcohol.

The research results showed poorer driving performance when using mobile phones than when driving under the influence of alcohol. The performance measurements included speed control, following distances, lane deviations, and reaction times to critical events. The best performance was obtained when participants drove under normal conditions (no alcohol, no phone) followed by the use of alcohol. The worst performances were obtained when mobile phones were used, with hand-held phones being worse than hands-free phones. These results demonstrate that the use of phones while driving distracts the drivers' attention from their primary task of controlling the vehicle. The use of mobile phones resulted in poorer driving performance in terms of speed control, recognition of road hazards, and maintaining distances with other vehicles. The use of alcohol resulted in the worst performance in terms of lane deviations.

The distraction of using a mobile phone may be manual, visual, mental, or auditory. More than one of these distraction modalities can occur simultaneously. The results of the report showed when and how the drivers are distracted. The manual distraction occurs when the driver holds the phone and not the steering wheel. Greater manual distraction occurs when the driver types into the phone on the phone to send text messages, while less occurs when using hands-free phones. Visual distraction occurs when the drivers take their eyes off the road to use the phone. The greatest visual distraction occurs when using text messages as well. Mental distraction occurs when the drivers take their mind off the driving task to try to concentrate on the phone call, resulting in poor achievement of both tasks. Auditory distractions occur while having a conversation on the phone. High distraction levels are also possible due to technical problems such as poor sound quality and poor phone reception.

Even though the use of hands-free mobile phones resulted in better driver performance than using hand-held phones, it does not mean that these do not present a risk. Hand-held phones have a greater degree of manual distraction, but both systems produce similar mental distraction. Sometimes, the potential risk that either type of mobile phone presents is misunderstood. Because hands-free phones are not held in the hands, they are not considered to be dangerous by some who do not consider the other types of distraction that phone use involves.

Strayer and Johnston (2002) also studied how the use of mobile phones affects the driving task. They not only wanted to confirm the distraction caused by mobile phones but also wanted to determine the nature of this interference. The studies were based on two hypotheses. The peripheral-interference hypothesis suggests that interference is due to peripheral factors, such as holding the phone. The attentional hypothesis suggests that interference is due to the attention allocated to the phone conversation instead of the driving task. The study consisted of two driving-simulation experiments.

The first experiment compared the use of hand-held and hands-free mobile phones. The number of missed traffic signals and the reaction times to detected traffic signals were measured. The use of the phones was compared to a third group whose task was to control the radio. Since no significant differences in performance were found between phone modalities, data from both groups were combined and compared to the radio control group. The results of this experiment show an increase in the probability of missing traffic signals and in reaction times to traffic signals when having conversations on the phone. The fact that there was no significant difference between phone modalities indicates that the interference was not due to peripheral factors but to active engagement in the conversation.

The second experiment attempted to localize the source of interference to the driving task while having a conversation on the mobile phone. Three tasks were tested at two levels of course difficulty, measuring task tracking errors. One of the tasks did not involve the use of phones, while phones were used for the other two tasks. One of the cases assessed peripheral factors (holding the phone, listening, and speaking), while the other assessed the attentional demands. For each of the tasks, the tracking errors increased from the easier to the more difficult course condition, and from one task to the other (no phone to peripheral factors to attentional factors). There was no significant difference between the control group and the group testing the peripheral factors in terms of driving interference, while the attention factors resulted in significant driving interference. These results indicate that the attentional demands may be the primary cause of interference during a phone conversation while driving, although is important to note that peripheral factors also cause interference at a lower level.

Nowakowski, Friedman, and Green (2002) conducted a simulator experiment with cellular phones focusing in the task of answering the phone while driving. The dependent variables of the study were age, gender, phone design, road curvature, and call timing. The road curvature and the timing of the call were used to manipulate the visual workload of the driver. Four phone designs were tested. Three phone designs used a HUD display and one used a common center console phone to display a caller ID and call timer. Two phones had a ring to acknowledge an incoming call while the other two used visual icons to advise of the incoming call. The dependent variables were four performance measures: incoming call response time, standard deviation of lane position, line-crossing rate, and speed loss during the trial. The last three were used to assess driving performance.

The response time was significantly affected by driver's age and phone design. It took older drivers longer to answer the phone than younger drivers. It took more time for all participants to answer using the center console design. There was no significant difference between the three HUD designs.

The driving performance measures were significantly affected by driver's age and phone design as well. Older drivers had more trouble keeping lane position and had a higher line-crossing rate than younger drivers. These results were mostly the same for each of the HUD designs. However, the performance measures were worst when the center console phone was used. Younger drivers' performance was mostly the same for each of the four phone designs. The speed loss measurement resulted in the same tendency as lane position and line-crossing rate measurements. There was no significant speed loss in young drivers, while older drivers did lose speed while performing the tasks.

The manipulation of the driver's visual demand had a significant effect on the response time and driving performance. As the road curvature increased, the response time increased and the driving performance deteriorated (increased lane position standard deviation and line-crossing rate). Again, the situation was worst with the center console phone than with the HUD designs. The call timing also had a significant impact on the response time. The response time was longer when the call was received during a curve than when received before a curve. The speed loss was significantly affected by the call timing as well, with a greater speed loss when the call was received during a curve than when received before a curve.

The subjective evaluation of the participants resulted in a preference of having the caller ID in the center HUD location and having a ring option. Not having an audio cue for incoming calls was rated as more stressful than having a ring, because the driver did not know there was a call until they saw the displayed icon.

This experiment resulted in HUD-based phones being better than center-console phones due to improved performance measures and response time. Although the participants preferred the ring option, there was no indication that driving performance was influenced by ring availability. Finally, the increase in visual demand due to the curvature of the road resulted in longer response times and worse driving performance.

The effects of cell phone use and radio tuning on driver distraction were studied by Siebert, Mouloua, Burns, Marino, Scagliola, Winters, Hancock, and Agliata (2002) in a driving simulator study. The objective of the experiment was to determine the impact of telematics on driver performance and workload. The independent variables were the use of telematics (none, talking on the phone, tuning the radio) and the allocation phases (pre-allocation, allocation, and post-allocation). The participants were required to drive through the three allocation phases. During the pre-allocation phase the participants had to drive while performing a secondary task that consisted of monitoring the occurrence of visual signals. During the allocation phase, the drivers had to do the same task with the addition of telematics use (either the phone or radio tuning). In the third phase (post-allocation), the drivers had to do the same task as in the first phase. The dependent measures were the number of correct, wrong, and missed visual signals (secondary task) and driving errors (collisions, crossing the median, leaving the road, maintaining the speed limit, and lane deviations).

The results showed a significant effect of phase on lane deviations and crossing the median. During the allocation phase (using either the phone or tuning the radio) there were more lane deviations and median crossings than during the other two phases. Secondary task performance was also affected by the phase. More errors were committed during the allocation phase.

These results indicate that workload is increased with the use of telematics, as demonstrated by the secondary task results. Driving performance is affected in a similar way. The authors concluded that the use of such devices should be controlled to avoid overloading of driver attention capacity.

1.9 Information Processing

The interaction between humans and human-made systems may be discussed and explained through the application of human information processing models. Rasmussen (1983) proposed a model with three levels of performance that interact with each other (see Figure 1). The three levels are Skill-Based Behavior, Rule-Based Behavior, and Knowledge-Based Behavior.

Harms-Ringdahl (2001) summarizes Rasmussen's behavioral levels as follows:

- *Skill-based behavior* refers to routine tasks that are familiar to people and that are performed through fairly direct actions. The errors associated with this level of performance are called slips or lapses. Driving a vehicle for many years is an example of this type of behavior. Certain familiar driving tasks reach the skill-based level. People are so familiar with the task of driving that they perform it almost instinctively.

- A *rule-based behavior* occurs when people are fairly familiar with the tasks to be performed and these tasks are based on established rules. When a rule is incorrectly applied due to a misjudged situation, an error occurs. The use of an information system is an example of rule-based behavior. People follow instructions to perform tasks associated with a particular system.
- *Knowledge-based behavior* is encountered when a problem arises and there are no rules to follow in order to solve it. People have to find a solution using their knowledge. The problem solving involves a series of steps that could be applied in any order: activation, observation, identification, interpretation, evaluation, goal selection, procedure selection, and activation. The errors at this level are due to incomplete information, incorrect information, or limited resources. An example of knowledge-based behavior could be a situation when a person is encountered with a vehicle navigation system without being trained on its use. The person needs to use their knowledge to perform the required tasks.

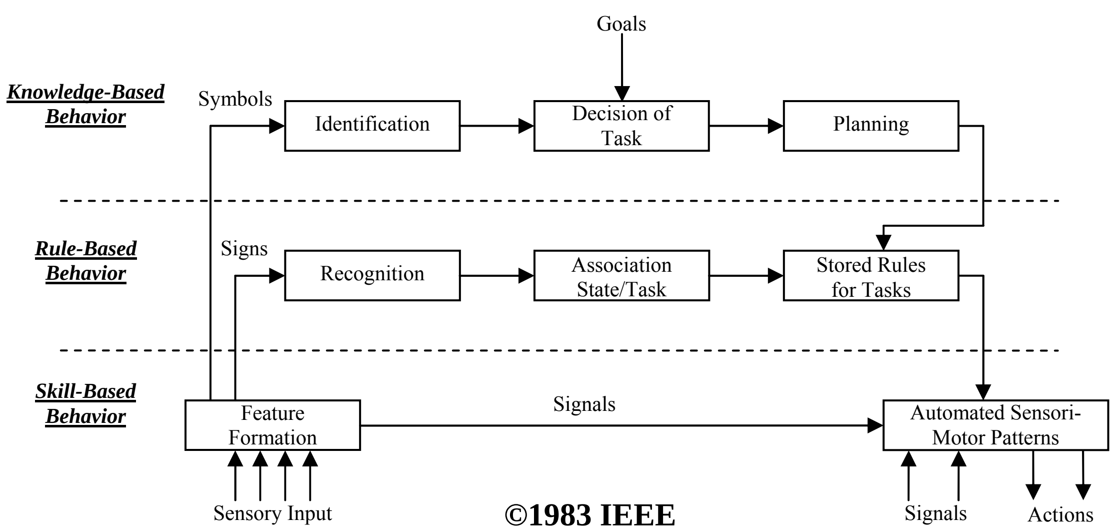


Figure 1. **Human Information Processing Model (Rasmussen, 1983).**

Rasmussen's model establishes three ways in which information is received. This depends on the context in which the information is perceived rather than how it is presented. These are particular to the level of performance. At the skill-based level, the information is received in the form of signals. These signals are defined as sensory data representing time-space variables from a dynamic, spatial configuration in the environment which can be processed as continuous variables. At the rule-based level, the information is received as signs. Signs are related to features in the environment and the associated conditions for action. These are not processed directly but activate stored patterns of behavior. At the knowledge-base level, the information is received as symbols that represent information, variables, relations, and properties which can be formally processed. These are used to explain or predict unfamiliar behavior of environmental information. Human information processing capabilities should be considered for the design of in-vehicle information systems to help avoid potential accidents that could be caused by errors in design.

1.10 Factors Affecting Display Design

Driving performance is not only a matter of which display is used to present information, but of a number of other factors that can affect the overall situation. A normal driving setting would have more external factors such as noise and traffic than would a controlled experiment environment such as a simulator or test track. Some of the factors that should be considered in the design of in-vehicle information systems displays are discussed in this section.

Workload - Workload can affect driving performance because of information processing times and attentional demands. Most of the experimentation involving workload has been done on simulators rather than with on-road driving. Of the studies performed on driving workload, Liu et al. (2000) tested low and high workload conditions presented via visual, auditory, and multi-modal conditions. Under both high and low workload conditions, the multi-modal display resulted in better performance. Any type of display causes some increased level of workload that may become a risk factor to the driving task.

Noise sources – Real driving environments have noise sources other than the auditory displays. These noises can interfere with the use of information systems, increasing the difficulty of use and mental demands. Examples of noise sources are citizens-band radios, stereo, vehicles (including the one being driven), passengers, and the outside environment.

False alarms – Driver performance may be affected when auditory warnings are wrongly identified by the driver or when the driver reacts to a nonexistent situation. A false alarm may cause the sudden reaction of the driver when no collision or emergency is imminent because the driver's perceived urgency is higher than it should be. The wrong identification or no identification at all of hazardous situations may be a source of distraction and confusion, degrading the driving task. Both of these scenarios will reduce the driver's confidence in and willingness to use an auditory warning system.

Demographics - Age is a factor that may affect the use and understanding of in-vehicle information systems. The Llaneras et al. (2000) experiment on auditory displays found that age is an influential factor in driving. Stephens (1990) found that age affected the driver's responses in a study of presentation of navigational information, while gender did not have a significant effect. Gender has not been found to be a great source of variability, so that it does not always need to be considered in driving studies. However, age has been shown to result in performance variability. As age increase, the trend is for a decrease of driving performance, such as slower reaction times.

Factors affecting the usability of auditory icons as well as other type of auditory displays have been discussed by Mynatt (1994) including the following: *Identifiability* (sounds must be recognizable by the drivers); *Conceptual Mapping* (how well the sound represents the event that it relates to); *Physical Parameters* (parameters such as duration and bandwidth of the sound); *Sound Quality* (the overall quality of the sound may affect the identifiability and the driver's subjective impression of the interface); and *User Preference* (how the user responds emotionally to the icon).

1.11 Human Factors Guidelines

The research done in the area of IVIS has led to human factors design and use guidelines. A summary of these guidelines is presented in Table 1.

Table 1. **Human Factors recommended guidelines for in-vehicle displays.**

System	*Guidelines*
IVIS	Use simple information.
	Use multi-modal displays for complex and critical information.
	Control the use of auditory components to avoid annoyance.
	Present textual information by vocal announcement.
	Limit the number of guidance instructions to be read to no more than two.
	Use symbols to present guidance information.
	Task time should not be more than 20 seconds.
	Glances to display should not be longer than 2.5 seconds.
	Tasks should not affect lateral and longitudinal vehicle control.
	Tasks should not affect driver's workload and situational awareness.
	System feedback should be instantaneous.
	Avoid flashing or moving graphics elements.
	Minimize visual clutter.
	Use maximum contrast between display elements.
	Consider color blindness and use colors sparingly.
	Keep backgrounds simple and muted.
	Group information logically considering frequency and sequence of use.
	Consider user's behavior and needs.
	Let user set pace and initiate interaction.
	Prioritize information.
	Accommodate for experience.
	Restrict information when necessary.
	Auditory icons should use easily recognizable sounds.
	Auditory icons should not sound similar.
	Auditory icons should have similar duration, intensity, and quality.
VISUAL DISPLAYS*	Color-luminance: Red at 50 cd/m^2.
	Temporal characteristics: Intermittent cycle = 0.2 sec, Rate = 30%
	Spatial characteristics: Visual angle = 6.0 deg, Shape = contoured square
AUDITORY DISPLAYS*	Sound pressure level = 80 dBA
	Frequency: Fundamental tone = 2.0 kHz, Secondary = 1.5 x fundamental
	Temporal characteristics: Intermittent cycle = 0.2 sec, rate = 70%

* Recommended guidelines for detection of critical and urgent events (Uno et al., 1997).

1.12 Conclusions

The continuous development of in-vehicle information systems has resulted in increased research interest in the safety and design of information displays. The most common types of displays are visual displays, auditory displays, and displays combining both visual and auditory components. Advantages and disadvantages have been discussed for each type of display and its applications (e.g., the display that works best for a certain task may not be as effective for other tasks).

Most in-vehicle displays are visual, but the incorporation of new information systems using visual displays can cause a visual overload for the driver. Auditory displays have become an option for presenting information to the driver. The use of auditory displays reduces visual workload, but it has to be noted that this type of display may increase mental workload. The combination of both types of displays into a multi-modal system has sometimes been recommended. For some cases, multi-modal displays have resulted in better driver performance. However, the possibility of excessive workload caused by the redundancy of information processing has to be considered as well for these types of displays.

The studies included in this literature review emphasize how in-vehicle information systems can degrade driving performance. The development of new technology has been continuous and these technologies are already being incorporated into vehicles. For these reasons, designers should consider incorporating safety features into display designs to decrease driving risks and promote optimal levels of driving performance.

The dynamic nature of IVIS development provides numerous opportunities to expand already existing research, as well as to introduce new research ideas. The number of information systems and the tasks that can be performed are continuously increasing, providing a series of variables that could be manipulated to obtain safety related in-vehicle performance measurements.

2. RESEARCH OBJECTIVES

2.1 Rationale

In-vehicle information systems (IVIS) have been associated with driver distraction. These systems provide a range of options that allow the driver to perform variable tasks, from office related tasks to entertainment. Many of these systems are already available to the consumer, others are currently under development, and others will be designed and developed in the near future.

The design, installation, and use of IVIS may have a direct impact on drivers' safety. Due to the safety concerns, the necessity and convenience of incorporating these systems into the driving environment have been discussed extensively. Despite these concerns, the use and development of these systems has been increasing. Therefore, the development of guidelines for the design and use of IVIS should be promoted to improve driving safety.

The development of human factors guidelines for the design and use of in-vehicle information systems was an expected outcome of this research. It was a desirable goal to identify the most suitable information presentation formats for certain tasks. The presentation format of the IVIS secondary tasks may influence the drivers' attention and driving performance. The factors of interest for this research included the types of display used to present the information, and in the case of auditory displays, the speech rate used by the system. Driver's behavior and performance may also be affected by the type of task performed and its level of difficulty. The investigation of all these factors provided information leading to specific IVIS design guidelines.

2.2 Research Questions

The design of in-vehicle information systems involves many considerations. The objectives of this study focused on how the factors of interest may affect drivers' attention and driving performance while performing IVIS secondary tasks related to specific applications. The research attempted to answer the following questions:

- For which types of IVIS secondary tasks is a redundant visual text display helpful in ensuring adequate levels of driving performance (redundant to an auditory speech display)?
- For auditory speech displays, how does fast or slow speech rate influence driving performance?
- For multi-modal displays, which speech rates create better driving performance?
- Given the answers to the above research questions, what are the appropriate guidelines for use and design of speech, text, and multi-modal displays for the specific applications?

2.3 Hypotheses

This research proposed to test the general hypothesis that the performance of IVIS secondary tasks while driving increases driver distraction. This was noted with the comparison of driver performance results of the baseline and experimental runs. Specific hypotheses based on the research questions were also established as follows:

- The use of multi-modal displays will increase the level of driving performance for calendaring and e-mail IVIS applications as compared to visual and auditory display results.
- When speech rates used for the auditory and multi-modal displays are compared, the fast speech rate (i.e., time-compressed rate) will result in better driving performance as compared to the slow speech rate (i.e., normal rate).
- Task complexity will negatively affect both external reaction time to an external stimulus and perceived workload. As the complexity of the IVIS secondary tasks increases, the external reaction time and the perceived workload will increase.
- Overall, the use of multi-modal displays will result in better driving performance as compared to a visual or auditory display.

3. EXPERIMENTAL METHOD

An on-road experiment was performed to achieve the research objectives. The experiment consisted of performing secondary tasks with an In-Vehicle Information System (IVIS) while performing the primary task of driving an instrumented vehicle. To evaluate the distraction that IVIS secondary tasks may cause to the drivers, performance measures were collected and analyzed. The experimental details are presented in the following sections.

3.1 Participants

Sixteen drivers participated in the experiment. The drivers' ages ranged from 23 to 55 years. The age mean was 39.19 years with a standard deviation of 10.33 years. There were participants of all age groups: three in their twenties, six in their thirties, three in their forties, and four in their fifties. The gender of the participants was balanced in order to have same number of females and males (eight each). Participants were gathered by accessing the Virginia Tech Transportation Institute (VTTI) participant database. The participants received $20 per hour of participation.

Each participant was required to: (1) hold a current driver's license, (2) pass a visual acuity screening test with a score of at least 20/40, and (3) pass a health screening questionnaire. All participants met these requirements.

The participants were screened by phone to determine if they were suitable for the experiment in terms of age and medical condition (Appendix A). Once selected, participants attended an experimental session that lasted approximately 3½ hours. The experimental session started by filling out an informed consent and a health questionnaire (Appendix B and C). A standard Snellen eye test was performed to ensure a visual acuity of 20/40 or better. A color blindness test was also performed. The session continued with a familiarization in the use of the IVIS interface, the instrumented vehicle, and the experiment road site. The participants were free to withdraw from the experiment at any time. One participant withdrew from the experiment after the familiarization with the use of the IVIS due to medical reasons.

3.2 Test Facility

The Virginia Tech Transportation Institute (VTTI) was the location for the experiment. Laboratory facilities were used for participants' screening and familiarization. The driving sessions were held at the Smart Road (see Figure 2). The Smart Road is a controlled 2.2 mile road segment located in Blacksburg, Virginia. The road is a test bed closed to public traffic. It is a two-way road with turnarounds at both ends. The experimental tasks were performed while driving through the straight segments of the road. The experimental sessions were held during daytime hours and under weather that did not affect road visibility or roadway traction.

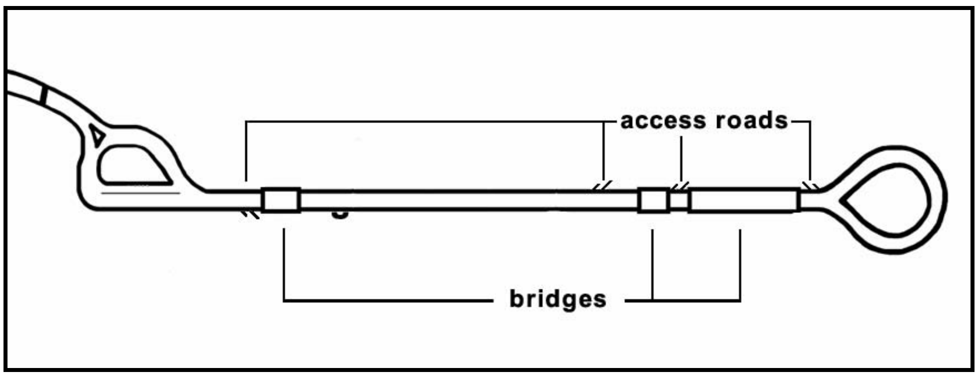


Figure 2. **Smart Road Diagram.**

3.3 Apparatus

The equipment used for the experiment consisted of: (1) instrumented vehicle, (2) cameras, (3) sensors, (4) software and hardware interfaces, (5) IVIS, and (6) safety equipment.

3.3.1 Instrumented Vehicle

The experimental vehicle was a 1997 Ford Taurus featuring an automatic transmission and standard instrument panel (Figure 3). In addition, the vehicle was instrumented with cameras, sensors, LCD array, computers, IVIS, and safety equipment. A diagram of the vehicle and the equipment is presented in Figure 4.

Figure 3. **Experimental Vehicle.**

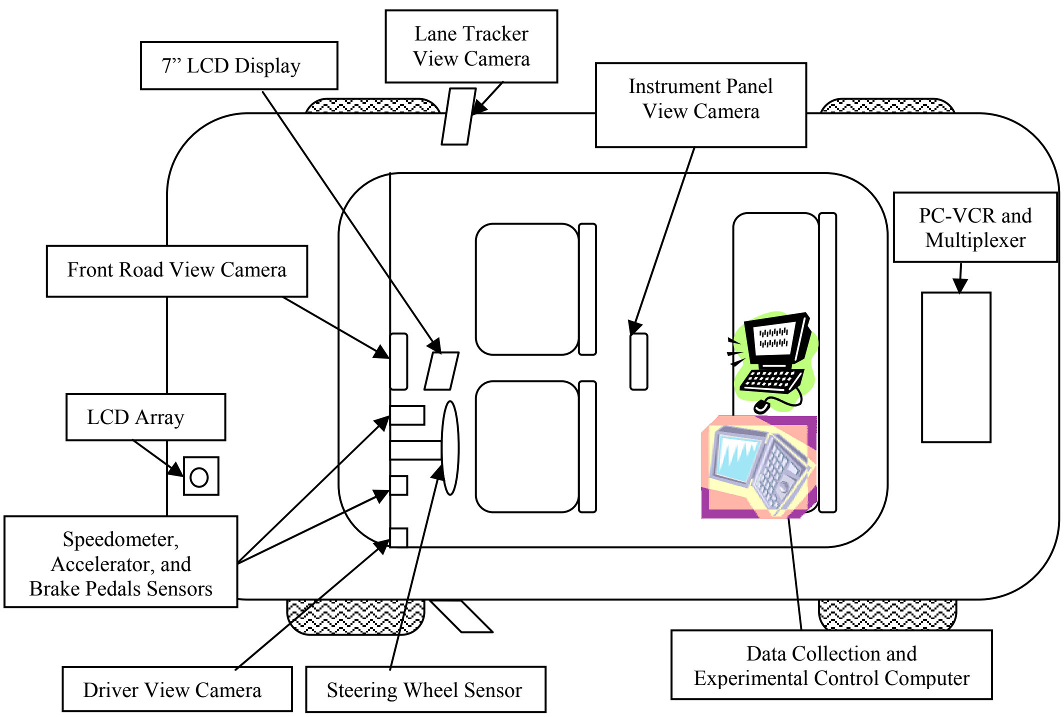


Figure 4. **Instrumented Vehicle Diagram.**

3.3.2 Cameras

Four cameras were installed in the vehicle (see Figure 5). One camera was located in the driver's side A-pillar. This was used to monitor eye movements (glances). Its field of view allowed for different seating positions and participant height. The second camera recorded the information panel and IVIS controls in front of the driver. This camera was located on the top of the vehicle's interior. The third camera recorded the forward view of the vehicle. It was located on the back of the center rear-view mirror. The fourth camera was located on the right side rear-view mirror (passenger's side). This camera was used to monitor lane positions with respect to the road outside line. The four video images were combined with a quad splitter as can be seen in Figure 6, and microphones were installed inside the vehicle to add audio to the visual images. A time counter was stamped on the video matching it to the collected data.

Figure 5. **Vehicle cameras.**

Clockwise from upper left: forward view, driver view, instrument panel view, and right lane view.

Figure 6. **Video image with quad splitter.**

3.3.3 Sensors

Sensors were installed to gather data related to driving performance. The steering wheel, speedometer, accelerator pedal, and brake pedal were instrumented. The data from these sensors were measured at a rate of 10 Hz. The steering wheel sensor provided steering position angles in radians. The speedometer sensor recorded speed variations throughout the run. The speed was measured in miles per hour (mph). The accelerator and brake pedal sensors provided pedal position. The position of the pedals was measured as the percentage of pedal depression. An accelerometer was installed to obtain lateral, longitudinal, and vertical acceleration and deceleration values. These values were measured as linear gravitational acceleration. The data obtained from these sensors were integrated with all additional data in a data collection computer.

3.3.4 LCD Array

An array of LCD lights was installed on the top of the hood right in front of the driver's view (Figure 7). This light was controlled by the vehicle computer. It was activated at random intervals of three to six seconds and would stay on until turned off by the driver. The deactivation device was a switch installed on the floor of the vehicle to the left of the pedals. The activation of the light was recorded by the system as a 1 (one) and as a 0 (zero) when the light was deactivated (i.e., if the light was on, the data reported ones; if the light was off, the data reported zeroes). With this information, the length of time the light was on could be calculated.

Figure 7. **LCD Array (Distracting Light).**

3.3.5 Data Collection Interface

The data collection computer was used to collect all data recorded from cameras, sensors, and the experimenter. This system was located inside the trunk and out of the view of the participants (Figure 8). The system provided a way to tie the data recorded from the sensors to the video. A stamped time (i.e., synchronized number) appeared on the video matching each video frame to each data point of the collected data. The video was recorded at 30 Hz (30 frames per second – 3 frames per sync number) and the data were recorded in tenth of a second (10 Hz) frames. The experimenter controlled the information flow for the IVIS secondary tasks through the use of commercial computer software (Macromedia® Authorware®) and a laptop computer held by the experimenter in the back seat of the vehicle. In addition to the laptop, a small monitor and a keyboard were mounted on a wooden base in the vehicle's back seat. Through these, the experimenter could control the data collection system from the interior of the vehicle (Figure 9).

Figure 8. **Data Collection Interface.**

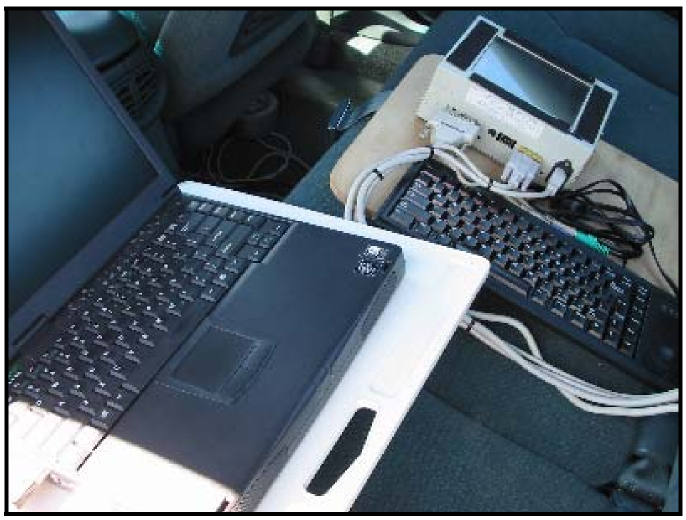


Figure 9. **Experimenter Interface.**

3.3.6 In-Vehicle Information System (IVIS)

The participants were given the instructions to perform each secondary task (described later) and told when to begin the tasks. The task would begin by verbally activating the IVIS. The IVIS interface was developed using Macromedia® Authorware® version 4 interactive multimedia software. The interface consisted of the applications that were included in the tasks (calendar, e-mail, and voice-mail). The IVIS was manipulated with a laptop by the experimenter. The image of the interface was projected into the IVIS display.

The Authorware® software was previously used by Julie Barker, a Virginia Tech Ph.D. graduate student. Ms. Barker developed a user interface to test tasks and driver performance while using an IVIS. This interface consisted of six applications: E-mail, Phone, Phone Book, Calendar, To Do List, and Memo. Ms. Barker provided all the basic materials pertaining to the software plus personal notes used for the development of the interface used for her dissertation experiment. She explained the basics for Authorware® programming and provided the mentioned materials in a face-to-face interview. The interface program developed by Ms. Barker was modified to suit the conditions of this study.

Two of the original six applications were used for this study. These applications were the Calendar and the E-mail applications. The original Memo application was modified to create the Voice-mail application. All the original synthesized voice messages were re-recorded at a faster synthesized speech rate to enable both normal and fast speech rates. TextAloud MP3 Version 1.499 was the text-to-speech software used to record the fast speech messages. A total of 192 text messages were converted to fast sound files. These sound files were incorporated into a duplicated fast version of the IVIS interface.

The modifications and manipulations of the original IVIS resulted in a three application interface. Two versions of this interface were used: a normal speech rate version and a fast speech version. Both versions were identical except for the speech rate used. By this means, the experimenter could activate either one of them to present the tasks to the drivers depending on the experimental condition to be tested. Samples of the main screens for the three IVIS applications are presented in Figures 10-12. The commands displayed beneath the screen messages show the possible commands to be given by the drivers and used by the experimenter to control the IVIS interface.

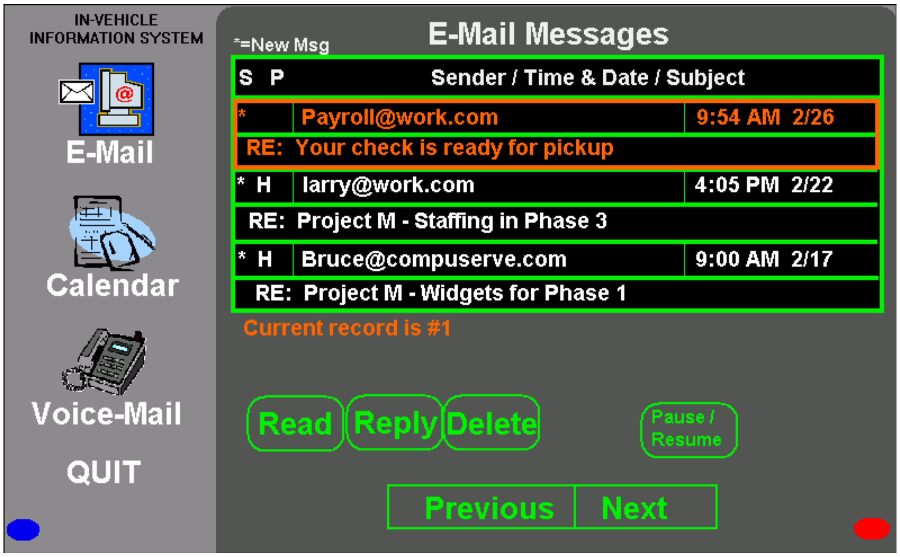


Figure 10. **IVIS E-mail Application Main Screen.**

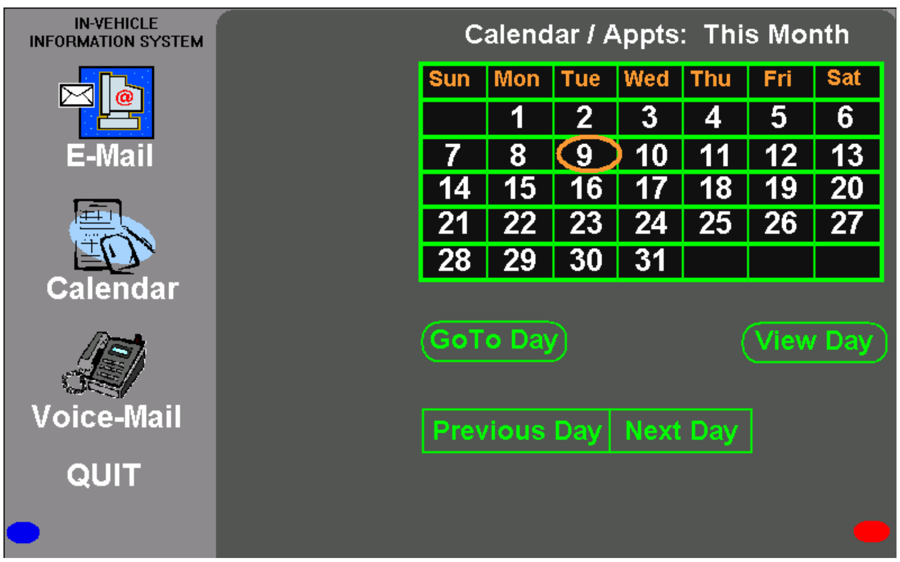


Figure 11. **IVIS Calendar Application Main Screen.**

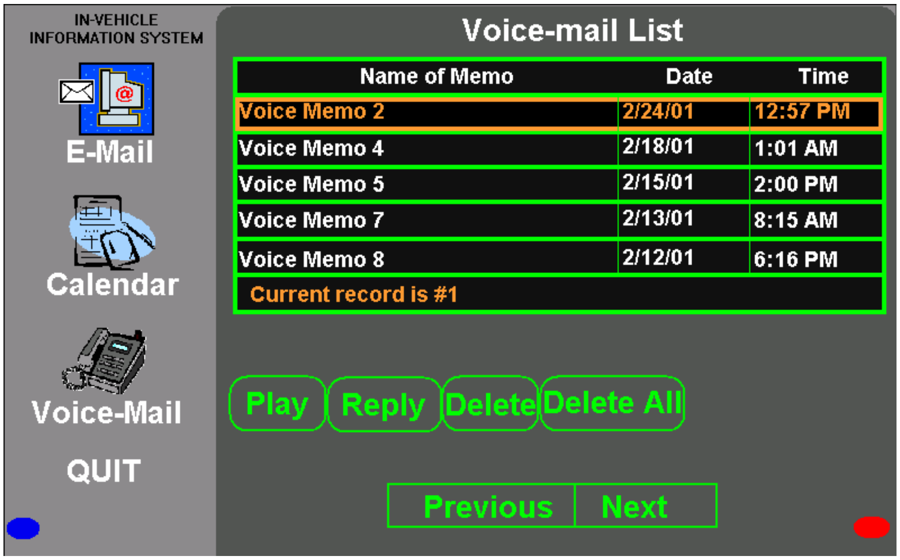


Figure 12. **IVIS Voice-mail Application Main Screen.**

Screen sequences for the performance of the IVIS tasks are presented in Appendix D. The screens presented for the voice-mail application were seen by the experimenter and not by the drivers. This application was performed using only the auditory displays, not having any visual presentation.

