SAVE-IT

SAfety VEhicles using adaptive Interface Technology (Task 3B)

Driving Performance for Dialing, Radio Tuning, and Destination Entry while Driving Straight Roads

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3.0 PROGRAM OVERVIEW

Driver distraction is a major contributing factor to automobile crashes. National Highway Traffic Safety Administration (NHTSA) has estimated that approximately 25% of crashes are attributed to driver distraction and inattention (Wang, Knipling, & Goodman, 1996). The issue of driver distraction may become worse in the next few years because more electronic devices (e.g., cell phones, navigation systems, wireless Internet and email devices) are brought into vehicles that can potentially create more distraction. In response to this situation, the John A. Volpe National Transportation Systems Center (VNTSC), in support of NHTSA's Office of Vehicle Safety Research, awarded a contract to Delphi Electronics & Safety to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems based on real-time monitoring of the roadway conditions and the driver's capabilities. The contract, known as SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT), is designed to mitigate distraction with effective countermeasures and enhance the effectiveness of safety warning systems.

The SAVE-IT program serves several important objectives. Perhaps the most important objective is demonstrating a viable proof of concept that is capable of reducing distraction-related crashes and enhancing the effectiveness of safety warning systems. Program success is dependent on integrated closed-loop principles that, not only include sophisticated telematics, mobile office, entertainment and safety warning systems, but also incorporate the state of the driver. This revolutionary closed-loop vehicle environment will be achieved by measuring the driver’s state, assessing the situational threat, prioritizing information presentation, providing adaptive countermeasures to minimize distraction, and optimizing advanced collision warning.

To achieve the objective, Delphi Electronics & Safety has assembled a comprehensive team including researchers and engineers from the University of Iowa, University of Michigan Transportation Research Institute (UMTRI), General Motors, Ford Motor Company, and Seeing Machines, Inc. The SAVE-IT program is divided into two phases shown in Figure i. Phase I spans one year (March 2003--March 2004) and consists of nine human factors tasks (Tasks 1-9) and one technology development task (Task 10) for determination of diagnostic measures of driver distraction and workload, architecture concept development, technology development, and Phase II planning. Each of the Phase I tasks is further divided into two sub-tasks. In the first sub-tasks (Tasks 1, 2A-10A), the literature is reviewed, major findings are summarized, and research needs are identified. In the second sub-tasks (Tasks 1, 2B-10B), experiments will be performed and data will be analyzed to identify diagnostic measures of distraction and workload and determine effective and driver-friendly countermeasures. Phase II will span approximately two years (October 2004--October 2006) and consist of a continuation of seven Phase I tasks (Tasks 2C--8C) and five additional tasks (Tasks 11-15) for algorithm and guideline development, data fusion, integrated countermeasure development, vehicle demonstration, and evaluation of benefits.

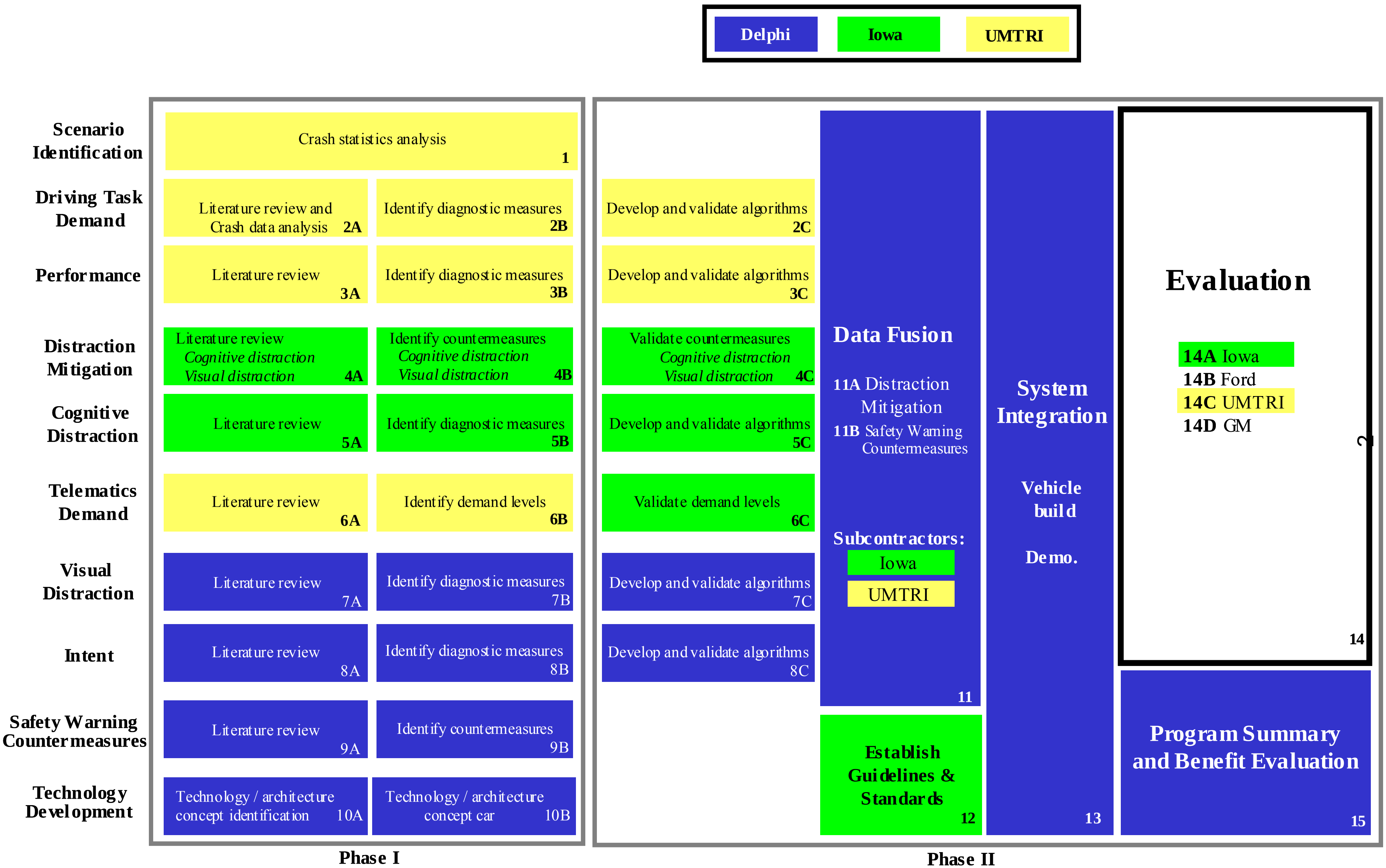


Figure i: SAVE-IT tasks

It is worthwhile to note the SAVE-IT tasks in Figure i are inter-related. They have been chosen to provide necessary human factors data for a two-pronged approach to address the driver distraction and adaptive safety warning countermeasure problems. The first prong (Safety Warning Countermeasures sub-system) uses driver distraction, intent, and driving task demand information to adaptively adjust safety warning systems such as forward collision warning (FCW) systems in order to enhance system effectiveness and user acceptance. Task 1 is designed to determine which safety warning system(s) should be deployed in the SAVE-IT system. Safety warning systems will require the use of warnings about immediate traffic threats without an annoying rate of false alarms and nuisance alerts. Both false alarms and nuisance alerts will be reduced by system intelligence that integrates driver state, intent, and driving task demand information that is obtained from Tasks 2 (Driving Task Demand), 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction), and 8 (Intent).

The safety warning system will adapt to the needs of the driver. When a driver is cognitively and visually attending to the lead vehicle, for example, the warning thresholds can be altered to delay the onset of the FCW alarm or reduce the intrusiveness of the alerting stimuli. When a driver intends to pass a slow-moving lead vehicle and the passing lane is open, the auditory stimulus might be suppressed in order to reduce the alert annoyance of a FCW system. Decreasing the number of false positives may reduce the tendency for drivers to disregard safety system warnings. Task 9 (Safety Warning Countermeasures) will investigate how driver state and intent information can be used to adapt safety warning systems to enhance their effectiveness and user acceptance. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of adaptive safety warning systems and evaluate and document the effectiveness, user acceptance, driver understandability, and benefits and weaknesses of the adaptive systems. It should be pointed out that the SAVE-IT system is a relatively early step in bringing the driver into the loop and therefore, system weaknesses will be evaluated, in addition to the observed benefits.

The second prong of the SAVE-IT program (Distraction Mitigation sub-system) will develop adaptive interface technologies to minimize driver distraction to mitigate against a global increase in risk due to inadequate attention allocation to the driving task. Two examples of the distraction mitigation system include the delivery of a gentle warning and the lockout of certain telematics functions when the driver is more distracted than what the current driving environment allows. A major focus of the SAVE-IT program is the comparison of various mitigation methods in terms of their effectiveness, driver understandability, and user acceptance. It is important that the mitigation system does not introduce additional distraction or driver frustration. Because the lockout method has been shown to be problematic in the aviation domain and will likely cause similar problems for drivers, it should be carefully studied before implementation. If this method is not shown to be beneficial, it will not be implemented.

The distraction mitigation system will process the environmental demand (Task 2: Driving Task Demand), the level of driver distraction [Tasks 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction)], the intent of the driver (Task 8: Intent), and the telematics distraction potential (Task 6: Telematics Demand) to determine which functions should be advised against under a particular circumstance. Non-driving task information and functions will be prioritized based on how crucial the information is at a specific time relative to the level of driving task demand. Task 4 will investigate distraction mitigation strategies and methods that are very well accepted by the users (i.e., with a high level of user acceptance) and understandable to the drivers. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of using adaptive interface technologies in distraction mitigation and evaluate and document the effectiveness, driver understandability, user acceptance, and benefits and potential weaknesses of these technologies.

In particular, driving task demand and driver state (including driver distraction and impairment) form the major dimensions of a driver safety system. It has been argued that crashes are frequently caused by drivers paying insufficient attention when an unexpected event occurs, requiring a novel (non-automatic) response. As displayed in Figure ii, attention to the driving task may be depleted by driver impairment (due to drowsiness, substance use, or a low level of arousal) leading to diminished attentional resources, or allocation to non-driving tasks[1]. Because NHTSA is currently sponsoring other impairment-related studies, the assessment of driver impairment is not included in the SAVE-IT program at the present time. One assumption is that safe driving requires that attention be commensurate with the driving demand or unpredictability of the environment. Low demand situations (e.g., straight country road with no traffic at daytime) may require less attention because the driver can usually predict what will happen in the next few seconds while the driver is attending elsewhere. Conversely, high demand (e.g., multi-lane winding road with erratic traffic) situations may require more attention because during any time attention is diverted away, there is a high probability that a novel response may be required. It is likely that most intuitively drivers take the driving-task demand into account when deciding whether or not to engage in a non-driving task. Although this assumption is likely to be valid in a general sense, a counter argument is that problems may also arise when the situation appears to be relatively benign and drivers overestimate the predictability of the environment. Driving

[1] The distinction between driving and non-driving tasks may become blurred sometimes. For example, reading street signs and numbers is necessary for determining the correct course of driving, but may momentarily divert visual attention away from the forward road and degrade a driver's responses to unpredictable danger evolving in the driving path. In the SAVE-IT program, any off-road glances, including those for reading street signs, will be assessed in terms of visual distraction and the information about distraction will be fed into adaptive safety warning countermeasures and distraction mitigation sub-systems.

environments that appear to be predictable may therefore leave drivers less prepared to respond when an unexpected threat does arise.

A safety system that mitigates the use of in-vehicle information and entertainment system (telematics) must balance both attention allocated to the driving task that will be assessed in Tasks 3 (Performance), 5 (Cognitive Distraction), and 7 (Visual Distraction) and attention demanded by the environment that will be assessed in Task 2 (Driving Task Demand). The goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment. For example, as shown in Figure ii, “routine” driving may suffice during low or moderate driving task demand, slightly distracted driving may be adequate during low driving task demand, but high driving task demand requires attentive driving.

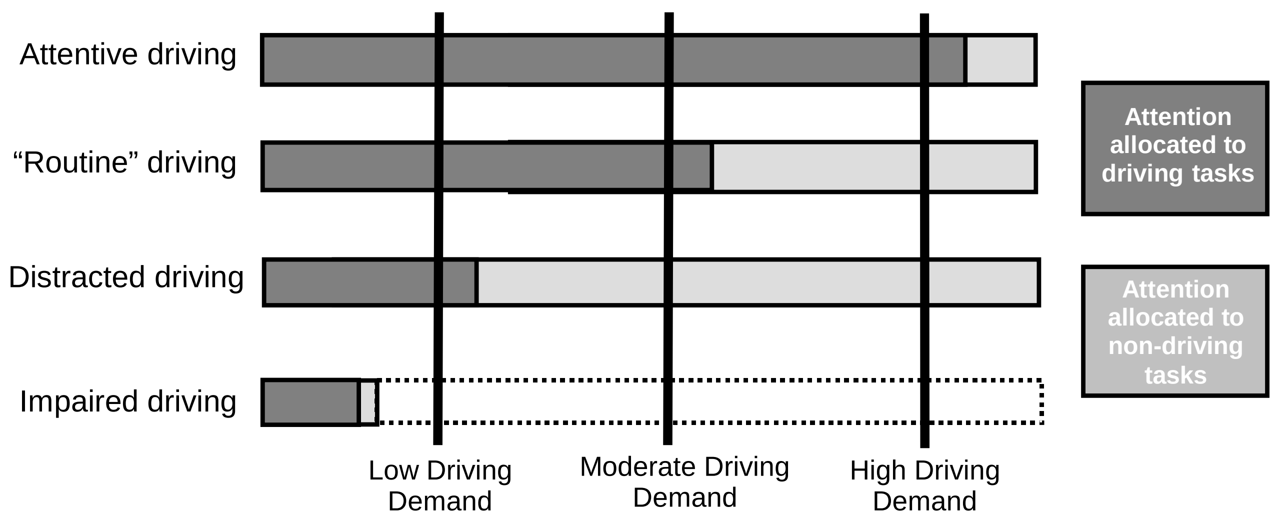


Figure ii. Attention allocation to driving and non-driving tasks

It is important to note that the SAVE-IT system addresses both high-demand and low-demand situations. With respect to the first prong (Safety Warning Countermeasures sub-system), the safety warning systems (e.g., the FCW system) will always be active, regardless of the demand. Sensors will always be assessing the driving environment and driver state. If traffic threats are detected, warnings will be issued that are commensurate with the real time attentiveness of the driver, even under low-demand situations. With respect to the second prong (Distraction Mitigation sub-system), driver state including driver distraction and intent will be continuously assessed under all circumstances. Warnings may be issued and telematics functions may be screened out under both high-demand and low-demand situations, although the threshold for distraction mitigation may be different for these situations.

It should be pointed out that drivers tend to adapt their driving, including distraction behavior and maintenance of speed and headway, based on driving (e.g., traffic and weather) and non-driving conditions (e.g., availability of telematics services), either consciously or unconsciously. For example, drivers may shed non-driving tasks (e.g., ending a cell phone conversation) when driving under unfavorable traffic and weather conditions. It is critical to understand this "driver adaptation" phenomenon. In principle, the "system adaptation" in the SAVE-IT program (i.e., adaptive safety warning countermeasures and adaptive distraction mitigation sub-systems) should be carefully implemented to ensure a fit between the two types of adaptation: "system adaptation" and "driver adaptation". One potential problem in a system that is inappropriately implemented is that the system and the driver may be reacting to each other in an unstable manner. If the system adaptation is on a shorter time scale than the driver adaptation, the driver may become confused and frustrated. Therefore, it is important to take the time scale into account. System adaptation should fit the driver's mental model in order to ensure driver understandability and user acceptance. Because of individual difference, it may also be important to tailor the system to individual drivers in order to maximize driver understandability and user acceptance. Due to resource constraints, however, a nominal driver model will be adopted in the initial SAVE-IT system. Driver profiling, machine learning of driver behavior, individual difference-based system tailoring may be investigated in future research programs.

Communication and Commonalities Among Tasks and Sites

In the SAVE-IT program, a "divide-and-conquer" approach has been taken. The program is first divided into different tasks so that a particular research question can be studied in a particular task. The research findings from the various tasks are then brought together to enable us to develop and evaluate integrated systems. Therefore, a sensible balance of commonality and diversity is crucial to the program success. Diversity is reflected by the fact that every task is designed to address a unique question to achieve a particular objective. As a matter of fact, no tasks are redundant or unnecessary. Diversity is clearly demonstrated in the respective task reports. Also documented in the task reports is the creativity of different task owners in attacking different research problems.

Task commonality is very important to the integration of the research results from the various tasks into a coherent system and is reflected in terms of the common methods across the various tasks. Because of the large number of tasks (a total of 15 tasks depicted in Figure i) and the participation of multiple sites (Delphi Electronics & Safety, University of Iowa, UMTRI, Ford Motor Company, and General Motors), close coordination and commonality among the tasks and sites are key to program success. Coordination mechanisms, task and site commonalities have been built into the program and are reinforced with the bi-weekly teleconference meetings and regular email and telephone communications. It should be pointed out that little time was wasted in meetings. Indeed, some bi-weekly meetings were brief when decisions can be made quickly, or canceled when issues can be resolved before the meetings. The level of coordination and commonality among multiple sites and tasks is un-precedented and has greatly contributed to program success. A selection of commonalities is described below.

Commonalities Among Driving Simulators and Eye Tracking Systems In Phase I
Although the Phase I tasks are performed at three sites (Delphi Electronics & Safety, University of Iowa, and UMTRI), the same driving simulator software, Drive Safety^{TM} (formerly called GlobalSim^{TM}) from Drive Safety Inc., and the same eye tracking system, FaceLab^{TM} from Seeing Machines, Inc. are used in Phase I tasks at all sites. The performance variables (e.g., steering angle, lane position, headway) and eye gaze measures (e.g., gaze coordinate) are defined in the same manner across tasks.

Common Dependent Variables An important activity of the driving task is tactical maneuvering such as speed and lane choice, navigation, and hazard monitoring. A key component of tactical maneuvering is responding to unpredictable and probabilistic events (e.g., lead vehicle braking, vehicles cutting in front) in a timely fashion. Timely responses are critical for collision avoidance. If a driver is distracted, attention is diverted from tactical maneuvering and vehicle control, and consequently, reaction time (RT) to probabilistic events increases. Because of the tight coupling between reaction time and attention allocation, RT is a useful metric for operationally defining the concept of driver distraction. Furthermore, brake RT can be readily measured in a driving simulator and is widely used as input to algorithms, such as the forward collision warning algorithm (Task 9: Safety Warning Countermeasures). In other words, RT is directly related to driver safety. Because of these reasons, RT to probabilistic events is chosen as a primary, “ground-truth” dependent variable in Tasks 2 (Driving Task Demand), 5 (Cognitive Distraction), 6 (Telematics Demand), 7 (Visual Distraction), and 9 (Safety Warning Countermeasures).

Because RT may not account for all of the variance in driver behavior, other measures such as steering entropy (Boer, 2001), headway, lane position and variance (e.g., standard deviation of lane position or SDLP), lane departures, and eye glance behavior (e.g., glance duration and frequency) are also be considered. Together these measures will provide a comprehensive picture about driver distraction, demand, and workload.