3.3.7 IVIS Display

A seven inch diagonal flat panel liquid crystal display (LCD) was installed in the vehicle as shown in Figure 13. This was mounted on the vehicle's dashboard, to the right of the driver. This display functioned as the IVIS presentation screen for the visual and multi-modal modalities. For the auditory display this display was turned off.

***Figure 13.* In-Vehicle Display.**

3.3.8 Safety Equipment

Safety equipment was provided in the vehicle in case of an emergency. This equipment included a fire extinguisher, a first-aid kit, and a cellular phone. The participants were required to wear the safety belt at all times while in the vehicle, and nothing obstructed the driver's forward view. The vehicle was also equipped with a driver's side and passenger's side airbag supplemental restraint system.

3.4 Experimental Design

The experimental design was an incomplete three factor within-subjects design. Display type (5 levels), task applications (3 levels), and task difficulty (2 levels) were within-subjects variables. A graphic presentation of the experimental design can be seen in Table 2.

Table 2. **Experimental Design.**

		Task Difficulty	
Display	***Application***	**Easy**	**Difficult**
Visual	**Calendar**	P_1-P_{16}	P_1-P_{16}
	Voice-Mail		
	E-Mail	P_1-P_{16}	P_1-P_{16}
Auditory Normal Rate	**Calendar**	P_1-P_{16}	P_1-P_{16}
	Voice-Mail	P_1-P_{16}	P_1-P_{16}
	E-Mail	P_1-P_{16}	P_1-P_{16}
Auditory Fast Rate	**Calendar**	P_1-P_{16}	P_1-P_{16}
	Voice-Mail	P_1-P_{16}	P_1-P_{16}
	E-Mail	P_1-P_{16}	P_1-P_{16}
Multi-Modal Normal Rate	**Calendar**	P_1-P_{16}	P_1-P_{16}
	Voice-Mail		
	E-Mail	P_1-P_{16}	P_1-P_{16}
Multi-Modal Fast Rate	**Calendar**	P_1-P_{16}	P_1-P_{16}
	Voice-Mail		
	E-Mail	P_1-P_{16}	P_1-P_{16}

[yellow box] = Untestable conditions

3.4.1 Independent Variables

The independent variables for the experiment were display type, IVIS application, and task difficulty. Five display types were tested: (1) visual, (2) auditory: normal speech rate, (3) auditory: time-compressed speech rate, (4) multi-modal: normal speech rate, and (5) multi-modal: time-compressed speech rate. The multi-modal displays combined both auditory and visual displays. The same two speech rates were used for the auditory displays and for the multi-modal displays. The normal and time-compressed rates were manipulated with a speech speed control featured in the text-to-speech software used to record the messages. The software used was TextAloud MP3 Version 1.499. This "write to file speed" feature did not specify the words per minute but rather the speed of creating .wav files from text. The settings of this speed option are expressed as multiples of normal speaking speed. Normal speaking speed is defined as 1x. The fast speed was achieved by setting the options to 30x, meaning that the file was produced in 1/30th the time.

Synthesized speech was used for the auditory display. All of the display types were accessed verbally by the participant, thus simulating a speech recognition system. In reality, the system was controlled by the experimenter through the Wizard of Oz technique. This technique simulates a speech recognition system that automatically recognizes what the participant says and displays the appropriate information to the participant (Gould, Conti, and Hovanyecz, 1981). The simulated system was assumed to have a perfect speech interface (Carlson, Barclay, O'Connor, Duckworth, Heine, Papazian, and Steele, 1995).

The IVIS provided three task applications: Calendar Management, Voice-Mail Management, and E-Mail Management. The Voice-Mail application could not be presented visually, and was thus only presented auditorily (not with the visual or multi-modal displays). Tasks were performed for each of the applications at two levels of difficulty: easy tasks (4-5 hierarchical steps) and difficult tasks (6-7 hierarchical steps).

3.4.2 Dependent Variables

The independent variables were manipulated to obtain information on driver performance and subjective assessment. The data obtained provided information on how the performance of IVIS secondary tasks applications while driving affects both driver performance, on the primary task, and driver workload perception. The driver performance measures included eye glance data, lane deviations, speed maintenance, and external reaction time.

Eye Glances. Eye glance behavior referred to the glances that a driver made to the IVIS while driving. This behavior was monitored (video recorded) for one minute during a practice lap on the road. This was a baseline lap. The same observations were made during the experimental run to be compared to the baseline data to determine how the IVIS secondary tasks affected this behavior. The number and duration of these glances were observed. The number of glances to the display indicated the number of times the driver glanced away from the forward view to look into the display. The length of these glances was averaged per task per participant. This average was divided by the total length of each task to obtain the eyes-off-road percent (EOR%). This was the percentage of time that the drivers were looking at the display rather than forward.

Lateral Driving Performance. Lateral driving performance was evaluated by the number and length of lane deviations. Lane deviations occurred when any part of the vehicle exceeded the traveling lane boundaries. The lane deviations were observed through a video recorded with the camera installed at the passenger's side rear view mirror.

Longitudinal Driving Performance. Longitudinal driving performance was determined by the driver's speed maintenance. The speed standard deviation was calculated for speed data obtained during the baseline lap. The same calculations were performed for speed data obtained during the experimental run. As before, the results were compared, in this case to determine how IVIS secondary tasks affected speed maintenance. This information was obtained from the sensors installed in the vehicle.

External Reaction Time. A measure for reaction time to an external stimulus was incorporated into the study as a way to introduce the possibility of environmental complexity. This was a controlled study where driving conditions such as road traffic, traffic lights, signs, and pedestrians were non-existent. This variable was originally intended to measure situational awareness. Through the development of the study and after reviewing some situational awareness literature, it was decided that this measurement was not an accurate method to measure situational awareness. However, this measurement could be used to determine the drivers' ability to react to an external stimulus while performing IVIS secondary tasks. The external reaction time was measured by the ability of the driver to detect a light while performing the IVIS secondary tasks. A light placed on the hood of the car was turned on at random intervals and the driver was instructed to turn it off by pressing a foot switch located to the left of the brake pedal. The elapsed time from the onset of the light and when the driver turned it off was calculated to determine the reaction time. The presence of the light had the intention of simulating an external situation (external to the performance of IVIS secondary tasks) of which the driver had to be aware.

Information Capture. In addition to the driving performance measures, it was of interest to examine IVIS secondary task performance. An information capture measurement was performed to study this behavior. Right after each IVIS secondary task, the participants were asked a question about the content of the information. This was used to determine if the driver was aware of the information handled during the IVIS secondary task.

Mental Workload. A subjective assessment measurement of workload was obtained by the use of a questionnaire. The participants provided their workload perception for each IVIS secondary task. A subset of the NASA Task Load Index (NASA-TLX) was used as the subjective workload rating technique (Hart and Staveland, 1987). This rating technique consists of six original dimensions of mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Only three dimensions were used in this study. Mental demand, temporal demand, and frustration level were the indicators used. Physical demand, performance, and effort indicators were not used. The IVIS secondary tasks were to be performed verbally and not manually, thus requiring no physical demand. The experiment was focused on the use of the IVIS and not in the performance of the particular IVIS tasks, so the performance scale was not used (reducing the chance of confusion between the two). Again, since the tasks were a way to observe and measure driving performance, the effort scale was not used to avoid confusion between the effort to perform a task and the effort of using the IVIS. Details of the NASA-TLX measurements are presented in Appendix E.

3.4.3 Controlled Variables

Gender. Based on previous experiments, gender was not expected to result in significant differences; therefore it was not considered a factor in this study. However, it was controlled such that an equal number of males and females (eight each) participated in the experiment.

Daylight and Weather. The experimental sessions were held during daytime hours and under weather that would not affect road visibility and roadway traction. There were no sessions during the night. If the weather was not appropriate (e.g., heavy rain, snow, ice) the participants were re-scheduled for another day.

3.5 Experimental Procedures

3.5.1 Participant Screening and Familiarization

Participants were screened over the telephone regarding age, driving experience, and general health (Appendix A). Qualified participants were scheduled to meet the experimenter at VTTI. At VTTI an overview of the experiment was given to the participants, and they were asked to read and sign an approved Virginia Tech Institutional Review Board Informed Consent Form (Appendix B) and a W-9 tax form. The participants were asked to complete a health screening questionnaire (Appendix C). A standard Snellen eye test was performed to ensure a visual acuity of 20/40 or better. A color blindness test was also performed. The tests results were recorded in the Vision and Hearing Tests form (Appendix F). After these steps were completed and if the participant was qualified, the familiarization session proceeded. The detailed experimenter protocol used is presented in Appendix G.

At a VTTI lab facility, the experimenter showed the participant the functioning of the IVIS interface. They were instructed how to perform the tasks associated with the experiment, and practice trials were performed (Appendix H). The practice trials consisted of practice scenarios for each of the IVIS secondary task applications only. The participant was instructed to practice using the software until all the scenarios were done. The familiarization session lasted approximately one hour. Once this was accomplished, the participant was guided to the test vehicle.

The experimenter explained to the participants how mental workload would be evaluated. Instructions for the mental workload subjective assessment and examples were discussed with the participants (Appendix E).

3.5.2 Vehicle and System Familiarization

While the vehicle was stationary, the experimenter reviewed general information concerning the adjustment and functioning of the features of the vehicle, such as seats and mirrors. The participants were asked to adjust these features to their comfort. The experimenter proceeded to perform an informal hearing test to test the participant's understanding of the experimenter and the synthesized voice used by the IVIS. The test required the participants to repeat phrases said by the experimenter and by the IVIS. The results of the test were recorded in the Vision and Hearing Tests form (Appendix F). All participants repeated the phrases correctly.

Copies of the IVIS and the mental workload subjective assessment instructions were provided in the vehicle for review. The distracting light functioning and deactivation were explained to the participants. The participants were instructed to inform the experimenter if they needed a break at any time. Once the participants were familiarized with the vehicle, system functioning, and instructions, the experimental run and data collection began.

3.5.3 On-Road Procedure

The participants were instructed to drive in the right lane of the road and to maintain a constant speed of 35 miles per hour (mph). If the participants were not comfortable performing a certain task or felt that performing the task could result in an unsafe situation, they were allowed to skip the task. None of the participants chose to skip a task.

Baseline Run. The participants drove through the experimental route without performing any IVIS secondary tasks to become familiar with the vehicle and the road. The participants were instructed to reach and maintain a speed of 35 mph and to perform the distracting light task while driving this run. Data were collected during this run to be compared to the experimental run data.

Experimental Run. With the vehicle stationary, the experimenter proceeded to give the task instructions to the participants. The task instruction was given twice and the participants were instructed to repeat it back to the experimenter to assure that the task was understood. The participants were allowed to review the IVIS instructions at that time. The experimenter would instruct the participant to enter the road and indicate when to start the tasks. The experimenter asked the participants a probe question immediately following the completion of each task. The participants were instructed to exit the road and stop the vehicle. The mental workload subjective assessment was administered at that time. The process was repeated until all tasks were performed.

Tasks. The primary task of the participants was to safely drive the vehicle, following standard road laws such as driving in the right lane and use of the restraining seat belt. In addition, it was requested that the drivers reach and maintain a velocity of 35 mph. The participants were requested to perform secondary tasks using an IVIS. This system was presented to the participants either visually, auditorily, or both (i.e., multi-modal). The IVIS consisted of three applications (calendar, e-mail, and voice-mail). Three types of tasks could be performed with each of these. Table 3 presents the types of tasks per application and the level of difficulty of each.

Table 3. **IVIS Experimental Tasks.**

Application	***Tasks***	***Difficulty Level***	***Hierarchical Steps***
Calendar	Go to a particular date and view/listen to the schedule for that day.	Easy	5
	Add an event to a particular date.	Difficult	7
	Delete an event note for a particular date.	Difficult	6
E-mail	Check a new or unread message.	Easy	4
	Check a message and send a reply to it.	Difficult	6
	Delete a particular message.	Easy	5
Voice-Mail	Listen to a specific Voice-mail message.	Easy	4
	Reply to a specific Voice-mail message.	Difficult	6
	Delete a Voice-mail message.	Easy	5

Twenty-four tasks were to be completed during the experimental run. A Balanced Latin Square presentation order was used to reduce learning effects (see Table 4).These 24 tasks covered all experimental conditions. The tasks were divided into ten calendar tasks, ten e-mail tasks, and four voice-mail tasks. An information capture question was asked after each task. The answers were categorized as either correct or incorrect. The tasks and the respective questions are presented in Appendix I.

***Table 4.* Task Presentation Order.**

	PARTICIPANT																		
Order	**Plt_1**	**Plt_2**	**Plt_3**	**P_1**	**P_2**	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**	**P_8**	**P_9**	**P_{10}**	**P_{11}**	**P_{12}**	**P_{13}**	**P_{14}**	**P_{15}**	**P_{16}**
1	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}
2	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}
3	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}
4	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}
5	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
6	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}
7	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}
8	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}
9	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}
10	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}
11	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}
12	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}
13	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}
14	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}
15	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}	T_{12}
16	T_{9}	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}
17	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}	T_{11}
18	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}
19	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}	T_{10}
20	T_{11}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}
21	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}	T_{9}
22	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}
23	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}	T_{8}
24	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}	T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{1}	T_{2}	T_{3}	T_{4}	T_{5}	T_{6}	T_{7}

In addition to the IVIS tasks, the participants were required to react to a distracting light located on the top of the hood of the vehicle. This light was activated at random intervals and the participants were instructed to turn it off by pressing a switch located on the floor, to the left of the pedals. This was an external reaction time measure in effort to provide a more realistic environment where drivers had to be aware of their external surroundings.

3.5.4 Data Collection

Data were collected while driving through the specified straight segments of the road. There was data collection during baseline conditions when no IVIS secondary tasks were performed, and during the experimental run while performing both primary and IVIS secondary tasks. The experimenter controlled the IVIS system from the rear seat so the Wizard of Oz ruse would not be noticeable. The data were collected from the input of the sensors installed in the vehicle, the video recording, the mental workload assessment questionnaire, and the information capture answers recorded by the experimenter. The collected data from the vehicle and the video were synchronized with the time stamp appearing on both the resulting data and the video.

3.5.5 Debriefing

After all required tasks were completed, the participants were instructed to return to VTTI facilities. A brief questionnaire was administered to determine their previous familiarization with similar systems (Appendix J). The participants were debriefed and paid for their time.

3.6 Data Reduction

The data for this study were obtained from video recordings during the development of the experiment, from instrumentation installed on the vehicle (e.g., sensors), and from responses to the questionnaire as well as subjective workload ratings. The generated data were saved into a zip disk and transferred to a server. The video tapes were identified by participant number. Both the vehicle data and the videos were used for data reduction. Terminology used for the reduction of data is presented in Appendix K.

The videos were digitized to make them accessible through the VTTI computer server as well. The lengths of the tasks per participant were identified using the videos. The vehicle data were modified to include only the data pertaining to the tasks. A Data Matrix was created to store the data.

An Eye Glance Reduction software program developed at VTTI was used to identify the eye glances to determine the eyes-off-road percentages. The software allowed reduction of data from the sections of interest of the video (i.e., task performance sections). The video was watched in slow motion and every glance was identified by pressing a pre-determined letter on the computer keyboard depending on the glance location. The glances were classified in seven categories: forward, display, speedometer, rear view mirror, other vehicle interior, other vehicle exterior, and unknown. The number and length of the glances was determined for each type of glance. The forward glances and the glances to the display were the two types of glances considered in the data analysis. This video data reduction process was performed by two data reductionists.

A reliability test was performed for the eyeglance reduction process. The test consisted of reducing a task per participant that had been previously reduced by the other reductionist. The results were compared, and a percentage was calculated resulting in an agreement percentage per participant. The reliability test resulted in a total average agreement of 82.3% with a standard deviation of 5.35%.

The lane deviations were determined by watching the video. The number of lane deviations was defined as the number of times the lane boundary lines were crossed. The length of these deviations was determined from the same video and was defined as the time from when the vehicle started moving towards the line to the time it went back to a steady position in the lane.

All data obtained from the video analysis were recorded in the data matrix mentioned before. The mental workload subjective assessment results were added to the matrix as well. This data matrix containing all the pertinent data was used as the source for the analyses of the data.

3.7 Data Analysis

The reduced data were analyzed using SAS® statistical package. Analyses of Variance (ANOVA) were conducted with the incomplete three factor within-subject design (5x3x2) reduced data to evaluate if the IVIS presentation combinations affected participant driving performance and mental workload perception. ANOVAs were performed by running a General Linear Model (GLM) procedure, which is designed to compute analyses of variance for unbalanced data. When a significant difference was found in the main effects (i.e., display type, application, difficulty level), a Student-Newman-Keuls (SNK) test was conducted to determine which effect levels differed from one another.

Information capture data were analyzed with Chi-Square statistical analysis. The criterion for overall statistical significance was set at $\alpha = 0.05$. Table 5 shows the ANOVA summary for the full model of the experimental design.

Post-test questionnaire data were summarized to determine the occurrence of participants' ratings. The number of participants that rated a question in the same way (i.e., same anchor descriptor) was graphed for each of the questions to see the tendencies across participants.

Table 5. **ANOVA Summary.**

Source	*Degrees of Freedom*
Between	
Participants	15
Within	
Display	4
Display x Participants	60
Application	2
Application x Participants	30
Difficulty Level	1
Difficulty Level x Participants	15
Display x Application	5
Display x Application x Participants	75
Display x Difficulty Level	4
Display x Difficulty Level x Participants	60
Application x Difficulty Level	2
Application x Difficulty Level x Participants	30
Display x Application x Difficulty Level	5
Display x Application x Diff Level x Participants	75
Total	383

4. RESULTS

The results of this study comprise several types of data analyses. The chapter is divided into two major sections: (1) IVIS Secondary Tasks Comparison and (2) Baseline vs. IVIS Secondary Tasks Comparison. The dependent measures analyzed are addressed in each section as pertinent. The last section presents the post-test questionnaire results. The measures collected and used for the analyses are presented in Table 6.

Table 6. **Dependent Measures.**

No.	*Dependent Measures*	*Variable Name*
	Eye Glances	
1	Number of eye glances to the display	DISPLAYGLANCES
2	Percent of task time spent glancing at display (%)	EORDISPLAY
	Lateral Driving Performance	
3	Number of lane deviations	TOUCHD
4	Mean length of the deviations (sec)	TOUCHDL
5	Lane deviation percentage of task time (%)	TOUCHTLPC
	Longitudinal Driving Performance	
6	Speed standard deviation (mph)	SPEEDSTDDEV
	External Reaction Time	
7	Time to react to distracting light	LIGHTREACTTIME
	Mental Workload	
8	Mental demand	MENTALD
9	Temporal demand	TIMED
10	Frustration level	FRUSTRATION
	Information Capture	
11	Number of correct/incorrect answers	INFOCAPTURE

4.1 IVIS Secondary Tasks Comparison

All dependent measures data (except Information Capture) were analyzed with ANOVAs. Information capture data were analyzed with Chi-Square analyses. The model for this portion of the study is a 5x3x2 incomplete within-subject factor design. The ten ANOVA summary tables for the full model are presented in Appendix L. The ANOVA results are presented in tables for each of the variables. Only the significant p-values are presented. Non-significant values are identified as “NS.” For the significant results, Student-Newman-Keuls (SNK) post-hoc analyses were performed and the results are presented graphically. The SNK tabulated results are presented in Appendix M. The effect levels' means with the same letter in their grouping are not significantly different from one another. ANOVA results showed significant interactions for some of the dependent variables. The two-factor interactions are also graphed with means and standard error data.

4.1.1 Eye Glances

The two measured dependent variables for eye glance behavior were the number of glances to the display and the percent of time the eyes were off the road while looking at the display. Table 7 shows how these measures were affected by the independent variables. Based on these results, the type of application and the difficulty level do not have a significant effect on eye glance measures.

***Table 7*. Eye Glance Measures.**

	Source (p-value)		
Dependent Variable	**Display**	**Application**	**Difficulty Level**
DISPLAYGLANCES	<0.0001	NS	NS
EORDISPLAY	<0.0001	NS	NS

NS = not significant

A significant main effect of display type was found for the number of eye glances to the display during IVIS secondary task performance ($F[4,60] = 58.01$, $p<0.0001$). Student-Newman-Keuls (SNK) post-hoc comparisons revealed that the largest number of glances occurred when either the visual display or the multi-modal fast speech display was used, yielding a mean number of glances of 13.23 and 12.83 glances respectively. Both of these displays required significantly more glances than any of the other displays, but they did not differ from one another. The multi-modal normal speech rate display required significantly more glances than either of the auditory displays, with a mean of 9.80 glances. The auditory displays yielded a mean of 1.01 glances for the auditory normal speech rate display and 0.99 for the auditory fast speech rate display. The auditory displays required significant fewer glances than the other display types, but did not differ significantly from one another. A graphic presentation of these results can be seen in Figure 14.

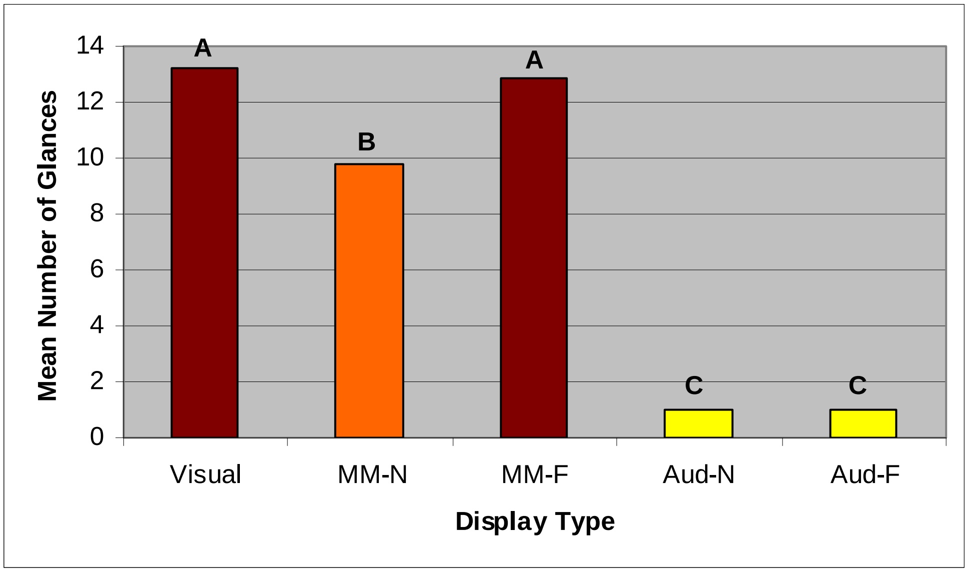


Figure 14. **Number of Display Glances per Display Type Post-Hoc Results. (Bars with same letters imply no significant difference between display types.)**

The ANOVA for the number of display glances also showed a significant two-way interaction for application and level of difficulty. Difficult tasks required a larger number of glances for the e-mail application than did easy tasks, while for the calendar application, the easy tasks required a larger number of glances than the difficult tasks. The voice mail application did not require the use of the visual display so it is not considered meaningful for this analysis. This interaction is presented in Figure 15.

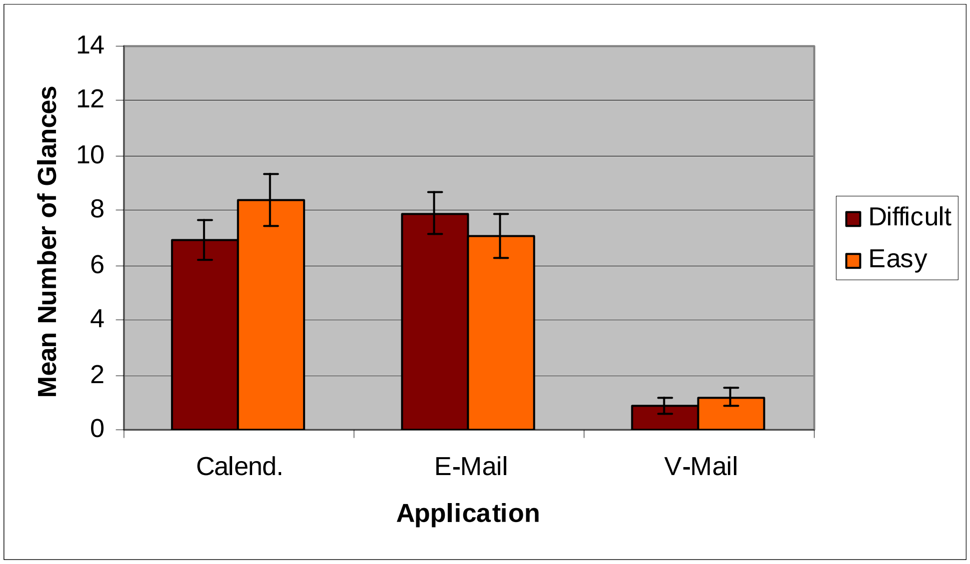


Figure 15. **Application x Difficulty Level Interaction for Display Glances.**

The percent of time spent glancing at the display while performing IVIS secondary tasks resulted in a display type significant main effect ($F [4,60] = 129.68$, $p<0.0001$). The SNK post-hoc results for the percent of time spent glancing at the display show that the drivers glanced at the display for 51.53% of the task time when using the visual display. This was significantly greater than for any of the other display types. The multi-modal displays did not differ significantly from one another (27.94% for the multi-modal fast display and 26.94% for the multi-modal normal speech). The use of the auditory fast speech display and the auditory normal speech rate display resulted in drivers attending the road for the greatest percentage of time, with 1.68% and 1.60% of the time spent glancing at the display respectively. Figure 16 shows a graphic presentation of these results.

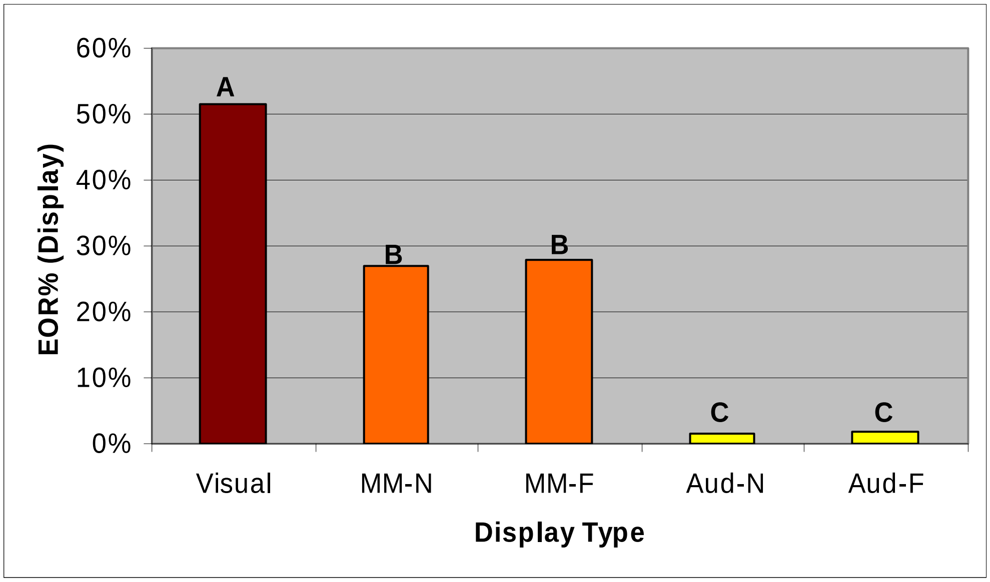


Figure 16. **Eyes-Off-Road Percent per Display Type Post-Hoc Results. (Bars with same letters imply no significant difference between display types.)**

The ANOVA for the percent of time spent glancing at the display also showed two significant two-way interactions. A display type by level of difficulty interaction showed that for the visual, multi-modal normal, and auditory fast displays, participants spent more time glancing at the display when easy tasks where performed than for the difficult tasks. For the multi-modal fast and auditory normal participants spent more time glancing at the display when difficult tasks where performed as compared to the easy tasks. An application and level of difficulty interaction showed that difficult tasks resulted in more time glancing at the display for the calendar application than did easy tasks, while for the e-mail application the easy tasks resulted in more time glancing at the display than the difficult tasks. These interactions are presented in Figure 17 and Figure 18.

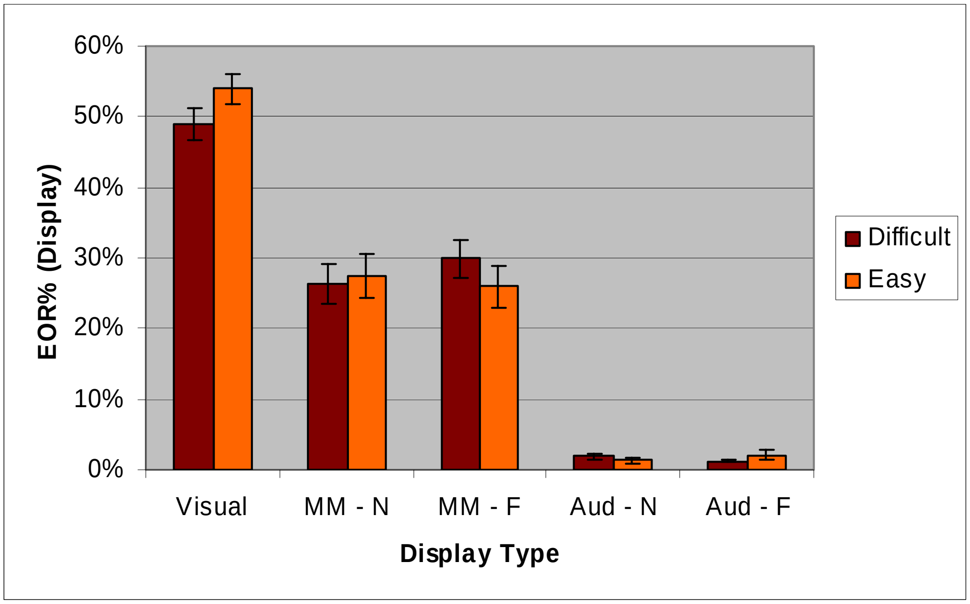


Figure 17. **Display Type x Difficulty Level Interaction for Eyes-Off-Road Percent.**

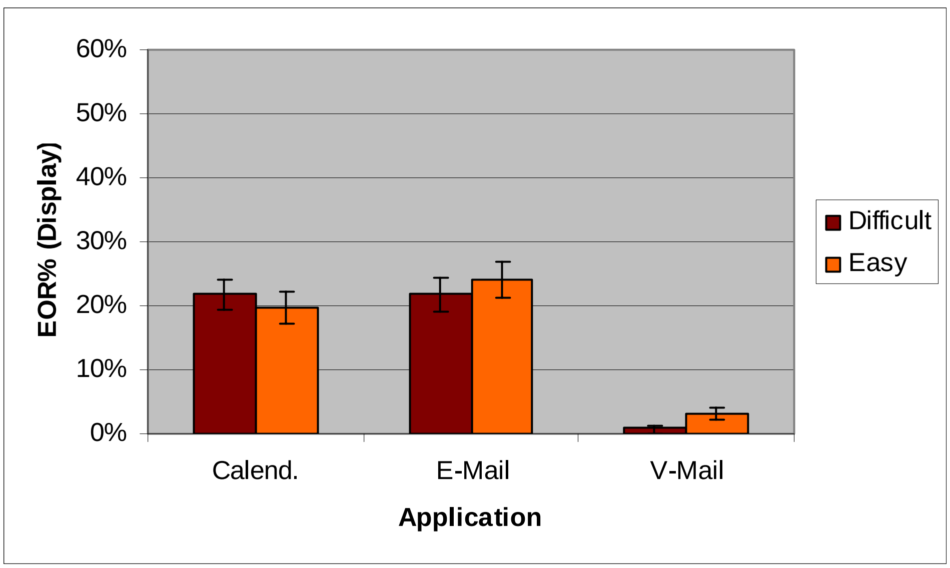


Figure 18. **Application x Difficulty Level Interaction for Eyes-Off-Road Percent.**

4.1.2 Lateral Driving Performance

Lateral driving performance was determined with three measurements: the number of lane deviations, the length of these lane deviations, and the percentage of total task time that the deviations occupied. The number of lane deviations during IVIS secondary tasks performance was significantly affected by the type of display used

(F [4,60] = 5.84, p = 0.0005). The length of the deviations and the percentage of total task time that the deviations occupied were similarly affected (F [4,60] = 4.21, p = 0.0045; and F [4,60] = 4.45, p = 0.0033 respectively). The application used or the level of difficulty presented did not significantly affect lateral driving performance. Participants were required to drive within the right lane limits at all times; lateral driving performance was measured as excursions outside the right lane. Table 8 presents the resulting significant p-values.