Common Driving Scenarios For the tasks that measure the brake RT, the "lead vehicle following" scenario is used. Because human factors and psychological research has indicated that RT may be influenced by many factors (e.g., headway), care has been taken to ensure a certain level of uniformity across different tasks. For instance, a common lead vehicle (a white passenger car) was used. The lead vehicle may brake infrequently (no more than 1 braking per minute) and at an unpredictable moment. The vehicle braking was non-imminent in all experiments (e.g., a low value of deceleration), except in Task 9 (Safety Warning Countermeasures) that requires an imminent braking. In addition, the lead vehicle speed and the time headway between the lead vehicle and the host vehicle are commonized across tasks to a large extent.

Subject Demographics It has been shown in the past that driver ages influence driving performance, user acceptance, and driver understandability. Because the age effect is not the focus of the SAVE-IT program, it is not possible to include all driver ages in every task with the budgetary and resource constraints. Rather than using different subject ages in different tasks, however, driver ages are commonized across tasks. Three age groups are defined: younger group (18-25 years old), middle group (35-55 years old), and older group (65-75 years old). Because not all age groups can be used in all tasks, one age group (the middle group) is chosen as the common age group that is used in every task. One reason for this choice is that drivers of 35-55 years old are the likely initial buyers and users of vehicles with advanced technologies such as the SAVE-IT systems. Although the age effect is not the focus of the program, it is examined in some tasks. In those tasks, multiple age groups were used.

The number of subjects per condition per task is based on the particular experimental design and condition, the effect size shown in the literature, and resource constraints. In order to ensure a reasonable level of uniformity across tasks and confidence in the research results, a minimum of eight subjects is used for each and every condition. The typical number of subjects is considerably larger than the minimum, frequently between 10-20.

Other Commonalities In addition to the commonalities across all tasks and all sites, there are additional common features between two or three tasks. For example, the simulator roadway environment and scripting events (e.g., the TCL scripts used in the driving simulator for the headway control and braking event onset) may be shared between experiments, the same distraction (non-driving) tasks may be used in different experiments, and the same research methods and models (e.g., Hidden Markov Model) may be deployed in various tasks. These commonalities afford the consistency among the tasks that is needed to develop and demonstrate a coherent SAVE-IT system.

The Content and Structure of the Report

The report submitted herein is a final report for Task 2 that documents the research progress to date (March 2003-March 2004) in Phase I. In this report, the major results from the literature review are summarized to determine the research needs for the present study, the experimental methods and resultant data are described, diagnostic measures and preliminary algorithms are identified, and human factors recommendations are offered.

3.1 INTRODUCTION

This report is part of a larger series of reports to develop a prototype driver interface for a workload manager (Eby and Kostyniuk, 2003a,b; Green, Cullinane, Zylstra, and Smith, 2004; Green and Shah, 2004; Cullinane and Green, 2004; Lee, 2003a,b; Smith and Zhang, 2003a,b; Zhang and Smith, 2003). As telematics systems (in-vehicle computers used to provide information to the driver) become more common in motor vehicles, there is increased concern that these systems will overwhelm drivers and detract from performing the primary driving task. Thus, instead of helping drivers, these systems (cell phones, navigation systems, collision warning and avoidance systems, etc.) could do harm. The overall impression is not that these systems are bad, but that some tasks at some times can create problems.

One way to prevent driver overload is to make use of these systems illegal while driving, such as some states have done with hand-held cell phones and others are proposing to do. (See the National Conference of State Legislatures web site, http://www.ncsl.org/programs/esnr/telematics_srch.cfm).

An alternative approach is to utilize a workload manager, a device that determines the driving workload at each moment. The device should know the demand of each task, and potentially even the driver's capabilities, to decide what the driver can and cannot do at each moment. For example, while driving in heavy traffic, incoming cell phone calls might be automatically rerouted to an answering machine. Similarly, a driver might be allowed to select points of interest using the navigation system, but not to enter street addresses. There have been a number of European studies relating to workload managers (e.g., Michon, 1993; Hoedemaeker, de Ridder, and Janssen, 2002). Motorola has been working on the problem in the U.S. (Remboski, Gardner, Wheatley, Hurwitz, MacTavish, and Gardner, 2000) and an industry-sponsored UMTRI study is nearing completion.

Several studies have collected data on how people drive under various circumstances (e.g., Green, 1993a,b; Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993; Katz, Green, and Fleming, 1995). However, there is very limited data comparing driving with and without various in-vehicle devices, and few distribution statistics based on that data.

To specifically address this topic, a literature review was conducted as part of this project (Green, Cullinane, Zylstra, and Smith, 2003). Only one measure, the standard deviation of lane position, was widely reported. That review found that typical values for standard deviation of lane position depended on the context, typically about .23 m on the road and .18 m for simulators. However, the standard deviation of the standard deviation was much less for roads (.04 versus .13 m). Averaging across all contexts and age groups, the baseline ("just driving") standard deviation of lane position was .21 m, with values of .24 m for drugs, .27 m for alcohol, and .31 m for task-related conditions (such as using a phone).

Furthermore, that review pointed out that for many of the measures of driving of interest data were lacking on the values of those measures for distracted and nondistracted conditions. Without such information, especially solid data on normal, baseline driving ("plain old driving"), it is uncertain what to measure to determine if a driver is distracted and what the difference is between normal and distracted driving.

To appropriately design a workload manager, this experiment was conducted to collect baseline and distracted driving data. Particularly important are data from easy driving conditions, straight roads where the impact of traffic is minimal.

In view of the state of knowledge and the project goals, the following issues were explored in this experiment:

1. How well do people drive normally and how does driving (control) performance change when drivers are distracted?

2. How do the means, standard deviations, distribution shape, and distribution types for various performance measures differ between the two classes of conditions?

3. What are typical total task times (and error rates) for tuning, dialing, and destination entry?

4. How risky were the in-vehicle tasks considered to be?

5. If they can be developed, what equation or equations based on driving performance measures discriminate between distracted and nondistracted drivers for various tasks?

As a footnote, the authors are looking forward to the findings from the soon be completed 100-car naturalistic driving study being conducted at Virginia Tech (Neale, Klauer, Knipling, Dingus, Holbrook, and Peterson, 2002), a study that will provide considerable insight into normal driving and complement the data reported here.

3.2 METHOD

3.2.1 Overview

This study focuses on how drivers perform driving tasks while distracted by a secondary in-vehicle task. In this experiment, subjects drove on an expressway (US-23) and on a two-lane rural road (Platt Road) east of Ann Arbor, Michigan while performing five in-vehicle tasks: 1) radio tuning, 2) phone dialing, 3) navigation system address entry, 4) a 10-second repeated glancing task, and 5) a 30-second repeated glancing task. Each task was performed once in each road direction (north and south, or east and west) on both road types. Driving performance and task times were recorded, and drivers were asked to rate the risk of each task.

3.2.2 Test Participants

The sample was comprised of two age groups (35-55 (mean of 42) and 65-75 (mean of 67)) that were equally balanced for gender. All participants were right handed. The subjects either responded to a classified advertisement placed in the Ann Arbor News regarding the driving study or were selected from a database of past participants. Subjects were expected to complete the experiment in about two hours and were paid $40 for their time.

The subjects were representative of the average U.S. driving population. While the average mileage reported by U.S. drivers is about 13,000 miles per year (http://www.fhwa.dot.gov/ohim/hs97/nptsdata.htm), the participants reported driving an average of 5,000 to 28,000 miles per year (mean of 13,000). Only one subject reported having more than one moving violation in the past five years, and five subjects had been in one accident within the past five years.

Every subject reported being familiar with touch screens, and all of the subjects stated they were familiar with tuning the radio and setting preset stations on their car radios.

Of the 16 subjects, 11 owned cell phones (7 women and 4 men), while none owned a vehicle with a navigation system.

More than half of the subjects wore contact lenses or glasses for reading, driving, or both. Each subject's near and far visual acuity was tested with the following results: Far visual acuity averaged 20/24, with a range of 20/15 to 20/50 (20/70 is minimum acuity required by State of Michigan for daytime driving). Near visual acuity averaged 20/30, with a range of 20/17 to 20/60. A summary of all of the biographical data collected is available in Appendix F.

3.2.3 In-Vehicle Tasks

The simulated in-vehicle tasks were developed in REALbasic and administered via a touch screen in the vehicle. The look and feel was similar to the menus in in-vehicle systems in imported luxury cars.

In-vehicle tasks were selected based on their (1) acceptance as distracting tasks, (2) connection with design standards, (3) linkage with prior research, (4) frequency of use while driving (and likely negative safety impact), (5) ease of implementation within project resource constraints, (6) realism, and (7) their ability to provide insight into driving task demands. The five secondary tasks were radio tuning, phone dialing, navigation destination entry, a repeated target glancing task (10 s), and a repeated target glancing task (30 s). In the glance tasks, subjects were "to look at a target on the touch screen for as long and as often as they felt it was safe, looking back and forth between the road and the target as necessary." No substantial cognitive demand was expected for this task.

(1) Given the goal of identifying how distracted and nondistracted driving differ, this experiment focused on visual-manual tasks (the most distracting tasks) spanning a range of durations, as well as on visual tasks with no substantial cognitive demand that would provide data on baseline looking behavior.

(2) A commonly cited design practice is SAE Recommended Practice J2364 (Society of Automotive Engineers, 2004), "the 15-Second Rule," which stipulates that navigation tasks that require more than 15 seconds to complete (when tested statically, that is, while parked) should not be carried out while driving. Though the scope of the Practice explicitly limits it to only navigation destination entry, given the nature of human performance, the constraints of J2364 should be applicable to other visual-manual tasks of a similar nature.

Based on the research of Nowakowski and Green (2001), static tasks that take 15 s to complete should take about 1.25 to 1.5 times longer while driving, or about 19-24 s. The radio tuning, phone dialing, and destination entry tasks varied in duration, spanning the range of safety/acceptability. They may be thought of as short, medium, and long, and were expected to be below, near, and above the threshold determined from J2364. The tasks were purposely selected to assess the merits of that threshold. Furthermore, radio tuning is a benchmark in the AAM Statement of Principles for Telematics (Alliance of Automobile Manufacturers, 2002), and the glance tasks span the 20 s plus time limit.

(3) In terms of prior research, as noted in an associated literature review (Green and Shah, 2004), radio tuning, phone dialing, and destination entry have been examined in a moderate number of studies and are the only in-vehicle tasks for which there is a substantial basis for comparison. Radio tuning has received some attention as a baseline task (Tijerina, 1999, 2002). However, there are considerable uncertainties about the demands of these tasks because much of the information needed to tie prior research together has not been reported.

(4) Clearly, there are significant safety implications for these tasks. Of the tasks associated with telematics, these 3 are reasonably common.

(5) Variations of all three tasks were used in prior UMTRI studies, facilitating prototyping. Of particular interest was an UMTRI simulator study of destination entry (Tsimhoni, Smith, and Green, 2002). The software was designed to facilitate data

capture and allow the experimenter to control the task, neither of which was feasible for real systems. Given the project resources, low cost was important. None of the prior studies used a main menu to link the tasks.

(6) Realism was an important consideration. The dialing, tuning and destination entry tasks all had interfaces that duplicated or strongly resembled real driver interfaces.

(7) Finally, the looking task was included because it provided a separation of the visual demand from the cognitive demand of an in-vehicle task, which is an important consideration.

The distraction associated with radio tuning, phone dialing, and destination entry was examined in a related literature review (Green and Shah, 2003), providing a substantial basis for comparison.

Secondary Task Menu

Each task began by navigating a hierarchical menu structure to select task types (similar to many contemporary driver interfaces and navigation interfaces in particular) via a touch screen. To begin a task, the subject pressed the start button, which brought up 3 menu headings: Radio, Phone, and Navigation (Figure 3.1). Pressing each of the entries (Radio, etc.) brought up a context-specific menu of four to six options. The submenu item Tuner activated the touch screen radio interface, Dial activated the phone interface, and Dest. Entry activated the navigation interface. An error tone was played for selecting an incorrect menu item.

Figure 3.1. Touch screen with all menu options displayed (6.2 x 3.6 inches)

Radio Tuning Task (Short Duration)

In the short duration radio tuning task, an index card displaying a decimal FM frequency (e.g., 95.3) was presented to the subject atop the center stack and the subject was instructed to set preset number 1 to that station. Subjects touched the up and down arrows on the right side of the radio (Figure 3.2) to increase or decrease the displayed frequency. Each station was either 2.8 MHz (14 button presses) or 4.2 MHz (21 button presses) up or down from the starting station, with each option occurring equally. Once subjects selected the appropriate station, they pressed the button for preset number 1 and feedback was given to indicate correct (celebratory sound) or incorrect (buzzer) entry.

Figure 3.2. Radio from 1991 Honda Accord station wagon (5.8 x 1.9 inches)
(presented full size on the touch screen as a jpeg image)

Phone Dialing Task (Medium Duration)

In the medium duration phone-dialing task, an index card displaying a 10-digit phone number was presented to the subject atop the center stack and the subject was instructed to enter it using the keypad on the touch screen (Figure 3.3). This task was similar to using a touch-tone phone. Errors made by the subject could be corrected by using the Del (delete) key to go back and remove errors. Once the entire number was entered, the subject pressed the Talk key and audio feedback was given to indicate if the number was entered correctly (a phone ringing) or incorrectly (error tones).

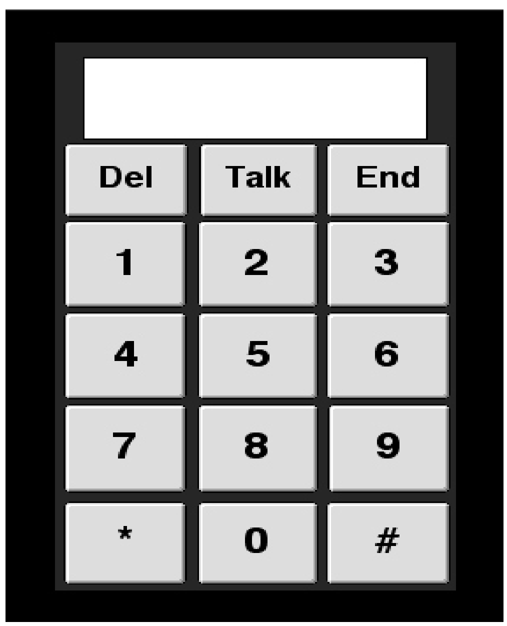


Figure 3.3. Touch-screen telephone interface used for dialing task (2.6 x 3.2 in)

Destination Entry Task (Long Duration)

In the long duration destination entry task, the subject was presented with an index card with address information (city, street, number) in the appropriate, though atypical, order to maintain consistency (and reduce experimental noise) due to order effects. The index card was placed atop the center stack in the same location as for previous tasks. Subjects then entered the entire address. All of the addresses contained the same number of total characters, balanced with varying street and city name lengths. A standard QWERTY touch screen keyboard (Figure 3.4) was used to enter the characters for each address. To indicate the active address line, the line the subject was manipulating was white while the other two lines were gray. After each line was complete, touching Return advanced to the next line, highlighted it, and made the previous line gray. Errors could be corrected using the back arrow. Touching Return on the third line ended the task and provided feedback if the address was entered correctly (celebratory feedback sounds) or incorrectly (buzzer sounds).

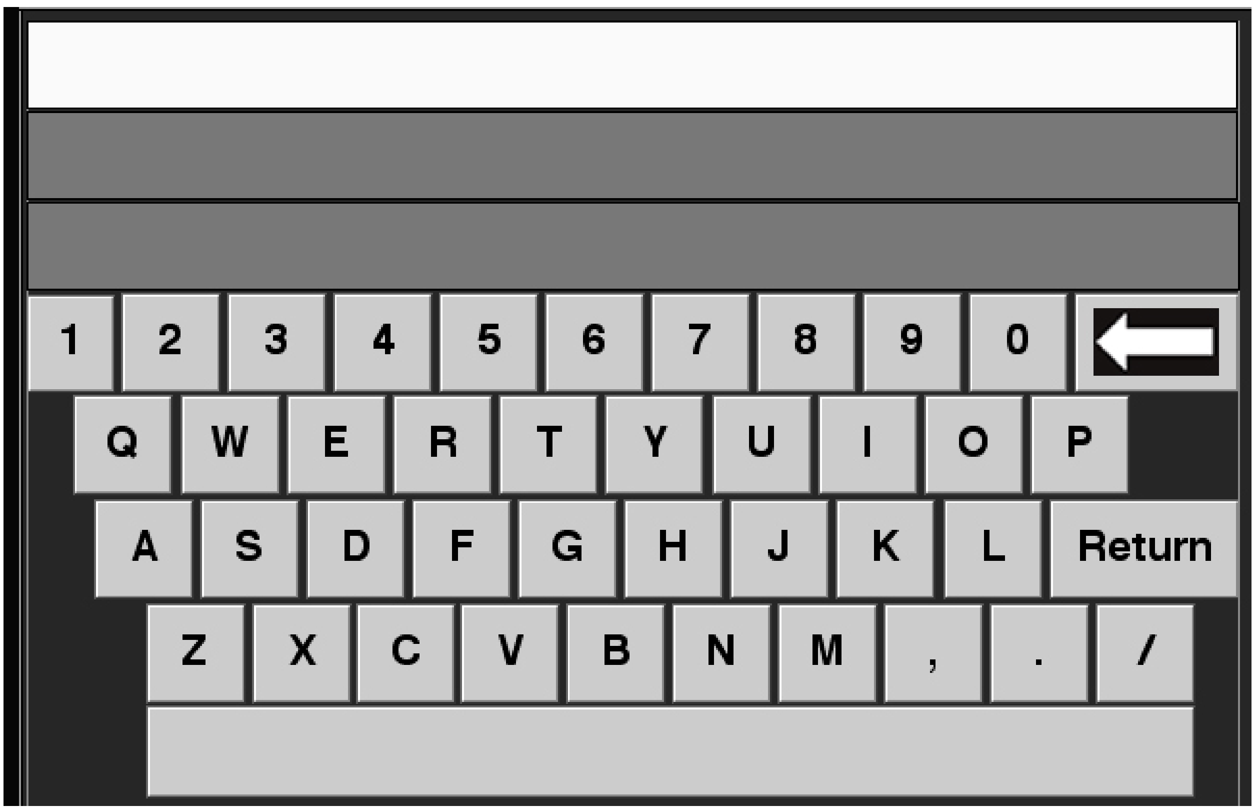


Figure 3.4. Touch screen interface used for the destination entry task (6.1 x 3.1 inches)

Baseline Glance Task

The goal of the repeated target glancing task was to determine how long a driver could safely look away from the road when making a series of glances. There were 2 durations for this task, 10 seconds and 30 seconds, providing a range and measure of sensitivity. On each trial, the subject repeatedly looked back and forth between the road and the target on the display, shown in Figure 3.5. Subjects interrupted the glance sequence whenever traffic or the road situation made it necessary. Subjects were informed when the 10 or 30 second period had ended. A similar task was explored by Hada (1994).

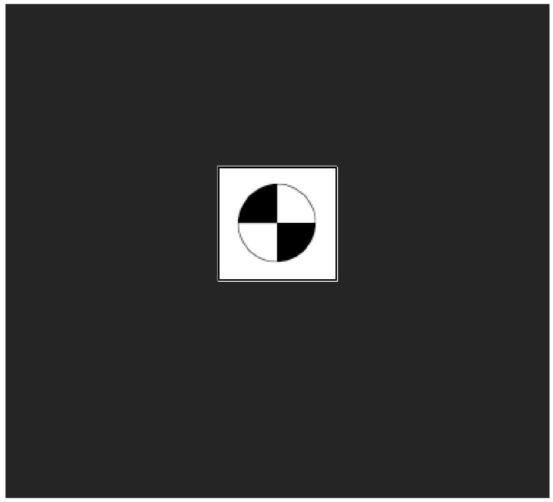


Figure 3.5. Target used for the repeated target glancing task (.7 x .7 inches)

Rating Task

To provide a sense of the risk of driving, subjects rated the risk of each of the five in-vehicle tasks each time they completed each task. (See Table 3.1.) An advantage of the risk rating scale used is that it is anchored to the real world and provides stable ratings, something that is not true of other ratings used in these situations such as NASA TLX (Hart and Stavelend, 1988; de Waard, 1996).

Table 3.1. Risk rating scale

Risk Rating	As risky as…
10	Driving with my eyes closed. A crash is bound to occur every time I do this
9	Pass a school bus that has its red lights flashing & the stop arm in full view
8	Driving just under the legal alcohol limit with observed weaving in the lane
7	
6	Driving 20 miles an hour faster than traffic on an expressway
5	
4	Driving 10 miles an hour faster than traffic on an expressway
3	
2	Driving on an average road under average conditions
1	Driving on an easy road with no traffic, pedestrians, or animals while perfectly alert

3.2.4 Roads

The experiment examined driving performance under distracted and nondistracted (baseline) conditions on 2 major road types: expressways, represented by US-23 from M-12 to Cone/Azalia Road, and rural 2-lane roads, represented by Platt Road from Ellsworth Road to Stony Creek Road. Sections used were to the east and south of Ann Arbor, Michigan, and a scene from each road type and a map of their locations are shown in Appendix D. One of the items lacking in the literature was true baseline data, in this case, roads that were perfectly (or almost perfectly) straight, which was a primary reason for examining these particular segments of road. The northern end of US-23 was straight for 6.5 miles, and the southern end was straight for 2.5 miles. Data was not collected on the 2 curves between sections (2.0 miles). The section of Platt Road examined was 6.0 miles long.

Each stretch of road was used twice, once in each direction. The lanes on US-23 were approximately 12 feet wide, with a 7-8 foot shoulder on the right side and a smaller 3-4 foot shoulder on the left. The lane on Platt Road was 10-11 feet wide with a minimal 0-2 foot shoulder (at times there was gravel in addition to the small paved shoulder). Table 3.2 summarizes other characteristics of each stretch of road.

Table 3.2. Road characteristics of the test route

Road Type	Road Name	# Lanes (1-Way)	Traffic Flow (*) (vehicles/day)	Speed Limit (km/hr)	Lane Width (m)	Shoulder Width (m)
Expressway	US-23	2	51600	113.7	3.7	2.1 (Rt) 1.2 (Lt)
Rural Road	Platt Road	1	2952	72.4	3.2	0.5

(*MDOT daily traffic volume records and the Washtenaw County Road Commission)

3.2.5 Experiment Design

Table 3.3 shows the sequence of activities for the experiment. A complete list of tasks can be seen in the instructions to the subject in Appendix B. As is typical of experiments of this type, the amount of time spent on set-up and practice was substantial, about half of the session time.

Table 3.3. Sequence of activities

#	Activity		Block	Purpose	Time (min)
1	Intro and Consent	Parked (or Office)		Obtain description of subject & consent, perform vision test	20
2	Eye Tracking Setup	Parked		Set up specific file/head model for each subject	10
3	Practice Tuning, Navigation, Dialing, Glancing	Parked	Practice	Learn how to perform each of the 3 tasks (3-6 trials of each), 1 glance task	15
4	Practice Tuning, Navigation, Dialing	Driving	Practice	Perform each of the 3 tasks once or twice	10
5 or 6	Test driving - Highway	Driving	Test	Obtain driving and task data while driving on highway. Each task is performed once, and baseline driving is in between tasks.	25
5 or 6	Test Driving – Rural Road	Driving	Test	Obtain driving and task data while driving on rural roads. Each task is performed twice, and baseline driving is in between tasks.	25
7	Post-test - Payment	Parked	Test	Obtain explanations for risk rating responses	10
	TOTAL				115

Landmarks along the route provided the triggers to start secondary tasks with the experimenter enabling each task when it was safe to do so (that is, when there were not merging vehicles, a vehicle changing lanes, or a lead vehicle braking sharply). For safety reasons, if such interference occurred during a task, experimenters interrupted and called a timeout. Such tasks were noted as incomplete. In addition, both road types were largely uniform and secondary tasks were not performed where the road was not uniform (curves, intersections, entrances/exits, construction zones).

To minimize the confounding unstable effects of rush hour traffic, experiments were only run between the hours of 9 a.m. and 4 p.m. For reasons of safety, there were two experimenters in the vehicle: a safety observer in the front seat and someone to control and monitor data collection in the back seat. After each task was complete, excluding the target glancing tasks, the subject was asked to rate the risk of completing that task while driving using a scale of 1 to 10. The scale was slightly modified after being developed for a prior on-road study of dual task performance. Table 3.1 shows the scale that was placed next to the speedometer so that the drivers could easily reference it throughout the experiment.

Table 3.4 shows the combination of tasks and roads. The number of repetitions per subject was limited (2 per subject-task-road type combination). Run 1 was out to some point, and Run 2 was the return. Likewise, Run 3 was out and Run 4 was back. At the times chosen, the traffic in both directions for the 2 roads of interest was roughly equal.

Table 3.4. Combination of tasks and road scenarios (5 and 6 from Table 3.3)

	Run	Task				
		Tune radio	Dial phone	Enter destination	Glancing task – 10 s	Glancing task – 30 s
Expressway (Step 5 or 6)	1	1	1	1	1	1
	2	1	1	1	1	1
Rural road (Step 5 or 6)	3	1	1	1	1	1
	4	1	1	1	1	1

The task and route order was counterbalanced among the subjects. Therefore, each subject from each age/gender category had a specific task and road order combination. Half of the subjects began on US-23 and finished on Platt Rd., while the other half did the opposite. Additionally, half the subjects began with the radio tuning task and finished with the destination entry task, while the other half began with destination entry and finished with the radio tuning.

3.2.6 Test Vehicle

An instrumented Honda Accord LX wagon was used as the test vehicle. Over the last 15 years, the sedan version of the Accord has often been the most widely sold car in the U.S., and hence is an appropriate vehicle to characterize how people normally drive. The instrumentation suite allows recording the driving environment, almost everything the driver does, and how the vehicle responds. A Gateway 486/33, running an in-house data-logging software package under DOS 5.0, collected vehicle data (steering wheel angle, throttle position, brake on/off, speed, lateral position, headway).

For video data collection, the car had a lipstick camera in the rear-view mirror to record the forward scene, an over-the-shoulder camera to record touch screen use, and 2-lane tracking cameras located in the side view mirrors. A summary of the video equipment appears in Table 3.16 in Appendix E.

For audio data collection, 2 Audio-Technica lavalier microphones (mounted in the A-pillar and above the rearview mirror) recorded all instructions and subject comments. The microphones were connected to a Shure (model M267) audio mixer connected to a Sony digital video recorder. By using cameras and microphones that are inconspicuous, drivers did not see the cameras and did not focus on being recorded.

Eye fixation data (head and gaze direction, object fixation, and glance duration, frequency, and transition probabilities) were determined using a Seeing Machines FaceLAB 3.0 eye tracking system. The system consisted of a stereo camera head mounted on the instrument panel eyebrow, with the cameras aimed at the driver. A Dell (model 340, 2.4 GHz Pentium) computer, which contained special video cards, collected the data. The video collected from the cameras aimed at the driver was used as the face camera. The eye fixation software sampled the direction of gaze and head vector at 30 Hz.

Finally, in-vehicle tasks were simulated on a 7-inch LCD touch screen (Xenarc 700TS/TSV) mounted in the center console. The display was connected to a Margi Display-to-Go 4 MB PCMCIA card in a Hewlett-Packard Pavilion N5350 that was running a REALbasic program under Windows XP. The program presented information on the display and recorded screen touches, errors, and task times. As a summary, Table 3.5 shows the parameters collected.

Table 3.5. Parameters collected by driver interface vehicle

Category	Value	Accuracy	Update Rate (Hz)
Vehicle	Headway	1 meter	8+
	Left/right lane edge	.03 meter	10
	Speed	.16 km/hr	30
Control	Steering wheel angle	.3 degree	30
	Throttle angle	.5%	30
	Brake actuation time	1 ms	-
	Turn signal/cruise on/off	1 ms	-
Head	Head vector (yaw, pitch, roll)	-	30
Eye	Gaze (direction and object in focus)	-	30
Task	Time of each keystroke (to determine task time, menu time)	1 ms	30
	Number of errors	-	-

The physical layout in the vehicle can be seen in Figure 3.25 in Appendix E. The computers were mounted in the back of the vehicle behind tinted windows to limit thermal loading and provide adequate ventilation. The video and audio controls were placed in a rack that was mounted where the driver’s side back seat would normally reside.

3.3 RESULTS

3.3.1 Total Task Times (and Error Rates)

Total task time was measured from the moment subjects pressed the start button until they were finished with the task (as defined below). Menu time was defined as the time until the subject finished navigating through the 3-step menu to the appropriate task screen. Data entry time was defined from the moment the appropriate data entry screen appeared until the end of the task. For radio tuning, the task ended with pressing preset 1. For dialing, the task ended when the Send key was pressed. For street address entry, the task ended after pressing Enter for the last line.

The mean menu and data entry times for each of the 3 in-vehicle tasks are shown in Figure 3.6. Overall, menu time was just over 6 s for the tuning and dialing tasks, and close to 8 s for the street address entry task. The data entry times were about 14, 18, and 51 s, respectively, for tuning, dialing, and street address entry.

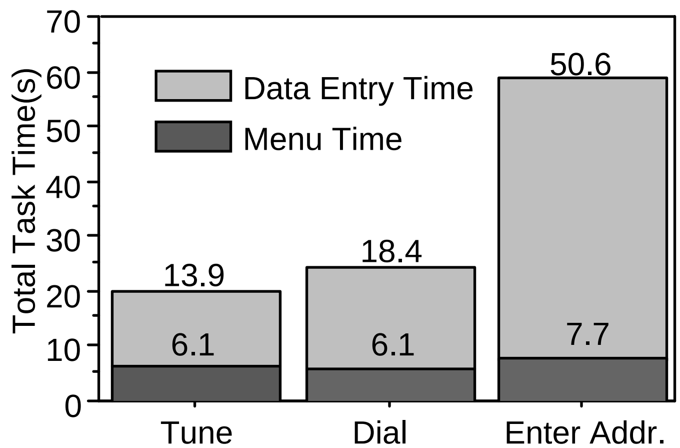


Figure 3.6. Total task time

Because navigating through the menu and entering data were quite different tasks, they were analyzed separately in detail using ANOVA. As a prelude to that analysis, the distribution of menu times is shown in Figure 3.7. Notice the distribution is approximately log normal, with an extremely long tail (mean 6.6 s, standard deviation 4.6, skew 1.7, kurtosis 3.2, range 1.8 to 28.2 s). The authors do not believe the departure from normality is sufficient to challenge the appropriateness of ANOVA in this case because of the robustness of ANOVA.

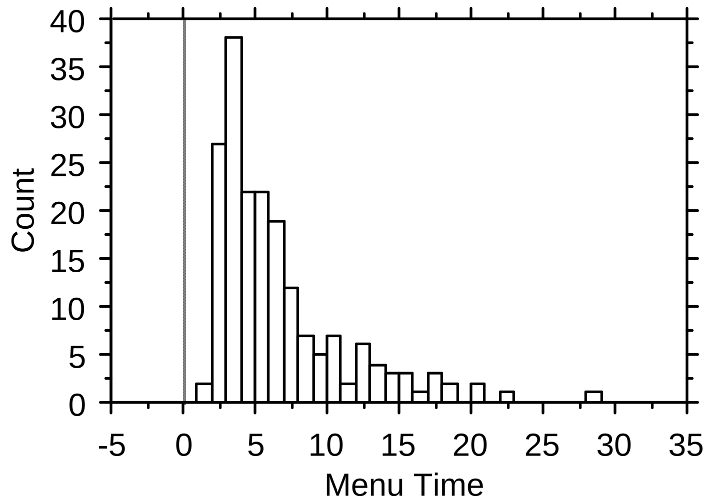


Figure 3.7. Menu times for all tasks

To identify the factors affecting menu selection time, ANOVA was used. Included in the ANOVA were 192 trials (16 subjects * 3 tasks * 2 roads * 2 trials/road). There were 3 missing trials, 1 for each device. Two of these missing trials were from 1 subject. The trials were not included because the subject forgot which input device they were told to bring up from the menu of options.

The main effects in the ANOVA were age (middle, older), sex (men, women), task (tune, dial, destination entry), road (expressway, rural), run (1 or 2), and subjects, nested within age and sex. For simplicity, all main effects and two factor interactions were included in the model except for interactions of subjects. The only factors that were significant were task ($p<.01$), the age by sex interaction ($p<.0001$), and subjects nested within age and sex. The ANOVA table is in Appendix J.

Figure 3.8 clearly shows there was no practical difference in menu task times between the two roads, with differences being less than 0.15 s. The authors do not believe that this has larger implications for these roads in general, only that two relatively safe driving conditions were selected on both roads, and, that as a result, task times were very similar.

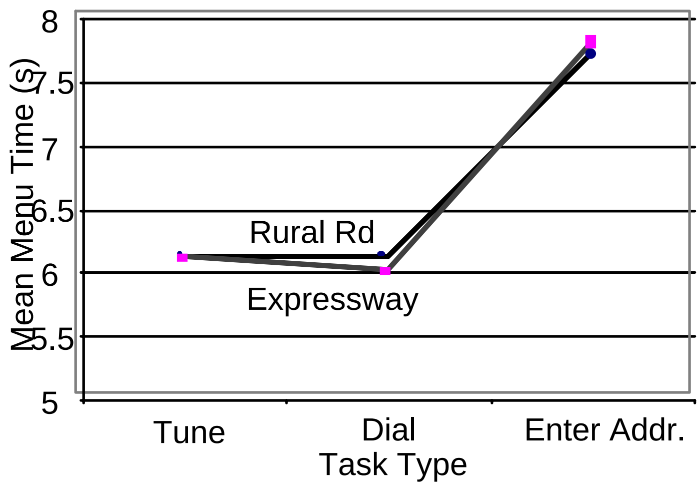


Figure 3.8. Effect of road type on task

Why then are the menu times for all three tasks so similar (though they were not statistically significant), with the navigation task being slightly longer than either dialing or tuning? Hick's Law (Welford, 1980) states that response time is proportional to the log of the number of alternatives. Accordingly, one would expect the navigation task to have the shortest time (4 choices), followed by the radio (5 choices), followed by the phone (6 choices). In fact, that did not occur.

Another perspective is that the serial position on the list matters because one needs to read to the desired item to select it (a self-terminating search). In that case, the ordering from shortest to longest time should be navigation (position 2), radio (position 3), and phone (position 4). That order is also not consistent with the data.

A third hypothesis is that subjects read the screen from left to right, and lateral position matters most (radio first, phone second, navigation third). The data are consistent with this hypothesis.

Finally, it could be that subjects were mentally preparing for the upcoming data entry task while navigating through the menu and selecting menu items. Accordingly, the address entry task should have a menu selection time far longer than the turning and dialing tasks, which were simpler, at least as indicated by the data entry time.

Use of in-vehicle menus has not been studied extensively (Manes and Green, 1997; Norman, 1991), but should be.

To provide a sense of differences between subjects, Figure 3.9 shows the mean menu time for each subject grouped by age and gender. Except for tuning the radio by the older female subjects (Figure 3.10), the between-group differences were quite consistent. As is often found, menu time for older women (11.0 s) was much longer than that for older men (6.1 s), whereas the difference in the middle age group was much smaller (4.4 s for women, 5.3 s for men). Thus, the times for older women were more than double those of all middle-aged subjects.

These results are atypical of what is usually found in studies with similar age groups. Typically, middle-aged men do better than middle-aged women (what the third author has called the “testosterone effect”), whereas older women do better than older men (survival effect). The testosterone effect reflects a desire of young men to compete and do well in the experiment. For older subjects, the women are in better health than the men and hence are able to perform tasks better. This is reflected in survival statistics. The older one gets, the greater the degree that women outnumber men. (See Green, 2001 for similar data from other telematics studies.) Other than possibly being due to random subject differences, the authors are uncertain why the age and sex interaction was the reverse of what is typically found.

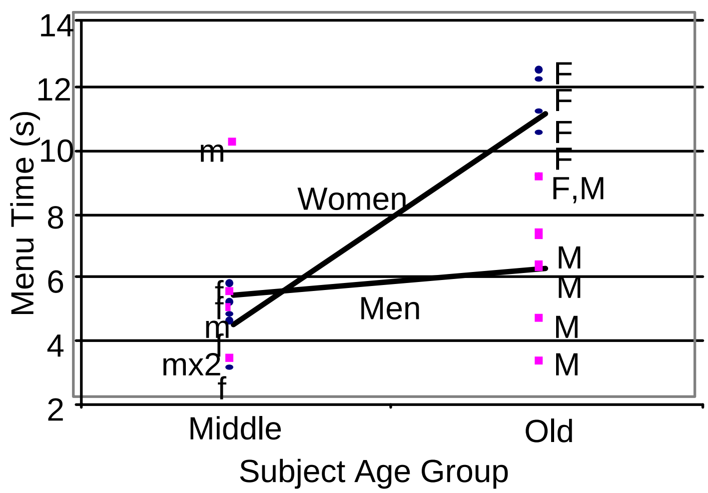


Figure 3.9. Effects of age and sex on menu time (shown by subject)
(Note: upper case is older, lower case is middle aged, f=female, m=male)

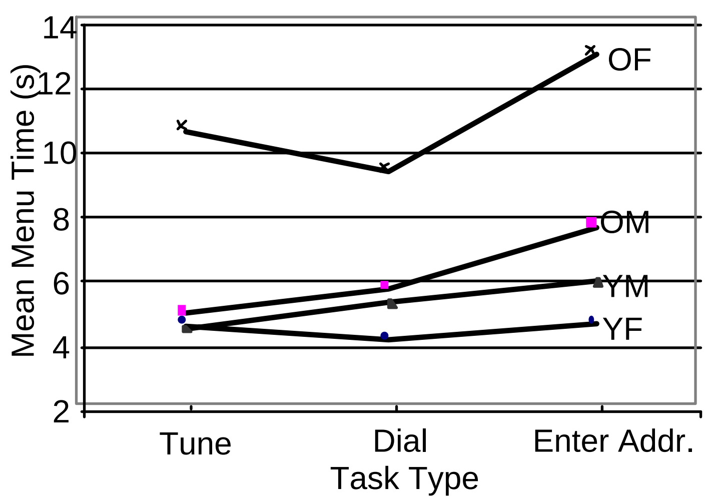


Figure 3.10. Menu time for each task as a function of driver age and sex (Note: OF, OM is older female, male, and YF, YM is younger female, male)

Similarly, the same approach (and model) was used for the data entry task times. In the final analysis, task ($p<.001$), sex ($p<.05$), and age * sex ($p<.01$) were the only factors that were statistically significant.