***Table 8*. Lateral Driving Performance Measures.**

	Source (p-value)		
Dependent Variable	**Display**	**Application**	**Difficulty Level**
TOUCHD	0.0005	NS	NS
TOUCHDL	0.0045	NS	NS
TOUCHTLPC	0.0033	NS	NS

NS = not significant

The SNK post-hoc analysis for the number of lane deviations shows that the visual and multi-modal fast speech rate display had a significantly greater mean number of lane deviations (0.27 and 0.20 mean lane deviations respectively) than the auditory fast speech rate display (*M* = 0.03) and the auditory normal speech rate display (*M* = 0.00). The multi-modal normal speech rate display (*M* = 0.13) did not differ significantly from the multi-modal fast speech display and the auditory fast speech display. For each of the displays, the number of lane deviations was small and no deviations were observed when the auditory normal speech rate display was used. Figure 19 shows these results.

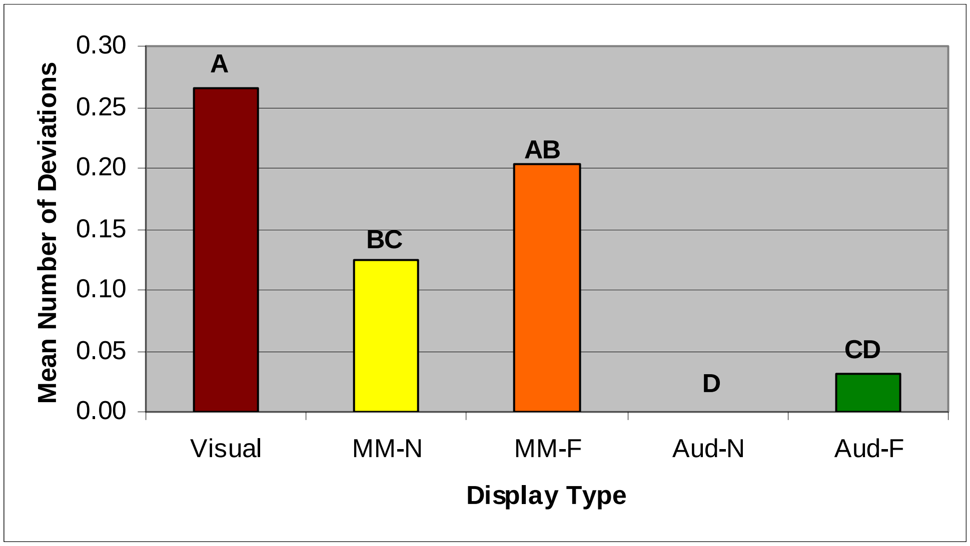


***Figure 19*. Number of Lane Deviations per Display Type Post-Hoc Results. (Bars with same letters imply no significant difference between display types.)**

The ANOVA for the mean number of lane deviations also showed a significant two-way interaction for application and level of difficulty. Difficult tasks resulted in a larger number of deviations for the calendar application than did easy tasks, while for the e-mail application, the easy tasks resulted in a larger number of deviations than the difficult tasks. No lane deviations occurred during the use of the voice-mail application. This interaction is presented in Figure 20.

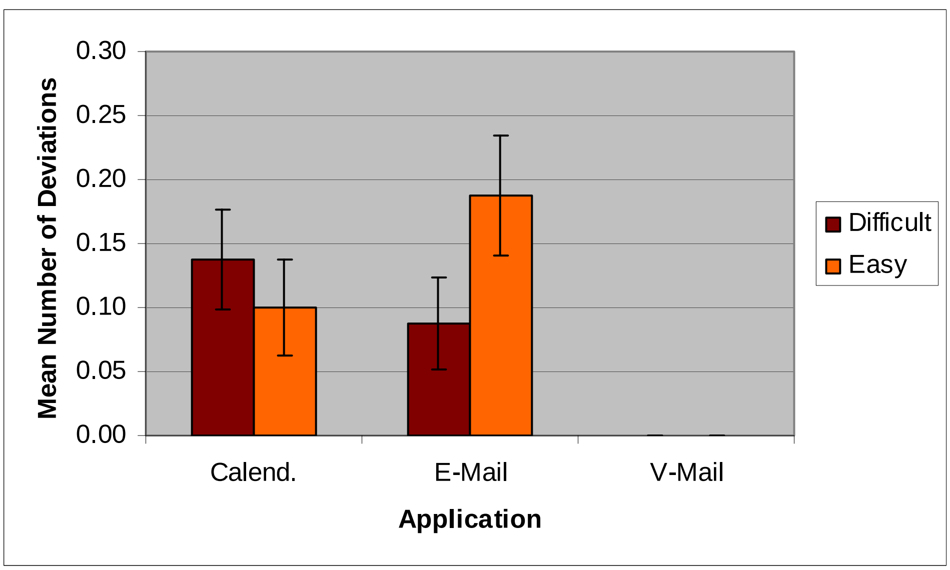


***Figure 20.* Application x Difficulty Level Interaction for Number of Deviations.**

The SNK post-hoc analysis for the average length of the lane deviations shows that the visual display ($M = 2.51$ sec) had significantly longer lane deviations than the multi-modal normal speech rate display ($M = 1.20$ sec), auditory fast ($M = 0.35$ sec), and auditory normal displays ($M = 0.00$ sec). The multi-modal fast display ($M = 1.74$ sec) had significantly longer lane deviations than the auditory fast and auditory normal conditions. The length of the deviations was generally short for each of the displays. Figure 21 shows these results.

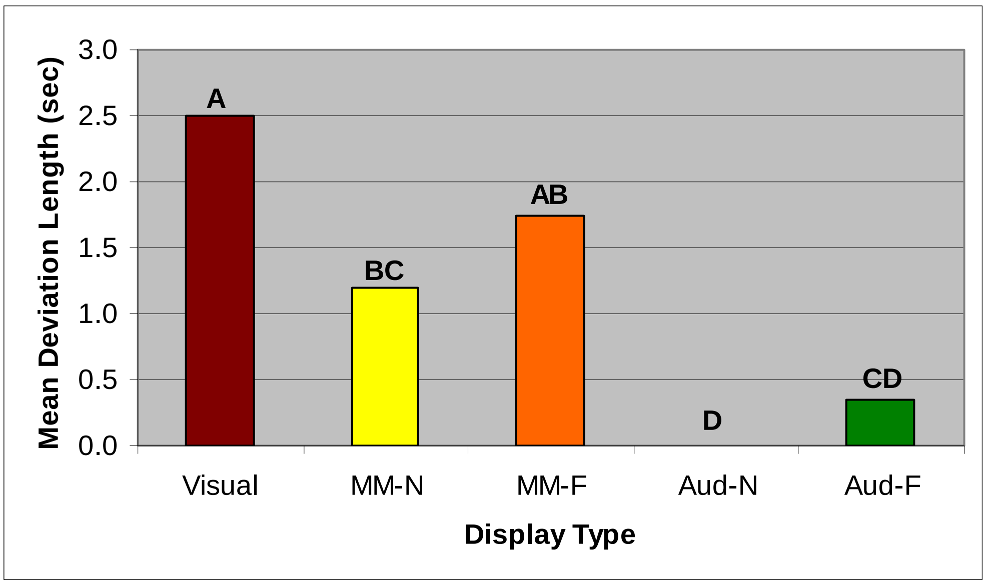


***Figure 21*. Lane Deviations Length per Display Type Post-Hoc Results.**
(Bars with same letters imply no significant difference between display types.)

The ANOVA for the mean length of lane deviations also showed a significant two-way interaction for application and level of difficulty. Difficult tasks resulted in larger deviation lengths for the calendar application than did easy tasks, while for the e-mail application, the easy tasks resulted in a larger number of deviations than the difficult tasks. No lane deviations occurred during the use of the voice-mail application. This interaction is presented in Figure 22.

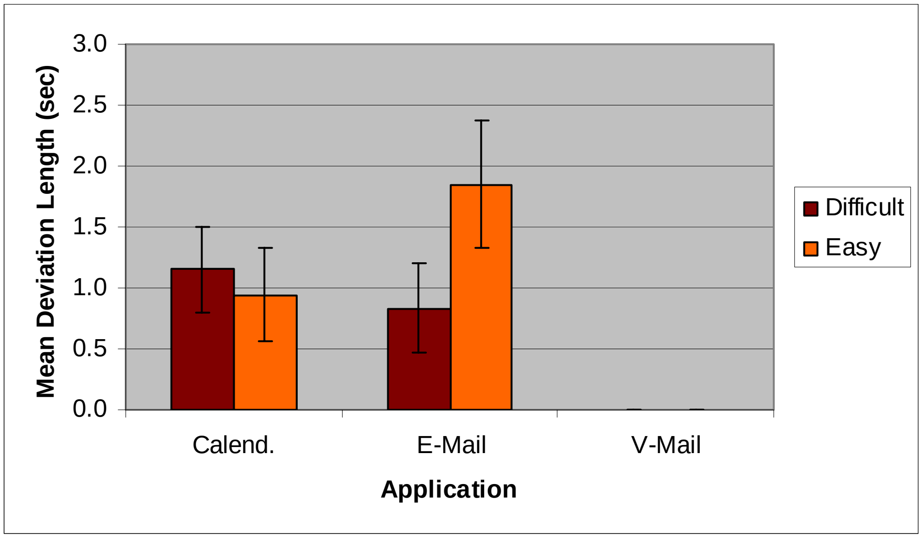


***Figure 22*. Application x Difficulty Level Interaction for Mean Deviation Length.**

The percent of total task time spent outside the driving lane differed significantly depending on the type of display used. The SNK post-hoc analysis showed that the visual display resulted in significantly greater lane deviation percentage (*M* = 7.34%) than any of the other displays. The multi-modal fast, multi-modal normal, auditory fast, and auditory normal displays did not differ significantly from one another with mean percentages of 2.94%, 2.76%, 0.61%, and 0.00% respectively. A graphic presentation can be seen in Figure 23.

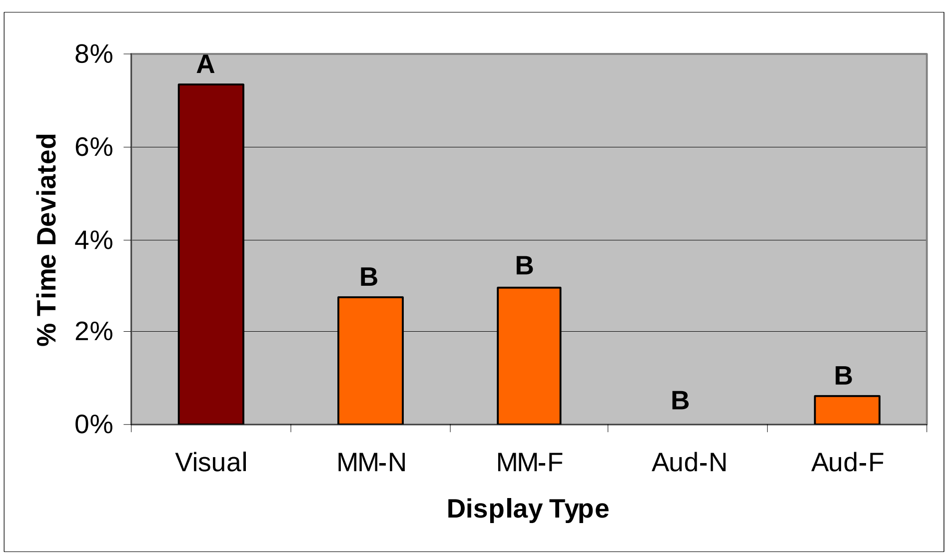


***Figure 23*. Lane Deviation Percentage per Display Type Post-Hoc Results. (Bars with same letters imply no significant difference between display types.)**

The ANOVA for the percent of total task time spent outside the driving lane also showed a significant two-way interaction for application and level of difficulty. Difficult tasks resulted in a larger percent of time deviated for the calendar application than did easy tasks, while for the e-mail application, the easy tasks resulted in a larger percent of time deviated than the difficult tasks. No lane deviations occurred during the use of the voice-mail application. This interaction is presented in Figure 24.

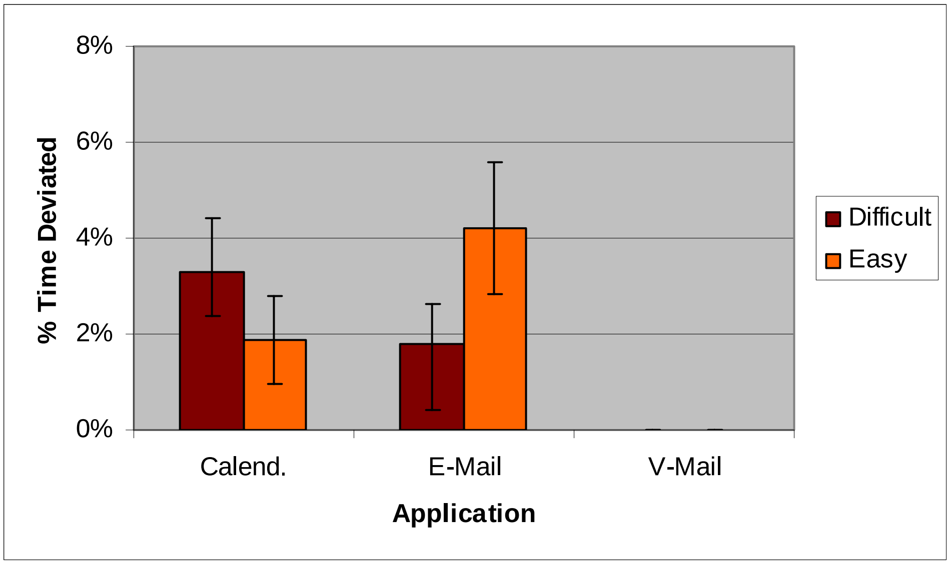


Figure 24. **Application x Difficulty Level Interaction for %Time Deviated.**

4.1.3 Longitudinal Driving Performance

Longitudinal driving performance was evaluated by measuring speed maintenance. The calculated dependent variable was the speed standard deviation. An ANOVA was performed, which showed no significance for any of the independent variables (i.e., display type, application, and difficulty level). Speed maintenance was consistent throughout the experiment, regardless of display type, application, or difficulty level.

4.1.4 External Reaction Time

Drivers' awareness of their surroundings was determined by measuring reaction time to a distracting light in seconds. This measurement was shown to be dependent on the type of display (F [4,60] = 4.80, p = 0.0020), while application and difficulty level were not significant for this dependent measure (see Table 9).

***Table 9*. External Reaction Time Measure.**

	Source (p-value)		
Dependent Variable	**Display**	**Application**	**Difficulty Level**
LIGHTREACTTIME	0.0020	NS	NS

NS = not significant

The SNK post-hoc analysis shows that it took significantly longer for the drivers to react to the distracting light when the visual display was used (*M* = 4.13 sec) than for any of the other displays. The multi-modal fast (*M* = 2.75 sec), multi-modal normal (*M* = 2.33 sec), auditory fast (*M* = 2.15 sec), and auditory normal (*M* = 1.93 sec) display reaction times were not significantly different from one another. Figure 25 show these results.

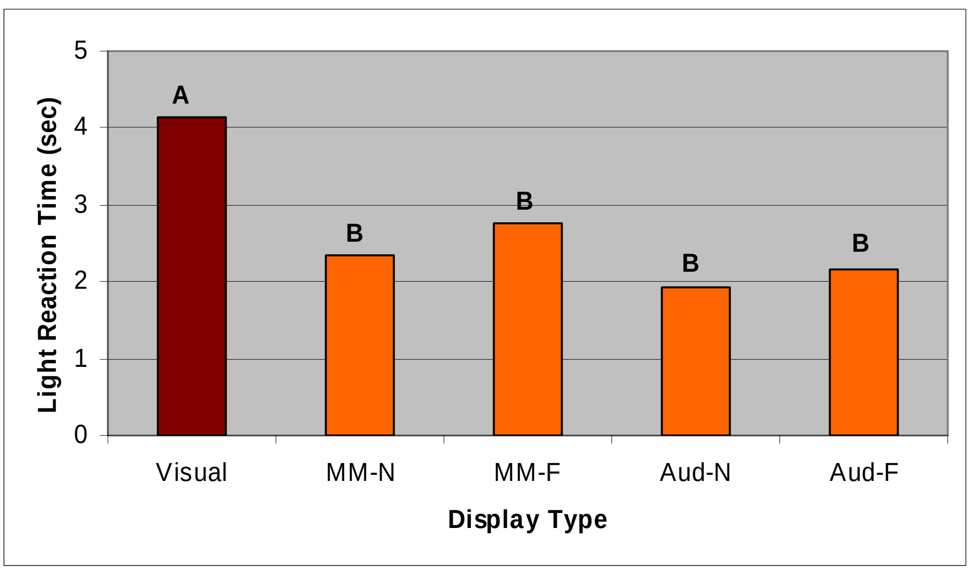


***Figure 25*. Distracting Light Reaction Time per Display Type Post-Hoc Results. (Bars with same letters imply no significant difference between display types.)**

The ANOVA for the distracting light reaction time also showed a significant two-way interaction for application and level of difficulty. Difficult tasks resulted in a larger reaction time for the calendar and voice-mail applications than did easy tasks, while for the e-mail application, the easy tasks there was no apparent difference in reaction time for the level of difficulty. This interaction is presented in Figure 26.

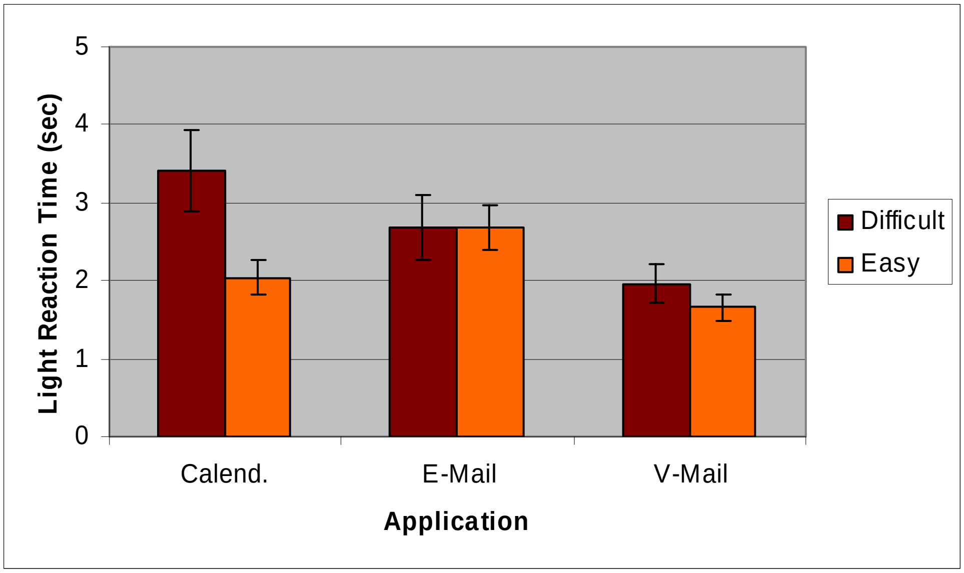


Figure 26. **Application x Difficulty Level Interaction for Light Reaction Time.**

4.1.5 Mental Workload

Mental workload was measured using three subjective ratings: mental demand, temporal demand, and frustration level. Rating scale values from 1 to 100 were used. The three subjective ratings were individually analyzed. Mental demand ($F [4,60] = 8.24$, $p<0.0001$), temporal demand ($F [4,60] = 6.00$, $p = 0.0004$), and frustration level ($F [4,60] = 5.19$, $p = 0.0012$) were affected by the type of display used. The level of difficulty of the tasks affected the perceived mental demand as well ($F [4,60] = 5.75$, $p = 0.0299$). None of the three measures was affected by the type of application used. Table 10 presents the resulting significant p-values.

Table 10. **Mental Workload Measures**

	Source (p-value)		
Dependent Variable	**Display**	**Application**	**Difficulty Level**
MENTALD	<0.0001	NS	0.0299
TIMED	0.0004	NS	NS
FRUSTRATION	0.0012	NS	NS

NS = not significant

The SNK post-hoc analysis for the mental demand comparison of displays shows that the visual display imposed a significantly higher mental demand (*M* = 47.69) than any of the other displays. Reported mental demand caused by the multi-modal fast (*M* = 38.48), auditory fast (*M* = 35.38), multi-modal normal (*M* = 32.97), and auditory normal (*M* = 32.55) displays were not significantly different from one another. Figure 27 shows these results.

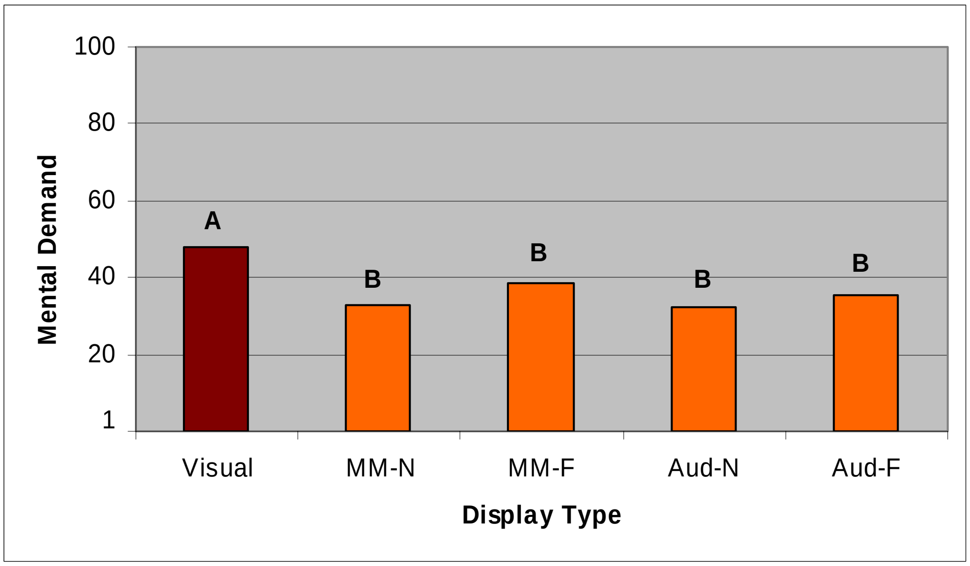


***Figure 27*. Mental Demand per Display Type Post-Hoc Results.**
(Bars with same letters imply no significant difference between display types.)

The mental demand ratings per difficulty level show that the difficult tasks (*M* = 39.05, *SD* = 21.53) imposed a significantly higher mental demand as compared to easy tasks (*M* = 34.63, *SD* = 21.48). Figure 28 shows these results.

***Figure 28*. Mental Demand per Difficulty Level Post-Hoc Results.**

The ANOVA for the mental demand also showed a significant two-way interaction. A display type by level of difficulty interaction showed that difficult tasks resulted in higher mental demand ratings for the visual, multi-modal normal, auditory normal, and auditory fast displays. Easy tasks resulted in higher mental demand ratings for the multi-modal fast display. This interaction is presented in Figure 29.

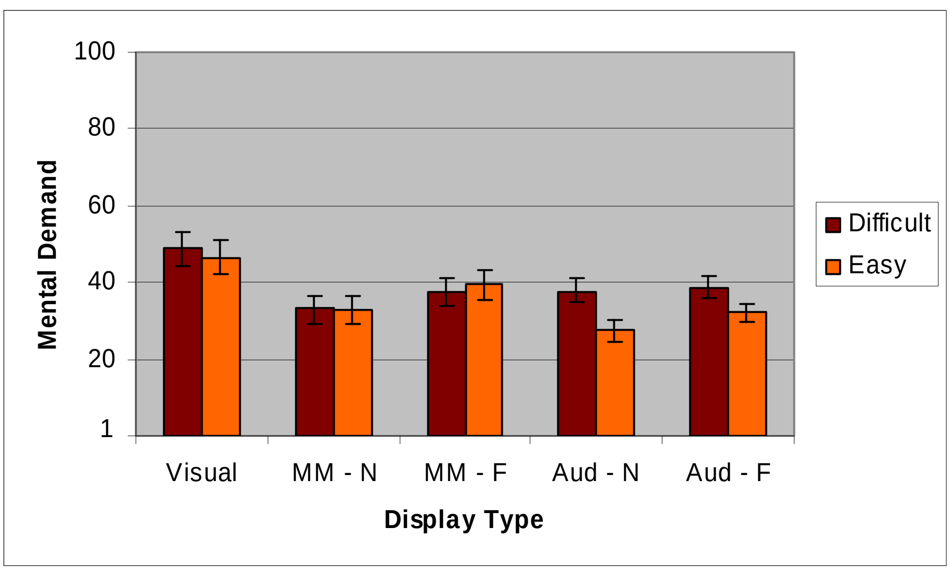


***Figure 29.* Display Type x Difficulty Level Interaction for Mental Demand.**

Temporal demand was shown to be affected by the type of display used. The SNK post-hoc analysis shows that the visual display resulted in significant higher temporal demand (*M* = 40.91) than the use of the auditory fast display (*M* = 31.01), multi-modal normal display (*M* = 28.38), and auditory normal display (*M* = 28.15). The auditory displays and the multi-modal normal speech rate display did not differ significantly from one another. The multi-modal fast speech rate display (*M* = 36.08) resulted in significantly higher temporal demand than the multi-modal normal speech rate display and the auditory normal speech rate display. Figure 30 shows these results.

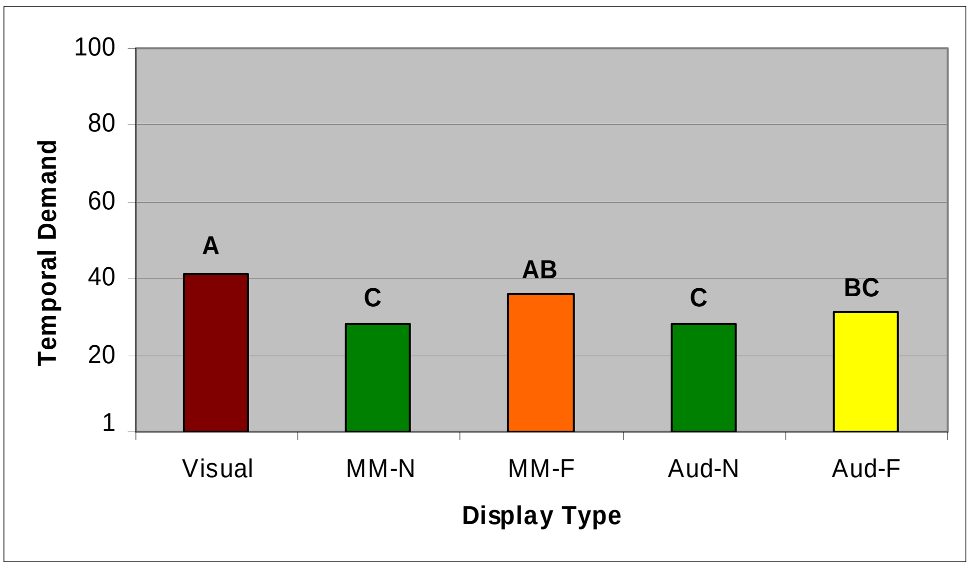


***Figure 30*. Temporal Demand per Display Type Post-Hoc Results.**
(Bars with same letters imply no significant difference between display types.)

The ANOVA for the temporal demand also showed a significant two-way interaction. A display type by level of difficulty interaction showed that difficult tasks resulted in higher temporal demand ratings for the visual, auditory normal, and auditory fast displays, while easy tasks resulted in higher temporal demand ratings for the multi-modal displays. This interaction is presented in Figure 31.

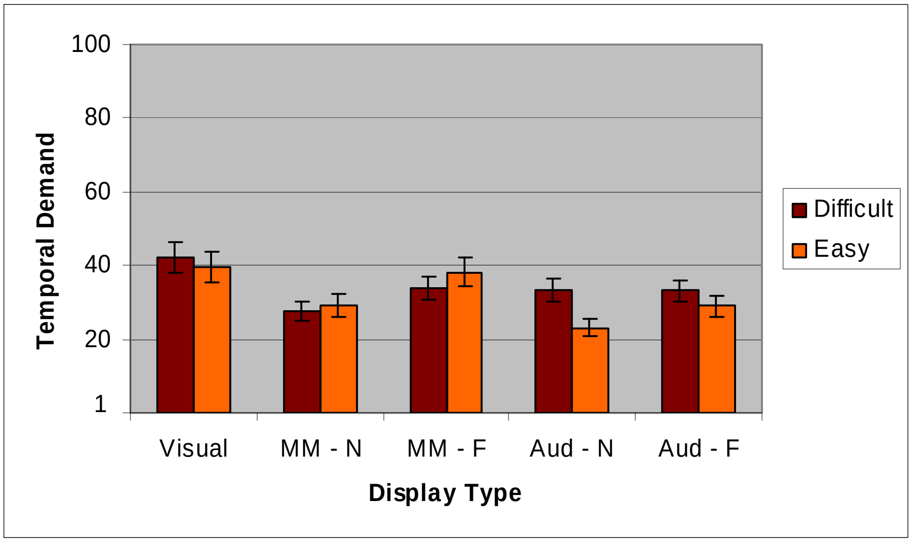


***Figure 31.* Display Type x Difficulty Level Interaction for Temporal Demand.**

The SNK post-hoc analysis for the frustration level experienced with the various display types showed a significant difference between the visual display and the other display types. Participants reported significantly higher frustration levels for the visual display (*M* = 40.61) than for the multi-modal fast (*M* = 28.98), auditory fast (*M* = 26.71), auditory normal (*M* = 24.39), and multi-modal normal (*M* = 23.77) displays. There was no significant difference in the perceived frustration level between these types of displays. Figure 32 shows these results.

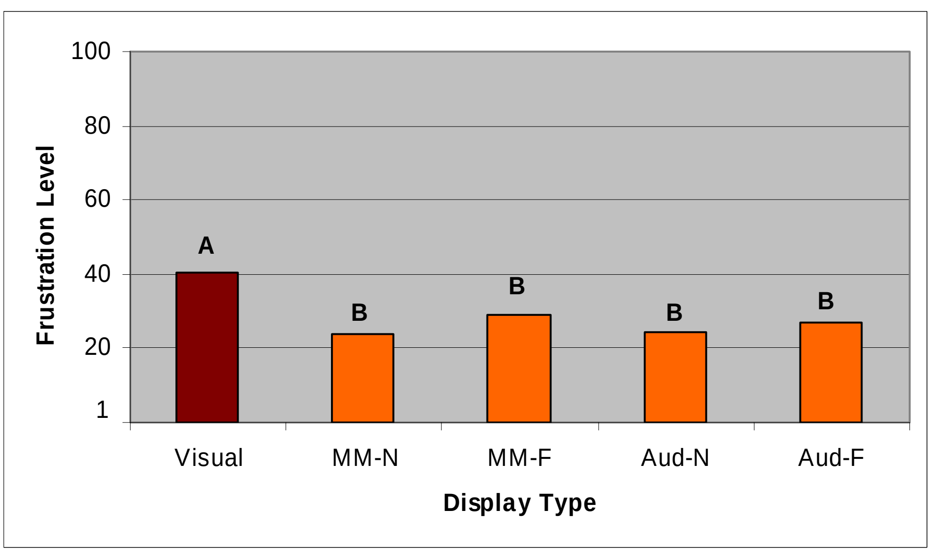


***Figure 32.* Frustration Level per Display Type Post-Hoc Results.**
(Bars with same letters imply no significant difference between display types.)

The ANOVA for the frustration level also showed a significant two-way interaction. A display type by level of difficulty interaction showed that difficult tasks resulted in higher frustration ratings for the auditory normal and auditory fast displays. Easy tasks resulted in higher frustration ratings for the visual, multi-modal normal, and multi-modal fast displays. This interaction is presented in Figure 33.