Figure 3.11 shows the distribution of data entry times by task. All three distributions were log-normally distributed, but the lower end tail is quite small, so the distributions almost appear exponential.

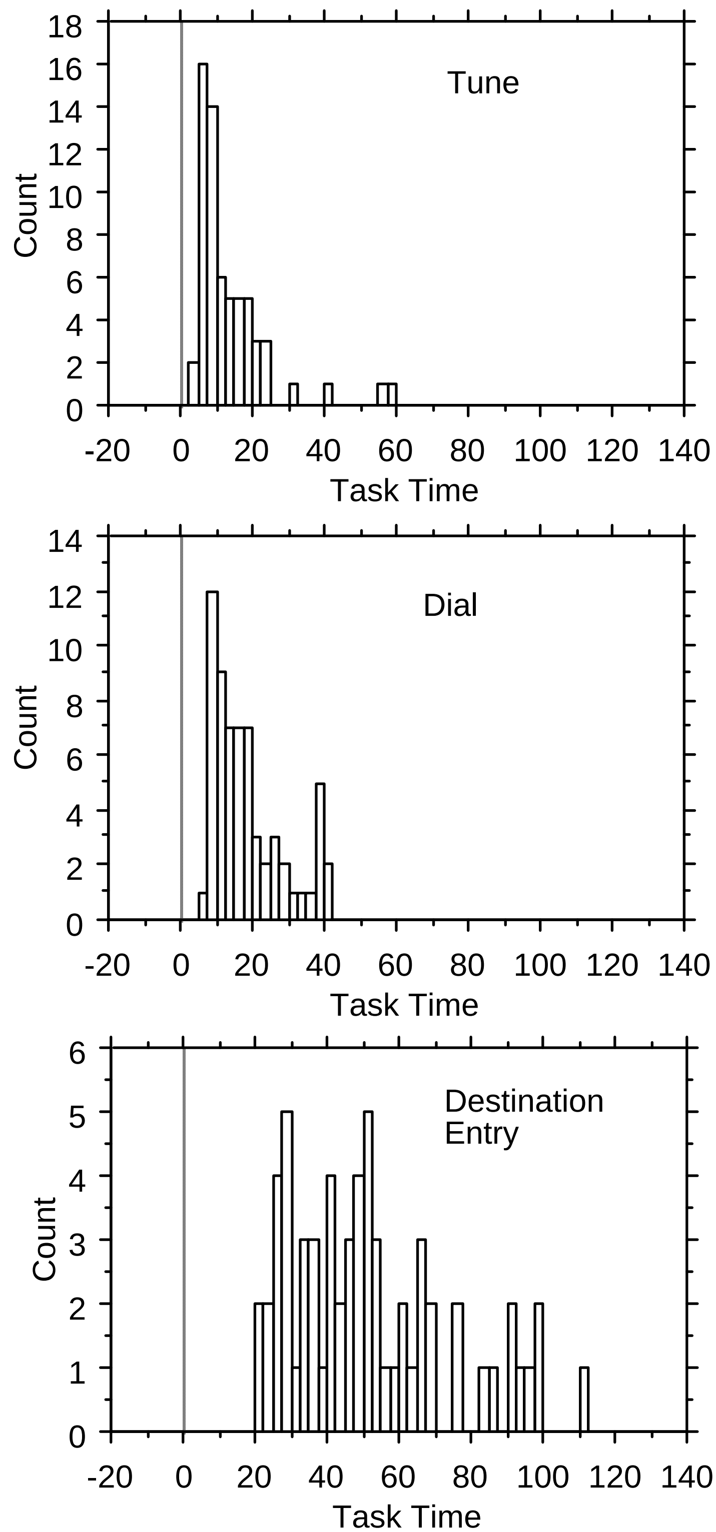


Figure 3.11. Task times for tuning the radio, dialing a phone, and entering a destination

Table 3.6 provides a more detailed examination of each of the three tasks. It is often the case that the standard deviation is about half of the mean time. The relationship for dialing and entering the destination are consistent with the rule of thumb.

Table 3.6. Statistics for each task type

	Tune	Dial	Enter Destination
Mean (s)	13.7	18.7	51.8
SD (s)	10.6	10.1	22.6
Minimum (s)	3.6	6.7	20.3
Maximum (s)	59.3	42.0	110.9
Skew	2.6	1.0	0.8
Kurtosis	7.7	0.1	-0.2

By way of comparison, the literature review by Green and Shah (2004) reported task times while driving as 8 to 20 s for dialing, 8 to 22 s for tuning, and 34 to 185 s for entering a street address. The values reported here are consistent with the literature.

The relationship between the three factors (age, gender, and task type) becomes more apparent when the factors are combined into the same figure, as shown in Figure 3.12. Clearly there were no overwhelming task-by-age interactions, allowing for some pooling over age groups to improve the mean time predictions.

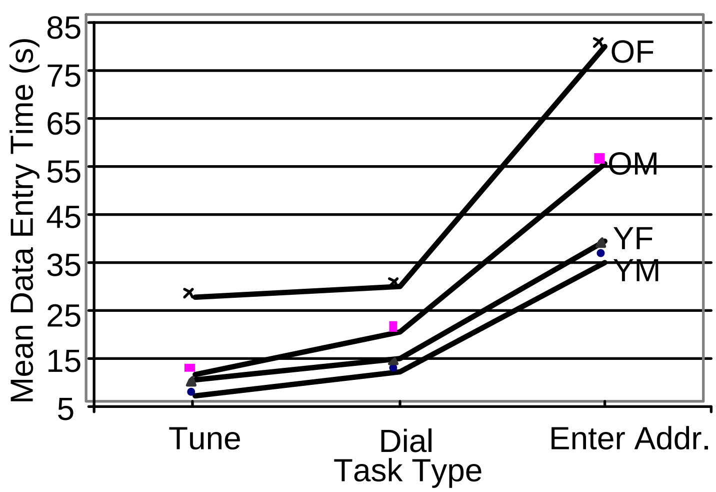


Figure 3.12. Data entry time for each task as a function of driver age and sex

Figure 3.13 shows the effect of road type on task time, which was nil. It may be that in selecting driving conditions that were reasonably safe, roads of equivalent demand were selected.

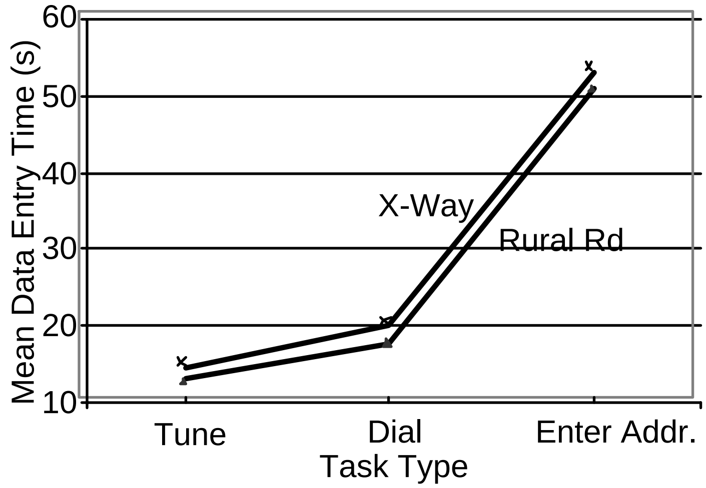


Figure 3.13. Data entry time for each task as a function of road type

Just as for the menu times, an important piece of data from this experiment is the time per keystroke for data entry—information that is needed for engineering purposes such as in SAE Recommended Practice J2365. Table 3.7 shows the mean time for keystroke for menu entry and data entry by driver age group, which is a factor in J2365. The menu keystroke times were determined by dividing the total menu time by 2, since there were 2 keystrokes after pressing the start button. The data entry keystroke times were determined by dividing the total data entry time by the actual number of keystrokes (including errors). The keystroke times for address entry for older subjects are surprisingly large.

Table 3.7. Measure time/keystroke (s)

Task Type	Age	Tune	Dial	Enter Address
Menu	Middle	2.27	2.35	2.65
	Older	3.85	3.73	5.12
Data Entry	Middle	0.43	1.09	1.56
	Older	0.97	1.96	3.37

As shown in Figure 3.14, the data entry times for tuning, dialing, and address entry were all log normal, though as with the menu times, the distributions almost appear exponential.

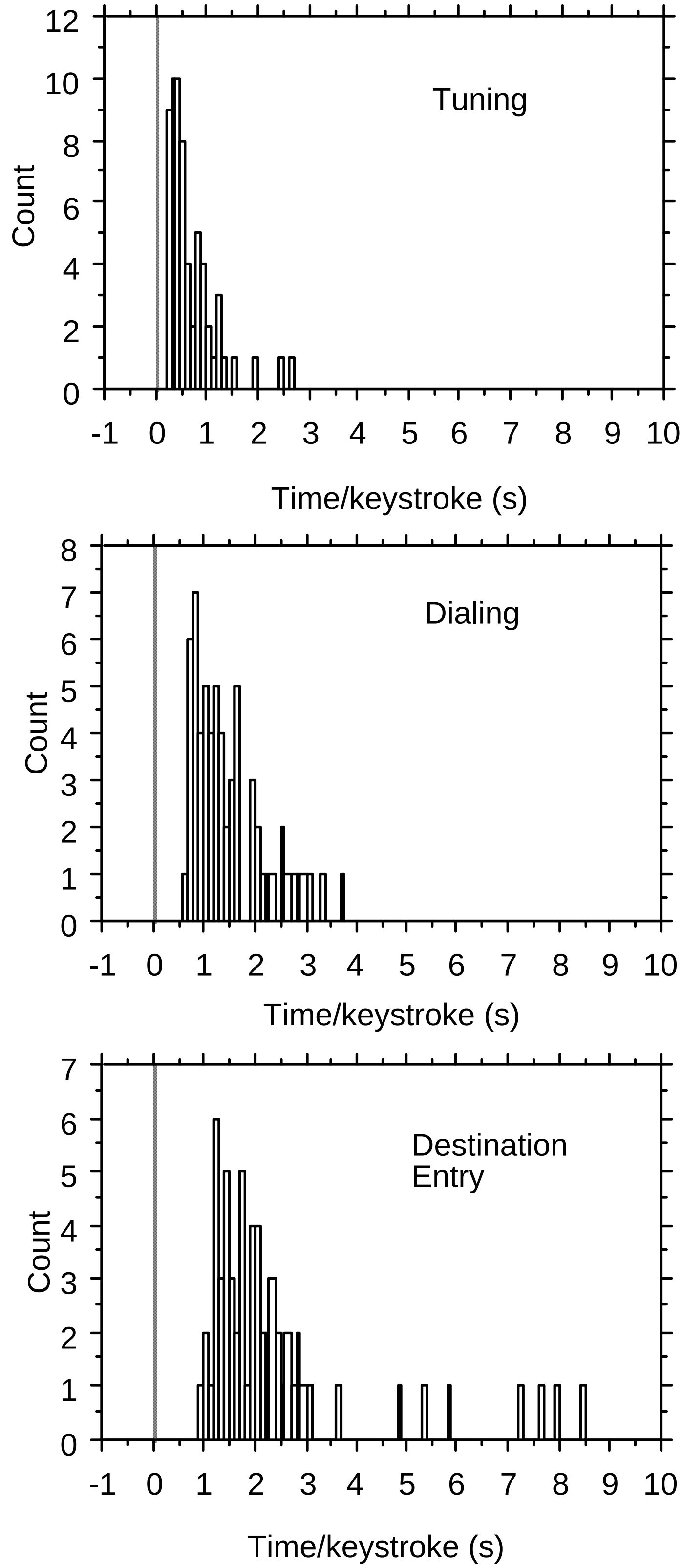


Figure 3.14. Time per keystroke for data entry for each of the 3 tasks

How well do the keystroke times agree with the estimates from SAE Recommended Practice J2365? To develop those estimates, the relevant operator times (Table 3.8) were identified in J2365 for younger subjects (18-30). The J2365 times are static data;, that is, the vehicle is parked. Using the data for younger drivers from J2365, estimates for the total task time for the menu task, and data entry times for tuning, dialing, and street address entry were developed. Tables presenting those calculations appear in Appendix G.

Table 3.8. Operator times (s) from SAE J2365

Code	Name	Operator Description	Time (s)	
			Young Drivers (18-30)	Older Drivers (55-60)
Rn	Reach near	From steering wheel to other parts of the wheel, stalks, or pods	0.31	0.53
Rf	Reach far	From steering wheel to center console	0.45	0.77
C1	**Cursor once**	**Press a cursor key once**	**0.80**	**1.36**
C2	**Cursor 2 times or more**	**Time/keystroke for the second and each successive cursor keystroke**	**0.40**	**0.68**
L1	**Letter or space 1**	**Press a letter or space key once**	**1.00**	**1.70**
L2	**Letter or space 2 times or more**	**Time/keystroke for the second and each successive cursor keystroke**	**0.50**	**0.85**
N1	**Number once**	**Press the letter or space key once**	**0.90**	**1.53**
N2	**Number 2 times or more**	**Time/keystroke for the second and each successive number key**	**0.45**	**0.77**
E	**Enter**	**Press the Enter key**	**1.20**	**2.04**
F	Function keys or shift	Press the function keys or Shift	1.20	2.04
M	**Mental**	**Time/mental operation**	**1.50**	**2.55**
S	Search	Search for something on the display	2.30	3.91
Rs	Response time of system-scroll	Time to scroll one line	0.00	0.00
Rm	Response time of system-new menu	Time for new menu to be painted	0.50	0.50

However, the subjects in the experiment were much older (slower) and they were driving, so adjustments to the J2365 estimates were needed. In Table 3.8, the times for older subjects are 1.7 times those for younger subjects. Given the mean ages of the 2 groups (24 and 57.5) and assuming a linear increase in task times with age (a reasonable first cut assumption based on the data used to develop the tasks times in Table 3.8), the increase in task time is 1.7/(57.5-24) = .00507/year. Hence, the times for middle-age subjects (35-55, mean 45) and older subjects (65-75, mean 60) are 1 +

((45-24)*.00507) = 1.1065 times and 1+ ((70-24)*.00507) = 1.2332 times the younger group times respectively.

Furthermore, these experimental times are dynamic (while driving), whereas the J2365 estimates are for static (parked) conditions. Furthermore, based on the data of Nowakowski and Green (2001), the times for on-the-road tasks are about 1.25 to 1.5 times greater than the static (parked) times for any age group. Given that these roads were fairly easy to drive, a value at the low end of the range, say 1.3, seems reasonable. As a rough estimate, this suggests that on-the-road times for middle-aged subjects measured in the experiment should be about 1.44 times the J2365 estimate for young subjects (1.1065*1.3) and about 1.60 times the estimate for older subjects (1.2332*1.3).

Using these correction factors, Table 3.9 shows a comparison of the estimated and actual times for each task for each age group. Overall, the results compare to the estimates passably, overestimating the middle subjects and underestimating the older subjects. In general, as the discussion in this section points out, the J2365 Recommended Practice will not provide relatively accurate estimates for very short tasks because the addition of a single element, in this case one mental operator, changes the estimate by a large percentage. For longer tasks, those decisions tend to even out the estimate.

Table 3.9. Comparison of actual and estimated times

Item	Data	Middle			Older		
		Tune	Dial	Enter Destination	Tune	Dial	Enter Destination
Menu	Actual	4.55	4.70	5.30	7.71	7.46	10.24
	Estimate	7.05	7.05	7.05	7.84	7.84	7.84
Task	Actual	8.46	13.03	37.4	19.07	24.5	66.86
	Estimate	14.5	17.7	33.8	16.1	19.6	37.6

Note: The J2365 estimates were 4.9 s for the menu, 10.1 s for tuning, 12.3 s for dialing, and 23.5 s for street address entry. See Appendix G for the calculations.

In assessing these results, keep in mind that the procedure for measuring task times, SAE Recommended Practice J2364 (Society of Automotive Engineers, 2004), calls for collecting data from 10 subjects for 3 trials each (or 30 trials total) after 5 practice trials. In this case, there were 8 subjects per age group who completed 4 trials each for a total of 32 trials. However, subjects had much less practice than called for by the J2364, so the results were less stable.

Furthermore, the temptation is to assume the data from drivers is the true value and the J2365 values are an estimate. In fact, the experimental data is just a sample from a group of subjects, and in this case, the ratio of the older to middle-age subject times is unusually large, close to a factor of 2 in many cases, when a more typical ratio might be closer to 1.5 or less.

Errors

An error was defined as when a completed entry did not match a desired entry. If an entry contained multiple errors, for example, if Main (as in Main Street) was spelled Msim (2 substitution errors), it was scored as a single incorrect entry. If errors were corrected prior to entry, the entry was scored as correct. So, in this example, if the subject entered M, a, o, backspace, i, n, the entry was scored as correct. Accordingly, the number of possible errors was 1 for each radio tuning trial, 1 for each phone dialing trial, but 3 for each destination entry trial (because there were 3 lines). (For further information on error measures, see Mackenzie and Surkoreff, 2002.)

Overall, as can be seen in Table 3.10, the entry error rates were 2% for tuning the radio, 10% for dialing a phone, and 40% for entering a destination; not very good performance.

Table 3.10. Entry errors by task

# of Entry Errors	Task		
	Tune Radio	Dial Phone	Enter Destination
0	62 (98%)	57 (90%)	38 (60%)
1	1 (2%)	6 (10%)	14 (22%)
2	-	-	8 (13%)
3	-	-	3 (5%)
Total	63	63	63

As shown in Table 3.11, the numbers of errors for the two types of roads were equivalent with the error rates being 16 % for the rural road and 18 % for the expressway, averaged across tasks.

Table 3.11. Entry errors by road

# of Entry Errors	Road	
	Rural	Expressway
0	81 (84%)	76 (82%)
1	11 (11%)	10 (11%)
2	2 (2%)	6 (6%)
3	2 (2%)	1 (1%)
>3	0	0
Total	96	93

The error data by age and sex are consistent with the task time data, with the older women (38 % of subjects had at least one error) doing much worse than the older men (15 %) or the middle-aged subjects (8 %). The number of errors for the older women was more than twice than that for the middle-aged subjects. (See Table 3.12.) Keep in mind that the 3 missed trials all involved older women.

Table 3.12. Entry errors by age and sex

# of Entry Errors	Task			
	Middle aged		Older	
	Men	Women	Men	Women
0	45	43	41	28
1	3	5	6	7
2	0	0	1	7
3	0	0	0	3
>3	0	0	0	0
Total	48	48	48	45

Finally, for reference purposes, the distribution of the total number of keystrokes appears in Appendix H.