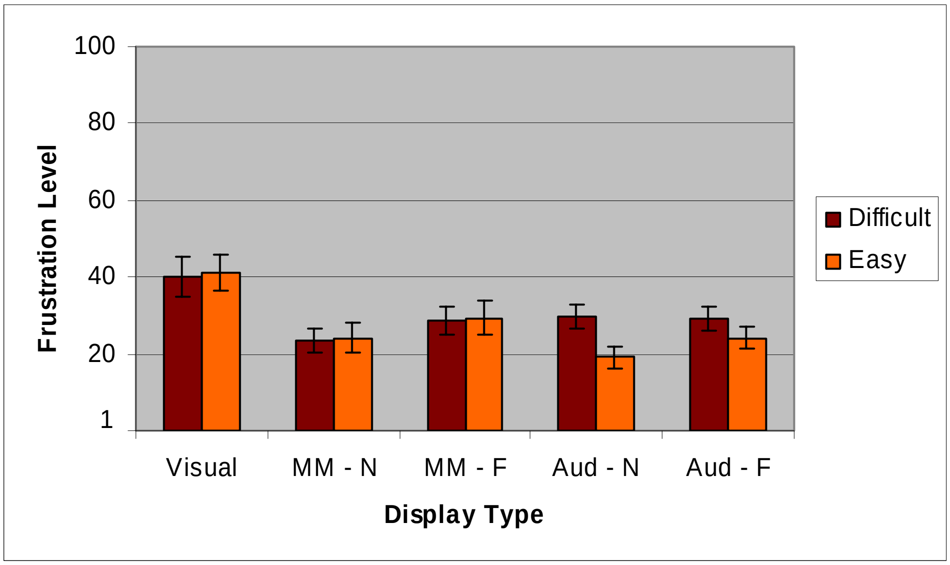


Figure 33. **Display Type x Difficulty Level Interaction for Frustration Level.**

4.1.6 Information Capture

Information capture performance was determined by counting how many correct and incorrect answers were given by the participants to the questions asked by the experimenter after each IVIS task. The actual totals were used to calculate the expected totals. Both actual and expected values were used to conduct Chi-square (X^2) tests of association. The X^2 was used to determine if the information capture was affected by the display type ($X^2[0.0002,4] = 1$), application ($X^2[0.0103,2] = 0.9949$), or difficulty level ($X^2[9.32E\text{-}11,1] = 0.9999$) applied to the tasks. There was no significance for any of the independent variables. Results are presented in Tables 11-13.

***Table 11*. Information Capture and Display Type X^2 Results.**

	ACTUAL			EXPECTED			
Display	*Correct*	*Incorrect*	**Total**	*Correct*	*Incorrect*	*X^2 Value*	*p-value*
Aud-F	50	46	96	61.25	34.75	**0.0002**	**1**
Aud-N	78	18	96	61.25	34.75		
MM-F	34	30	64	40.8333	23.1667		
MM-N	40	24	64	40.8333	23.1667		
Visual	43	21	64	40.8333	23.1667		
Total	245	139	384				

***Table 12*. Information Capture and Application X^2 Results.**

	ACTUAL			EXPECTED			
Application	*Correct*	*Incorrect*	**Total**	*Correct*	*Incorrect*	*X^2 Value*	*p-value*
Calendar	115	45	160	102.0833	57.91667	**0.0103**	**0.9949**
E-Mail	89	71	160	102.0833	57.91667		
Voice-Mail	41	23	64	40.83333	23.16667		
Total	245	139	384				

***Table 13*. Information Capture and Difficulty Level X^2 Results.**

	ACTUAL			EXPECTED			
Diff. Level	*Correct*	*Incorrect*	**Total**	*Correct*	*Incorrect*	*X^2 Value*	*p-value*
Difficult	92	100	192	122.5	69.5	**9.32 E-11**	**0.9999**
Easy	153	39	192	122.5	69.5		
Total	245	139	384				

4.2 Baseline vs. IVIS Secondary Tasks Comparison

Participants were required to drive the experimental vehicle without performing IVIS secondary tasks before the experimental run. During the baseline, as well as during the experimental run, participants were required to drive within the right lane limits at all times and lateral driving performance was measured as excursions outside the right lane. Longitudinal driving performance was measured during the baseline run as well by measuring speed maintenance. External reaction time during the baseline was measured as during the experimental run, by measuring the reaction time to the distracting light. IVIS tasks were not performed during the baseline run, so the eye glance behavior, perceived mental workload, and information capture dependent measures could not be compared between experimental and baseline runs.

All baseline dependent measures were analyzed with ANOVAs. Analyses were performed for each of the main effects independently. Significant findings are presented in Table 14. Significant F-values and p-values are presented and non-significant values are identified as "NS." For the significant results, Student-Newman-Keuls (SNK) post-hoc analyses were performed to determine if the baseline condition was significantly different from any of the other conditions. The SNK results are presented graphically for those that showed that the baseline differed significantly from some levels of the independent variables but not others. The SNK tabulated results are presented in Appendix N. Effect levels' means with the same letter in the graphs are not significantly different from one another.

***Table 14*. Baseline Dependent Measures Significance.**

	Source		
Dependent Variable	**Display**	**Application**	**Difficulty Level**
Lateral Driving Performance			
TOUCHD	$F_{5,75}$=7.25, p<0.0001	$F_{3,45}$=4.57, p=0.0071	$F_{2,30}$=3.88, p=0.0318
TOUCHDL	$F_{5,75}$=5.23, p=0.0004	$F_{3,45}$=3.61, p=0.0202	$F_{2,30}$=4.50, p=0.0195
TOUCHTLPC	$F_{5,75}$=5.02, p=0.0005	NS	$F_{2,30}$=3.45, p=0.0449
Longitudinal Driving Performance			
SPEEDSTDDEV	NS	NS	NS
External Reaction Time			
LIGHTREACTTIME	$F_{5,75}$=5.35, p=0.0003	$F_{3,45}$=3.42, p=0.0251	$F_{2,30}$=4.37, p=0.0215

NS = not significant

Results show that lateral driving performance was affected by the IVIS presentation in most of the experimental conditions. The percent of total task time spent outside the driving lane was the only dependent variable not affected by the application used. The SNK post-hoc comparison shows that the baseline condition did not differ significantly with the auditory normal, auditory fast, and multi-modal normal displays.

The baseline condition yielded a significant lower number of lane deviations (M = 0.00) when compared with the visual display (M = 0.27) and the multi-modal fast display (M = 0.20). These results are shown in Figure 34.

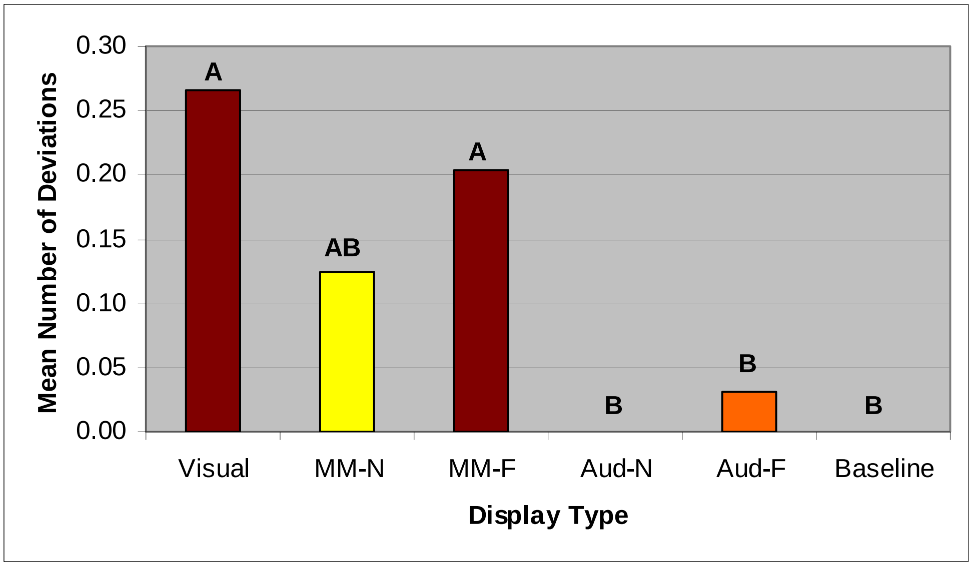


Figure 34. **Number of Lane Deviations per Display Type as Compared to Baseline. (Bars with same letters imply no significant difference between display types.)**

The SNK post-hoc analyses for the comparison of applications and level of difficulty affecting the number of lane deviations showed no significant differences. Therefore, baseline conditions did not differ significantly from any of the three application types or two levels of difficulty for mean number of lane deviations.

Results from the SNK post-hoc comparison for the length of lane deviations as affected by the type of display used show that the length of the lane deviations during the baseline run was not significantly different than for the multi-modal normal, auditory fast, and auditory normal displays. The length of the deviations during the baseline was significantly shorter (M = 0.00 sec) than the length of the deviations when the visual display (M = 2.51 sec) and the multi-modal fast display (M = 1.74 sec) were used. The results are shown in Figure 35.

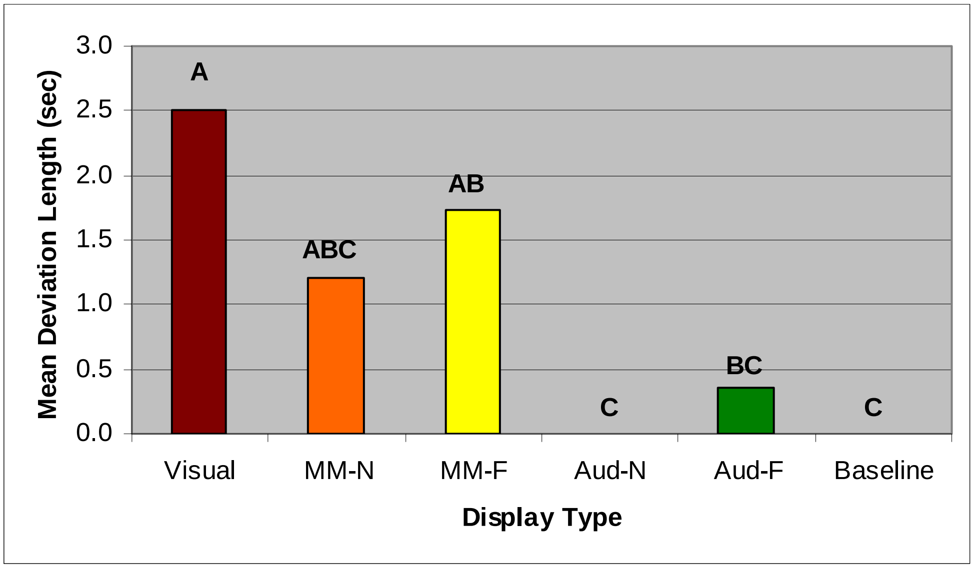


***Figure 35*. Length of Lane Deviations per Display Type as Compared to Baseline. (Bars with same letters imply no significant difference between display types.)**

The SNK post-hoc analyses for the comparison of applications and level of difficulty affecting the length of the lane deviations showed no significant differences. The length of the lane deviations during the baseline run did not differ significantly from the experimental data for any of the types of applications or difficulty levels.

The SNK post-hoc analysis for the percent of total task time spent outside the driving lane shows that there was no significant difference between the baseline data and the auditory and multi-modal displays. The baseline condition yielded significant lower lane deviation percentage (M = 0.00%) than the visual display (M = 7.35%). A graphic presentation can be seen in Figure 36.

The SNK post-hoc analysis for the comparison of level of difficulty affecting the percent of total task time spent outside the driving lane showed no significant differences. Therefore, baseline conditions did not differ significantly from any of the two levels of difficulty.

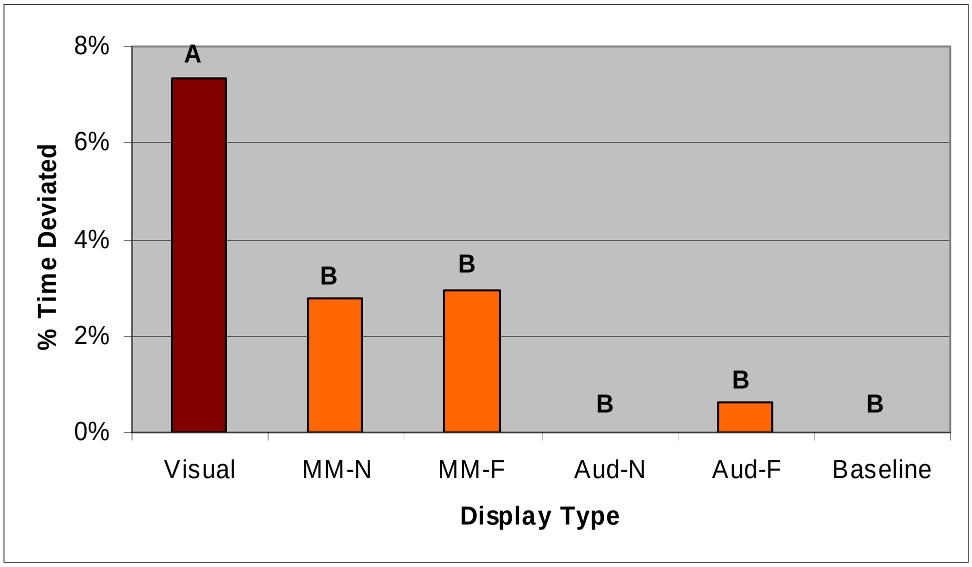


Figure 36. **Lane Deviation Percentage per Display Type as Compared to Baseline. (Bars with same letters imply no significant difference between display types.)**

The SNK post-hoc comparison of external reaction time depending on display type shows that the baseline condition did not differ significantly from the auditory normal, auditory fast, and multi-modal normal displays. The baseline condition yielded a significantly shorter light reaction time (M = 1.31 sec) than the visual display (M=4.13 sec) and the multi-modal fast display (M = 2.75 sec). These results are shown in Figure 37.

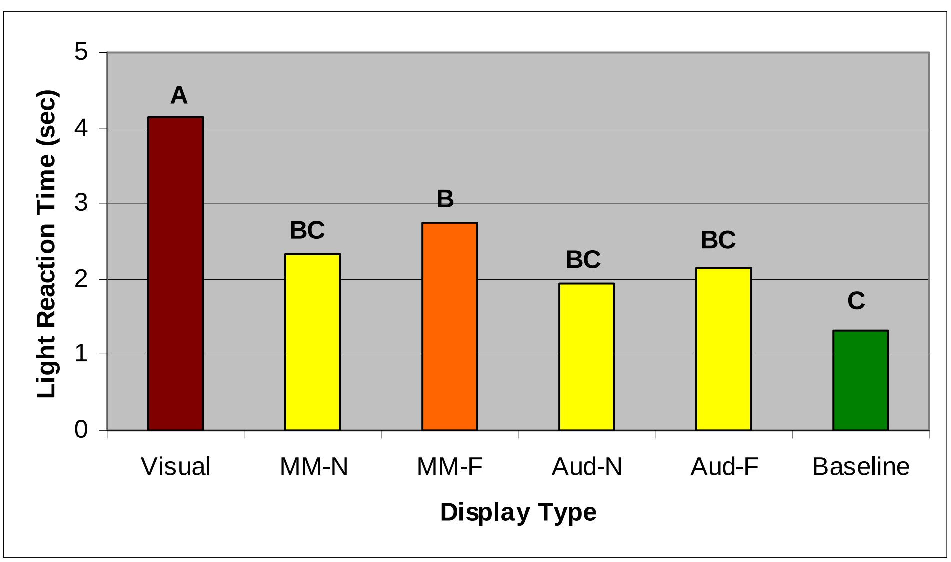


Figure 37. **Light Reaction Time per Display Type as Compared to Baseline. (Bars with same letters imply no significant difference between display types.)**

The SNK post-hoc analysis for the comparison of applications affecting the distracting light reaction time showed no significant differences. Therefore, baseline conditions did not differ significantly from any of the three types of application.

The SNK post-hoc comparison of light reaction time depending on the level of difficulty of tasks shows that the baseline condition yielded a significantly shorter light reaction time (M = 1.31 sec) than when difficult tasks were performed (M = 2.87 sec). No significant difference was found between baseline and easy tasks. These results are shown in Figure 38.

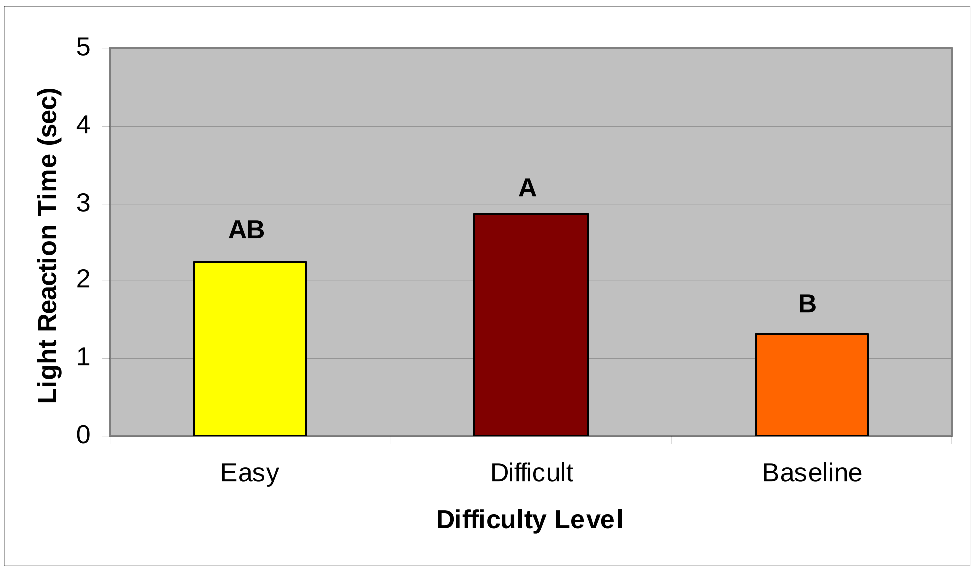


***Figure 38.* Light Reaction Time per Difficulty Level as Compared to Baseline. (Bars with same letters imply no significant difference between display types.)**

4.3 Post-Test Questionnaire

A post-test questionnaire was administered to the participants after the experimental run. The questionnaire inquired about the participants' familiarity with similar information systems, how often the participants would be willing to use these systems, and how complex the system applications were perceived to be.

Most of the participants reported being "very familiar" with personal computers and e-mail systems. Voice-mail systems were reported to be "very familiar" to "borderline familiar" for most of the participants. Only one participant reported being "barely familiar" with voice-mail systems. The familiarity with electronic calendaring varied from “very familiar” to “very unfamiliar,” with a fairly even distribution among all categories. These results are graphically presented in Figures 39-42.

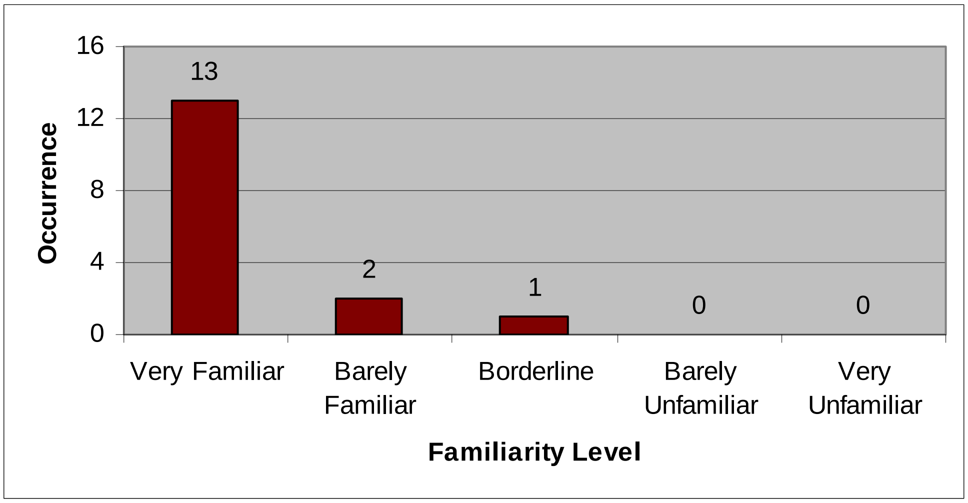


***Figure 39*. Participants Familiarity with Personal Computers.**

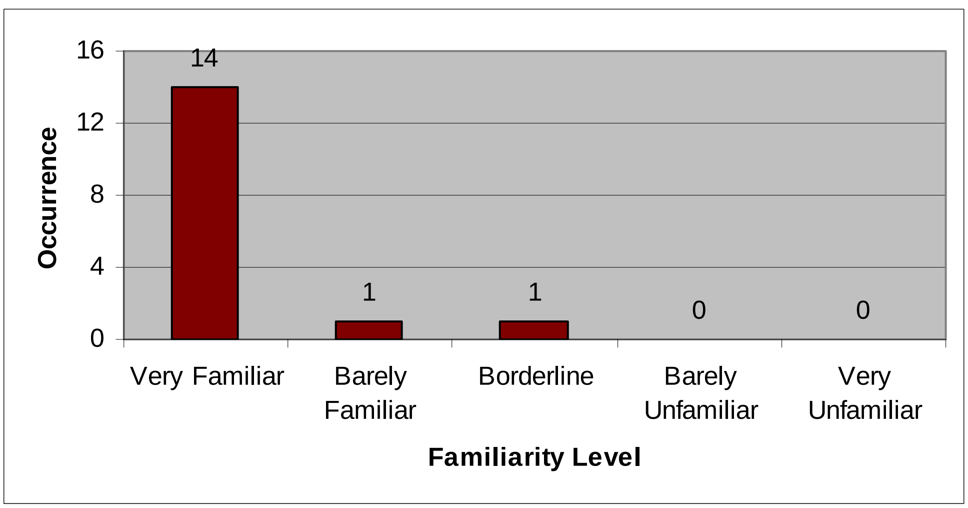


***Figure 40*. Participants Familiarity with E-mail Systems.**

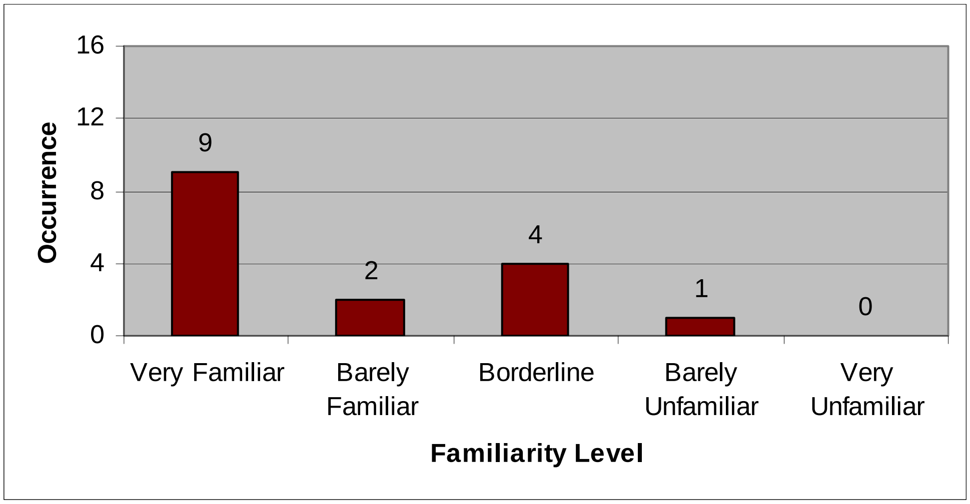


***Figure 41*. Participants Familiarity with Voice-mail Systems.**

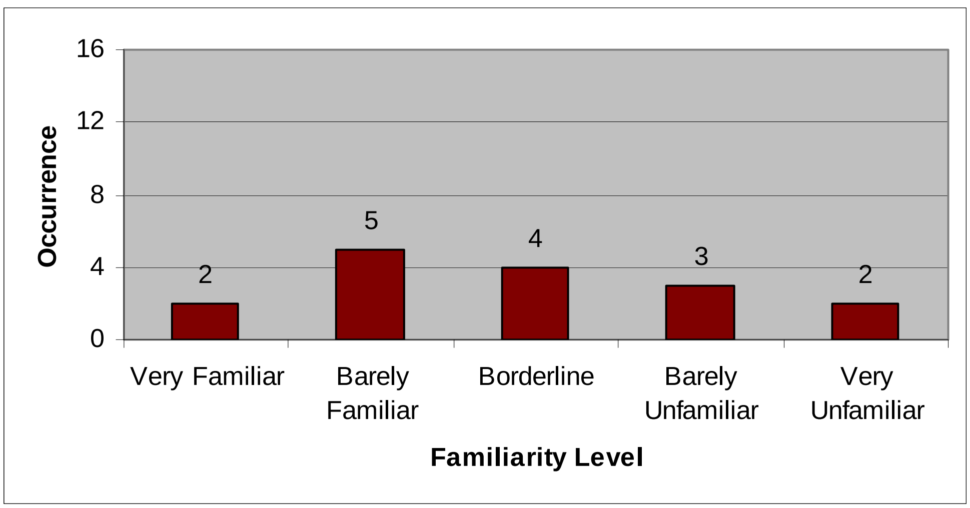


***Figure 42*. Participants Familiarity with Electronic Calendar Systems.**

Participants were asked about the willingness to use these types of systems if they were available in their vehicles. The responses in these cases varied among participants. Thirty-eight percent of the participants reported that they would “seldom” use the e-mail system while driving. One participant reported that it would “always” be used, and two participants reported that they would “never” use it. The same tendency was observed when the participants were asked the same question about the use of voice-mail and electronic calendar systems. Most participants said they would use them “seldom” to “frequently,” and only one or two reported that they would use them either “always” or “never.” These results are graphically presented in Figures 43-45.

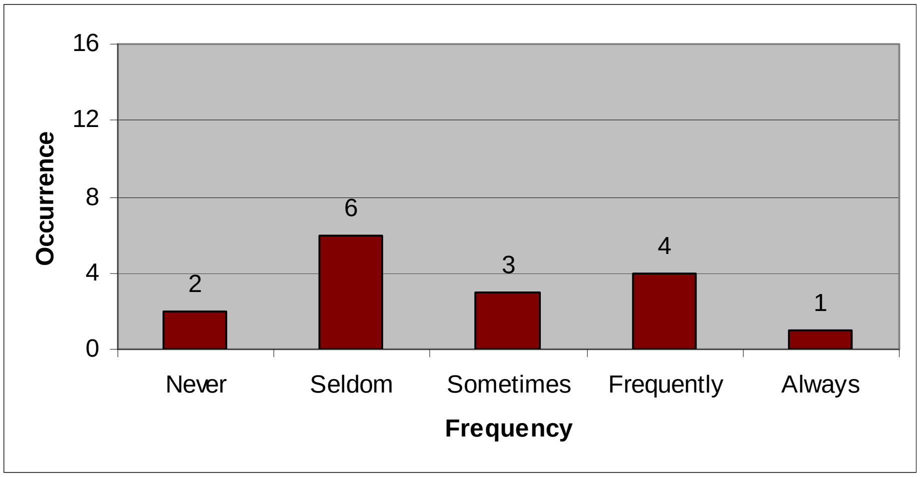


Figure 43. **Participants Willingness to use E-mail Systems while Driving.**

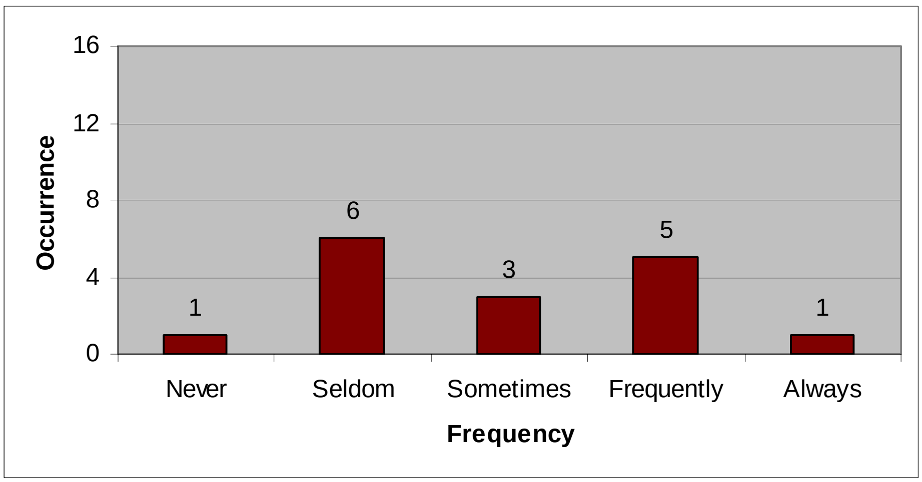


Figure 44. **Participants Willingness to use Voice-mail Systems while Driving.**

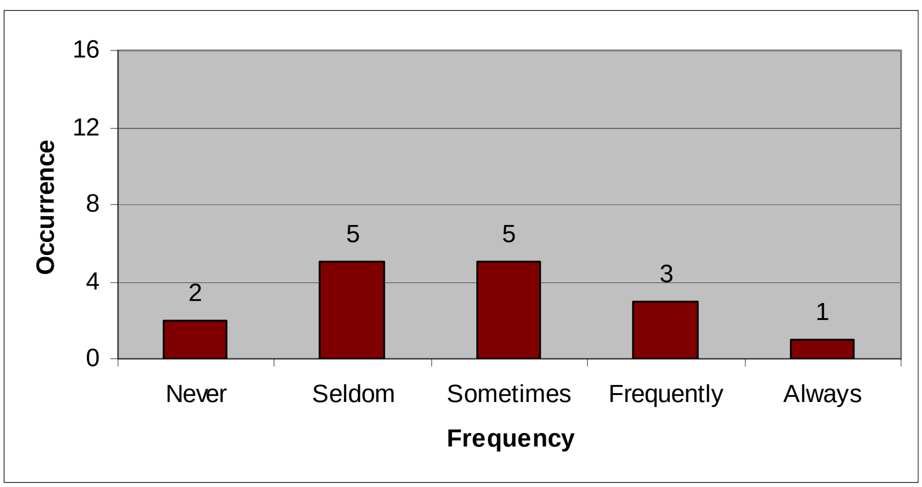


Figure 45. **Participants Willingness to use Electronic Calendars while Driving.**

The participants were asked to rate the perceived complexity of the system used during the study for each of the three applications. Forty-four percent of the participants reported that the e-mail system was "not complex" and 56% rated the voice-mail systems as "not complex." No participants rated these applications as "quite" or "extremely complex." Thirty-eight percent of the participants rated the calendaring application as "slightly complex" with one person rating it as being "quite complex." These results are graphically presented in Figures 46-48.

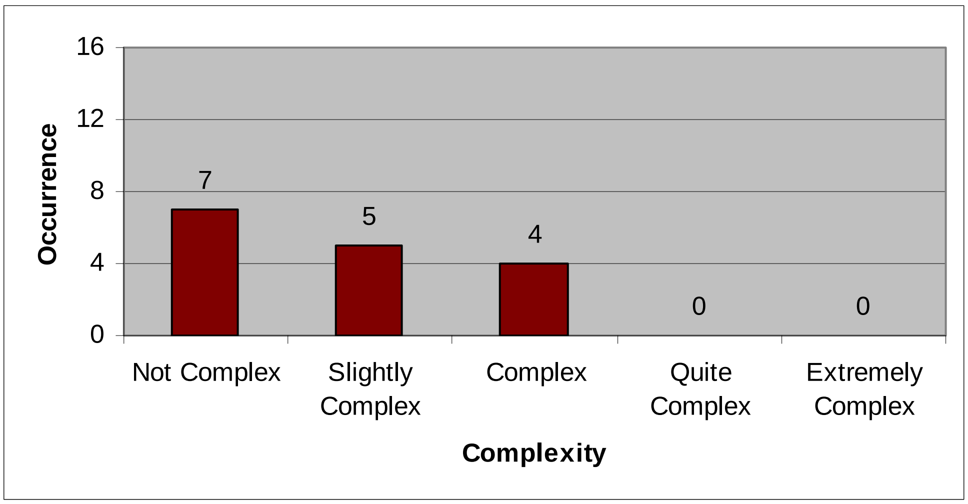


***Figure 46*. Perceived E-mail Complexity.**

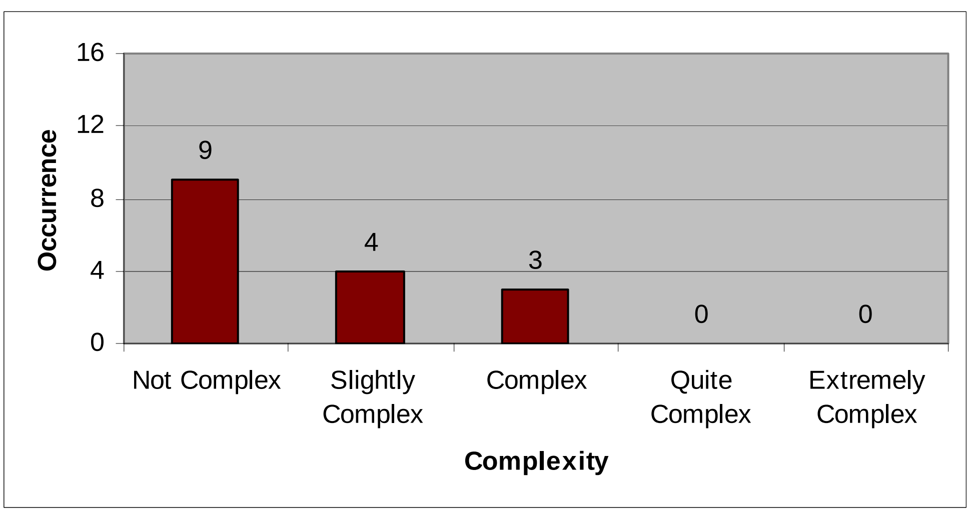


***Figure 47*. Perceived Voice-mail Complexity.**

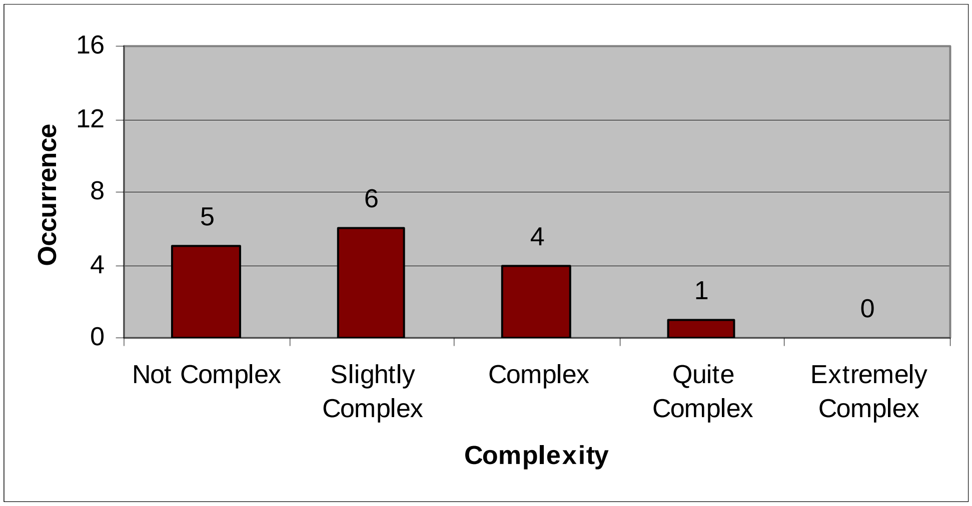


***Figure 48*. Perceived Electronic Calendar Complexity.**

5. DISCUSSION

The development of human factors guidelines for the design and use of in-vehicle information systems (IVIS) was one of the objectives of this study. An experimental study was performed to evaluate the factors of interest to be included in the guidelines. The factors of interest were the type of display used to present information, the type of IVIS application, and the level of difficulty of the IVIS tasks. The study focused on how the factors of interest affected drivers' attention and driving performance while performing IVIS secondary tasks related to specific applications.

Driving performance measures included eye glance data, lateral driving performance, longitudinal driving performance, and external reaction time. All driving performance measures, with exception of longitudinal driving performance, were significantly affected by the type of display used to perform the IVIS tasks. Driving performance measure results will be discussed in this section addressing the research questions stated in the Research Objectives chapter.

For which types of IVIS secondary tasks is a redundant visual text display helpful in ensuring adequate levels of driving performance (redundant to an auditory speech display)?

Overall, eye glance measurements were better with auditory displays than with the multi-modal and visual displays. Participants were less likely to glance at the LCD display with the auditory displays. Even though the installed LCD display was turned off during the auditory tasks, some participants glanced to it. Having performed a visual or multi-modal task previous to the auditory task could explain why participants glanced at the display. Another reason to glance at the display while performing auditory tasks could be the participants' need for information reassurance. Participants that glanced at the display during auditory tasks tended to do it at the beginning of the tasks.

Multi-modal displays resulted in more glances to the display than the auditory display. This was expected since the information was presented both visually and auditorially. The visual display produced the largest number of display glances. Information was presented to the participants using the LCD display exclusively, forcing the participants to glance at the display to be able to complete the tasks.

The percent of task time spent glancing at the display was affected in a similar way. Participants spent a smaller percentage of time glancing at the display during auditory tasks than during multi-modal and visual tasks. The short duration of these glances was the result of noticing that there was no information presented in the LCD display. Multi-modal tasks resulted in a higher percentage of task time spent glancing at the display than for the auditory tasks, but lower than for the visual tasks. In this case, participants could have glanced at the display as another source of information rather than as a primary way to complete a task. The percentage of time spent glancing at the display during visual tasks was significantly higher than during multi-modal and auditory tasks. This could be caused by the fact that in order to perform a task, participants had to read all the information on the display, taking their eyes off the road for a significantly greater percentage of time than with any of the other types of display.

Neither of the eye glance measurements was compared with baseline data. No IVIS tasks were performed during the baseline run, so there were no baseline data for comparison.

Lateral driving performance was affected by the type of tasks performed. Overall, the best lateral driving performance was obtained during auditory tasks. The worst lateral driving performance was obtained during the visual tasks. The number of lane deviations, the length of lane deviations, and the percent of total task time spent outside the driving lane followed the same tendency. The best performance resulted from the auditory tasks followed by the multi-modal tasks. The worst performance resulted from the visual tasks. Although multi-modal tasks resulted in overall poorer lateral driving performance than the auditory tasks, the multi-modal normal speech rate performance was not significantly different from the auditory results in terms of the number of lane deviations and the average length of the lane deviations. Both of the multi-modal displays results were not significantly worse than the auditory results for the percent of total task time spent outside the driving lane. In this case, participants spent significantly more time outside the driving lane while performing visual tasks than when using any of the other displays. Visual tasks resulted in more and longer lane deviations than multi-modal normal speech rate tasks, but these were not significantly different than the multi-modal fast speech rate tasks.

Longitudinal driving performance was measured calculating speed standard deviations. The results obtained showed that speed maintenance was not affected by the type of display. Participants were instructed to maintain a constant speed and were reminded of this throughout the experiment. This, in addition to the facility to monitor the speed by glancing at the speedometer could have been factors that allowed participants to achieve consistent speed maintenance. Speed was successfully maintained throughout both baseline and experimental runs.

The reaction time to the distraction light was measured to determine the drivers' awareness of their surroundings. The best performance was obtained during the baseline run. This performance was followed by the results obtained during the auditory tasks. Although the reaction time was longer than the baseline data when auditory displays and the multi-modal normal speech rate display were used, these were not significantly different. Reaction time to the distracting light was significantly longer when the visual display was used. As the participants' glances increased, the reaction time to the distracting light increased. Participants' reaction time to the distracting light decreased when attention was directed to the road.

The results discussed above show that the auditory displays produced better driving performance than any of the other displays. The use of the visual display resulted in the worst driving performance. If a visual display is used for any of these applications (email, voice mail, or calendar systems), it should be used in conjunction with an auditory display (i.e., multi-modal display). The eye glance data were significantly worse when the multi-modal displays were used as compared to the auditory displays. For the lateral driving performance there was no significant difference between the auditory and multi-modal displays. The same was true for the external reaction time measurement and for longitudinal driving performance. As stated before, participants performed the best with the auditory displays, but if visual displays are to be used it should be as a multi-modal display. Visual displays alone should not be used based on the overall results.

In addition to the participants' driving performance, it was an objective of this experiment to determine how the IVIS tasks affected the participants' perception of mental workload associated with the use of the IVIS system. The results would be considered in the development of design and usage guidelines. Mental workload was evaluated in terms of mental demand, temporal demand, and frustration level. The three dependent measures were significantly affected by the type of display used to perform the IVIS tasks. Lower mental demand was reported by participants when the auditory normal speech rate display was used, followed by the multi-modal normal speech rate display. The mental demand was reported to increase with the auditory and multi-modal fast speech rate displays. The highest mental demand was perceived with the use of the visual display. The mental demand perceived with the use of the auditory and multi-modal displays did not differ significantly from each other. Mental demand ratings support the poorer driving performance when visual displays were used.

Temporal demand was perceived in the same way as mental demand. It was lowest when the auditory normal speech rate was used, followed by the multi-modal normal speech rate display. The use of the visual display resulted in the highest temporal demand. The perceived temporal demands of the auditory displays and the multi-modal normal speech rate display were not significantly different from one another. Both fast speech rate displays (i.e., auditory and multi-modal) were not significantly different from one another, and no significant difference was found between the visual and the multi-modal fast speech rate displays. These were reported to cause the highest temporal demands. Temporal demand ratings show concordance with the driving performance results. For the visual display, display glances and lane deviations took longer than with auditory and multi-modal displays. Participants rated visual tasks as the most demanding tasks.

Participants reported the lowest frustration level when the multi-modal normal speech rate was used, followed by the use of the multi-modal normal speech rate display. The highest frustration level was reported when the visual display was used.

The mental workload results are consistent with the driving performance results, showing that the participants' evaluation of the most challenging tasks was reflected by their driving performance during these tasks. *The results show that a redundant visual display is not helpful in ensuring adequate levels of driving performance for the IVIS secondary tasks. No significant improvements in driving performance resulted from the use of multi-modal displays over the use of auditory displays.*

For auditory speech displays, how does fast or slow speech rate influence driving performance?

Auditory displays were presented to the participants at two speech rate levels, one faster than the other. The slower rate was identified as a normal speech rate and the faster speech rate was identified just as that, a fast speech rate. *No significant differences were found between the two speech rates used for auditory displays for any of the dependent measures.* None of the driving performance measures, external reaction time measure, or perceived mental workload measures differed significantly between the speech rates.

When the fast speech rate was used, the phrases and messages were spoken at a faster pace by the synthesized voice, but produced larger pauses between messages when used with the IVIS software (Authorware®). This was a software fault and no way could be found to correct it. These pauses could have caused anxiety to the participants waiting for an IVIS response, resulting in worse driving performance (although not significantly) than when the auditory normal speech rate was used.

For multi-modal displays, which speech rates create better driving performance?

Multi-modal displays were presented to the participants in the same two speech rates used for the auditory displays. The number of display glances was the only driving performance measure to show a significant difference between the speech rates for the multi-modal displays. The use of the multi-modal normal speech rate resulted in significantly fewer glances to the display than the multi-modal fast speech rate. The normal speech rate was perceived by the participants to cause significant lower temporal demand than the fast speech rate. The fast speech problem explained for the auditory displays was also present for the multi-modal displays, causing similar results. *Overall, although not always significantly, the normal speech rate created better driving performance than the fast speech rate for multi-modal displays.*

Given the answers to the above research questions, what are the appropriate guidelines for use and design of speech, text, and multi-modal displays for the specific applications?

The results obtained in this study show consistencies that can be developed into human factors design and usage guidelines for IVIS systems. Table 15 and Table 16 show a summary of the results discussed above. The dependent measures have been numerically rated by display type. Rates range from worst performance (-2) to best performance (+2). Display types that are not significantly different from one another have the same numeric value identification. A zero value means that there was no significant difference from the compared condition, meaning it is neither significantly better nor significantly worse than the baseline data (Table 15) or the visual display data (Table 16). As seen in Table 15, there was no display type which showed improved driving performance over baseline driving. Likewise, in Table 16, it can be seen that no display ever produced worse driving performance than the visual display.

Table 15. **Display Type Performance as Compared to Baseline Driving.**

	Display Type				
Dependent Measures	**Visual**	**MM-N**	**MM-F**	**Aud-N**	**Aud-F**
Display Glances	N/A	N/A	N/A	N/A	N/A
Task Time % Glancing at Display	N/A	N/A	N/A	N/A	N/A
Lane Deviations	-1	0/-1	-1	0	0
Length of Deviations	-2	0/-1/-2	-1/-2	0	0/-1
Lane Dev % of Task Time	-1	0	0	0	0
Speed Std Dev	NS	NS	NS	NS	NS
Distracting Light Reaction Time	-2	0/-1	-1	0/-1	0/-1
Mental Demand	N/A	N/A	N/A	N/A	N/A
Temporal Demand	N/A	N/A	N/A	N/A	N/A
Frustration Level	N/A	N/A	N/A	N/A	N/A
Information Capture	N/A	N/A	N/A	N/A	N/A

Table 16. **Multi-Modal and Auditory Displays as Compared to the Visual Display.**

	Display Type			
Dependent Measures	**MM-N**	**MM-F**	**Aud-N**	**Aud-F**
Display Glances	1	0	2	2
Task Time % Glancing at Display	1	1	2	2
Lane Deviations	0/1	0	1	1
Length of Deviations	0/1/2	0/1	2	1/2
Lane Dev % of Task Time	1	1	1	1
Speed Std Dev	NS	NS	NS	NS
Distracting Light Reaction Time	1/2	1	1/2	1/2
Mental Demand	1	1	1	1
Temporal Demand	2	0/1	2	1/2
Frustration Level	1	1	1	1
Information Capture	NS	NS	NS	NS

The following guidelines are based on the discussed findings of this study. These guidelines are suggested if IVIS must be used:

Guideline #1: **<u>IVIS systems should be presented auditorially to the drivers.</u>**

Overall, the use of auditory displays resulted in a significant better driving performance than visual and multi-modal displays. For every dependent measure, the auditory tasks resulted in better driving performance than the visual tasks. The results were not as strong when the auditory and multi-modal displays were compared. Only for the eye glances measures (i.e., number of display glances and percent of task time glancing at the display) was there a significantly better driving performance for auditory tasks over the multi-modal tasks. This result may have been due to the fact that the drivers were not supposed to glance at the display during the auditory tasks. For the same reason, the time spent glancing at the display was significantly shorter than when the other displays were used. Significantly fewer and shorter lane deviations were observed while performing auditory tasks as compared to the visual tasks. The percent of total task time spent outside the driving lane was significantly smaller for the auditory tasks than for the visual tasks. No significant differences in lateral driving performance (i.e., number and length of lane deviations, and percent of total task time spent outside the driving lane) were found between auditory and multi-modal tasks. The same type of results was observed with the light reaction time and perceived mental workload.

The results obtained in this study support previous findings in the literature in that auditory tasks result in better driving performance than visual tasks. Belz et al. (1999), Gish et al. (1999), and Robinson et al. (1985) found that the use of auditory interfaces results in better driving performance than the use of visual interfaces. However, multi-modal tasks have previously resulted in better driving performance than auditory tasks (e.g., Belz et al., 1999).

Guideline #2: **<u>IVIS systems should not be presented with only visual displays.</u>**

As explained in the previous guideline, the use of the visual display for the performance of IVIS secondary tasks resulted in significantly worse driving performance than the use of auditory displays. With the exception of the longitudinal driving performance and the information capture measures, which resulted in no significant difference among display types, the visual display resulted in significant worse driving performance for each of the dependent measures as compared to the auditory displays. When compared to the multi-modal displays, five of the nine dependent measures were significantly worse when the visual display was used. The measures that resulted in no significant difference were the number of glances to the display, the number of lane deviations, the length of the lane deviations, and the perceived temporal demand. It is worth mentioning that two of these four measures were significantly different than the use of the multi-modal normal speech rate display and not the multi-modal fast speech rate display.

This findings support existing literature. Belz et al. (1999) concluded that since driving is primarily a visual task, adding visual displays to present warning signals can overload the driver's visual effort; therefore, they recommended not using visual displays alone.

Guideline #3: **<u>If a visual display should be used it must be in a multi-modal display where audio is used as well.</u>**

It is recommended that a multi-modal interface be used instead of a visual interface. This is suggested based on the results obtained. The sole use of visual displays should be avoided. Since there were no significant differences among auditory and multi-modal displays for some of the dependent measures, it is suggested that the multi-modal displays be used. The only significant differences were found for the eye glance measures. These differences were caused by the fact that the drivers were not supposed to glance at the display during the performance of auditory tasks, since the display was disabled. This is the recommended guideline for cases in which a visual presentation is desired in an information presentation interface.

This guideline agrees with the recommendations of previous studies where multi-modal displays were recommended over auditory and visual displays. Belz et al. (1999), Liu et al. (2000), and Fussell et al. (2002) conducted experiments that resulted in the recommendation of the use of multi-modal displays for the presentation of information in highly visual demanding environments such as driving a vehicle.

Guideline #4: **Auditory displays could use either normal or fast speech rates to present verbal information.**

The comparison of the auditory normal speech rate display and the fast speech rate display resulted in no significant differences for any of the dependent measures. These results may have been affected by difficulties with the sound files and interface software used. When the fast messages were incorporated into the interface program, gaps of time were created between messages. This situation may have affected drivers' performance by adding an anxiety factor and/or confusion. Participants may have thought that they did something wrong or that the system was not working properly since it took longer to get feedback from the system as compared to the normal speech.

Previous related literature shows that there have been significant differences among speech rates. Llaneras et al. (2000) compared normal speech rate and time-compressed speech rate for an IVIS. The results showed that the time-compressed speech rate resulted in better driving performance than the normal speech rate.

It must be stated that the speech rates comparison results obtained in the present study should be considered carefully. The software fault may have affected these results. Further studies related to speech rates should be performed to reach unbiased conclusions.

Guideline #5: **Multi-modal displays should use a normal speech rate to present verbal information.**

The comparison of the multi-modal normal speech rate display and the fast speech rate display showed only two significant differences out of the nine dependent measures. The results showed that there were significantly more glances to the display when the multi-modal fast speech rate display was used than when the multi-modal normal speech rate display was used. Drivers perceived a higher temporal demand when the multi-modal fast speech rate display was used. The reason for these results may be due to the software failure discussed above. The drivers may have glanced more times to the display trying to complete the tasks faster since the system was taking a long time before responding to them. Consequently, drivers perceived the tasks more time consuming than when the normal speech rate was used.

As stated before, the results obtained from the comparison of speech rates may have been affected by the gaps of time during the fast speech application. Further investigation must be done to obtain more data and performed an unbiased comparison.

Guideline #6: **Design systems where tasks can be performed with minimal hierarchical steps.**

The comparison of the IVIS secondary tasks showed that the level of difficulty of the tasks negatively affected the perceived mental demand. The drivers perceived a higher mental demand when the difficult tasks were performed as compared to the easy tasks. When the performance of the IVIS secondary tasks were compared to the baseline data, it was found that the light reaction time significantly increased when the difficult tasks were performed.

Lee et al. (2001) obtained similar results to this study; the complexity of systems affected drivers' mental workload. In a study by Ranney et al. (2002), task completion time was significantly shorter for the easy tasks as compared to the complex tasks. This result agrees with the results of this study. The easy and difficult tasks performed in this study varied by only one or two steps. This difference may have not been large enough to produce significant effects among all the dependent variables. Further studies should be performed to compare task complexity.

Multiple-Resource Theory

The results obtained in this study may be associated with the Multiple-Resource Theory described by Wickens (2000). The theory proposes a cube-like structure of processing resources that tries to explain variations in task time-sharing efficiency in terms of resource differences. The cube is divided in modalities, codes, stages, and responses. Both auditory and visual modalities go through the three processing stages (perception, working memory and cognition, and responding) in either of the verbal or spatial codes. Responses are performed either vocally or manually. The theory is graphically presented in Figure 49.

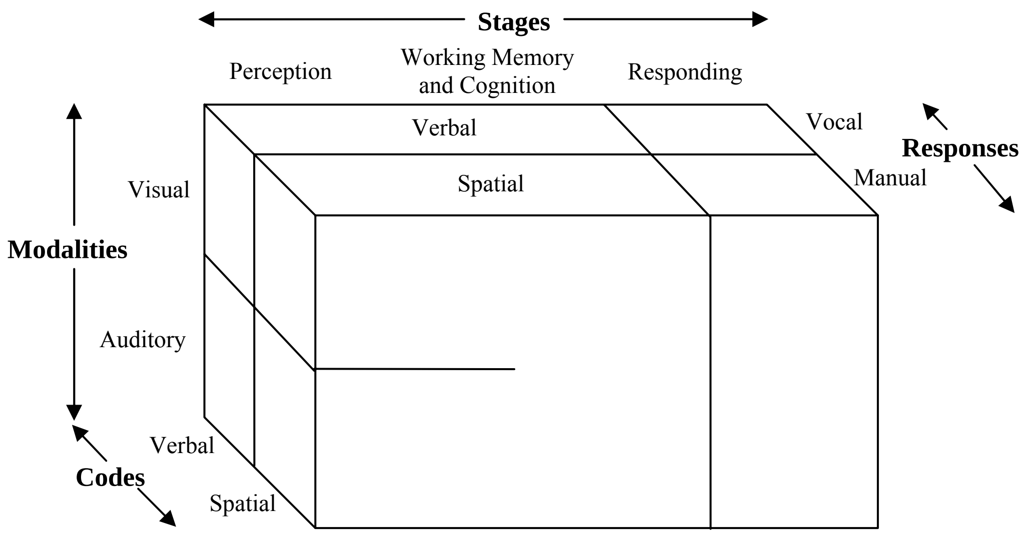


Figure 49. **Multiple-Resource Theory Diagram.**

(Reprinted from Varieties of Attention, C.D. Wickens, *Processing Resources in Attention*, Page 81, Copyright 1984, with permission from Elsevier.)

This research study imposed three major tasks on the participants. The primary task was driving a vehicle. This is a visual task that is spatially processed producing a manual response. Secondary tasks using the IVIS consisted of three types of processes: (1) visual tasks processed verbally resulting in vocal response; (2) auditory tasks processed verbally resulting in vocal response; and (3) multi-modal tasks using both visual and auditory modalities processed verbally resulting in vocal response.

Responding to the distracting light was another task to be performed by the participants. The task was presented visually, processed spatially, and responded to manually.

The multiple-resource theory states that cross-modal time-sharing is more efficient than intramodal time-sharing. That is, performing a visual and an auditory task can result in better performance than performing two visual or two auditory tasks. The results obtained in this study support this theory. Better driving performance was achieved when auditory IVIS tasks were performed than with visual tasks, while performing the primary task of driving, which is a visual task. When both visual tasks (i.e., driving and visual IVIS tasks) were performed, driving performance worsened, external reaction time increased, and perceived mental workload increased.

6. CONCLUSIONS

This research project was developed to test the general hypothesis that *the performance of IVIS secondary tasks while driving would increase driver distraction while decreasing driver performance*. Driver performance results from baseline and experimental runs were compared to test this hypothesis. The results showed that driver performance while performing IVIS secondary tasks was mostly dependent on the type of display used for the presentation of information rather than on application type or difficulty level. Driver performance was significantly worse than baseline when the visual display and the multi-modal fast speech rate display were used. No driver performance significant differences were found between the baseline run and the use of auditory displays and the multi-modal normal speech rate display. Therefore, the general hypothesis is true for certain display conditions.

Not rejected *for visual display and multi-modal fast display.*

Rejected *for auditory normal, auditory fast, and multi-modal normal displays.*

In addition to the general hypothesis, four specific hypotheses were stated based on the research questions. A brief discussion of these hypotheses' conclusions follows:

Hypothesis #1: **The use of multi-modal displays will increase the level of driving performance for calendaring and e-mail IVIS applications as compared to visual and auditory displays results.**

Before the study was performed it was hypothesized that the use of multi-modal displays would result in better driving performance for both calendar and e-mail applications as compared to visual and auditory displays. The use of multi-modal displays resulted in significantly better driving performance than the use of the visual display for five of the nine dependent variables measured regardless of application. For two of the other four dependent measures, one of the multi-modal display versions (multi-modal normal speech rate display) resulted in significantly better driver performance than when the visual display was used. However, multi-modal displays were not significantly different than auditory displays. Of the nine dependent measures, only two of them were significantly worse for the multi-modal displays as compared to the auditory displays. For this case, the null hypothesis has to be rejected.

Not rejected *for visual display.*

Rejected *for auditory normal and auditory fast displays.*

Hypothesis #2: **When speech rates used for the auditory and multi-modal displays are compared, the fast speech rate (i.e., time-compressed rate) will result in better driving performance as compared to the slow speech rate (i.e., normal rate).**

The hypothesis stating that the fast speech rate would result in better driving performance than the normal speech rate has to be rejected. For all cases, the auditory normal speech rate display did not reflect a significantly different driving performance than the auditory fast display. When the multi-modal normal speech rate display and the multi-modal fast speech rate display were compared, the multi-modal normal resulted in better driver performance than the multi-modal fast speech rate for two of the dependent measures (number of glances to the display and perceived temporal demand). For most dependent measures, auditory displays resulted in significantly better driving performance than the multi-modal displays, no matter what speech rate was used.

Rejected: *No significant difference was found in driver performance between normal speech rate and time-compressed (fast) speech rate.*

Hypothesis #3: **Task complexity will negatively affect both external reaction time to an external stimulus and perceived workload. As the complexity of the IVIS secondary tasks increases, the external reaction time and the perceived workload will increase.**

The level of difficulty of the IVIS tasks was hypothesized to negatively affect external reaction time and perceived mental workload. This was true for the mental workload but not for the external reaction time. The perceived mental demand was significantly affected by the IVIS task difficulty level. The easy tasks were perceived to cause less mental demand than the difficult tasks. The other two measures of mental workload (i.e., temporal demand and frustration level) were not significantly affected by the tasks' complexity. The external reaction time measure was not significantly affected by the level of difficulty of the IVIS tasks. The reaction time to the distracting light did not vary significantly depending on the level of difficulty of the tasks performed.

Not rejected *for perceived mental workload.*

Rejected *for light reaction time.*

Hypothesis #4: **Overall, the use of multi-modal displays will result in better driving performance as compared to a visual or auditory display.**

The last hypothesis stated that the use of multi-modal displays would result in overall better driving performance as compared to the visual or auditory displays. The results showed this to be true in the case of the visual display. Driver performance when using multi-modal displays was almost always significantly better than when using the visual display. In some cases this depended on the speech rate of the multi-modal display. For several of the dependent measures, the use of auditory displays resulted in better driving performance than did the multi-modal displays.

Not rejected *for visual display.*

Rejected *for auditory normal and auditory fast displays.*

It was expected that this research study would result in the generation of human factors guidelines for the design and use of in-vehicle information systems. The recommended guidelines are based on those conditions that are less intrusive to the driving task: a shorter number of glances to the display, shorter glances length, better lateral driving performance, better awareness of the surroundings, and less mental workload. The following guidelines are suggested:

Guideline #1: **IVIS systems should be presented auditorially to the drivers.**

Guideline #2: **IVIS systems should not be presented with only visual displays.**

Guideline #3: **If a visual display should be used it must be in a multi-modal display where audio is used as well.**

Guideline #4: **Auditory displays could use either normal or fast speech rates to present verbal information.**

Guideline #5: **<u>Multi-modal displays should use a normal speech rate to present verbal information.</u>**

Guideline #6: **<u>Design systems where tasks can be performed with minimal hierarchical steps.</u>**

The results obtained from this study confirm some findings from previous research such as the better performance of auditory displays over visual displays. Some contradictory results were found as well, such as the normal speech rate resulting in better performance than the fast speech rate. These results show the importance of continuous research in the transportation safety area. There are a large number of factors that affect driving performance.

In summary, this research project had the objective of testing important factors related to the design and use of IVIS. The fact that calendar and e-mail tasks have been traditionally associated with visual displays does not mean that this is the most appropriate method to present this type of information while the person is driving. The results of this study support previous findings about information processing with the use of these systems. This study confirms that the visual displays are not the best way for information presentation due to driving performance deterioration. Similar findings were obtained by Blanco, Beaver, Gallagher, and Dingus (2004). As stated previously, driving is mostly a visual task and when other visual tasks are presented the attentional resources are divided between the two tasks. The use of auditory displays allows drivers to perform IVIS tasks by different means. Auditory displays allow the driver to gather information without an overload of the visual channel. In conclusion, speech is a better method for presenting information than text only. The study successfully met the objective by generating results that are distinctive and important for transportation safety. It is hoped that this research, its results, and concluding guidelines will be relevant to the continuous research, development, and improvement of IVIS. This work emphasizes the importance of safety and human factors in the early design stages and deployment of these systems in transportation, thus to humans as the users.

Future Research and Limitations

This research study has produced significant results that can be applied to the design and use of IVIS. More research, however, can be done to address other factors that can have significant implications for the development of these systems.

Age is an important factor that should be tested. These types of systems are being installed in vehicles that are more popular among older drivers than younger people. Research has shown that attention and perception decrease with age. This makes the age of drivers a factor that could prove to be important. This study did not include age as a factor due to the design complexity that it would have added. The other variables were considered more important than age, so the decision was made to eliminate age as an independent variable. Participants' age in this study ranged from 23 to 55 years, with a mean of 39.19 years and a standard deviation of 10.33 years.

All the participants in this study had English as their first language. Although English is the official language of the United States of America, it is not the first language of all its inhabitants. The large diversity of this country's population should be of importance to IVIS designers and vehicles' manufacturers. The fact that a Spanish speaking person encounters an English information system could lead to safety related problems on the road. Drivers could be more distracted if they misunderstand what the system says or do not understand the whole message. It could take more time for drivers to perform tasks, thus increasing driver distraction and decreasing driving performance. The use of multiple languages for IVIS should be considered for future research given that this trend of linguistically diverse drivers is already existent and will increase in the future.

Information display presentation was tested in this study, resulting in significant differences between the types of display used. However, the format used in each of the displays was not part of the study. In the future, different factors could be studied for each type of display. Synthesized versus natural voice, male versus female voice, and speech format are factors that could be studied for auditory presentations. Type of format such as prose versus list text and full versus abbreviated text are potential study factors for the visual display presentation. Speech and format studies should include the length of the text as well as the length of time of the message. In this study it was observed that pauses between messages and system feedback could have affected drivers' performance. Although not intentional, this led to the questioning that could be part of future research.

More research should be performed to identify specific information system needs, driver preferences, and best methods to present information using IVIS. The IVIS used in this study was an interface prototype that covered the purpose of presenting basic application systems. It is important to note that the results obtained may not be universal; that is, the suggested guidelines may not be applied to specific systems. Commercial systems should be tested depending on the particular applications, presentation format, and system purposes. The suggested guidelines may be used as a guide and as a comparison instrument for future research.

REFERENCES

Almén, L. (2002). Comparing Audio and Tactile Inputs as Driver Attention Control. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp. 1777-1781). Santa Monica, CA: Human Factors and Ergonomics Society.

Belz, S. M., Robinson, G. S., Casali, J. G. (1999). A New Class of Auditory Warning Signals for Complex Systems: Auditory Icons. *Human Factors*, 41, 608-618.

Blanco, M., Biever, W. J., Gallagher, J. P., and Dingus, T. A. (approved 2004). The impact of secondary task cognitive processing demand on driving performance. *Human Factors*. Santa Monica, CA: Human Factors and Ergonomics Society.

Bouis, D., Voss, M., Geiser, G., Haller, R. (1979). Visual vs. Auditory Displays for Different Tasks of a Car Driver. In *Proceedings of the Human Factors Society 23rd Annual Meeting* (pp.35-39). Santa Monica, CA: Human Factors Society.

Burns, P.C., Lansdown, T.C. (2002). E-Distraction: The Challenges for Safe and Usable Internet Services in Vehicles. *Internet Forum on the Safety Impact of Driver Distraction When Using In-Vehicle Technologies*.

Carlson, S., Barclay, C., O'Connor, J., Duckworth, G., Heine, J., Papazian, B., Steele, M. (1995). Application of Speech Recognition Technology to ITS Advanced Traveler Information Systems. In *Vehicle Navigation and Information Systems 6th Conference Proceedings* (pp.118-125). Seattle, WA.

Ceci, R., Högman, L., Patten, C. (2001). Measures of Driver Behavior and Cognitive Workload in a Driving Simulator and In Real Traffic Environment: Experiences from Two Experimental Studies in Sweden. In Driving Assessment 2001: The First *International Driving Symposium on Human Factors in Driver Assessment,* *Training, and Vehicle Design* (pp. 137-142). Iowa City, IA: University of Iowa public Policy Center.

Direct Line Motor Insurance. (2002). *The Mobile Phone Report: A Report on the Effects of Using a 'Hand-Held' and 'Hands-Free' Mobile Phone on Road Safety.* United Kingdom: Direct Line Insurance.

Fussell, S. R., Grenville, D., Kiesler, S., Forlizzi, J., Wichansky, A. M. (2002). Accessing Multi-Modal Information on Cell Phones While Sitting and Driving. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp. 1809-1813). Santa Monica, CA: Human Factors and Ergonomics Society.

Gish, K. W., Staplin, L. K., Stewart, J., Perel, M. (1999). Sensory and Cognitive Factors Affecting Automotive Head-Up Display Effectiveness. Presented at the *78th Annual Meeting of the Transportation Research Board* (pp. 10-19). Washington, D.C.: Transportation Research Board.

Gould, J. D., Conti, J., Hovanyecz, T. (1981). Composing Letters with a Simulated Listening Typewriter. In *Proceedings of the Human Factors Society 25th Annual Meeting* (pp. 505-508). Santa Monica, CA: Human Factors Society.

Graham, R., Hirst, S. J., Carter, C. (1995). Auditory Icons for Collision Avoidance Warnings. In *Proceedings of the ITS America 1995 Annual Meeting* (pp. 1057-1063). Washington, D.C.: ITS America.

Green, P. (1999). The 15-Second Rule for Driver Information Systems. In *Conference Proceedings of ITS America 9th Annual Meeting: New Thinking in Transportation* (10 p.). Washington D.C.: ITS America.

Harms-Ringdahl, L. (2001). *Safety Analysis: Principles and Practice in Occupational Safety.* New York: Taylor and Francis, Inc.

Hart, S.G. and Staveland, L.E. (1987). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In P.A. Hancock and N. Meshkati (Eds.), *Human Mental Workload*. Amsterdam: Elsevier.

Lee, J. D., Brent, C., Haake, S., Brown, T. L. (2001). Speech-Based Interaction with In-Vehicle Computers: The Effect of Speech-Based E-Mail on Drivers' Attention to the Roadway. *Human Factors*, 43, 631-640. Human Factors and Ergonomics Society.

Liu, Y. C., Schreiner, C. S., Dingus, T. A. (2000). The Effect of Advanced Traveler Information Display Modality on Driver Performance. In *Proceedings of the IEA 2000/HFES 2000 Congress: Ergonomics for the New Millennium* (pp. 3-234-3-237). Santa Monica, CA: Human Factors and Ergonomics Society.

Llaneras, R., Lerner, N., Dingus, T., Moyer, J. (2000). Attention Demand of IVIS Auditory Displays: An On-Road Study under Freeway Environments. In *Proceedings of the International Ergonomics Association 14th Congress* (pp. 3-238-3-241) Santa Monica, CA: Human Factors and Ergonomics Society.

Mynatt, E. R. (1994). Auditory Presentation of Graphical User Interfaces. In G. Kramer (Ed.), *Auditory Display* (pp. 533-555). Reading, PA: Addison-Wesley.

Nowakowski, C., Friedman, D., Green, P. (2002). An Experimental Evaluation of Using Automotive HUDs to Reduce Driver Distraction While Answering Cell Phones. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp.1809-1813). Santa Monica, CA: Human Factors and Ergonomics Society.