3.3.2 How Was Driving Performance Affected by Distracting In-Vehicle Tasks?

Sample Driving Performance of a Selected Subject

To provide a sense of the data, Figure 3.15 shows the performance of a typical subject driving on an expressway. The left half of the figure shows baseline driving (no in-vehicle task), while the right half shows performance while entering a destination. Notice that the right lane tracker values are much smoother than the left tracker, which has much more of a quantized appearance. Also notice that there are sudden jumps in the reported position of the vehicle for the right tracker, on the order of 0.5 ft. It does not make sense for the vehicle to move that distance over a single sample (.05 seconds).

Also noteworthy in this example were other consequences of the driving situation and of distraction. First, note that there was not much headway data for a significant fraction of the baseline task and for much of the distracted condition.. In fact, because of safety concerns, distraction trials were not started if there was a lead vehicle with headway of 45 feet (approximately 3 car lengths) or less, and trials were suspended if the vehicle came within 30 feet of the car ahead. Furthermore, to avoid false positives where fixed objects, such as roadside signs, were picked up by the headway sensor, all range data in excess of 1,000 feet were discarded. It is unlikely than any object at 1,000 feet or more ahead would have much influence on how a person drove. Nonetheless, even the small amount of headway present, along with the speed data, show a common trend described in detail later. If drivers are presented with a distracting in-vehicle task (a minute or less) in light to moderate traffic on a reasonably straight road, they gradually slow down and increase their headway with the lead vehicle, assuming the gap between them and the lead vehicle is not filled by another vehicle.

Another interesting finding regards the throttle percentage and is explored in detail later. When presented with a distracting task, 13 of the 16 subjects, for at least part of the time, alternated between periods of no throttle correction (“throttle-holds” or “flat lining”) and periods of adjustment. When not distracted, adjustment was mostly continuous, as shown in Figure 3.15. Recall that subjects were driving on a very straight and level road, that traffic flow was fairly steady, and there were not major wind gusts to perturb the their speed.

Also noted, at least in this subject's data, was the tendency to make larger steering corrections, that is a shift in the correction frequency from low to high, when distracted.

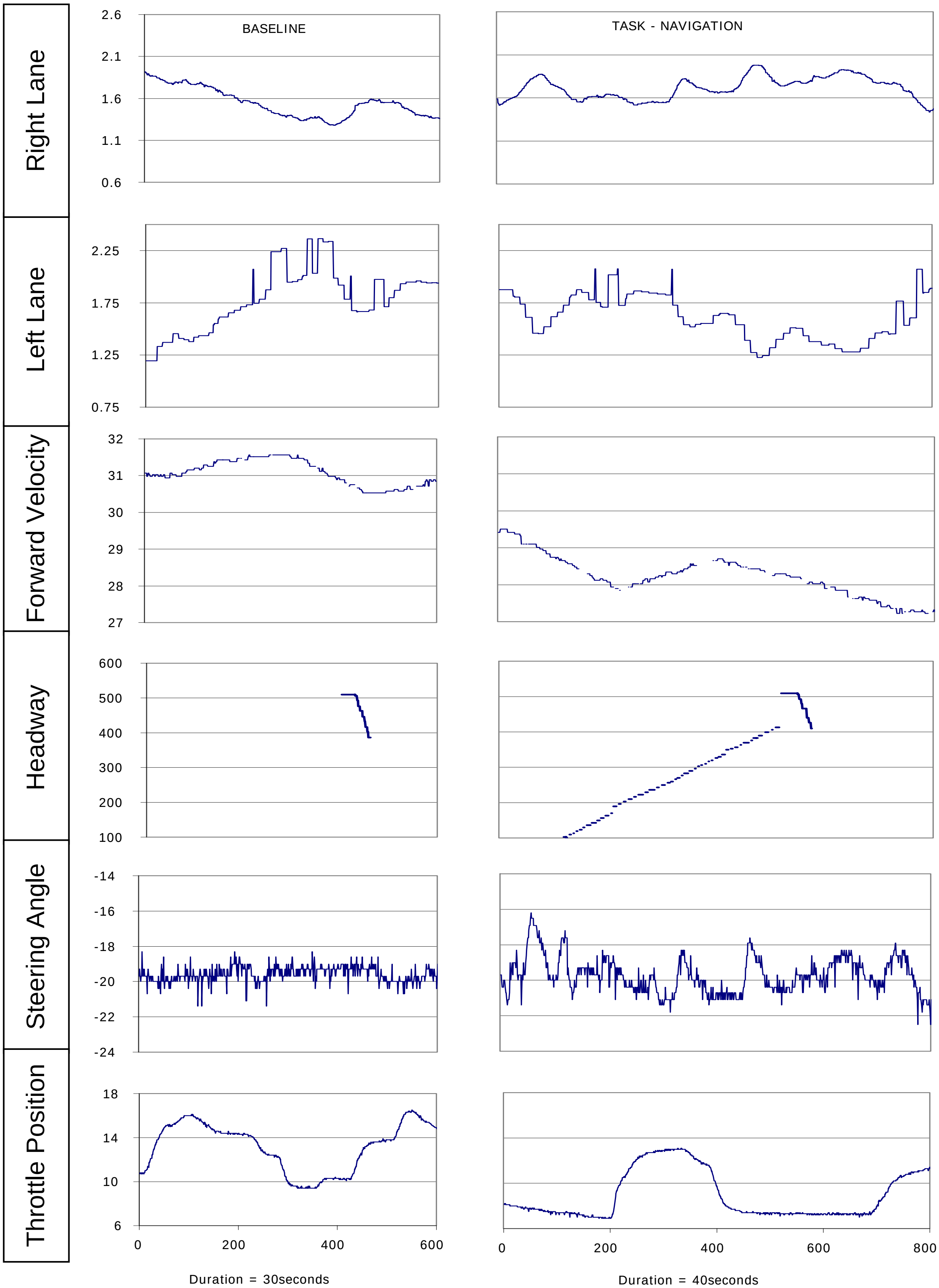


Figure 3.15. Driving performance of a middle-aged female subject (04) on US-23 S.

Summary Statistics on the Driving of All Subjects

Thirteen dependent measures of driving performance were extracted from the data for each of 6 trials for each subject. To address an expected bias due to trial length, the dependent measures are reported as the mean across 5-second intervals. For each dependent measure, there were 192 data points, which represented 16 subjects x 2 roads (US-23 and Platt) x 2 runs (North and South) x 3 conditions (baseline, looking-away tasks, and in-vehicle tasks). Of these 192 data points, 3 baseline trials were missing and 8 in-vehicle task conditions consisted of less than 3 trials. To simplify the analysis, the in-vehicle tasks of each road were combined to one reported value, and both looking-away tasks were combined as well. It should be noted that separate analyses were run with the 3 in-vehicle tasks (tune, dial, and address entry) as an independent measure but no significant differences were found between them.

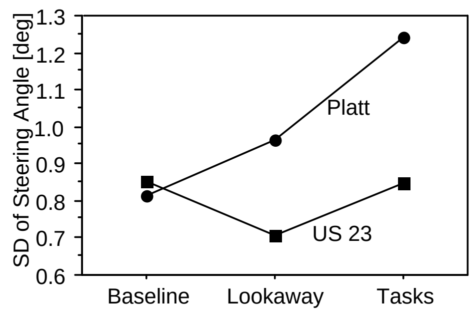
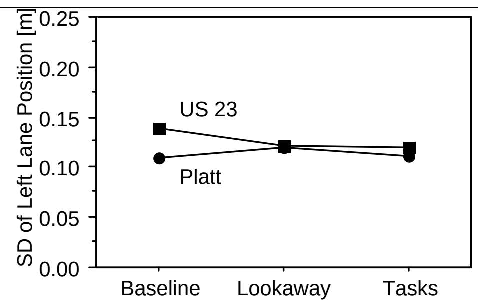
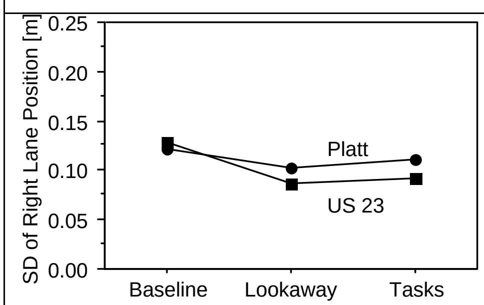
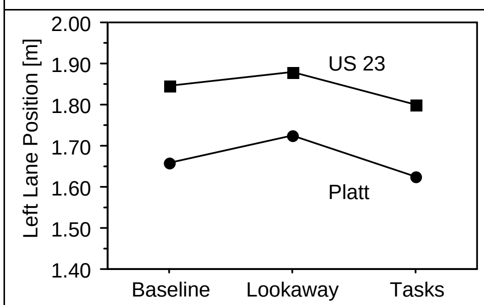
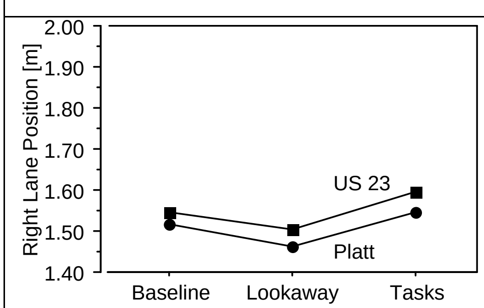
A repeated measures ANOVA was run for each of 13 dependent measures of driving performance and 2 nested within-subject variables: (1) road driven – Platt Rd. and US-23 and (2) In-vehicle task – baseline driving, looking-away tasks, and in-vehicle tasks. Age and gender were included in the model but were not found to be significant. Table 3.13 presents the main effects of in-vehicle task and road for each of the driving performance dependent measures. Comments about the graphs and the accompanying ANOVA appear in the cell adjacent to each figure.

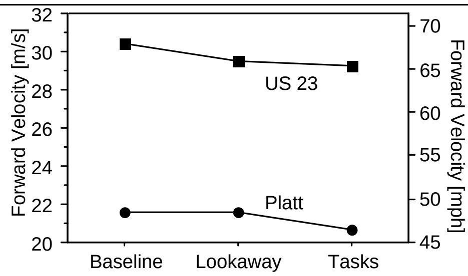
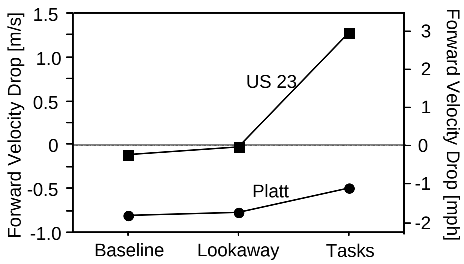
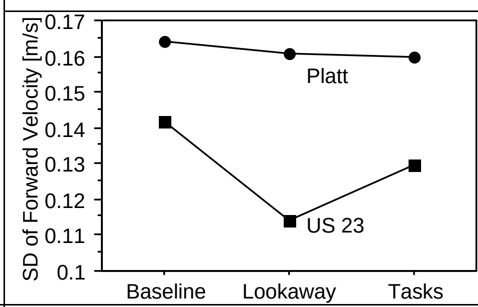
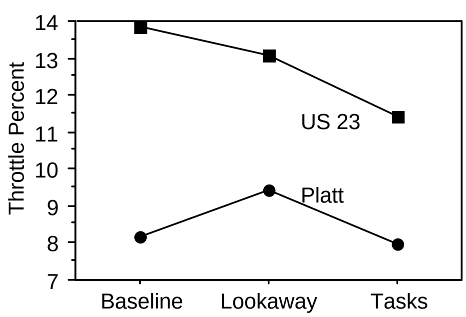
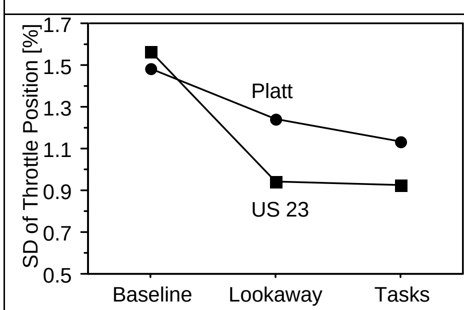
Overall, these data show few differences in the means and standard deviations of most of the measures examined (speed, throttle angle, lateral position, steering wheel angle, etc.) between the various conditions explored. In some sense, this could be interpreted to suggest that there are no ill effects of distraction, at least as assessed by most of the driving performance measures examined. However, keep in mind that the test conditions selected were the most innocuous possible to avoid placing subjects, experimenters, and the driving public at risk – straight roads with stable traffic driven in daylight and in good weather, where data collection was suspended when possibly risky situations arose. Furthermore, no data were collected near intersections with signals or where the subject would respond to a stop sign.

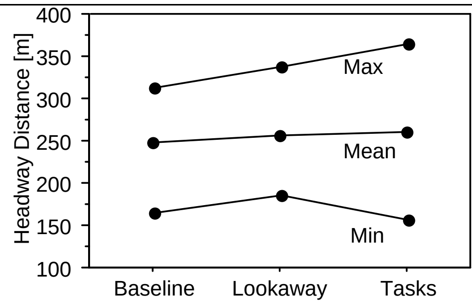
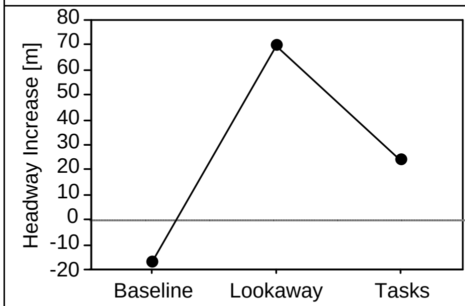
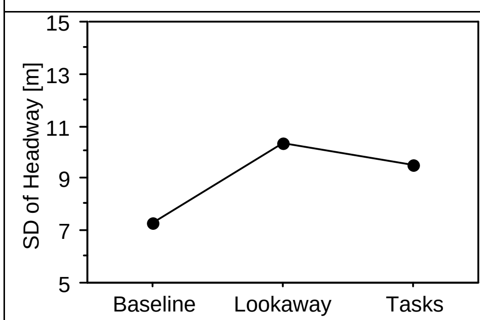
Thus, because there were few risky situations to detect, few were found. In some sense, this is a desired approach because it filters out the less sensitive measures, so that those that do change with even modest levels of distraction are quite useful, assuming they meet other criteria of reliability, validity, and so forth.

Of the measures examined, speed drop seemed to be the most sensitive indicator of distraction. In the look-away task, speed drop had quite similar results to that of baseline driving. In examining the speed drop measure, the negative drop (meaning subjects accelerated) just indicates that for the points selected, subjects were traveling faster at the end of the trial than at the beginning. This was probably due to the choice of the particular baseline locations.

Table 3.13. The effect of task condition on driving performance measures

Steering Angle		Standard deviation of steering wheel angle on Platt Road increased from 0.81 deg on baseline driving to 0.96 deg when glancing at the target (look-away) and 1.24 deg when performing in-vehicle tasks, *F*(2, 18) = 29.87, *p*<.0001. This effect was not apparent on US-23. The interaction effect of task and road was significant, *F*(2, 18) = 18.10, *p*<.0001.
Lane Position		Standard deviation of left lane position remained unchanged (0.12 m) across conditions.
		Standard deviation of right lane position on baseline (0.13 m) was higher than when glancing at the target (0.09 m) and when performing in-vehicle tasks (0.10 m). The effect of task was significant, *F*(2, 18) = 7.88, *p*<.01.
		Distance to the left lane marker when performing an in-vehicle task (1.7 m) was lower than baseline (1.75 m) and when glancing at the target (1.80 m), *F*(2, 18) = 7.66, p<.01. Distance from the left lane on US-23 (1.84 m) was greater than on Platt Road (1.67 m), *F*(1, 9)=32.9, *p*<.001.
		Distance to the right lane marker when performing an in-vehicle task (1.57 m) was greater than baseline (1.53 m) and when glancing at the target (1.48 m), *F*(2, 18) = 10.95, *p*<.001. The difference between roads was not significant.

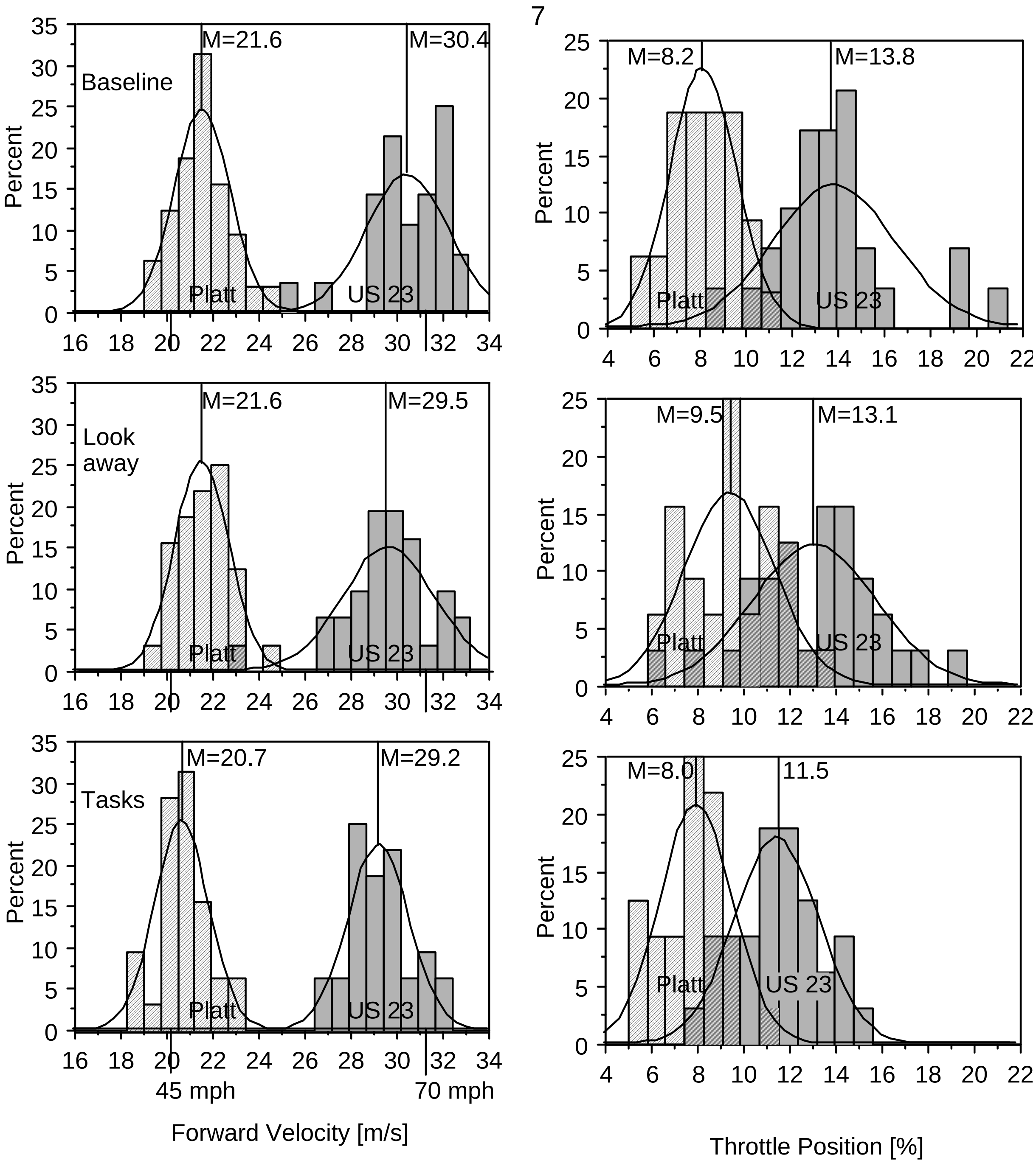
<table>
<tr>
<td rowspan="3">Forward Velocity/Velocity Drop</td>
<td>
</td>
<td>Forward velocity on US-23 (29.7 m/s) was higher than on Platt Road (21.3 m/s). On both roads, forward velocity when performing in-vehicle tasks was 1.2 m/s lower than baseline driving, $F(2, 16) = 12.56$, $p<.001$.</td>
</tr>
<tr>
<td>
</td>
<td>A drop in forward velocity occurred when performing in-vehicle tasks on US-23 (1.3 m/s). On Platt Road, forward velocity increased in all conditions. The effect of task and the interaction of task and road were significant, $F(2, 16) = 7.21$, $p<.01$, $F(2, 16) = 3.96$, $p<.05$, respectively.</td>
</tr>
<tr>
<td>
</td>
<td>Standard deviation of forward velocity was higher on Platt Road (0.16 m/s) than on US-23 (0.13 m/s), but across tasks it did not change significantly.</td>
</tr>
<tr>
<td rowspan="2">Throttle</td>
<td>
</td>
<td>On US-23, mean throttle position decreased from 13.8% on baseline to 13.1% when glancing at the target and 11.5% when performing in-vehicle tasks. On Platt, it was higher when glancing at the target (9.5%) than baseline (8.2%) and in-vehicle task (8.0%). The effect of task was significant $F(2, 18) = 19.95$, $p<.0001$ and so was the interaction between task and road $F(2, 18) = 30.1$, $p<.0001$.</td>
</tr>
<tr>
<td>
</td>
<td>Standard deviation of throttle position on baseline (1.5%) was higher than when glancing at the target (1.1%) and when performing the in-vehicle task (1.0%), $F(2, 18) = 10.78$, $p<.001$.</td>
</tr>
</table>