Ranney, T. A., Harbluk, J. L., Noy, Y. I. (2002). The Effects of Voice Technology on Test Track Driving Performance: Implications for Driver Distraction. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp.1814-1818). Santa Monica, CA: Human Factors and Ergonomics Society.

Rasmussen, J. (1983). Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models. *IEEE Transactions on Systems, Man, and Cybernetics*, Vol.13, No.3. (pp.257-266).

Robinson, C. P., Base, S. J., Eberts, R. E. (1985). Eyes/Ears; Spatial/Verbal: How Should a Cockpit Talk to a Pilot? *Trends in Ergonomics/Human Factors II*. (pp. 51-58). North Holland, Amsterdam: Elsevier Science Publishers.

Sakaguchi, Y., Higuchi, K., Nakano, T., Yamamoto, S. (1998). Simulation of the Adaptation Property and Application to On-Board Displays. *Fourth International Conference on Virtual Systems and Multimedia* (pp. 66-71). Amsterdam: IOS Press.

Siebert, P., Mouloua, M., Burns, K., Marino, J., Scagliola, L., Winters, L., Hancock, P., Agliata, D. (2002). The Effects of Telematics on Driver Distraction. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp.1868-1870). Santa Monica, CA: Human Factors and Ergonomics Society.

Stephens, B. W. (1990). Comparison of Alternative Methods for Presenting Trip Navigational Information to Motorists. *European Transport and Planning 18th Annual Meeting* (pp.129-141). London, England: Transport Research and Computation International Association.

Strayer, D. L., Johnston, W. A. (2001). Driven to Distraction: Dual-Task Studies of Simulated Driving and Conversing on a Cellular Telephone. *Psychological Science*, Vol.12, No.6. American Psychological Society.

Uno, H., Hiramatsu, K., Ito, H., Atsumi, B., Akamatsu, M. (1997). Detectability of Criticality and Urgency under Various Conditions of Visual and Auditory Indications. In *Proceedings of the World Congress on Intelligent Transport Systems 4th Meeting* (9 p.). Brussels, Belgium: ITS Congress Association.

Wickens, C. D., Hollands, J.G. (2000). Attention, Time-Sharing, and Workload. In *Engineering Psychology and Human Performance* (pp.447-453). New Jersey: Prentice-Hall Inc.

APPENDIX A – *Screening Questionnaire*

Name: ________________________

DRIVER SCREENING AND DEMOGRAPHIC QUESTIONNAIRE:
Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

Note to Researcher:
Initial contact with the potential participants may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire (if they agree to participate). Regardless of how contact is made, this questionnaire must be administered before a decision is made regarding suitability for this study.

Introductory Statement (Use the following script as a guideline in the screening interview):

Hello. My name is _____ and I'm a researcher at the Virginia Tech Transportation Institute in Blacksburg, VA. I'm recruiting drivers for a study to evaluate in-vehicle information displays.

This study will begin with a simple vision test. It will also involve questionnaires and coming to the Transportation Institute one time for approximately 4 hours. During the experiment, you would help us evaluate information system's displays by driving a vehicle on the Smart Road while performing some tasks. The vehicle will be equipped with data collection equipment and we will pay you $20 per hour. Would you like to participate in this study?

If they agree:
Next, I would like to ask you several questions to see if you are eligible to participate.

If they do not agree:
Thanks for your time. Do you want me to remove you from the database?

QUESTIONS

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

   Yes _____ No _____

2) How often do you drive each week?

   Every day _____ At least 2 times a week _____ Less than 2 times a week ____

3) How old are you? ______ (Stop if not 18-30 or 55+ years old.)

4) What is your date of birth? ________________

5) Have you previously participated in any experiments at the Virginia Tech Transportation Institute? If so, can you briefly describe the study?

   No _____ Yes _____ Description: _____________________________________

6) How long have you held your drivers' license? ____________________________________

7) Are you able to drive an automatic transmission without assistive devices or special equipment?

Yes _____ No _____

8) Have you had any moving violations in the past 3 years? If so, please explain.

No _____ Yes _____ ____

9) Have you been involved in any accidents within the past 3 years? If so, please explain.

No _____ Yes _____ ____

10) Do you have a history of any of the following? If yes, please explain.

Heart condition	No _____	Yes ________________________________
Heart attack	No _____	Yes ________________________________
Stroke	No _____	Yes ________________________________
Brain tumor	No _____	Yes ________________________________
Head injury	No _____	Yes ________________________________
Epileptic seizures	No _____	Yes ________________________________
Respiratory disorders	No _____	Yes ________________________________
Motion sickness	No _____	Yes ________________________________
Inner ear problems	No _____	Yes ________________________________
Dizziness, vertigo, or other balance problems	No _____	Yes ________________________________
Diabetes	No _____	Yes ________________________________
Migraine, tension headaches	No _____	Yes ________________________________

11) (Females only, of course) Are you currently pregnant?

Yes _____ No _____

(If "yes" then read the following statement to the subject: "*It is not recommended that pregnant women participate in this study. However, female subjects who are pregnant and wish to participate must first consult with their personal physician for advice and guidance regarding participation in a study where risks, although minimal, include the possibility of collision and airbag deployment.*")

12) Are you currently taking any medications on a regular basis? If yes, please list them.

No _____ Yes _____ ____

13) Do you have normal or corrected to normal hearing and vision? If no, please explain.

Yes _____ No _____ ____

14) Have you ever had radial keratotomy, LASIK, or other eye surgeries? If yes, please specify.

No _____ Yes _____ ____

15) Would you be willing and able to drive without sunglasses or tinted lenses while you are participating in this research study?

Yes _____ No _____

16) What language or languages do you speak at home with your family?

English only _____ English and some other language (specify) _____________

I would like to take your name, phone numbers where you can be reached and days and times when it is best to reach you:

Name ____ Male / Female

Phone Numbers (Home)__________________(Work)__________________(Other)__________

Best Time to Call ____

Best Days to Participate ____

Note: When contacting participants for scheduling purposes, the following statement must be included in the conversation: "*We ask that all participants refrain from drinking alcohol and taking any substances that will impair their ability to drive prior to participating in our study.*" We also need to ask them to bring their driver's license in the building with them when they arrive.

Criteria for Participation:

1. ***Must hold a valid driver's license.***
2. ***Must be 18-30 or 55+ years of age.***
3. ***Must drive at least 2 times a week.***
4. ***Must have normal (or corrected to normal) hearing and vision.***
5. ***Must be able to drive an automatic transmission without special equipment.***
6. ***Must not have more than two driving violations in the past three years.***
7. ***Must not have caused an injurious accident in the past two years.***
8. ***Cannot have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, lingering effects from respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.***
9. ***Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).***
10. ***No history of radial keratotomy, LASIK eye surgery, or any other ophthalmic surgery.***
11. ***Must be willing to drive without sunglasses or tinted lenses.***
12. ***Must speak English as first language.***

Accepted: _____ Rejected: _____ Reason: ______________________________________

Screening Personnel (print name): ______________________________ Date: ____________

APPENDIX B – *Informed Consent*

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

Investigators: María C. Fumero Aguiló, Industrial and Systems Engineering Graduate Student and Graduate Research Assistant at the Virginia Tech Transportation Institute

Dr. Suzanne E. Lee, Research Scientist at the Virginia Tech Transportation Institute

I. The Purpose of this Research Project

The purpose of this research is to develop guidelines for the design of In-Vehicle Information Systems (IVIS) to improve safety and user accessibility of information. The experiment will evaluate to what extent the performance of secondary tasks using an IVIS affects driver's performance and results in driver distraction.

II. Procedures

In the study, you will be asked to perform specific tasks using an In-Vehicle Information System (IVIS) as you drive on the Smart Road at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, VA. A trained experimenter 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 operation of the vehicle at all times. You must treat the driving task as the primary task and perform the other instructed tasks 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 instrumented American car. The vehicle is equipped with an automatic transmission, analog instrument cluster, entertainment system (audio), climate-control, and driver information systems. The car is also equipped with an IVIS. 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 measurements 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. In addition, a fire extinguisher, 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 experimental stages 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, you will be asked to fill a health screening questionnaire and we will give you a simple vision test. We will ask to see your driver's license. Once you successfully complete all of these preliminaries we will begin your familiarization. The first stage is expected to last about 10 minutes.

2) Familiarization Stage
   You will be instructed on how to perform the tasks associated with the IVIS. Sample tasks will be demonstrated on a computer set-up in the lab. You will then be taken to the research vehicle where familiarization with the use of the IVIS will be performed. Since the instrument panel and controls may differ from the vehicle you normally drive, it is necessary to familiarize you on the in-vehicle tasks that you will be performing throughout the experiment. You will then be asked to perform a series of tasks using the IVIS with which you were just familiarized. An informal hearing test will be performed at this moment. This stage should take approximately 40 minutes.

3) Driving Stage
   After a brief rest break, you will begin driving the vehicle on the Smart Road and you will be asked to begin performing a series of instructed in-vehicle tasks. The driving stage will be alternated between periods of regular driving and driving while performing the various tasks with which you have been familiarized. This stage is expected to last approximately 3 hours depending on the amount of re-familiarization required. At the end of the drive, you will return to the Transportation Institute building.

4) Debriefing and Payment Stage
   On returning to VTTI, you will be paid and dismissed. This stage should take about 10 minutes.

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

If during the experiment 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 choose to withdraw while driving, you will be asked to drive back to the VTTI. If you do not wish to drive further, the experimenter will drive back to the VTTI.

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 risks or discomforts to which you could be exposed upon volunteering for this research. They include the following:

1) The risk of an accident normally associated with driving an automobile.
2) Possible fatigue due to the length of the experiment. However, you will be given rest breaks during the experimental session.
3) The risk associated with driving an unfamiliar vehicle.
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 you:

1) An experimenter will monitor your driving and will ask you to stop if she 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 save, legal manner.
2) You will be required to wear the lap and shoulder belt restraint system while in the car. The vehicle is also equipped with a driver’s side and passenger’s side airbag supplemental restraint system.
3) The vehicle is equipped with a fire extinguisher, cell phone, and first-aid kit, which may be used in an emergency.
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.
5) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
6) None of the data collection equipment or the display technology interferes with any part of the driver’s normal field of view present in the automobile.
7) You do not have any medical condition that would put you at a greater risk, including but not restricted to epilepsy, balance disorders, and lingering effects of head injuries and stroke.

IV. Benefits of this Research Project

There are no direct benefits to you from this research other than payment for participation. No promise or guarantee of benefits will be made to encourage you to participate. Your participation may have an impact on the improved designs of IVIS. Improvements in the design of IVIS 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 anonymity. Shortly after you have participated, your name will be separated from your data. A coding scheme will be employed to identify your data by participant number only.

Eye movement behavior is measured using a video camera and recorder during the experiment. The camera is positioned inside the center rearview mirror. The video image recorded is of the driver’s head with some additional space around to accommodate any head movements by the driver during data collection. The videotapes will be stored in a locked filing cabinet at VTTI.

Access to the tapes will be under the supervision of Dr. Suzanne E. Lee. María Fumero will have access to the tapes. The videotapes will be erased one year after the data has been analyzed and the results documented. 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 $20.00 per hour for your participation in this study. Payment will be made immediately after you have finished your participation.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time for any reason. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. You are free not to answer any questions or respond to any research situations without penalty.

VIII. Approval of Research

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

IX. Participant's Responsibilities

If you voluntarily agree to participate in this study, you will 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.
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 a vehicle. It is my responsibility to inform the experimenter 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, 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 vehicle 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 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 understand that I may withdraw at any time without penalty. I agree to abide by the rules of this research project.

______________________________	__________________
Participant's Signature	Date
______________________________	__________________
Experimenter's Signature	Date

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

Mrs. María C. Fumero (540) 231-1536
Principal Investigator

Dr. Suzanne E. Lee (540) 231-1511
Faculty Advisor

David Moore (540) 231-4991
Chair of the Virginia Tech Institutional Review Board

Participants must be given a complete copy (or duplicate original) of the signed Informed Consent.

APPENDIX C – *Health Screening Questionnaire*

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? (If yes, please describe.)

Visual impairment Yes _____ No _____

____

____

Hearing impairment Yes _____ No _____

____

____

Seizures or other lapses of consciousness Yes _____ No _____

____

____

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

____

____

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 above?

Yes _____ No _____

________________________________ Signature

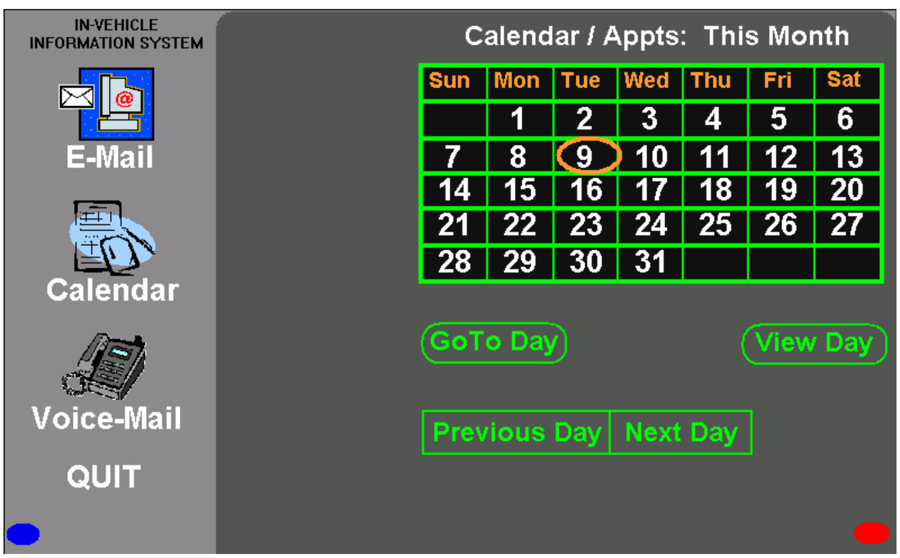
___________________________ Date

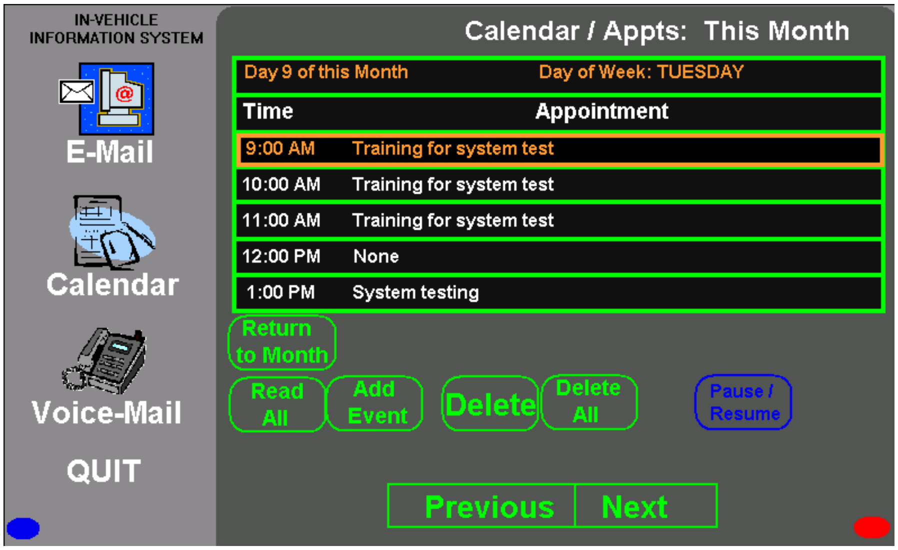
APPENDIX D – *IVIS Interface Screen Sequences*

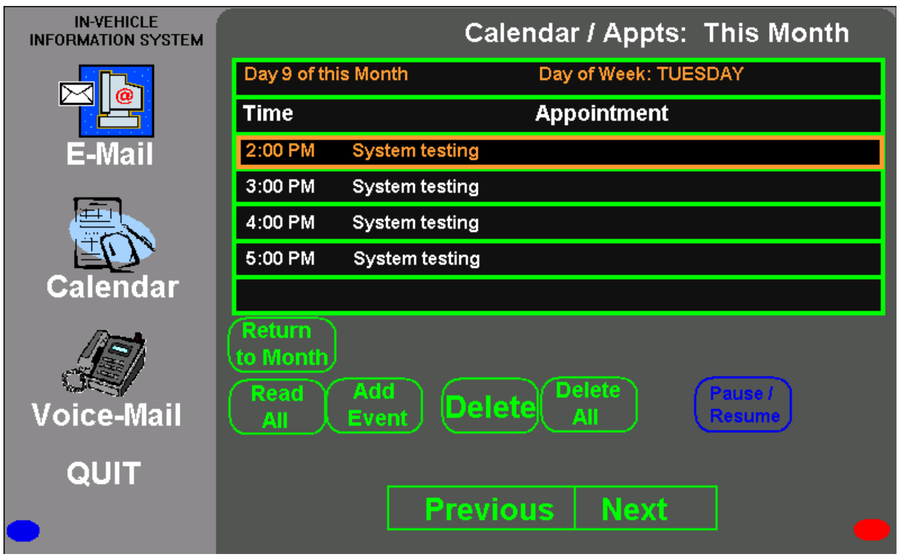
D.1 IVIS Main Screen

D.2 Calendar Application Tasks

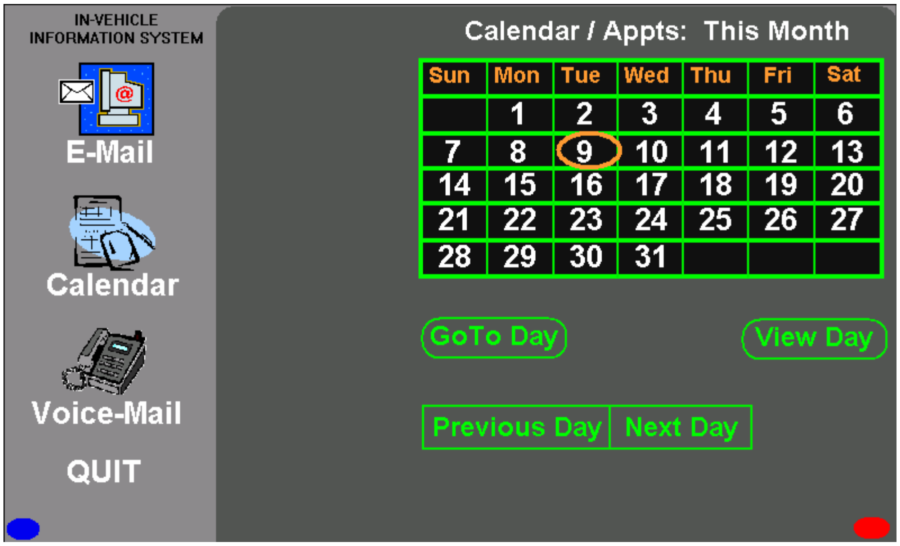
D.2.1 Go to a particular date and view/listen to the schedule for that day:

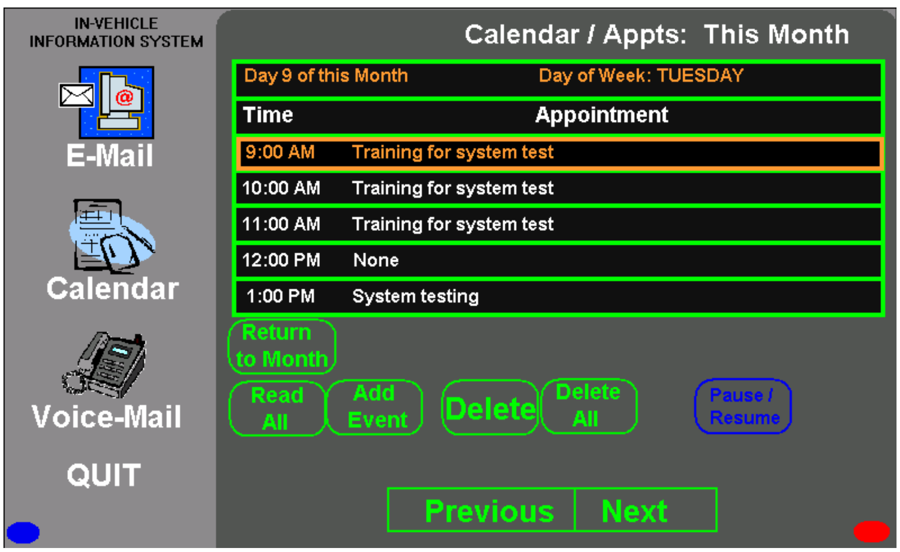


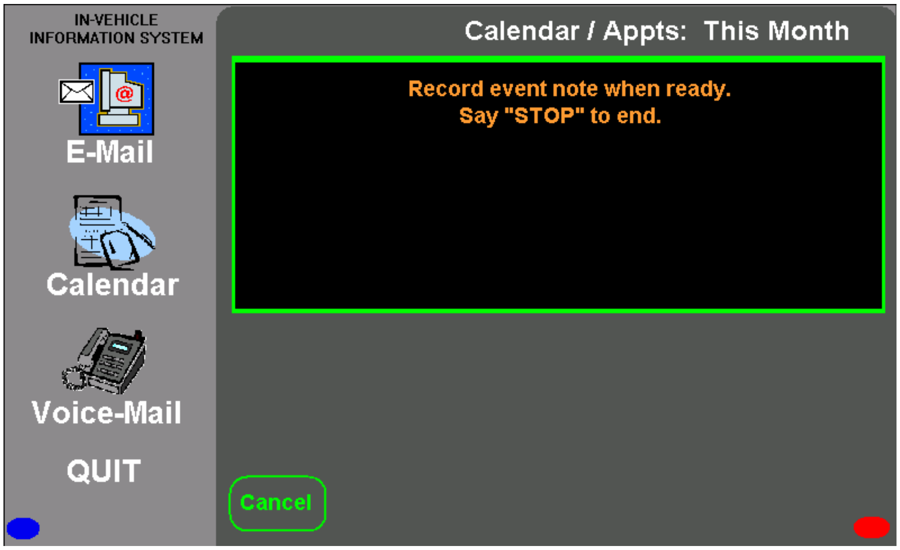

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Calendar / Appts: This Month
Day 9 of this Month
Day of Week: TUESDAY
Time
Appointment
9:00 AM Training for system test
10:00 AM Training for system test
11:00 AM Training for system test
12:00 PM None
1:00 PM System testing
Return to Month
Read All
Add Event
Delete
Delete All
Pause / Resume
Previous
Next

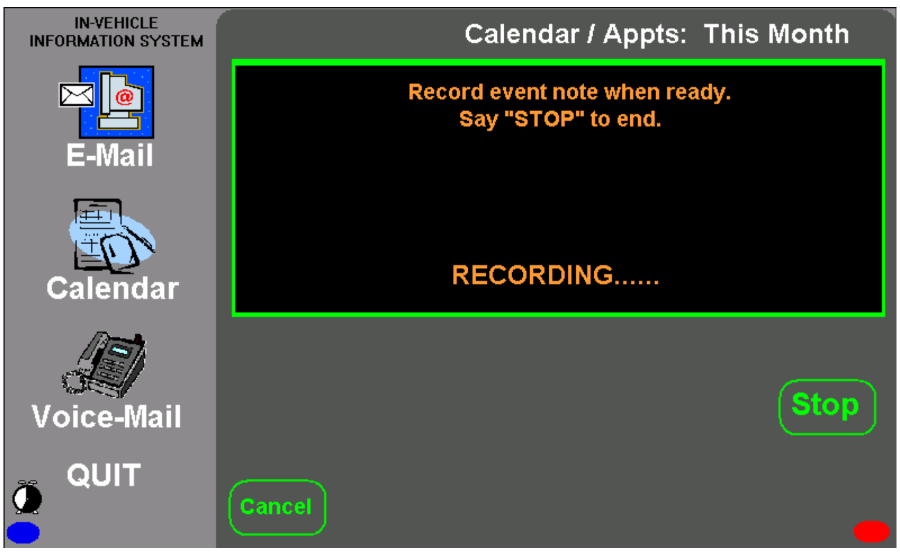

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Calendar / Appts: This Month
Day 9 of this Month
Day of Week: TUESDAY
Time
Appointment
2:00 PM System testing
3:00 PM System testing
4:00 PM System testing
5:00 PM System testing
Return to Month
Read All
Add Event
Delete
Delete All
Pause / Resume
Previous
Next

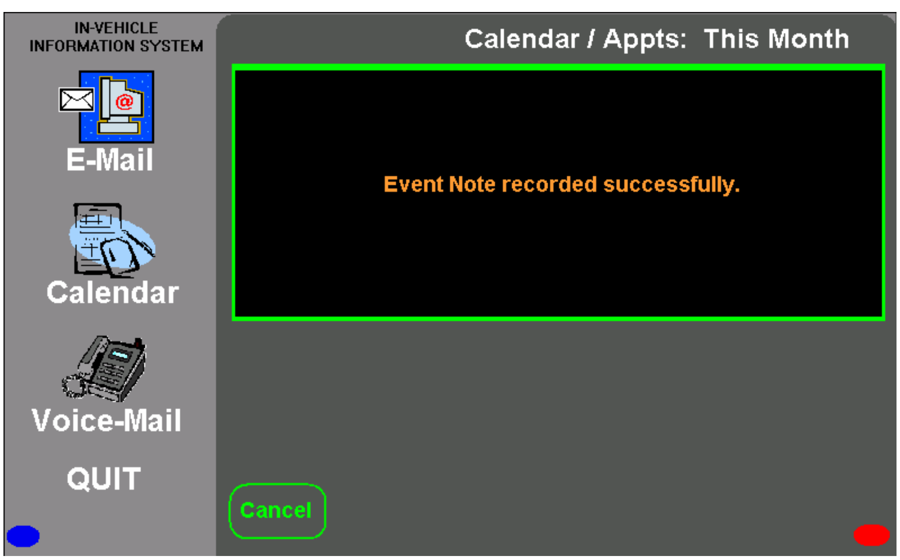
D.2.2 Add an event to a particular date:



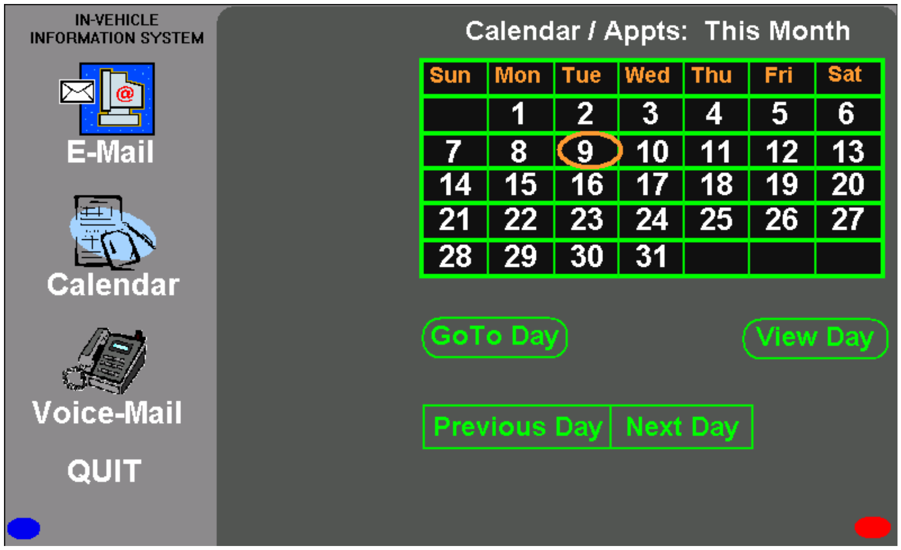


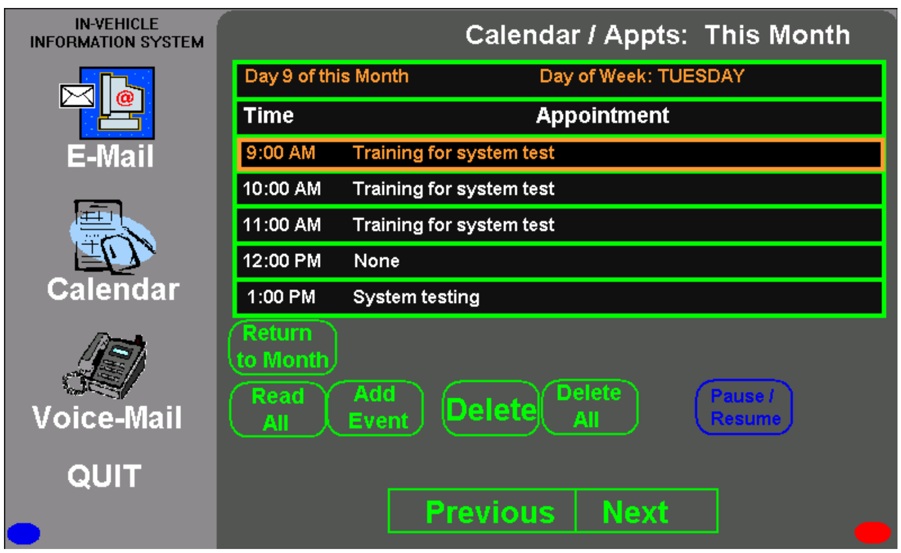

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Calendar / Appts: This Month
Record event note when ready.
Say "STOP" to end.
Cancel


IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Calendar / Appts: This Month
Record event note when ready.
Say "STOP" to end.
RECORDING......
Stop
Cancel


IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Calendar / Appts: This Month
Event Note recorded successfully.
Cancel

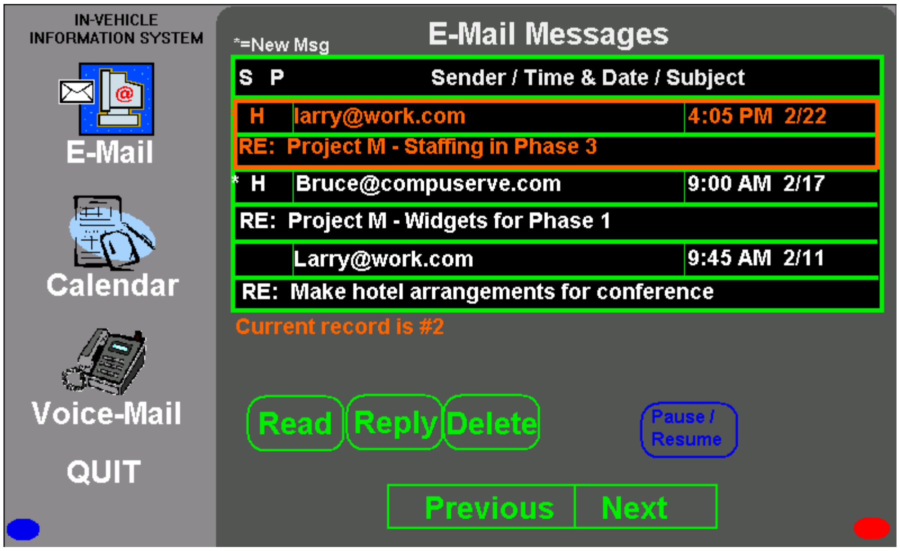
D.2.3 Delete an event note for a particular date:

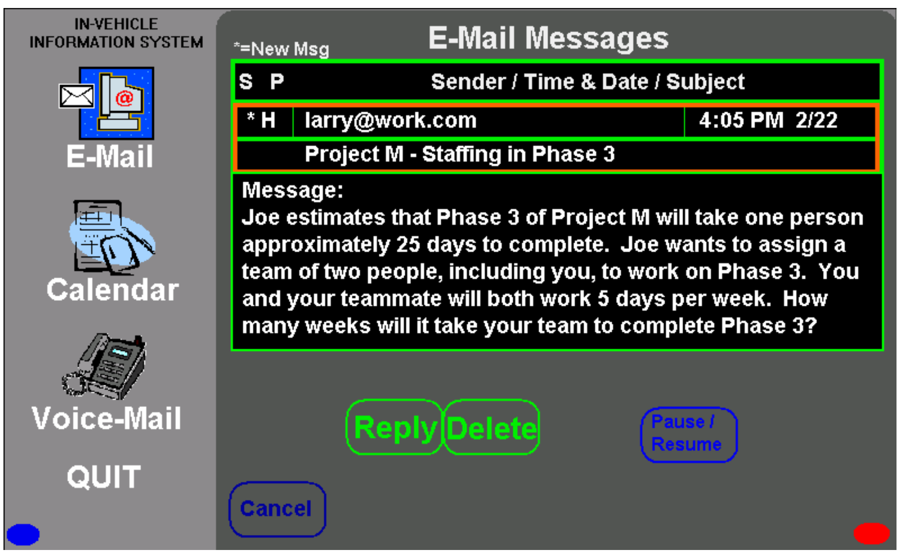




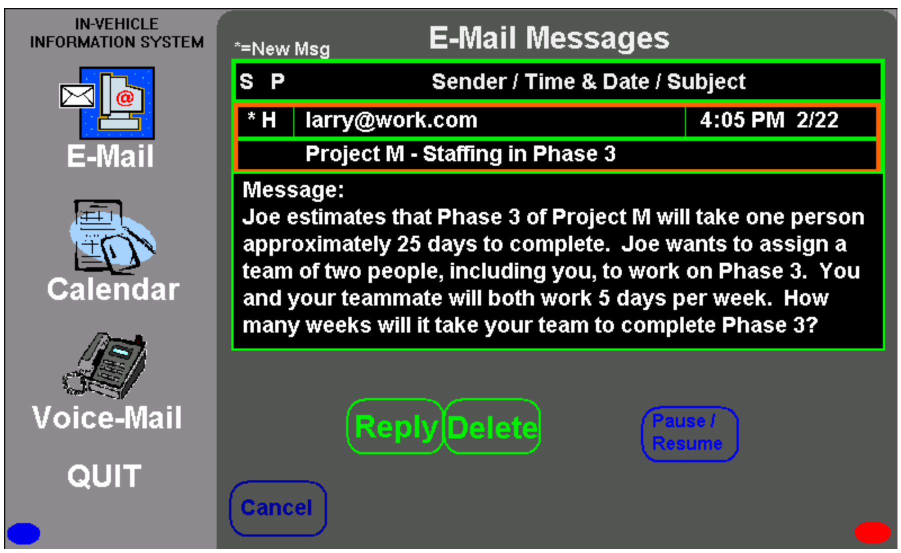
D.3 E-mail Application Tasks

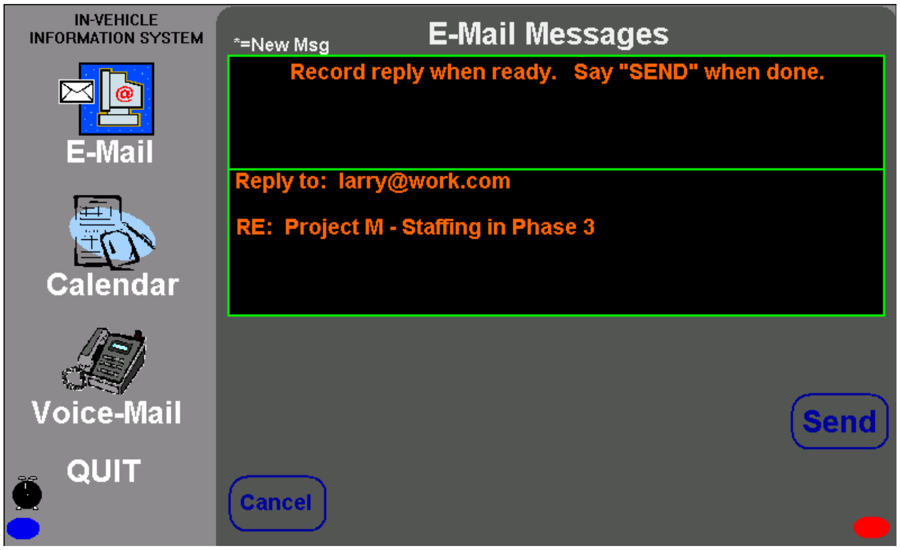
D.3.1 Check a new or unread message:

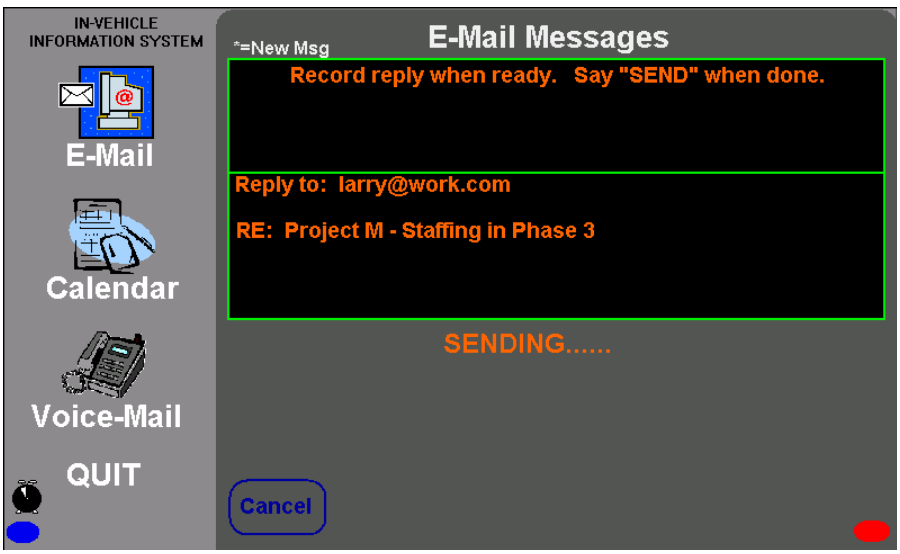


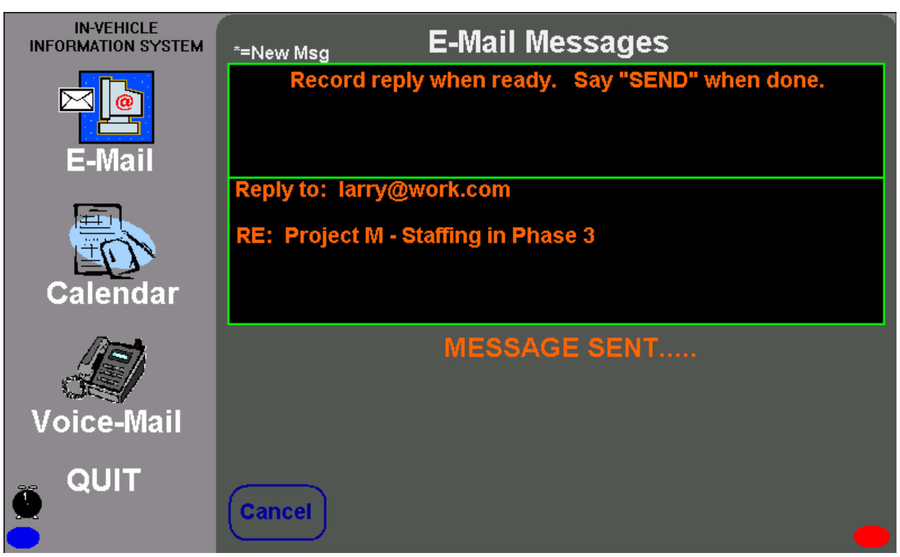


D.3.2 Check a message and send a reply to it:




IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
*=New Msg
E-Mail Messages
Record reply when ready. Say "SEND" when done.
Reply to: larry@work.com
RE: Project M - Staffing in Phase 3
Send
Cancel

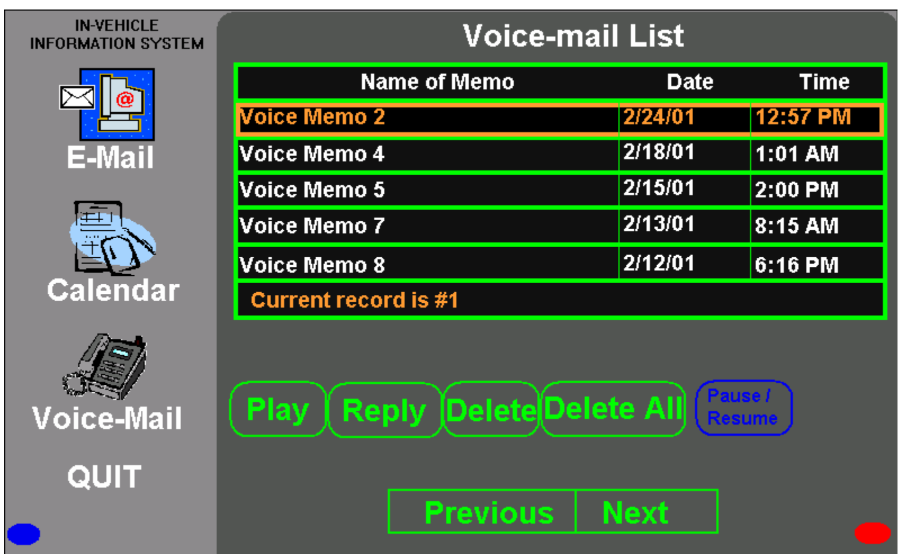

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
*=New Msg
E-Mail Messages
Record reply when ready. Say "SEND" when done.
Reply to: larry@work.com
RE: Project M - Staffing in Phase 3
SENDING......
Cancel

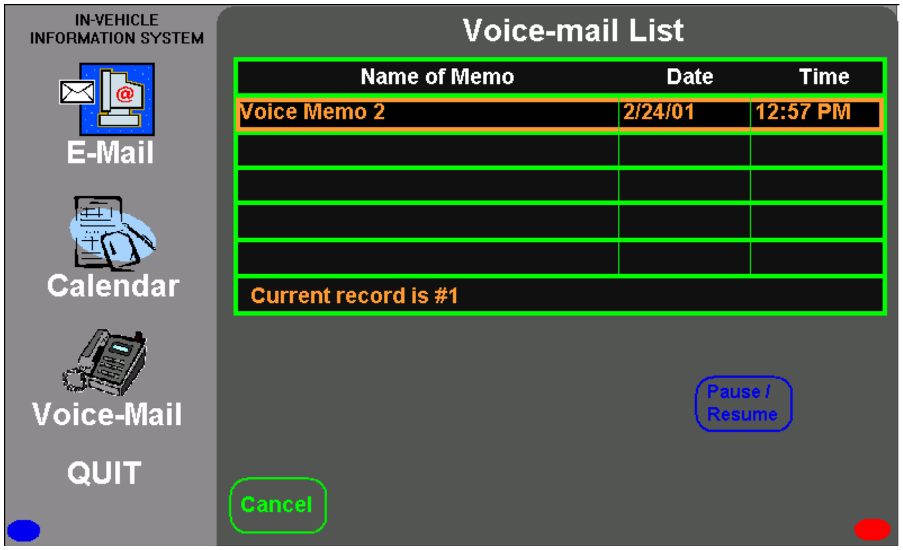

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
*=New Msg
E-Mail Messages
Record reply when ready. Say "SEND" when done.
Reply to: larry@work.com
RE: Project M - Staffing in Phase 3
MESSAGE SENT.....
Cancel

D.3.3 Delete a particular message:

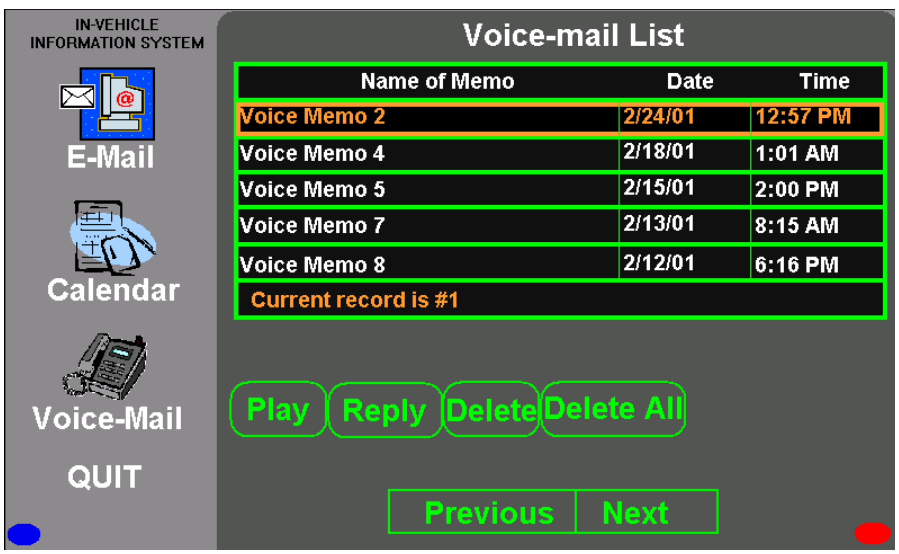
D.4 Voice-mail Application Tasks

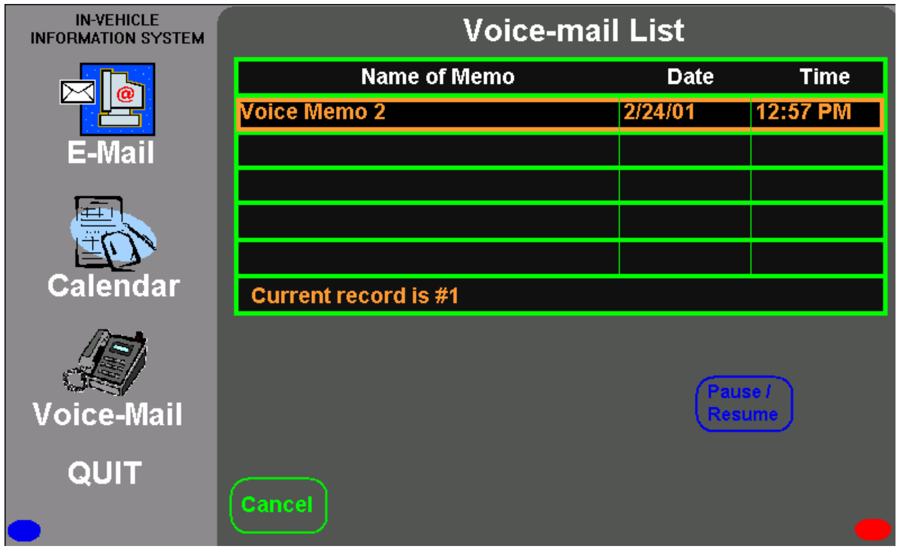
D.4.1 Listen to a specific voice-mail message:

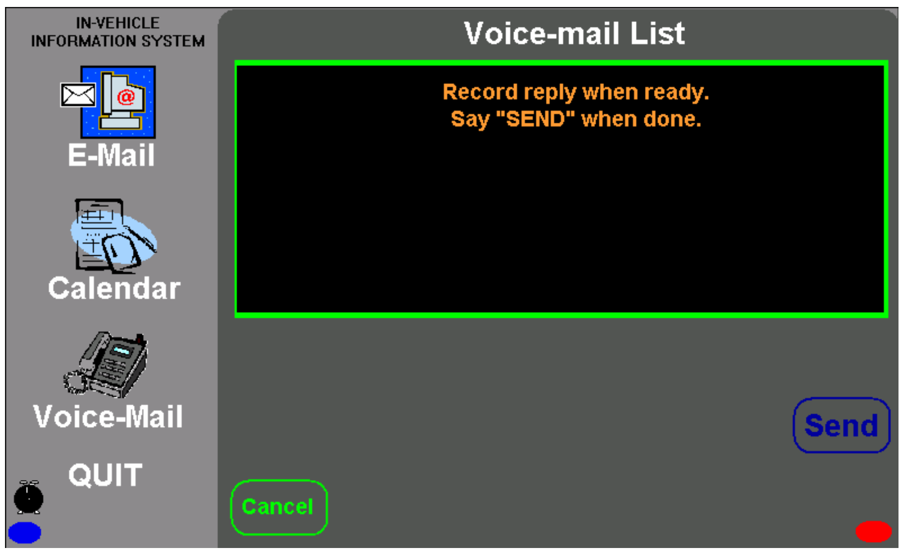


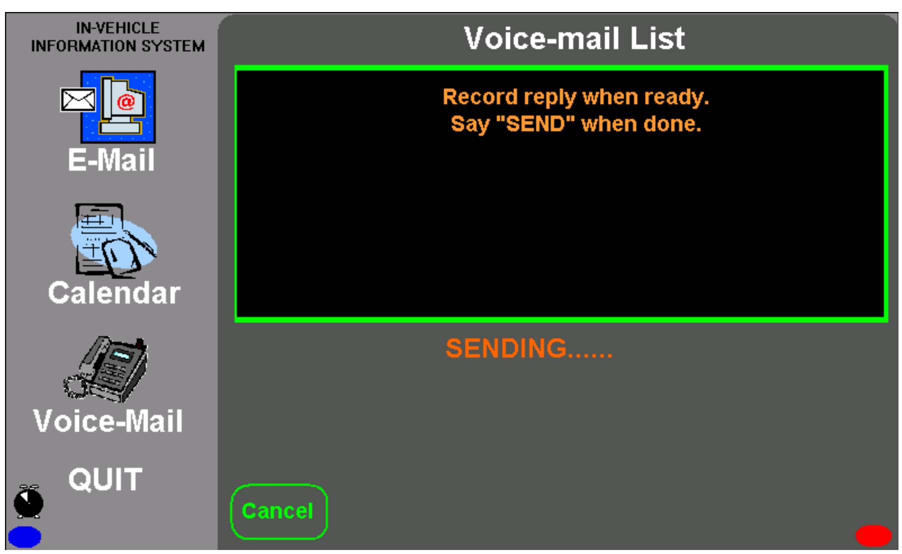


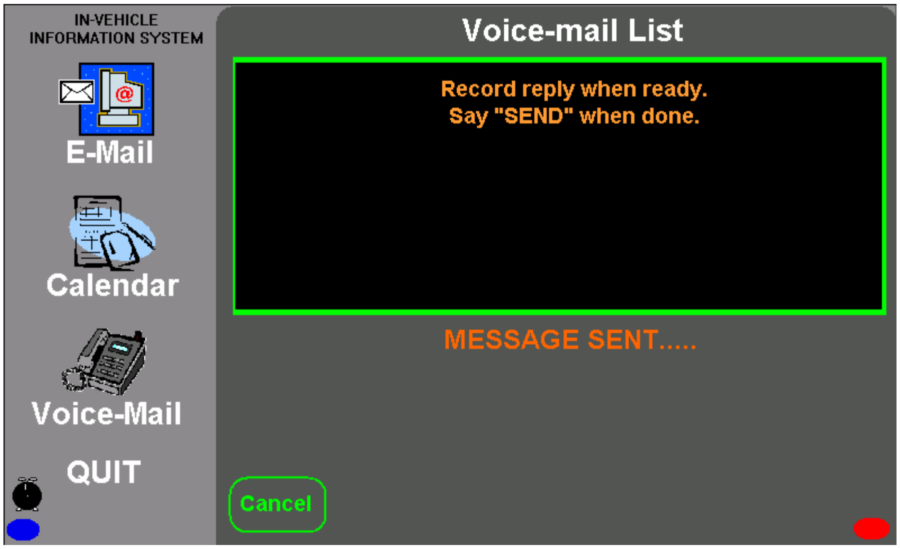
D.4.2 Reply to a specific voice-mail message:



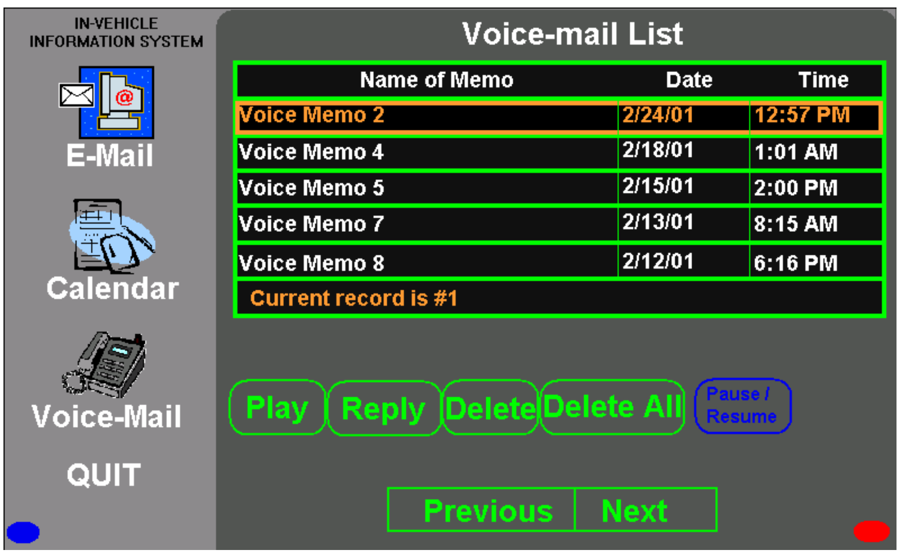

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Voice-mail List
Name of Memo
Date
Time
Voice Memo 2
2/24/01
12:57 PM
Current record is #1
Pause / Resume
Cancel

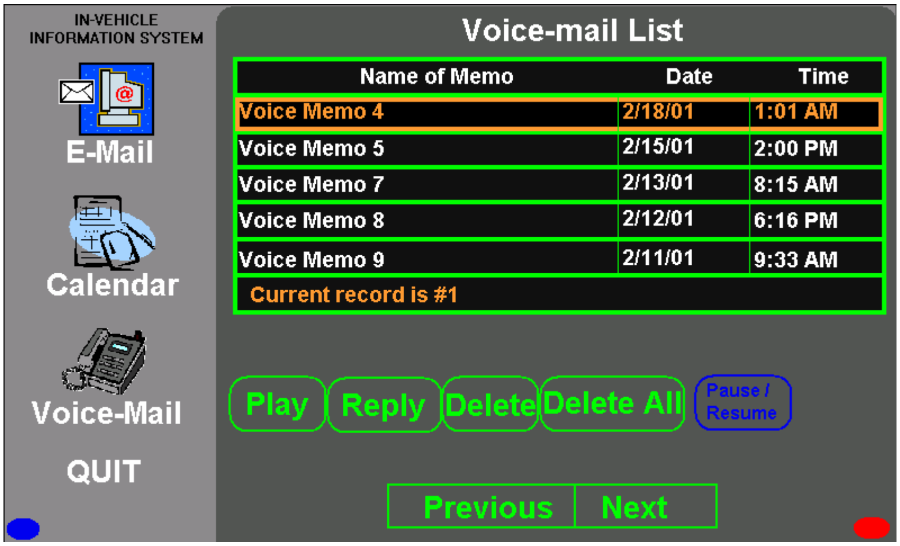

IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Voice-mail List
Record reply when ready.
Say "SEND" when done.
Send
Cancel


IN-VEHICLE
INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Voice-mail List
Record reply when ready.
Say "SEND" when done.
SENDING......
Cancel



D.4.3 Delete a voice-mail message:




IN-VEHICLE INFORMATION SYSTEM
E-Mail
Calendar
Voice-Mail
QUIT
Voice-mail List
Name of Memo
Date
Time
Voice Memo 4
2/18/01
1:01 AM
Voice Memo 5
2/15/01
2:00 PM
Voice Memo 7
2/13/01
8:15 AM
Voice Memo 8
2/12/01
6:16 PM
Voice Memo 9
2/11/01
9:33 AM
Current record is #1
Play
Reply
Delete
Delete All
Pause / Resume
Previous
Next

APPENDIX E – *Mental Workload Evaluation Instructions*

VIRGINIA TECH TRANSPORTATION INSTITUTE
Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

MENTAL WORKLOAD SUBJECTIVE ASSESSMENT INSTRUCTIONS

We are not only interested in assessing your performance, but also your experiences during the different task conditions. The technique to examine your experiences will be a subjective rating to measure your perceived workload. The perceived workload is something that is experienced individually for what there are no specific rules to estimate the workload related to different activities. One way to evaluate workload is to describe your experienced feelings related to an activity or task. The workload contributed by different task elements may change as you get more familiar with a task, perform an easier or harder version of it, or move from one task to another. Instead of having an overall evaluation, factors that may cause workload should be evaluated individually. The three factors evaluated in this subjective assessment will be mental demand, temporal demand, and frustration level.

Please read the descriptions of the scales carefully. If you have a question about any of the scales, please ask me about it. It is extremely important that they be clear to you. You may require a description of the scales if you wish at any time during the experiment.

Mental demand is described as how much thinking you felt was required to perform the task correctly. Low mental demand would result from a task that was easily performed. High mental demand would be felt when a task required extensive thinking and you are not sure of having performed it correctly.

Temporal (time) demand ratings assess how difficult it is to drive and perform a secondary task at the same time. Low time demand could occur if you do not need to focus on the task. High time demand may be indicated by the difficulty in concentrating and the need to switch back and forth between driving and the secondary task.

Frustration level may be indicated by the frustration felt depending on the level of complexity, confusion, and interference of the secondary task with the main task of driving. A low level of frustration would occur if the secondary task makes sense and is not difficult to perform. High level of frustrations would be obtained when a secondary task is confusing and interferes with driving.

After performing each task, you will be asked to evaluate the secondary task with the explained scales. A numerical value from one to 100 must be selected for each of the three scales. Each scale has two endpoint descriptors that go from low (1) to high (100). For example, Mental Demand goes from 1 (not demanding) to 100 (extremely demanding). The following table presents the three scales to be used and their corresponding rating-scale definitions. The experimenter will provide you with a sheet of paper with the three scales and you will mark down your evaluation of the task you just completed. 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.

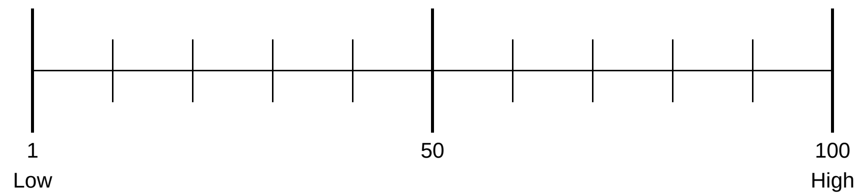
RATING-SCALE DESCRIPTIONS

Title	Endpoints	Descriptions
Mental Demand	Low, High 1 - 100	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?
Temporal Demand	Low, High 1 - 100	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	Low, High 1 - 100	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

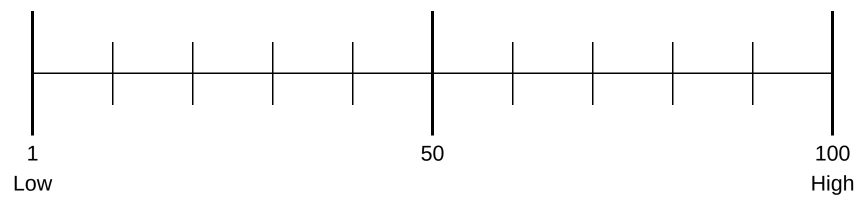
Example:

Solve a mathematical problem while riding a bicycle.
How would you rate your mental workload using the following scales?

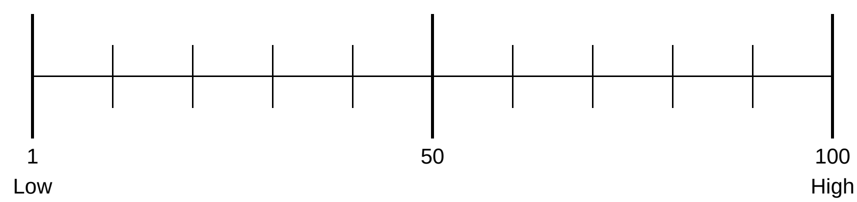
Mental Demand



Time Demand



Frustration Level



APPENDIX F – ***Vision and Hearing Tests Form***

VIRGINIA TECH TRANSPORTATION INSTITUTE
Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

VISION AND HEARING TESTS

1. Snellen Eye Chart Test

Acuity Score: ___________

2. Ishihara Test for Color Blindness

1. ______ 3. ______ 5. ______ 7. ______

2. ______ 4. ______ 6. ______

3. Informal Hearing Test

	CORRECT	INCORRECT
TASK 1	_________	__________
TASK 2	_________	__________
TASK 3	_________	__________
TASK 4	_________	__________

APPENDIX G – *Experimenter Protocol*

VIRGINIA TECH TRANSPORTATION INSTITUTE

<u>Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech</u>

EXPERIMENTER PROTOCOL

1. **Contact participants (using VTTI's participants database)**
2. ***Driver Screening and Demographics Questionnaire* (over the phone)**
3. **Make appointment**
4. **Get Participant Pack**
    a. *Debriefing Form*
    b. *Informed Consent Form* (2 copies)
    c. *W-9 Tax Form*
    d. *Health Screening Questionnaire*
    e. *Vision and Hearing Tests Form*
    f. *Tasks Presentation Order*
    g. *In-Vehicle Experimenter Log*
    h. *Mental Workload Rating Scales*
    i. *Post-Test Questionnaire*
5. **Get Experimenter Pack**
    a. Experimenter Comments Form
    b. IVIS Familiarization and Tasks Instructions
    c. Mental Workload Subjective Assessment Instructions
    d. Participant Payment Receipt Log
    e. Laptop
    f. Radio
6. **Prepare vehicle**
    a. Unlock vehicle
    b. Turn on current inverter (behind back seat)
    c. Open system box inside the trunk
    d. Place cassettes on VCRs
    e. Place zip disk on zip drive
    f. Close and lock system box and trunk
    g. Start vehicle
    h. Check gasoline level
    i. Warm-up vehicle
    j. Turn on A/C / heater
    k. Drive vehicle to lobby entrance
    l. Turn off current inverter and vehicle

7. Set-up Meeting Room

a. Participant Pack
b. Experimenter Pack
c. Close shades and turn on lights
d. Connect monitor to laptop
e. Get vision tests materials (eye chart and color blindness test)

8. Greet Participant

a. Record date and arrival time in *Debriefing Form* and *Experimenter Comments Form*
b. Record weather conditions in the *Experimenter Comments Form*

"The goal of this experiment is to evaluate in-vehicle information system's displays. The study will consist of driving on the Smart Road. I will be riding in the back seat and will ask you to perform some tasks. I will also ask you questions after you complete each task.

Along the drive, I will ask you to perform tasks using the IVIS. You will always access the system verbally and the system will be presented to you either visually, auditory, or both. If at any time you feel that the information is too complex to read or listen while driving, simply say skip. I will not be testing your ability to perform a task, but the system used.

There is some paperwork that we have to go through. Some will provide you with more information about the study. Before we begin, do you have any questions?"

9. Ask for driver's license and check expiration date

10. Informed Consent

"Please read and sign this Informed Consent Form. It outlines what is expected of you during this experiment and what you can expect of the researchers. Please read it carefully. If you have any questions, please ask. When you are finished, and all your questions have been answered, please sign and date the form if you agree to participate."

a. Give the form to the participant and encourage him/her to read it
b. Answer any questions the participant may have
c. Have the participant sign and date the form
d. Give the participant a copy of the Informed Consent Form

11. Tax form

a. Fill in name, Tax ID number (SSN), and address
b. Sign and date the form

<u>NOTE</u>: If the participant makes more than $500.00 doing studies from January 1st to December 31st this will be reported to the IRS as income.

c. Back of the form

"This says that we are not hiring you full time. There will not be any health benefits, paid vacations, etc. We cannot fire you because we are not really hiring you. You can quit at any time without being held liable for services by the university. You are a one-time contractor. If you already work for Virginia Tech, this is completely separate from your job, and your performance will not have any effect on your employment with Virginia Tech."

12. Health Screening Questionnaire

"This is a health questionnaire. Your answers to these questions will be treated confidentially. We ask these questions to ensure that driving the experimental vehicle will not pose a greater than normal risk to you."

a. Give questionnaire to the participant
b. Answer any questions the participant may have
c. Have the participant fill, sign, and date the form

NOTE: The participant must be in good general health, have revealed no medical conditions, and be taking no medications and/or drinks that would adversely affect his driving.

13. Vision Tests

Record the vision tests results in the *Vision and Hearing Tests Form*.

a. Snellen Eye Chart Vision Test

   1) Take the participant to the eye chart test area
   2) Line up his/her toes to the line on the floor (20 feet from the chart).
   3) Participants should wear his/her glasses or contact lenses if prescribed for driving.

"Look at the wall and read aloud the smallest line you can comfortably read."

   4) If the participant reads every letter on the first line correctly, have him/her try the next line.
   5) Repeat this until he/she misses a letter and record the acuity of the last line they got completely correct.
   6) If the participant does not correctly read every letter on the first line, move up a line and have him/her try again.
   7) Repeat as needed and record the acuity of the first line they got completely right.

b. Ishihara Test for Color Blindness

   1) Take the participant back to the desk
   2) Place the book containing the plates on the testing apparatus

"Please hold the red end of this handle to your nose and read the number on the following plates."

   3) Record the participants' answers.

14. IVIS training

a. Take the participant to the training monitor
b. Follow the *IVIS Familiarization and Tasks Instructions*

15. Mental Workload Subjective Assessment Instructions

a. Read and discuss the *Mental Workload Subjective Assessment Instructions* with the participant
b. Make sure the participant understands that the rate could be ***ANY*** number from 1 to 100.

16. Distracting Light (External Reaction Time Measure)

"A light located on the top of the vehicle's hood will light up during the run. Every time you see this light, you must push with your left foot, the switch located to the left of the vehicle's pedals. This is to be done while the vehicle is moving at the road, not at the turnarounds or when it stops."

17. In-Vehicle familiarization

a. Start the vehicle
b. Connect the following to the laptop: display monitor, audio tape, current source
c. Turn on current inverter
d. Start Authorware® programs
e. Take participant to the vehicle
f. Have the participant to do the following:
   1) Adjust seat and mirrors
   2) Locate and become comfortable with vehicle controls (wipers, lights, etc.)

g. Perform informal hearing test
   1) Participant must be in driver's seat
   2) Experimenter must be in back seat
   3) Ask participant to repeat experimenter's instructions
   4) Ask participant to repeat system's message
   5) Ask participant if he/she would like to increase/decrease volume
   6) If the participant is unable to understand the information presented auditorily, excuse the participant.

h. Enter participant information in the computer software (part. #, age, and gender)
i. Review IVIS functions, mental workload assessment, and distracting light function
j. Press "REC" on VCR to start recording
k. Drive practice lap without tasks / Collect baseline data

   "First we will drive down the road to get you used to the road and the vehicle. Go ahead and drive down the road at 35 miles per hour and turn off the light at the hood with the switch on the floor as explained before."

l. Instruct participants to inform the experimenter if they need a break at any time.
m. Proceed with experimental run and data collection

18. Experimental Run

a. Experimenter presents/gives tasks to the participant by predetermined presentation order. Experimenter will give the task instructions twice.
b. Ask participant to repeat the task instructions and remind him/her to reach and maintain 35 mph and to turn off the hood light.
c. Ask participant to start moving and enter the road: *"You can enter the road now"*.
d. Experimenter presses the space bar in the vehicle's computer keyboard to mark the beginning of the task.
e. When the participant reaches 35 mph the experimenter says *'GO"* to indicate the participant that he/she can begin to perform the task.
f. Participant performs the task
g. Experimenter writes down any observations on the *Comments/Observations Form*

h. Immediately following each task, a probe question will be asked
i. Ask participant to exit the road into a turnaround at the side of the road.
j. After each task, when the vehicle is at a stop, the participant will rate mental workload with the *Mental Workload Rating Scales*
k. Repeat the process a-j until all tasks are performed. Half-way through, ask the participant if he/she needs a break.
l. After all tasks are performed ask participant to drive back to the lobby area

19. Post-Test Questionnaire

a. Give questionnaire to the participant

20. Debriefing Form

a. Record end time, total number of hours, and payment
b. Sign the form

21. Participant Payment Receipt Log

a. Enter date and amount paid
b. Ask participant to write his/her name, SSN, and signature in the log

22. Pay Participant

23. Thank Participant

24. Experimenter Comments Form

a. Enter end time and any comments

25. Actualize Petty Cash Custodian Log

26. After Experimental Run Protocol

a. Open trunk
b. Open system box
c. Save data onto Zip disk
d. Take cassettes from VCRs
e. Take Zip disk from Zip drive
f. Shut off the computer
g. Close and lock system box
h. Close trunk
i. Turn off current inverter
j. Check gasoline level
k. Drive vehicle to parking lot
l. Turn off vehicle
m. Lock vehicle

APPENDIX H – *IVIS Instructions*

VIRGINIA TECH TRANSPORTATION INSTITUTE

Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

IN-VEHICLE INFORMATION SYSTEM FAMILIARIZATION AND TASKS INSTRUCTIONS

Please, feel free to ask any questions you may have at any time.