<table>
<tr>
<td rowspan="3">Headway</td>
<td>
</td>
<td>Statistical analysis was not performed on the headway distance data because there were too many missing cells.</td>
</tr>
<tr>
<td>
</td>
<td>The mean headway increase when performing an in-vehicle task was 24 m and 69 m when glancing at the target, relative to a headway decrease of 17 m on baseline.</td>
</tr>
<tr>
<td>
</td>
<td>The standard deviation of headway was 7.1 m on baseline, 10.2 m when glancing at the target, and 9.5 when performing in-vehicle tasks.</td>
</tr>
</table>

<u>Distributions of Longitudinal Driving Performance Measures</u>

Given the findings concerning speed drops and holding the throttle relatively constant (throttle-holds), the throttle and speed data were examined further. Table 3.14 shows the distribution of trial means for forward velocity and throttle position. Each bar represents the relative probability that a trial mean would be of a certain velocity or throttle position. Forward velocity while performing the in-vehicle tasks was lower than baseline driving, as can be seen by the shift to the left across graphs. A similar effect was seen for throttle position, but with larger magnitude and especially on US-23.

Table 3.14. Distribution of trial means of forward velocity and throttle position



Given the apparent sensitivity of mean throttle position to performing in-vehicle tasks, further analysis was performed. A timeline plot of throttle position for each of the subjects confirmed that the mean throttle position when performing in-vehicle tasks was lower than during baseline driving. In addition, there were long intervals in which the throttle was kept constant. Some subjects kept the throttle at a fixed position for an entire trial. Throttle position of a typical subject (S4, young female) is shown in

Figure 3.16 (the same figure for every subject can be found in Appendix I). Note that subjects 7 and 13 had missing baseline data for that particular route. The abbreviations L10 and L30 stand for the 10 and 30 second glancing tasks, respectively. Intervals in which the throttle was fixed are apparent in the figure.

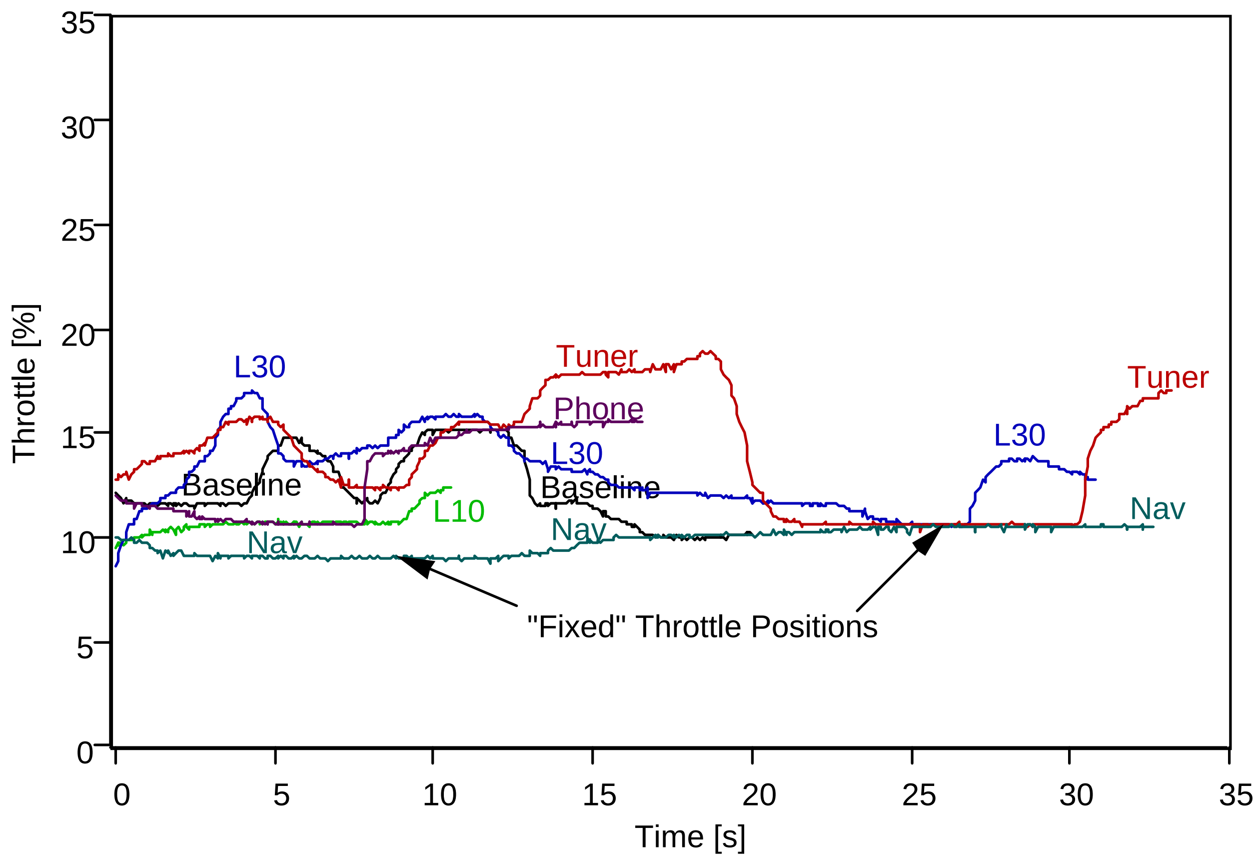


Figure 3.16. Throttle position as a function of time for 6 trials on US-23 N

As a behavior, throttle-holds make sense. Subjects' priorities are, in order, to avoid crashing into another vehicle, to stay in their lane, and to complete the in-vehicle task. They reduce the crash probability by avoiding small headways, an easily achieved goal, and they do steer. However, they are unable to attend to the throttle (and perform minor speed corrections) and perform the in-vehicle task at the same time, so they stop correcting their speed. The lack of corrections indicates that drivers are being asked to do more than they can handle, but this conclusion is not directly supported by the data.

In an attempt to quantify this phenomenon, throttle positions of all trials were filtered for time-based change. A moving window of 2 s (which at the 20 Hz sampling rate, with 1 sample every 50 ms, contained 40 data points) was applied to the data and the change of throttle position between the two edges of the window was recorded. Two seconds corresponds to a moderately, but not extraordinarily, long glance from the road. This procedure was designed to capture intervals in which the throttle position was kept fixed. Figure 3.17 shows the overall distribution of throttle changes for 3 of the 6 trials. (Each trial of each subject was given similar weight.) This is an example demonstrating how the throttle distribution changes as the level of distraction increases. This led to the authors examining the throttle in more detail. The proportion of intervals with no change or close to no change increased from 0.33 on baseline driving to 0.42 on looking away for 30 s to 0.62 when performing the phone task.

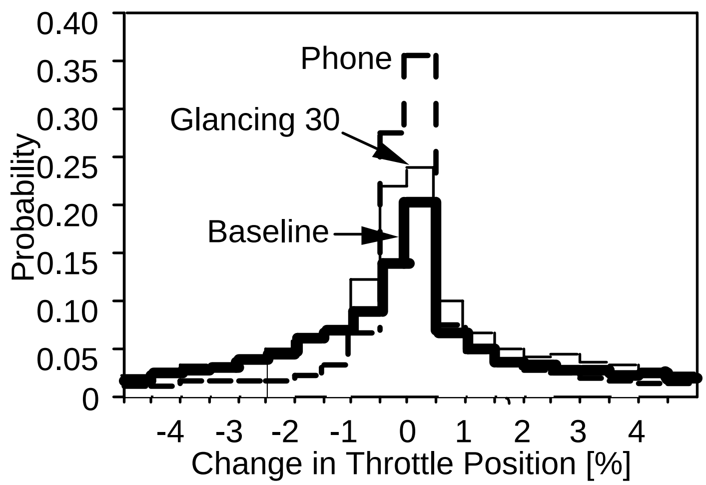


Figure 3.17. Distribution of the change in throttle position over 2 s intervals as a function of in-vehicle task performance

3.3.3 Throttle Detection Algorithm

This outcome led to an analysis to determine the most sensitive combination of a sample time window and a change in throttle position that would separate distracted and non-distracted conditions. A visual examination of the raw data revealed that this phenomenon did not occur for 3 of the 16 subjects. For the remaining 13, it occurred at least some of the time.

One of the problems with the raw throttle data was a fault of unknown origin that led to single point spikes in the throttle signal. (There were also spikes in the speed signal suggesting a 2 mi/hr increases in speed in 50 ms, an acceleration not possible in even a highly modified Honda Accord.)

To eliminate high frequency noise in the throttle signal, a 1-second (20 cells) moving average was computed for each data point. Next, the Excel LINEST function (LINEST(filtered throttle data, time (s)) was used to determine a least squares best fit straight line for each 2-second window of data.

The resulting slope values were compared to a threshold value that was set by inspection of plots of data from subjects. Since it was desired to find locations where the throttle was virtually stable, only very small slope values (less than .03) were considered. To verify that peaks and valleys in the data were not represented (that is, that the overall change was small), the difference between maximum and minimum throttle values over the 2-second window was computed. The throttle range was required to be small in order for the existence of a “constant throttle” event (less than .15, a value determined by inspection). Also, to ensure that instances when the driver was stopped were not included, the throttle percent was required to be significantly greater than zero (under 0.5 is considered zero).

Examination of the raw data showed that the throttle was not held in a fixed position for the entire period subjects were distracted by the in-vehicle task. Rather, the throttle was fixed, then subjects made adjustments, and then it was fixed again. These adjustment periods could be as short as 10 samples (.5 s). As an aside, because the experimenter pressed a button at the start and end of each task, it was obvious in the data when subjects were distracted by the in-vehicle task. Given this intermittent throttle-hold behavior, holds were grouped to identify periods of distraction.

Figure 3.18 illustrates actual detections of throttle-hold intervals and the resulting grouped detection based on a custom algorithm. The throttle holds appear as a train of square waves, with the peaks representing periods during which the intermittent throttle holds occurred and were detected by the algorithm. However, both the interval of the peaks and the valleys represent instances when drivers were distracted and it was necessary to group them, as indicated by the large rectangle. The task line represents time when the subject was actually performing a task (in this case it was the destination entry task.)

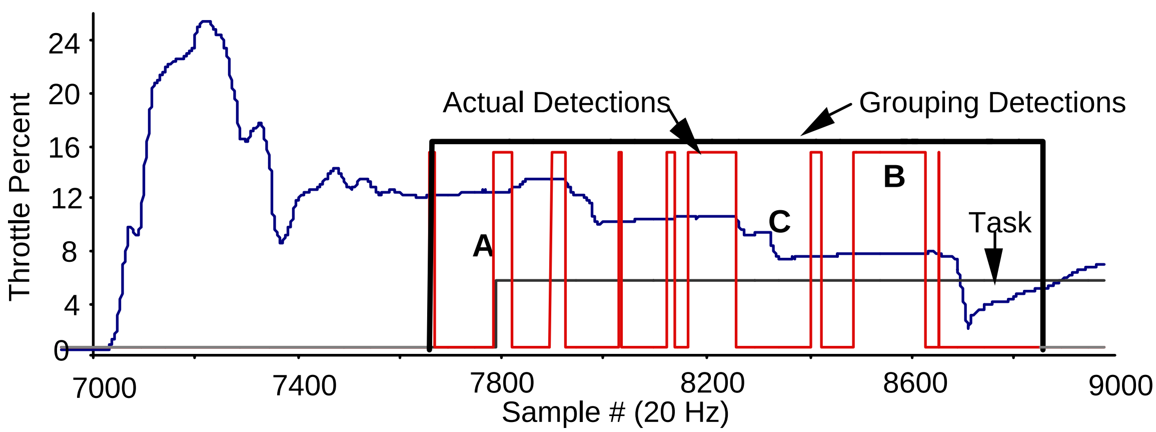


Figure 3.18. Visual representation of throttle-hold detections

Note:

A –Each time a new flat was detected, 1 point was added.

B – Every fraction of a second the flat remained, .25 points per s (.005 points per sample) were added.

C – Every fraction of a second after the flat had disappeared, .25 points per s were subtracted.

To group throttle holds, and algorithm provided a reward for each time a “flat” was detected, where the longer the event, the higher the reward. As soon as the event ends, a penalty was deducted, and these 3 parameters (reward per detection, reward per duration of detection, and penalty after detection ended, all updated at 20 Hz) determined the sensitivity of the algorithm. These values were also determined by inspection, and are illustrated by points A, B, and C in Figure 3.18

To determine when the driver was thought to be distracted, at least according to the algorithm, all the raw throttle data from each run were classified using a signal detection approach.   If the driver was engaged in a secondary task (distracted) and a "constant throttle" situation was detected, the point would be classified as a "hit," and if it was not detected it would be a "miss." If the driver was not participating in a secondary task and a "constant throttle" situation was detected it would be a "false alarm," and if no detection took place it would be a "correct rejection." A sample signal detection chart (1 subject, 1 run) as well as a sample graph of the throttle output is shown in Table 3.27 in Appendix K.

The signal detection analysis from each subject for each run was used to compute sensitivity values and create receiver operating characteristic (ROC) curves for each subject. The sensitivity values for each subject for each route can be seen in Table 3.28 in Appendix K, and each subject's ROC plot can be seen in Figure 3.30. Because of the complexity of the individual ROC plots and likely effects, ROC data were partitioned by road type and direction as shown in Figure 3.19.

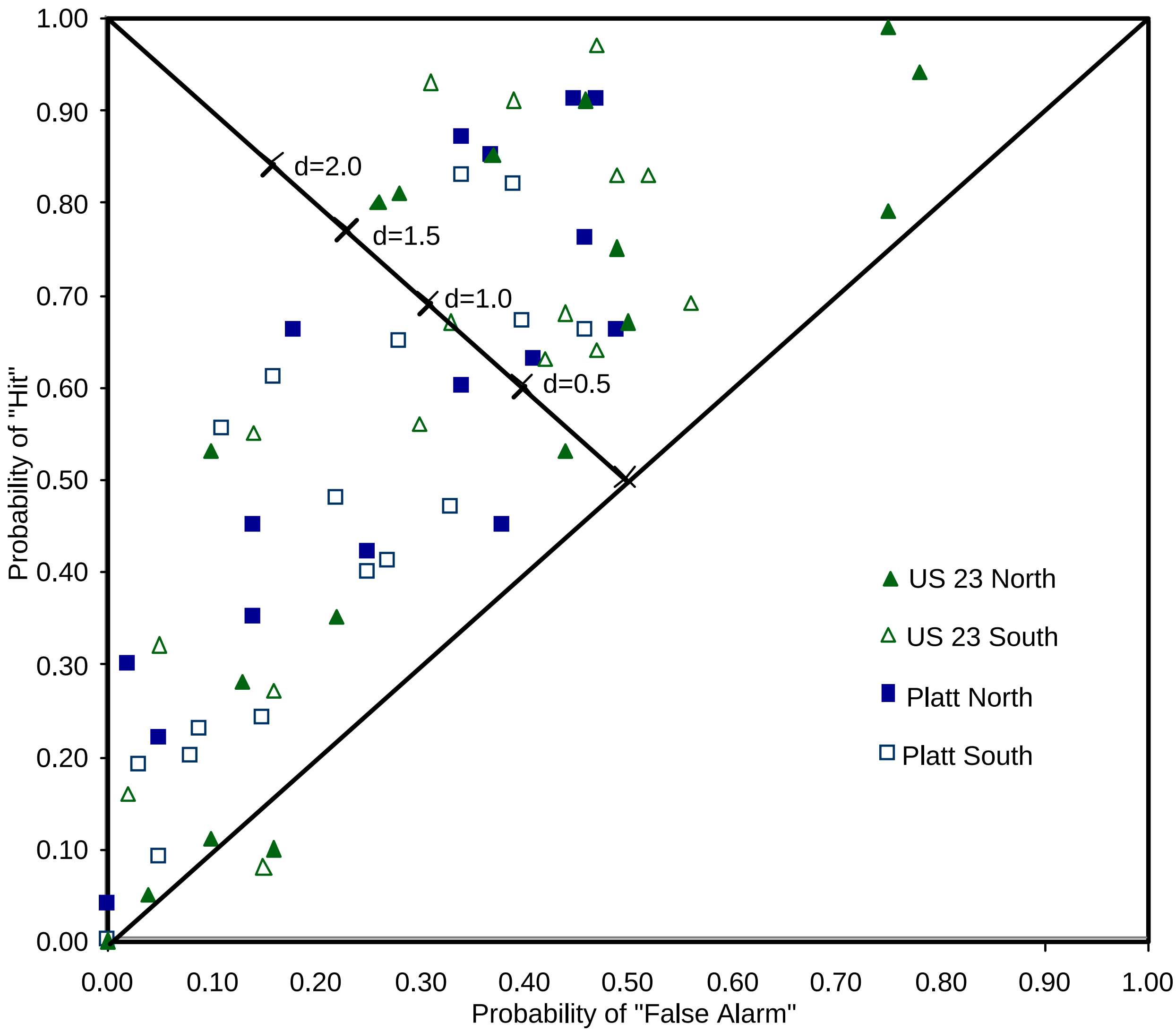


Figure 3.19. ROC plot based on road route

D-prime values ranged from 2.5 to 1.5 with values close to 1 being fairly typical, and reasonable for a first-cut, nonoptimized algorithm. Note that there were 2 instances where d-prime was less than 1, indicating there were more false alarms than hits. This reflects the underlying statistical variability in the data and that not all subjects held the throttle when completing an in-vehicle task, that is while distracted.