Your primary task is to safely drive the vehicle; you should allow nothing to interfere with this. As you are driving, you will be requested to perform tasks using an In-Vehicle Information System that will be presented to you either visually, auditorily, or both. These are secondary tasks and you should not allow them to interfere with safely driving the vehicle.

The following will cover an explanation, instructions, and examples of the tasks you will be performing in the vehicle with the In-Vehicle Information System (IVIS). The IVIS consists of three applications: (1) Calendar, (2) E-Mail, and (3) Voice-Mail. I will show you three types of tasks that could be performed with each of the three applications. Please, have in mind that there may be more than one sequence of steps to perform each task. The sequences that I will show you are intended to aid you in understanding how the device works. The practice tasks will be presented using the multi-modal display (using both, visual and audio).

I will show you how to perform each task. Then you may practice each task three times. I will tell you when to begin. When you feel the task has been completed you should say "DONE". Now we will practice the tasks so that you may understand how the system works.

I will present the tasks instructions verbally. You will access the system and perform the tasks verbally. After each task, I will ask you a probe question and you will rate the mental workload associated with each task.

CALENDAR

TASK: *Go to a particular date and view/listen to the schedule for that day.*

INSTRUCTIONS:

Say CALENDAR

Say GO TO DAY ___ or say NEXT/PREVIOUS to scroll to the desired day of the month

Say VIEW DAY to view the schedule for the selected day

Say READ ALL to view/listen to the notes for the selected day

Say DONE to finish

PRACTICE TASKS:

Demo	Go to *Wednesday Day 10* and listen to the schedule for that day.
Practice 1	Go to *Monday Day 8* and listen to the schedule for that day.
Practice 2	Go to *Sunday Day 14* and listen to the schedule for that day.
Practice 3	Go to *Friday Day 26* and listen to the schedule for that day.

CALENDAR

TASK: *Add an event to a particular date.*

INSTRUCTIONS:

Say CALENDAR

Say GO TO DAY ___ or say NEXT/PREVIOUS to scroll to the desired day of the month

Say VIEW DAY to view the schedule for the selected day

Say NEXT/PREVIOUS to scroll to desire time of day

Say ADD EVENT and give event information for the specified time of day

Say STOP to end recording event note

Say DONE to finish

PRACTICE TASKS:

Demo	Go to *Monday Day 1* and add a *Staff Meeting* at *3:00 PM*.
Practice 1	Go to *Friday Day 19* and add a *Staff Meeting* at *10:00 AM*.
Practice 2	Go to *Thursday Day 11* and add a *Staff Meeting* at *2:00 PM*.
Practice 3	Go to *Sunday Day 28* and add a *Staff Meeting* at *11:00 AM*.

CALENDAR

TASK: *Delete an event note for a particular date.*

INSTRUCTIONS:

Say CALENDAR

Say GO TO DAY ___ or say NEXT/PREVIOUS to scroll to the desired day of the month

Say VIEW DAY to view the schedule for the selected day

Say NEXT/PREVIOUS to scroll to desire time of day

Say DELETE

Say DONE to finish

PRACTICE TASKS:

Demo	Go to *Monday Day 1* and delete *9:00 AM* event. *(Meeting with Accounting).*
Practice 1	Go to *Wednesday Day 10* and delete *8:00 AM* event. *(Business Travel).*
Practice 2	Go to *Tuesday Day 23* and delete *3:00 PM* event. *(System Testing).*
Practice 3	Go to *Friday Day 26* and delete *12:00 PM* event. *(Lunch with Dithers).*

E-MAIL

TASK: *Check a new or unread message.*

INSTRUCTIONS:

Say E-MAIL

Say NEXT/PREVIOUS to scroll to the desired message

Say READ to listen/view the message

Say DONE to finish

PRACTICE TASKS:

Demo	Select and listen/view message from *Payroll Office*.
Practice 1	Select and listen/view message from *Boss* about *Equipment Problem*.
Practice 2	Select and listen/view message from *Larry* about *Project M*.
Practice 3	Select and listen/view message from *Bruce*.

E-MAIL

TASK: *Check a message and send a reply to it.*

INSTRUCTIONS:

Say E-MAIL

Say NEXT/PREVIOUS to scroll to the desired message

Say READ if you want to listen/view the message

Say REPLY and say the reply message

Say SEND to end recording and transmit the message

Say DONE to finish

PRACTICE TASKS:

Demo	Select and reply to message from *Payroll Office*. *Reply: Please hold the check until Monday.*
Practice 1	Select and reply to message from *Boss* about *Equipment Problem*. *Reply: We need to get the equipment repaired as soon as possible.*
Practice 2	Select and reply to message from *Larry* about *Project M*. *Reply: We will need at least 2½ weeks to do the job.*
Practice 3	Select and reply to message from *Bruce*. *Reply: $5,000 is too much to spend for 5 widgets.*

E-MAIL

TASK: *Delete a particular message.*

INSTRUCTIONS:

Say E-MAIL

Say NEXT/PREVIOUS to scroll to the desired message

Say READ if you want to listen/view the message

Say DELETE to erase the message

Say DONE to finish

PRACTICE TASKS:

Demo	Select and delete the message from *Payroll Office*.
Practice 1	Select and delete the message from *Larry* about *Project M*.
Practice 2	Select and delete the message from *John* about *the proposal submission*.
Practice 3	Select and delete the message from *Boss* about *Equipment Problem*.

VOICE-MAIL

TASK: *Listen to a specific Voice-Mail message.*

INSTRUCTIONS:

Say VOICE-MAIL

Say NEXT/PREVIOUS to scroll to the desired message

Say PLAY to listen the message

Say DONE to finish

PRACTICE TASKS:

Demo	Listen to *Voice Memo 7*.
Practice 1	Listen to *Voice Memo 2*.
Practice 2	Listen to *Voice Memo 9*.
Practice 3	Listen to *Voice Memo 5*.

VOICE-MAIL

TASK: *Reply to a specific Voice-Mail message.*

INSTRUCTIONS:

Say VOICE-MAIL

Say NEXT/PREVIOUS to scroll to the desired message

Say PLAY if you want to listen to the message

Say REPLY and say the reply message

Say SEND to end recording and transmit the message

Say DONE to finish

PRACTICE TASKS:

Demo	Select and reply to *Voice Memo 7*. *Reply: They are on the third floor.*
Practice 1	Select and reply to *Voice Memo 2*. *Reply: We should do it by Wednesday.*
Practice 2	Select and reply to *Voice Memo 9*. *Reply: They don't give any discounts.*
Practice 3	Select and reply to *Voice Memo 5*. *Reply: Ask for a 25% discount.*

VOICE-MAIL

TASK: *Delete a Voice-Mail message.*

INSTRUCTIONS:

Say VOICE-MAIL

Say NEXT/PREVIOUS to scroll to the desired message

Say PLAY if you want to listen to the message

Say DELETE to erase the message

Say DONE to finish

PRACTICE TASKS:

Demo	Delete *Voice Memo 2*.
Practice 1	Delete *Voice Memo 4*.
Practice 2	Delete *Voice Memo 8*.
Practice 3	Delete *Voice Memo 9*.

APPENDIX I – *Tasks and Probe Questions*

T	APP.	DISPL.	DIFF.	TASK	QUESTION	ANSWER
1	Calend.	Aud - F	E	Go to Tuesday, day 2 and listen to the schedule for the day.	What is to be done during the afternoon?	System testing.
2	Calend.	Aud - F	D	Go to Thursday, day 4 and add a Lunch with John Smith at 12:00 PM.	Is there any meeting during the day?	No.
3	Calend.	Aud - N	E	Go to Thursday, day 18 and listen to the schedule for the day.	What is the main schedule for the morning?	Business travel.
4	Calend.	Aud - N	D	Go to Monday, day 15 and delete 2:00 PM event.	What was the event just deleted?	Meeting with Peter Raines.
5	Calend.	MM - F	E	Go to Sunday, day 21 and view/listen to the schedule for the day.	Are there any meetings during the day?	Yes, with team for training debriefing.
6	Calend.	MM - F	D	Go to Tuesday, day 23 and add a Meeting with team at 5:00 PM.	What was the existing event at 5:00 PM?	System testing.
7	Calend.	MM - N	E	Go to Friday, day 5 and view/listen to the schedule for the day.	How many meetings are scheduled during the day?	3 meetings (and 1 business lunch).
8	Calend.	MM - N	D	Go to Friday, day 19 and delete 12:00 PM event.	What was the event just deleted?	Business lunch with Joe Dithers.
9	Calend.	Visual	E	Go to Wednesday, day 31 and view the schedule for the day.	Is there something scheduled for lunch?	No. Business travel.
10	Calend.	Visual	D	Go to Saturday, day 27 and add an Emergency Meeting with John Smith at 9:00 AM.	What was the existing event at 9:00 AM?	None.
11	E-Mail	Aud - F	E	Select and listen message from Larry about hotel arrangements.	Where are they going?	Chicago
12	E-Mail	Aud - F	D	Select and reply to message from Larry about hotel arangements. *Reply: I won't be able to go with you* .	When Larry will get back to you?	When he knows who will coordinate details for them.
13	E-Mail	Aud - N	E	Select and delete message from Payroll Office.	What was the message about?	Check ready for pickup.
14	E-Mail	Aud - N	D	Select and reply to message from John about project proposal. *Reply: I need a decision before that* .	In what procees is the proposal now?	Review process.
15	E-Mail	MM - F	E	Select and view/listen message from John about proposal submission.	When you should hear from them?	By the end of the month.
16	E-Mail	MM - F	D	Select and reply to message from Larry about Project M. *Reply: I need a team of three, not two people* .	How many days will it take one person to complete Phase 3?	25 days.
17	E-Mail	MM - N	E	Select and delete message from Larry about hotel arrangements.	What was the message about?	Trip to Chicago.
18	E-Mail	MM - N	D	Select and reply to message from Bruce about Project M. *Reply: Good, we need to start working on Phase 2* .	How many widgets are needed?	5.
19	E-Mail	Visual	E	Select and view message from Boss.	What was the message about?	Equipment problem.
20	E-Mail	Visual	D	Select and reply to message from Boss about equipment problem. *Reply: Buy new equipment if needed* .	When should know if reparable?	By COB (Close of Business).
21	V-Mail	Aud - F	E	Listen to Voice Memo 4.	Where are the new customers files located?	Filing cabinets on the second floor.
22	V-Mail	Aud - F	D	Select and reply to Voice Memo 7. *Reply: The new customer files are locted in the copy room.*	When will the new filing system be in place?	This week.
23	V-Mail	Aud - N	E	Listen to Voice Memo 8.	To whom you need to talk to?	To Pat.
24	V-Mail	Aud - N	D	Select and reply to Voice Memo 5. *Reply: Lets place the order as soon as possible.*	What discount % is guaranteed?	20%.

APPENDIX J – *Post-Test Questionnaire*

VIRGINIA TECH TRASPORTATION INSTITUTE

Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

POST-TEST QUESTIONNAIRE

1. How familiar are you with personal computers?

Very Familiar	Barely Familiar	Borderline	Barely Unfamiliar	Very Unfamiliar

2. How familiar are you with electronic mail (e-mail) systems?

Very Familiar	Barely Familiar	Borderline	Barely Unfamiliar	Very Unfamiliar

3. How familiar are you with voice-mail systems?

Very Familiar	Barely Familiar	Borderline	Barely Unfamiliar	Very Unfamiliar

4. How familiar are you with electronic calendars?

Very Familiar	Barely Familiar	Borderline	Barely Unfamiliar	Very Unfamiliar

5. How often would you use electronic mail (e-mail) while driving?

Never	Seldom	Sometimes	Frequently	Always

6. How often would you use voice-mail systems while driving?

Never	Seldom	Sometimes	Frequently	Always

7. How often would you use electronic calendar systems while driving?

Never	Seldom	Sometimes	Frequently	Always

8. How technologically complex do you consider the e-mail system to be?

Not Complex	Slightly Complex	Complex	Quite Complex	Extremely Complex

9. How technologically complex do you consider the voice-mail system to be?

Not Complex	Slightly Complex	Complex	Quite Complex	Extremely Complex

10. How technologically complex do you consider the calendar system to be?

Not Complex	Slightly Complex	Complex	Quite Complex	Extremely Complex

APPENDIX K – *Operational Definitions*

Development of Guidelines for In-Vehicle Information Presentation: Text vs. Speech

OPERATIONAL DEFINITIONS

Task Beginning Sync. No. – Moment in time at which the task begins. It is determined by the moment at which the Back Seat Experimenter (BSE) said the word "Go" – This is the sync. number associated with the beginning of the word (i.e., when it is first heard). For cases in which the "Go" could not be heard, an estimate was made as to when the word was said based on the BSE's movements on the video.

Task Ending Sync. No. – Moment in time at which the task ends. It is determined by the moment at which the participant said the word "Done" – This is the sync. number associated with the closing of the participant's mouth at the end of the iteration of the word "Done." For cases in which "Done" was not stated (i.e., the participant forgot to say it) an estimate was made to indicate the end of the task. For cases in which another word was stated, such as "Stop", that word was used to indicate the end.

Task Duration *(Task Ending Sync. Number – Task Beginning Sync. Number)* – Duration of the task in seconds. This was calculated by subtracting the beginning sync. number from the end sync. number, divided by 10. Sync. numbers were reported in tenths of a second.

Lane Deviation Levels – Lane deviations were categorized in three levels:

0 = Stable driving; no lateral movements
1 = Close to either side lane line but not over it
2 = Wheel goes over either side lane line

Lane Deviation Duration *(Lane Deviation End – Lane Deviation Beginning)* – Duration of the lane deviation event in seconds. Subtraction of the lane deviation beginning sync. number from the lane deviation ending sync. number.

- *Lane Deviation Beginning* – Moment in time at which lateral movement toward either side of the lane first started.
- *Lane Deviation End* – Moment in time at which the vehicle "settled" back and is stable in the lane (i.e., the point at which lateral movement away from the lane line ended).

Eye Glance Positions – Locations at which the participant was looking while performing the tasks. The eye glance positions were categorized as follows:

F = Forward (road)
D = Display
S = Speedometer
R = Rear View Center Mirror
I = Other vehicle interior
E = Other exterior
U = Unknown

Eye Glance Beginning – An eye glance begins at the moment that the eyes of the participant rest on a new location.

Eye Glance End – An eye glance ends at the moment that the eyes of the participant rest on a new location minus one (Beginning of new eye glance -1).

Eye Glance Duration (Eye Glance End – Eye Glance Beginning) = ((Next Eye Glance Beginning – 1) – Eye Glance Beginning) – Duration of the eye glance event. Subtraction of the eye glance beginning sync. number from the eye glance ending sync. number.

Baseline – Period of time where the participant drives the vehicle without performing tasks. Eye glances and speed maintenance data were collected to be compared to eye glance and speed maintenance data while performing tasks. Baseline data was collected for two time periods of 30 seconds (60 seconds total) across the same stretch of road for each participant.

Baseline Start (going ***down*** *Smart Road)* – Pavement change near the beginning of the weather towers (i.e., synch 2935 for Participant #2).

Baseline End (going ***down*** *Smart Road)* – Point 30 seconds after baseline start (i.e., 3235 for Participant #2).

Baseline Start (going ***up*** *Smart Road)* – Pavement change at end of first bridge (i.e., synch 5282 for Participant #2).

Baseline End (going ***up*** *Smart Road)* – Point 30 seconds after baseline start (i.e., 5582 for Participant #2).

APPENDIX L – *Full Model ANOVAs*

Table L.1. Dependent Measure: Number of Eye Glances to the Display (DISPLAYGLANCES)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	1387.00	92.47			
Within						
Display	4	9678.56	2419.64	58.01	<0.0001	*
Display x Part	60	2502.78	41.71			
Application	2	1.82	0.91	0.10	0.9032	
Application x Part	30	267.68	8.92			
DiffLevel	1	21.04	21.04	1.65	0.2187	
DiffLevel x Part	15	191.57	12.77			
Display x Application	5	18.45	3.69	0.33	0.8923	
Display x Application x Part	75	834.46	11.13			
Display x DiffLevel	4	75.24	18.81	1.37	0.2551	
Display x DiffLevel x Part	60	823.83	13.73			
Application x DiffLevel	2	112.25	56.13	7.54	0.0022	*
Application x DiffLevel x Part	30	223.32	7.44			
Display x Application x DiffLevel	5	232.65	46.53	4.19	0.0021	*
Display x Application x DiffLevel x Part	75	833.53	11.11			
Total	383	17204.18				

* $p < 0.05$ (significant)

Table L.2. Dependent Measure: Percent of Task Time Spent Glancing at Display (EORDISPLAY)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	0.85	0.06			
Within						
Display	4	11.39	2.85	129.68	<0.0001	*
Display x Part	60	1.32	0.02			
Application	2	0.04	0.02	3.09	0.0604	
Application x Part	30	0.20	0.01			
DiffLevel	1	0.01	0.01	0.90	0.3571	
DiffLevel x Part	15	0.10	0.01			
Display x Application	5	0.06	0.01	1.26	0.2895	
Display x Application x Part	75	0.75	0.01			
Display x DiffLevel	4	0.07	0.02	2.93	0.0281	*
Display x DiffLevel x Part	60	0.36	0.01			
Application x DiffLevel	2	0.05	0.02	4.70	0.0168	*
Application x DiffLevel x Part	30	0.15	0.01			
Display x Application x DiffLevel	5	0.02	0.00	0.84	0.5288	
Display x Application x DiffLevel x Part	75	0.38	0.01			
Total	383	15.75				

* $p < 0.05$ (significant)

Table L.3. Dependent Measure: Number of Lane Deviations

(TOUCHD)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	2.84	0.19			
Within						
Display	4	3.02	0.76	5.84	0.0005	*
Display x Part	60	7.75	0.13			
Application	2	0.05	0.03	0.26	0.7693	
Application x Part	30	2.92	0.10			
DiffLevel	1	0.03	0.03	0.57	0.4602	
DiffLevel x Part	15	0.87	0.06			
Display x Application	5	0.10	0.02	0.18	0.9708	
Display x Application x Part	75	8.92	0.12			
Display x DiffLevel	4	0.07	0.02	0.19	0.9419	
Display x DiffLevel x Part	60	5.50	0.09			
Application x DiffLevel	2	0.40	0.20	7.79	0.0019	*
Application x DiffLevel x Part	30	0.77	0.03			
Display x Application x DiffLevel	5	1.00	0.20	2.21	0.0620	
Display x Application x DiffLevel x Part	75	6.82	0.09			
Total	383	41.06				

* $p < 0.05$ (significant)

Table L.4. **Dependent Measure: Mean Length of Lane Deviations**

(TOUCHDL)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	368.41	24.56			
Within						
Display	4	246.02	61.50	4.21	0.0045	*
Display x Part	60	876.67	14.61			
Application	2	9.86	4.93	0.46	0.6385	
Application x Part	30	324.77	10.83			
DiffLevel	1	6.20	6.20	1.30	0.2722	
DiffLevel x Part	15	71.52	4.77			
Display x Application	5	7.14	1.43	0.12	0.9884	
Display x Application x Part	75	919.59	12.26			
Display x DiffLevel	4	28.85	7.21	0.93	0.4539	
Display x DiffLevel x Part	60	466.40	7.77			
Application x DiffLevel	2	32.85	16.42	7.46	0.0023	*
Application x DiffLevel x Part	30	66.05	2.20			
Display x Application x DiffLevel	5	91.02	18.20	2.08	0.0767	
Display x Application x DiffLevel x Part	75	655.26	8.74			
Total	383	4170.61				

* $p < 0.05$ (significant)

***Table L.5.* Dependent Measure: Lane Deviation Percentage of Task Time**

(TOUCHTLPC)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	0.29	0.02			
Within						
Display	4	0.20	0.05	4.45	0.0033	*
Display x Part	60	0.69	0.01			
Application	2	0.00	0.00	0.16	0.8553	
Application x Part	30	0.22	0.01			
DiffLevel	1	0.00	0.00	0.26	0.6178	
DiffLevel x Part	15	0.04	0.00			
Display x Application	5	0.00	0.00	0.06	0.9970	
Display x Application x Part	75	0.60	0.01			
Display x DiffLevel	4	0.02	0.00	1.12	0.3549	
Display x DiffLevel x Part	60	0.27	0.00			
Application x DiffLevel	2	0.03	0.02	7.80	0.0019	*
Application x DiffLevel x Part	30	0.06	0.00			
Display x Application x DiffLevel	5	0.06	0.01	2.27	0.0560	
Display x Application x DiffLevel x Part	75	0.41	0.01			
Total	383	2.89				

* $p < 0.05$ (significant)

Table L.6. **Dependent Measure: Speed Standard Deviation**

(SPEEDSTDDEV)

Source	***DF***	***SS***	***MS***	***F value***	***P value***
Between					
Part	15	60.14	4.01		
Within					
Display	4	1.43	0.36	1.09	0.3701
Display x Part	60	19.64	0.33		
Application	2	2.57	1.28	1.76	0.1900
Application x Part	30	21.93	0.73		
DiffLevel	1	0.08	0.08	0.16	0.6986
DiffLevel x Part	15	7.79	0.52		
Display x Application	5	2.97	0.59	1.39	0.2385
Display x Application x Part	75	32.10	0.43		
Display x DiffLevel	4	1.08	0.27	0.85	0.5007
Display x DiffLevel x Part	60	19.10	0.32		
Application x DiffLevel	2	1.56	0.78	2.84	0.0745
Application x DiffLevel x Part	30	8.27	0.28		
Display x Application x DiffLevel	5	3.94	0.79	1.42	0.2261
Display x Application x DiffLevel x Part	75	41.52	0.55		
Total	383	224.12			

* $p < 0.05$ (significant)

***Table L.7.* Dependent Measure: Time to React to Distracting Light**

(LIGHTREACTTIME)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	994.87	66.32			
Within						
Display	4	179.82	44.95	4.80	0.0020	*
Display x Part	60	562.10	9.37			
Application	2	5.34	2.67	0.45	0.6438	
Application x Part	30	179.06	5.97			
DiffLevel	1	36.03	36.03	3.66	0.0750	
DiffLevel x Part	15	147.62	9.84			
Display x Application	5	17.30	3.46	0.50	0.7767	
Display x Application x Part	75	521.08	6.95			
Display x DiffLevel	4	21.64	5.41	1.33	0.2707	
Display x DiffLevel x Part	60	244.80	4.08			
Application x DiffLevel	2	37.91	18.96	4.68	0.0171	*
Application x DiffLevel x Part	30	121.60	4.05			
Display x Application x DiffLevel	5	4.62	0.92	0.13	0.9862	
Display x Application x DiffLevel x Part	75	551.25	7.35			
Total	383	3625.04				

* $p < 0.05$ (significant)

Table L.8. **Dependent Measure: Mental Workload - Mental Demand**

(MENTALD)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	68770.04	4584.67			
Within						
Display	4	9071.58	2267.89	8.24	<0.0001	*
Display x Part	60	16511.81	275.20			
Application	2	1869.80	934.90	1.95	0.1598	
Application x Part	30	14378.81	479.29			
DiffLevel	1	878.24	878.24	5.75	0.0299	*
DiffLevel x Part	15	2290.08	152.67			
Display x Application	5	2597.86	519.57	1.81	0.1218	
Display x Application x Part	75	21572.95	287.64			
Display x DiffLevel	4	2399.45	599.86	3.22	0.0185	*
Display x DiffLevel x Part	60	11181.97	186.37			
Application x DiffLevel	2	969.32	484.66	2.40	0.1082	
Application x DiffLevel x Part	30	6064.52	202.15			
Display x Application x DiffLevel	5	3464.92	692.98	5.52	0.0002	*
Display x Application x DiffLevel x Part	75	9420.65	125.61			
Total	383	171442.00				

* $p < 0.05$ (significant)

Table L.9. Dependent Measure: Mental Workload - Temporal Demand (TIMED)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	56706.30	3780.42			
Within						
Display	4	6611.21	1652.80	6.00	0.0004	*
Display x Part	60	16537.32	275.62			
Application	2	2616.75	1308.38	2.86	0.0733	
Application x Part	30	13746.38	458.21			
DiffLevel	1	304.05	304.05	1.69	0.2133	
DiffLevel x Part	15	2700.20	180.01			
Display x Application	5	2626.62	525.32	1.72	0.1402	
Display x Application x Part	75	22898.00	305.31			
Display x DiffLevel	4	2899.65	724.91	4.95	0.0016	*
Display x DiffLevel x Part	60	8785.68	146.43			
Application x DiffLevel	2	668.29	334.15	1.79	0.1851	
Application x DiffLevel x Part	30	5615.24	187.17			
Display x Application x DiffLevel	5	2584.70	516.94	3.99	0.0029	*
Display x Application x DiffLevel x Part	75	9707.52	129.43			
Total	383	155007.9				

* $p < 0.05$ (significant)

Table L.10. **Dependent Measure: Mental Workload - Frustration Level**

(FRUSTRATION)

Source	*DF*	*SS*	*MS*	*F value*	*P value*	
Between						
Part	15	75568.71	5037.91			
Within						
Display	4	11420.20	2855.05	5.19	0.0012	*
Display x Part	60	32977.34	549.62			
Application	2	752.66	376.33	1.14	0.3333	
Application x Part	30	9905.10	330.17			
DiffLevel	1	367.00	367.00	2.13	0.1651	
DiffLevel x Part	15	2584.66	172.31			
Display x Application	5	3054.74	610.95	2.09	0.0758	
Display x Application x Part	75	21913.42	292.18			
Display x DiffLevel	4	2847.05	711.76	4.18	0.0047	*
Display x DiffLevel x Part	60	10221.56	170.36			
Application x DiffLevel	2	817.87	408.93	2.85	0.0738	
Application x DiffLevel x Part	30	4310.76	143.69			
Display x Application x DiffLevel	5	2322.04	464.41	3.03	0.0153	*
Display x Application x DiffLevel x Part	75	11513.26	153.51			
Total	383	190576.4				

* $p < 0.05$ (significant)

APPENDIX M – *SNK Post-Hoc IVIS Tasks Comparisons*

M.1. Display Glances Post-Hoc results per Display Type.

SNK Grouping	*Mean*	*Display*
A	13.23	Visual
A	12.83	MM-F
B	9.80	MM-N
C	1.01	Aud-N
C	0.99	Aud-F

M.2. Eyes-Off-Road Percent Post-Hoc results per Display Type.

SNK Grouping	*Mean*	*Display*
A	51.53%	Visual
B	27.94%	MM-F
B	26.94%	MM-N
C	1.68%	Aud-F
C	1.60%	Aud-N

M.3. Number of Lane Deviations Post-Hoc results per Display Type.

SNK Grouping	*Mean*	*Display*
A	0.27	Visual
A / B	0.20	MM-F
B / C	0.13	MM-N
C / D	0.03	Aud-F
D	0.00	Aud-N

***M.4.* Average Length of Lane Deviations Post-Hoc results per Display Type.**

SNK Grouping	*Mean (sec)*	*Display*
A	2.51	Visual
A / B	1.74	MM-F
B / C	1.20	MM-N
C / D	0.35	Aud-F
D	0.00	Aud-N

***M.5.* Lane Deviation Percentage Post-Hoc results per Display Type.**

SNK Grouping	*Mean*	*Display*
A	7.34%	Visual
B	2.94%	MM-F
B	2.76%	MM-N
B	0.61%	Aud-F
B	0.00%	Aud-N

***M.6.* Light Reaction Time Post-Hoc results per Display Type.**

SNK Grouping	*Mean (sec)*	*Display*
A	4.13	Visual
B	2.75	MM-F
B	2.33	MM-N
B	2.15	Aud-F
B	1.93	Aud-N

***M.7.* Mental Demand Post-Hoc results per Display Type.**

SNK Grouping	*Mean*	*Display*
A	47.69	Visual
B	38.48	MM-F
B	35.38	Aud-F
B	32.97	MM-N
B	32.55	Aud-N

***M.8.* Mental Demand Post-Hoc results per Difficulty Level.**

SNK Grouping	*Mean*	*Difficulty Level*
A	39.05	Difficult
B	34.63	Easy

***M.9.* Temporal Demand Post-Hoc results per Display Type.**

SNK Grouping	*Mean*	*Display*
A	40.91	Visual
A / B	36.08	MM-F
B / C	31.01	Aud-F
C	28.38	MM-N
C	28.15	Aud-N

***M.10.* Frustration Level Post-Hoc results per Display Type.**

SNK Grouping	*Mean*	*Display*
A	40.61	Visual
B	28.98	MM-F
B	26.71	Aud-F
B	24.39	Aud-N
B	23.77	MM-N

APPENDIX N – *SNK Post-Hoc Baseline Comparisons*

N.1. Number of Lane Deviations per Display Type as Compared to Baseline.

SNK Grouping	*Mean*	*Display*
A	0.27	Visual
A	0.20	MM-F
A / B	0.13	MM-N
B	0.03	Aud-F
B	0.00	Aud-N
B	0.00	None (Baseline)

N.2. Number of Lane Deviations per Application as Compared to Baseline.

SNK Grouping	*Mean*	*Application*
A	0.14	E-mail
A	0.12	Calendar
A	0.00	Voice-mail
A	0.00	None (Baseline)

N.3. Number of Lane Deviations per Difficulty Level as Compared to Baseline.

SNK Grouping	*Mean*	*Difficulty Level*
A	0.12	Easy
A	0.09	Difficult
A	0.00	None (Baseline)

***N.4.* Average Length of Lane Deviations Post-Hoc results per Display Type as Compared to Baseline.**

SNK Grouping	*Mean (sec)*	*Display*
A	2.51	Visual
A / B	1.74	MM-F
A / B / C	1.20	MM-N
B / C	0.35	Aud-F
C	0.00	Aud-N
C	0.00	None (Baseline)

***N.5.* Average Length of Lane Deviations Post-Hoc results per Application as Compared to Baseline.**

SNK Grouping	*Mean*	*Application*
A	1.34	E-mail
A	1.05	Calendar
A	0.00	Voice-mail
A	0.00	None (Baseline)

***N.6.* Average Length of Lane Deviations Post-Hoc results per Difficulty Level as Compared to Baseline.**

SNK Grouping	*Mean*	*Difficulty Level*
A	1.16	Easy
A	0.83	Difficult
A	0.00	None (Baseline)

***N.7.* Lane Deviation Percentage Post-Hoc results per Display Type as Compared to Baseline.**

SNK Grouping	*Mean*	*Display*
A	7.35%	Visual
B	2.94%	MM-F
B	2.76%	MM-N
B	0.61%	Aud-F
B	0.00%	Aud-N
B	0.00%	None (Baseline)

***N.8.* Lane Deviation Percentage Post-Hoc results per Difficulty Level as Compared to Baseline.**

SNK Grouping	*Mean*	*Difficulty Level*
A	2.53%	Easy
A	2.12%	Difficult
A	0.00%	None (Baseline)

***N.9.* Light Reaction Time Post-Hoc results per Display Type as Compared to Baseline.**

SNK Grouping	*Mean (sec)*	*Display*
A	4.13	Visual
B	2.75	MM-F
B / C	2.33	MM-N
B / C	2.15	Aud-F
B / C	1.93	Aud-N
C	1.31	None (Baseline)

***N.10.* Light Reaction Time Post-Hoc results per Application as Compared to Baseline.**

SNK Grouping	*Mean (sec)*	*Application*
A	2.73	Calendar
A	2.68	E-mail
A	1.81	Voice-mail
A	1.31	None (Baseline)

***N.11.* Light Reaction Time Post-Hoc results per Application as Compared to Baseline.**

SNK Grouping	*Mean (sec)*	*Difficulty Level*
A	2.87	Difficult
A / B	2.25	Easy
B	1.31	None (Baseline)

CURRICULUM VITAE

María Fumero was born and raised in Mayagüez, Puerto Rico. She obtained a B.S. degree in Industrial Engineering from the University of Puerto Rico in 1997. Upon graduation, she worked for three years at Molex Caribe, Inc. as a Manufacturing Engineer at Ponce, Puerto Rico. There she performed tasks related to safety, ergonomics, layout design, production, and development of new products among others. In 2000 she moved to Blacksburg, Virginia and started working as data reductionist at the Virginia Tech Transportation Institute (VTTI). In 2001 she returned to school, and in 2004 she obtained an M.S. degree in Human Factors Engineering and Ergonomics with a certification in Safety Engineering from the Department of Industrial and Systems Engineering at Virginia Polytechnic Institute and State University. Ms. Fumero focused her master's research in the presentation of information of in-vehicle information systems. During her master's studies she served as a graduate research assistant at VTTI and by the end of her degree she obtained a position as Research Associate at the institute. Ms. Fumero is member of the Human Factors and Ergonomics Society, the Society of Hispanic Engineers, and has served as Treasurer of the Virginia Tech Student Chapter of the American Society of Safety Engineers. She is member of the Industrial Engineering Honor Society, Alpha Pi Mu. Ms. Fumero currently lives with her husband and son in Blacksburg, Virginia.