Further, to put the throttle-hold data in context, the experimenters returned to the test road segments several months after data collection was completed and attempted to replicate "holding" the throttle. They found that fixing the throttle was not difficult to do voluntarily, suggesting that the throttle-holds were not an artifact of the data collection hardware or software.

The purpose of this project was not to develop an optimal algorithm for using throttle-holds to detect distraction by in-vehicle tasks, only to determine if it such an algorithm could feasibly detect when drivers were distracted. That has been demonstrated. Admittedly, a great deal of additional analysis is needed to refine the smoothing algorithms, the time window for sampling throttle, the effect of sampling rate, and the reward and penalty functions for grouping throttle-holds. The signal processing to clean up the throttle signal could be vehicle or sensor specific. Much of what was done here was based on inspection of plots of the data to select reasonable values. Clearly, the algorithm needs further work, and further work is needed to determine if throttle-holds occur when drivers are distracted in other driving situations—when the road curves when there is more traffic, and so forth. Also, some thought should be given to the appropriate trade-off of falsely identifying periods of nondistraction as being distracted and missing periods of distraction.

3.3.3 How Risky Did Subjects Rate the Experimental Conditions?

What Are the Risk Ratings for Each Task and How Do Ratings Vary Among Subjects?

It is important to link the driving performance and task time data to what drivers think should be done when those results occur. To provide that information, subjects rated the difficulty of performing each task while driving immediately after it was performed. There were 192 ratings (16 subjects * 2 roads * 2 runs/road * 3 tasks). There was no data missing. An ANOVA of those post-test ratings can be seen in Appendix J. Task ($p<.0001$) and task, road, and gender ($p<.1$) were significant.

As shown in Figure 3.20, the younger subjects and the older men rated risk of the tasks similarly (just over 4, equivalent to driving 10 mi/hr faster than traffic on an expressway). ANOVA shows that the relationship between age and gender is moderately significant ($p<0.1$), with older female subjects rating tasks at close to 7, halfway between 6 (driving 20 mi/hr fast than traffic on an expressway) and 8 (driving while just under the legal alcohol limit (with observed weaving)).

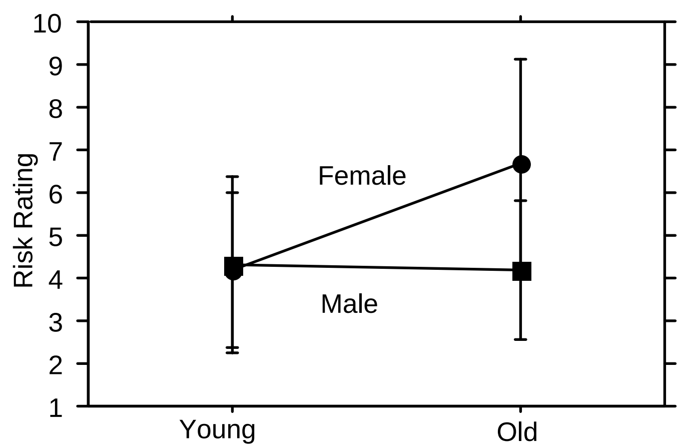


Figure 3.20. Effects of age and gender on risk ratings

Figure 3.21 clearly shows that there were task differences but not differences between the rural road and expressway in terms of the rated risk, as found by the ANOVA. The risk of tuning the radio (3.7) and dialing the phone (4.5) was rated similarly to driving 10 mi/hr faster than traffic on an expressway. Destination entry was rated (at 6.4) as equivalent to driving more than 20 mi/hr faster. ANOVA was used to test the significance of the risk ratings between tasks, and the effects of tasks was significant ($p < .0001$).

As an anchor to other literature, such as SAE J2365, these ratings correspond to measured task times (dynamic times) of approximately 14, 18, and 51 s respectively. As was noted earlier, static times are roughly 1.25 to 1.5 times greater than dynamic (on-the-road) times, so these three dynamic times (dividing by 1.3 for this situation) correspond to static (parked) times of 10.8, 13.8, and 39.2 s. Assuming linear interpolation between the tuning and dialing tasks, a risk rating of 4 is roughly associated with a static time of 11.9 s and a risk rating of 6 corresponds to a static task time of 33.9 s. Using linear interpolation further, a static task time of 15 s would therefore correspond to a risk rating of 4.3. Again, assuming linearity, that is equivalent to driving 13 mi/hr faster than traffic on an expressway. The authors realize the relationship is nonlinear and based on a sample of only a few subjects for a few tasks, but it does provide a link between task time and perceived risk, and if the crash data are available, a potential relationship between static task time and crash rate.

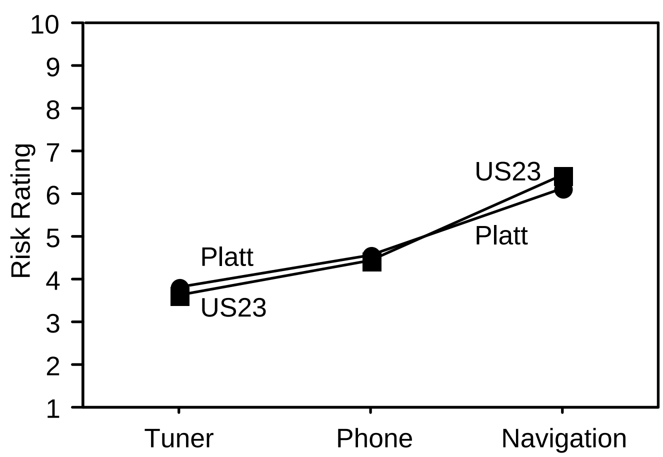


Figure 3.21. Road type effects on risk ratings

How Reliable Are the Risk Ratings?

Getting a sense of the rating reliability is difficult. If one were to immediately ask a subject a second time for a rating, they would remember the prior rating, so the independence necessary for a reliability assessment would be missing. The approach taken was to ask each subject, at the end of the study, to rate the level of safety in performing each task on the expressway (16 subjects * 3 tasks = 48 data points). There were no missing data points from either the post-test ratings or the on-road ratings. The scale that was used for risk ratings was provided earlier in Table 3.1, and the scale used for the post-test rating is given in Appendix C. The scales are similar, but the idea was to relate the subjects' perception of risk in performing these tasks on the road with the overall feeling of the safety of each task after the fact.

Figure 3.22 shows a scatter plot of the mean risk rating while driving on the expressway averaged over both directions versus the post-test rating, by all subjects. Prior to further data analysis, six data points (outliers) were removed because of spurious conditions that occurred in particular trials (subject was severely drifting while performing the task, there was glare affecting visibility of the task on the screen, a vehicle or pedestrian on the side of the road). As shown in the figure, there was a moderate correlation between on-road and post-test ratings (r=.84) suggesting some degree of reliability. When the data is collapsed across subjects, as is often the case (since the focus is on which tasks should be performed), three points result that were well fit by a straight line. Overall, subjects tended to give higher ratings on the post-test than immediately after performing the task on the highway, with the difference likely resulting from the subjects' perception of risk and that correlation to overall safety.

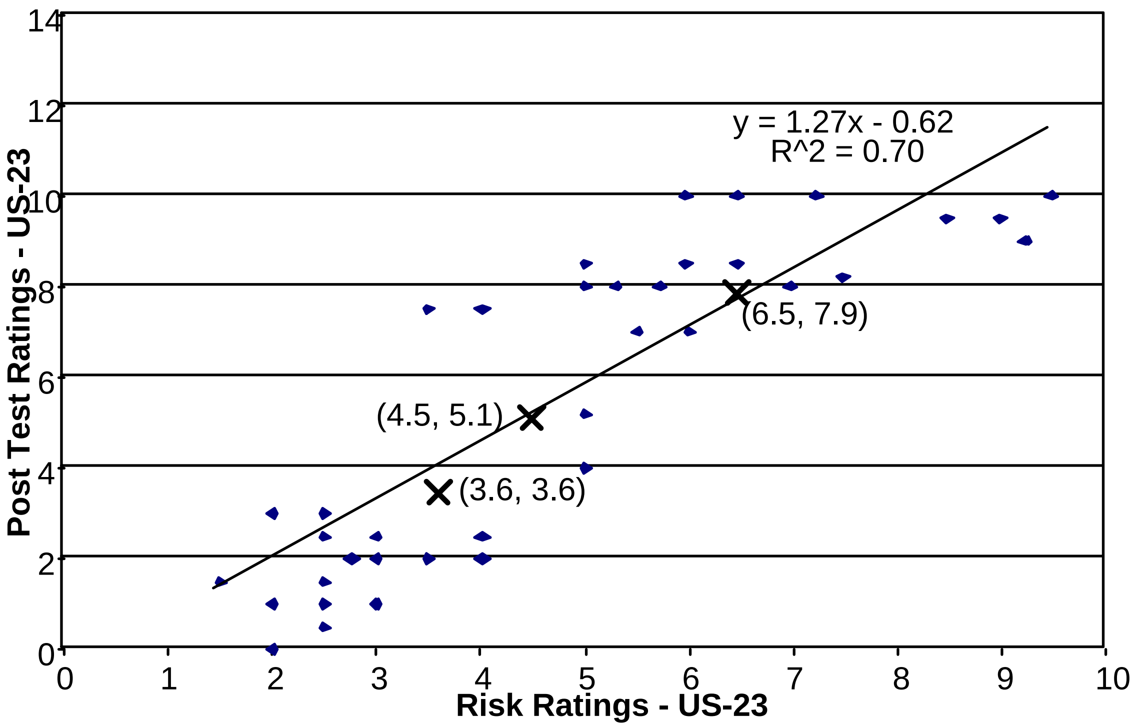


Figure 3.22. Regression on post-test ratings and on-road ratings

Overall, Do Drivers Think They and Others Should Be Allowed to Tune Radios, Dial Phones, and Enter Destinations while Driving (At Least under These Conditions)?

In the post-test, subjects were asked if "in-vehicle functions, such as the ones you encountered today, [should] be available to the public? (1=Never, 2=Only when parked, 3=Sometimes, 4=Always)." The mean response for the 16 subjects was 2.69 with a standard deviation of .60. Thus, subjects generally felt these in-vehicle functions should be available either only when parked or only some of the time, hinting at the potential benefits of a workload manager.

When asked, “What should the government and auto manufacturers do about the tasks you performed while driving? (1=nothing, 2= manufacturers should limit them, 3=some of them should be illegal, 4=all should be illegal),” the mean response for the 16 subjects was 2.44, with a standard deviation of .89. Most of the subjects felt that manufacturers should limit these in-vehicle functions, or some of them should be made illegal by the government. Though not described as an option, this also hints at the potential value of a workload manager.

Overall, as can be seen in Figure 3.22, subjects rated the tuning task as somewhat safe (3.6), the phone task as neither safe nor unsafe (5.1), and the navigation task as somewhat unsafe (7.9). Again, the task times and risk ratings were (14, 3.7) for the tuner, (18, 4.5) for the phone, and (51, 6.4) for the navigation task.

3.4 SUMMARY AND CONCLUSIONS

3.4.1 How well do people drive normally and how does driving (control) performance change when drivers are distracted?

In this experiment, 16 subjects drove on an expressway and 2-lane rural road and either just drove, or concurrently performed tuning, dialing, or address entry tasks, or glanced at the center console. The roads driven were perfectly straight and the traffic was light to medium. The data collected should be considered to characterize those conditions, not all driving, though the conditions selected may typify driving.

The measures examined pertain to driving inputs to the vehicle steering wheel angle and throttle position, and the resulting vehicle outputs, lane position, speed, and headway. Both means and standard deviations were examined.

The key point to make, also covered in detail below, is that except for throttle position, many of the measures were relatively unaffected by concurrent performance of the secondary task. That does not mean that these tasks were not distracting, and in fact, the throttle data suggest overload. As was noted before, the test conditions selected were relatively innocuous when compared with the range of driving conditions the motoring public encounters—straight roads with light to moderate traffic—conditions selected to minimize risk to test subjects. If there are any negative signs from these conditions, then driving when risk is greater—in bad weather, at night, with heavier traffic, where there are intersections, and so forth—should lead to changes in other measures and more negative consequences to driving safety.

<u>Steering Angle</u>

Overall, for the rural road, the standard deviation of steering angle was greater when performing in-vehicle tasks (1.24 deg) than for the look away tasks (0.9 deg), than for baseline driving (0.81 deg), that is, loading the driver increased the standard deviation of steering wheel angle (led to more steering wheel movement). In contrast, there were not statistically significant differences on the expressway, and in fact, the standard deviation of steering wheel angle was slightly less for look away task than other conditions. It is possible that while driving at higher speeds on straight roads the drivers tended to “lock” their steering position while attending to the look away and secondary tasks. These findings suggest that the standard deviation of steering wheel angle was not a reliable indicator of distraction for all of the roads examined.

<u>Lane Position</u>

The driving condition seemed to have almost not effect on lane position except in the look away task, when drivers positioned the vehicle about 4 cm farther to the left, an amount too small to be meaningful. This occurred for both the rural road and the expressway.

When performing an in-vehicle task, drivers tended to be slightly farther from the right lane and maintained a smaller standard deviation of lane position. Hugging the left or right side of the lane does affect mean lateral position, but not the change in SDLP between the baseline and distracted driving conditions.

In terms of variability, there was no difference between roads or conditions in terms of distance to the left lane marker (0.12 m). For the right marker, the standard deviation was slightly less for the look away and in-vehicle task conditions (about 0.10 m) than for the baseline condition (0.13 m). Although the difference was statistically significant, it is practically unimportant. Further, if anything, the opposite result was expected with standard deviation increasing with task demands. It could be that given the relatively easy driving situation, that subject chose to protect the safety-critical steering task.

Forward Velocity

Performing a task in addition to driving (looking away, performing an in-vehicle task) led to a very minor decrease in speed averaged across a task trial and a slight drop in variability. However, the major finding was the drop in speed across a trial, essentially no change for the baseline and look away conditions, a 1.3 m/s drop for the expressway and a 0.5 m/s increase for the rural road. The increase reflects random variation of the speed on various sections. Thus, the speed drop data suggest that merely looking away is not a distraction, but engagement in a task is key. The speed drop is the likely the results of distraction, with drivers slowing down to reduce the workload on themselves.

Throttle

The throttle data change in the expected manner for the expressway, with the mean throttle being greatest for the baseline condition (13.8%), followed by the look away task (13.1%) followed by the in-vehicle tasks (11.5%). For the rural road, there was no difference between the baseline and in-vehicle task conditions, and the throttle position for the look away condition was slightly greater. Further more, the standard deviation was greater when either looking away or performing a task than for the baseline driving condition. This suggests drivers were slowing down and making fewer speed corrections. The speed and throttle data were consistent, decreasing somewhat as task demands increased. Further investigation revealed that most subjects kept the throttle position fixed for some period of time during the performance of in-vehicle tasks. This finding deserves further investigation.

3.4.2 Which driving performance measures discriminate between distracted and nondistracted drivers for various tasks?

For the conditions tested in this experiment, namely straight roads with light to moderate traffic, changes in lateral control variables were not good indicators whether drivers were performing an in-vehicle task. However, longitudinal control measures were affected by in-vehicle task performance. In general, when performing a task, drivers slowed down (when comparing the beginning and end of the task). Of the longitudinal control variables, throttle position was most sensitive to performing an in-vehicle task.

Specifically, 13 of the 16 subjects alternated between periods of no throttle correction ("flat lining") and periods of adjustment when performing an in-vehicle task, at least part of the time. When not distracted, throttle adjustment was mostly continuous. It was as if drivers could not perform the in-vehicle task, steer the vehicle, and fine tune their speed all at the same time, so they stopped adjusting their speed from time to time.

An algorithm was created for the detection of performing an in-vehicle task based on simulated real time throttle position data. To determine when throttle-holds occurred, the first step was to filter out noise in the throttle signal by computing a 1 second moving average of the throttle signal. The need for this filter may be unique to the sensor package on the test vehicle. Next, least squares regression was used to calculate the slope for each 2-second sample of throttle positions. To filter out instabilities not indicative of distraction (for example, where the throttle was applied and returned to its original value in 2 seconds), the maximum difference in throttle positions for each 2-second window (maximum – minimum) was computed. If the value was equal to or greater 0.15 percent, that sample was discarded. Any period for which the slope was less that 0.03 and the throttle was not 0 was considered to be a constant throttle. (Note: The parameter values of this algorithm were determined by inspection of the data and are not considered to be optimal. Further development is needed.)

The driving data showed that throttle-holds were intermittent across a period during which drivers were distracted by an in-vehicle task. To link these together, three parameters were set: reward per detection=1 point, reward per detection duration=.25 points per second, and price after detection ended =-.25 points per second. These values were also determined by inspection, and are demonstrated by points A, B, and C in Figure 3.18 presented previously.

False Alarm (FA) values computed using this algorithm ranged from 0 to .78 with values close to .25 being fairly typical. Hit values ranged from .04 to .99, with values close to .6 being fairly typical. This is a reasonable for a first cut, nonoptimized algorithm.

3.4.3 What are typical task completion times (and error rates) for tuning, dialing, and destination entry?

For driving on straight roads, both expressways and rural roads, in light to moderate traffic, selection of an item from a 2-level menu took approximately 6-8 seconds while driving, depending on the menu. It was strange, however, that the menu time is longest (7.7 s) for the navigation task, which has the fewest number of alternatives (4). A possible explanation is that subjects were reading the screen from left to right, so it took longer to get to the navigation task menu item on the right. Another explanation is that the subjects were mentally preparing for entering the address, and because destination entry was the longest task, more time would be needed for preparation than for other tasks.

Data entry depended very much on the task—14 seconds for tuning a radio, 18 seconds for dialing a phone, and 51 seconds to enter a street address. Task ($p<.001$), gender ($p<.05$), and the age/gender interaction ($p<.01$) were all significant. Older women took longer than others in entering the data for each of the tasks, and differences between older and middle age subjects were a factor of 2, much larger than was expected. This can possibly be explained by the care and caution older women took in performing the tasks while driving, but this should be examined in future studies.

Given the unexpectedly large difference due to age, SAE J2365 predictions of task time were not perfect but still reasonable, overestimating the middle-age driver times by about 25% and underestimating the older subject times by about the same amount.

Error rates for tuning were low (2%), moderate for dialing (10%), and high for destination entry (40%). This can be explained since there is much more room for error in entering a three line address (21 characters) using a QWERTY keyboard compared to entering a phone number (10 digits) and pressing an arrow repeatedly (14 or 21 times). There are more degrees of freedom for entering the address compared to dialing the phone and tuning the radio.

3.4.4 How risky were the in-vehicle tasks considered to be?

Subjects rated the risk of tuning the radio to be 3.7 and dialing a phone as 4.5, both close to driving 10 mi/hr faster than traffic on an expressway, anchored at 4.0. Destination entry (6.4) was close to being equivalent to driving 20 mi/hr than traffic on an expressway (6.0). As a point of reference, a task with a static task time of 15 s would have a risk rating of 4.3 (equivalent to driving 13 mi/hr faster than traffic on an expressway).

Older women rated the tasks unsafe (almost 7) compared to the other subject groups (just over 4). On average, older women felt performing the tasks was almost as risky as driving just under the legal limit of alcohol with observed weaving; while the rest of the subjects felt performing the tasks was similar to driving 10 m/hr faster than traffic on the expressway.

Overall, subjects felt these in-vehicle functions should be available (2.7) either only when parked (2) or sometimes (3). Subjects favored some restrictions (2.4), where manufacturers should limit them (2) and some of them should be illegal (3). Subjects rated the tuning task as somewhat safe (3.6), the phone task as neither safe nor unsafe (5.1), and the navigation task as somewhat unsafe (7.9). Therefore, subjects felt that the current laws must be changed to limit the use of such devices, specifically navigation devices where text must be entered.

3.4.5 Limitations/future developments

Data collection in the real world always presents challenges and this experiment was no exception, especially with regard to the need to continually update sensor suites (e.g., the headway sensor) and data collection hardware. To coordinate the various data collection computers, manual workarounds were used.

The eye tracking system was new and eye tracking on public roads is pushing the state of the art, especially for older subjects (over age 65) all of whom wore glasses. Markers should be used in future studies to overcome problems associated with sunlight washing out facial features, thereby improving head tracking accuracy.

There were significant technical challenges in minimizing the extent to which sunlight veiled the touchscreen. An oversized hood around the touchscreen, covering the interior with black cloth, and even asking subjects to wear dark clothes provided an effective solution.

Considering the resources available, a large amount of useful data was collected in this experiment. The data collected suggests that several traditional measures of driving performance are not likely to be useful in the detection of in-vehicle task performance, at least for straight roads. On the other hand, this report provides convincing evidence that throttle-holds are a useful real-time indicator of such conditions. The throttle-hold finding is new and somewhat surprising and should therefore be further confirmed before generalized conclusions are made. It needs to be examined for a wider variety of drivers, vehicles, road types and driving situations, and the detection algorithm needs to be refined. Even if a throttle-hold algorithm only works reliably for some drivers under limited driving conditions, it nonetheless has the prospect of providing a real-time and easily implemented function to determine if a driver is distracted. This method is particularly easy to implement in steer-by-wire vehicles because the throttle position data is already available and likely to be on the data bus, minimizing the needs for additional sensors and support hardware.

3.5 REFERENCES

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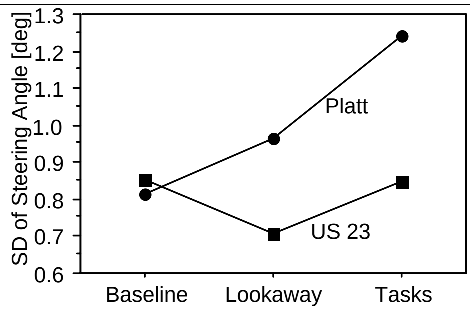
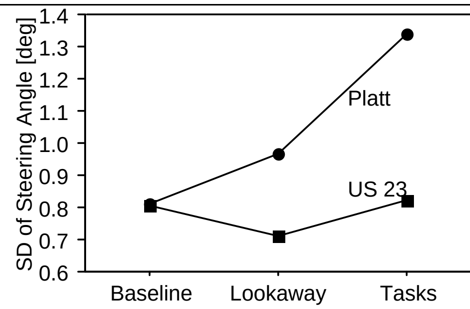
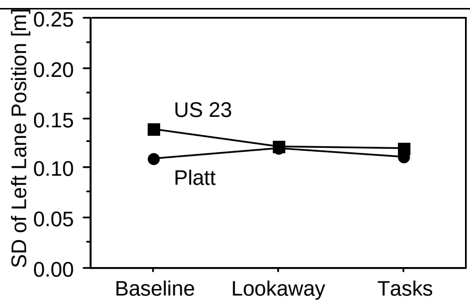
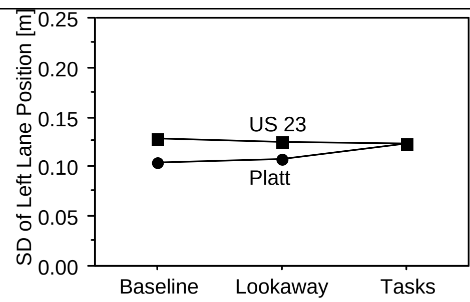
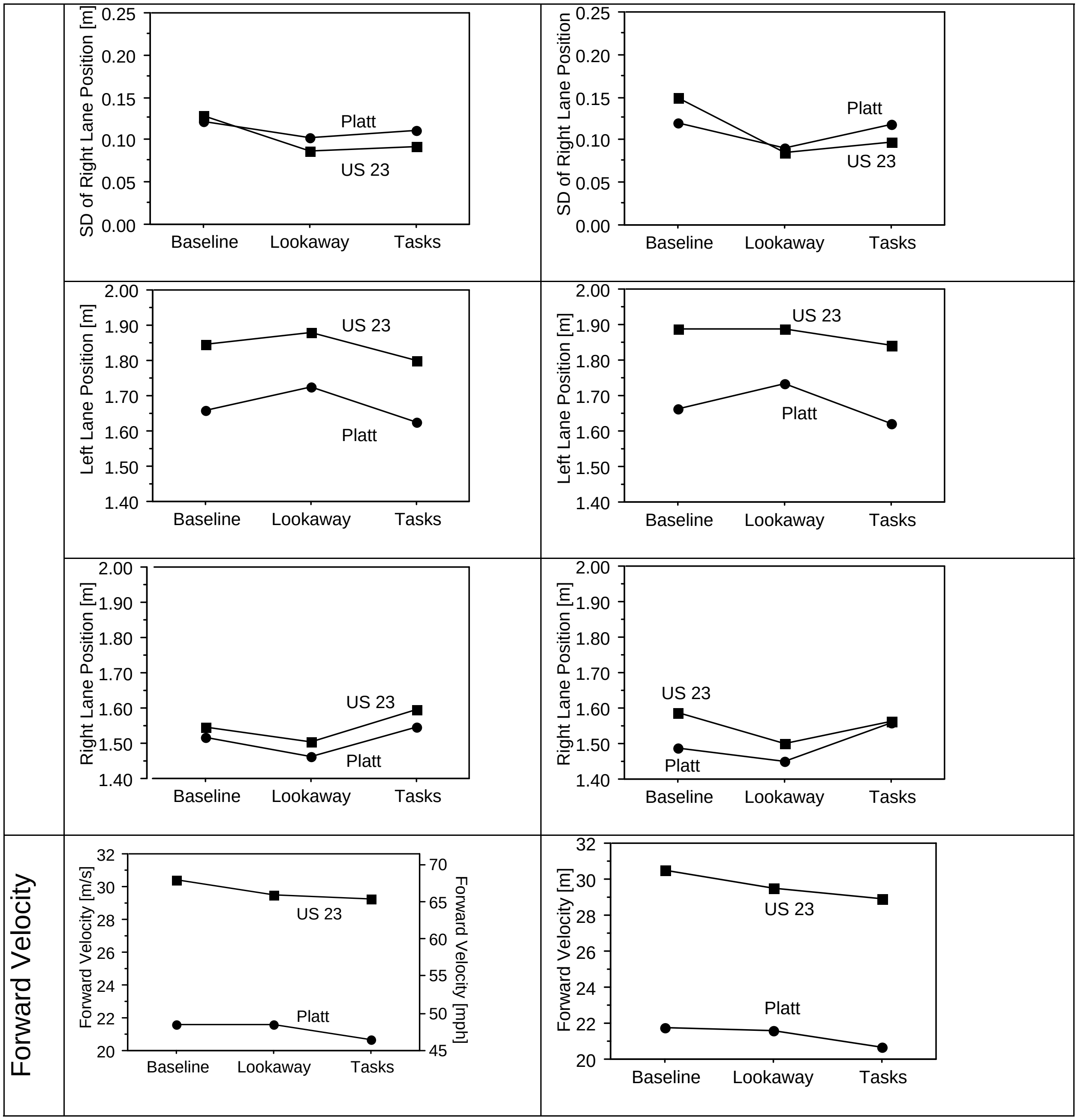
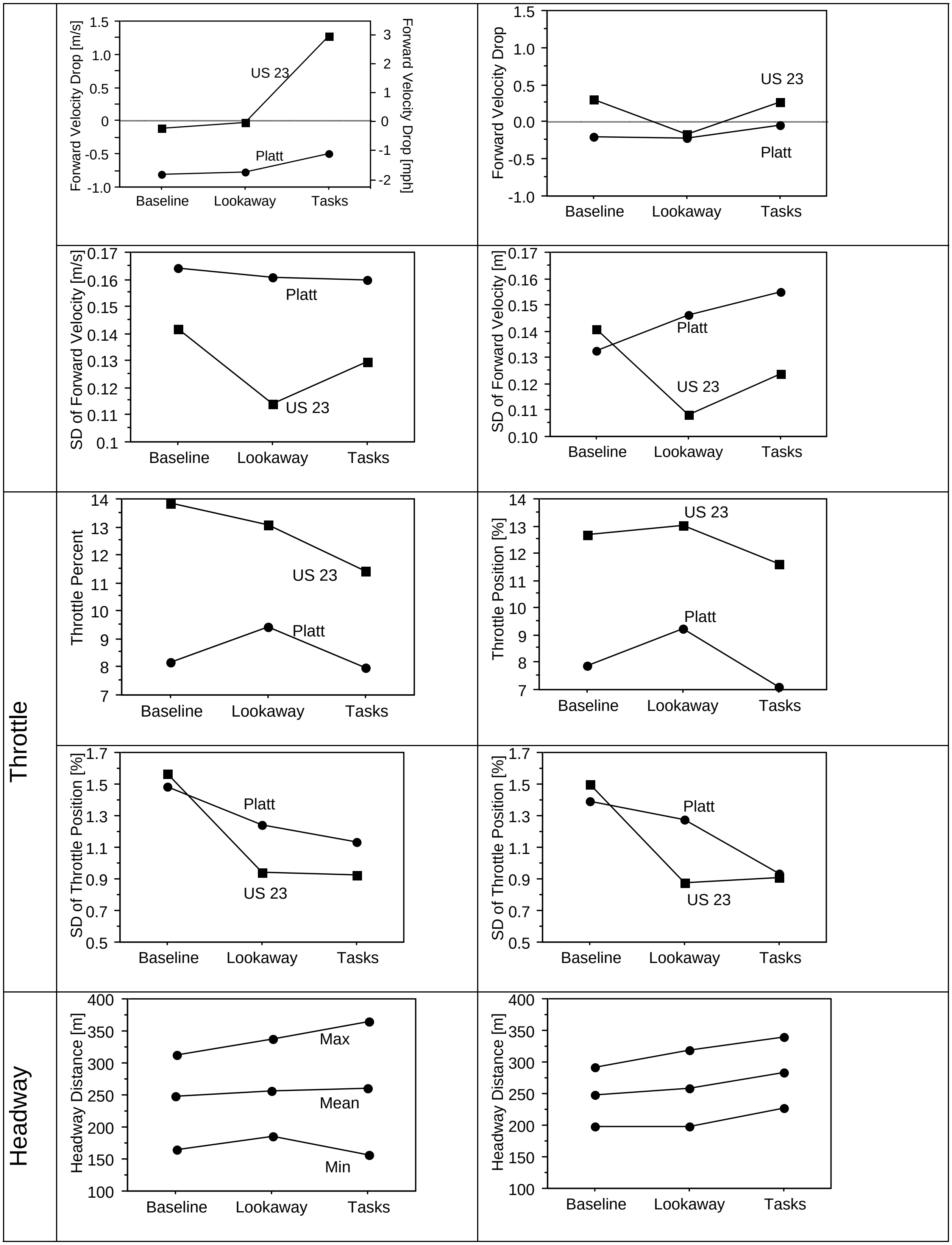
3.6 APPENDIX A. ADDITIONAL ANALYSIS OF DRIVING DATA

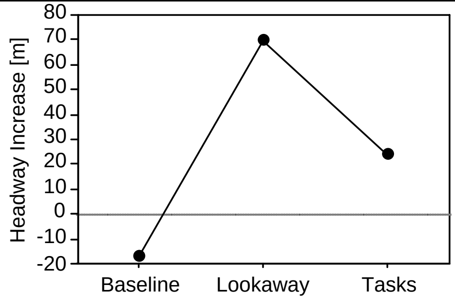
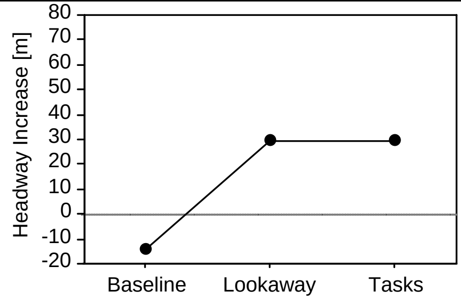
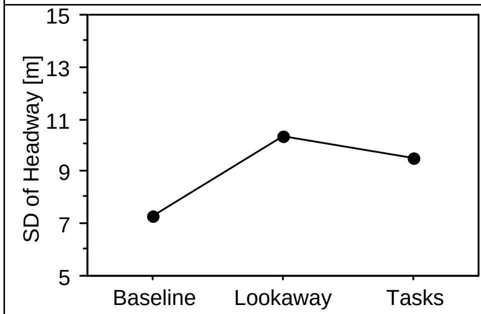
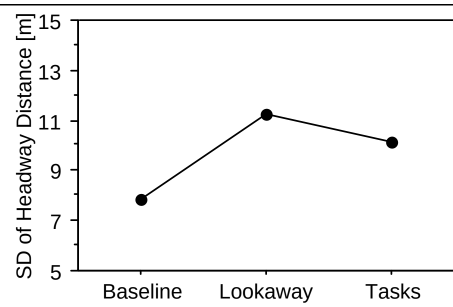
A similar analysis was performed on the last 10 s of each trial. Although one might expect the adverse effects on driving performance to be larger on the last 10 s than on the entire length of a task, the effects were similar in trend and in magnitude and are therefore not reported here.

Table 3.15. Additional analysis of driving data

	Analysis of Entire Duration of Task	Analysis of Last 10 s of Task
Steering Angle		
Lane Position		


SD of Right Lane Position [m]
0.25
0.20
0.15
0.10
0.05
0.00
Platt
US 23
Baseline
Lookaway
Tasks
SD of Right Lane Position
Left Lane Position [m]
2.00
1.90
1.80
1.70
1.60
1.50
1.40
Right Lane Position [m]
Forward Velocity
Forward Velocity [m/s]
Forward Velocity [mph]
32
30
28
26
24
22
20
70
65
60
55
50
45


Forward Velocity Drop [m/s]
Forward Velocity Drop [mph]
US 23
Platt
Baseline
Lookaway
Tasks
Forward Velocity Drop
SD of Forward Velocity [m/s]
SD of Forward Velocity [m]
Throttle
Throttle Percent
Throttle Position [%]
SD of Throttle Position [%]
Headway
Headway Distance [m]
Max
Mean
Min

	Headway Increase [m] 80 70 60 50 40 30 20 10 0 -10 -20 Baseline Lookaway Tasks	Headway Increase [m] 80 70 60 50 40 30 20 10 0 -10 -20 Baseline Lookaway Tasks
	SD of Headway [m] 15 13 11 9 7 5 Baseline Lookaway Tasks	SD of Headway Distance [m] 15 13 11 9 7 5 Baseline Lookaway Tasks

3.7 APPENDIX B. Experiment Instructions

Experiment Instructions: Save-IT 3B

EXPERIMENT SET-UP

Pre-Subject Setup

- Make sure all the forms are present for the subject
- Consent Form
- Biographical data form
- Instructions
- Post test form
- Payment form

Honda pre-flight checks

- Check FUEL
- Check oil
- Check water
- Check air in tires
- Disconnect battery charger

Honda Power-up:

Power, Computers

- Turn on Honda ignition (motor)
- Set AC to INTERNAL
- Set Inverter to ON
- Set unregulated DC to ON
- Turn on HP Laptop (secondary task computer)
- Turn on ext HD for 486 (on power strip)
- Turn on Gateway 486 (on power strip)
- Set KVM to D and take a look-this is the 486 booting up
- Turn on Dell eye tracking computer
- Set KVM to A and take a look-this is the Dell booting up

Honda Power-up: Video/Audio

- Turn on cameras (two switches on the boxes under the mixer)
- Turn on mixer (on the upper right corner)
- Put tape in DVR
- Turn on ViewSonic video tuner
    - Press INPUT button until the display shows the images from the cameras
    - Verify all the images are present (Forward, face, task, quad with alternate face, 486, and lane trackers). You can adjust the 486 image using the black TView on top of the DVR. If the image for the eye tracker is poor, unplug the scan converter power (that beige plug on top of the silver box zip tied to the rack next to the DVR) and plug it back in.

Honda Power-up: Software

- Set KVM to 486 (D)
- Exit to DOS (0)-type "allinone"
- Type Honda.am5 to get back to options
- Select 1 to set up initial data file.

    - Open Practice 9 and go to (2,0) for phone and Albany for Navigation. Verify touchscreen working, etc.
    - Fire up eye tracker to be calibrated with subject.
    - Start the eye tracking program – Facelab3, Start FaceLab.
    - Setup a new file for the subject – set up new head model.
- Once all systems are up and verified, move Honda out front.

SUBJECT SET-UP

Subject Greeting

- Meet the subject in the lobby
- Introduce yourself and verify the subject:
  "**Hello, my name is** - **<u>State your name,</u> You must be - <u>State Subject Name</u>"**
- Ask if subject wants to go to the restroom or get a drink
- Go to the break room
- Verify Everyone's Cellular phone / pagers are OFF

Subject Forms

- Check driver's license for vision restrictions and correct date of birth.
- **"May I please see your driver's license?"**
- Fill Consent Form
- Fill bio form
- Return driver's license

Vision test

- **"For the entire test, please keep looking straight ahead"**
- Test visual acuity (FAR #2)

- **"Can you see in the first diamond that one of the circles is complete but the other three are incomplete? For each diamond, tell me its number and the location of the complete circle - Top, Bottom, Left, or Right.**

- Test near vision (80 cm) (FAR #2) with Lenses
- **"Can you see in the first diamond that one of the circles is complete but the other three are incomplete? For each diamond, tell me its number and the location of the complete circle - Top, Bottom, Left, or Right.**
- Color-abnormality (FAR #6)
- **"In each circle, there is a number. Starting with Circle A, could you tell me the number?"** (Circle F does not really have a number).

Show map of route
"This is the map of the route for the experiment. We will remind you where to go and help you through the route."

IN-VEHICLE: PARKED

Car

<u>Seating</u>

- Seat the subject in the car.
- Adjust seat

Eye Tracking & Risk Rating

- "Now we are going to calibrate our eye tracking system, this should take about 5 minutes. The system is going to be used to collect data on glance location and glance duration.
- **Brad Speaking**
- **"Can you please look in front of the car at the target and try to not make sudden movements. Also, please sit like you will when you are driving the car with your hands on the steering wheel." ***Take 20 degree and 90 degree shots.

Ask experimenter if he/she is ready to move on.

Explain Risk Rating and Provide Anchor Sheet

"In the session today, we will ask you to evaluate the risk associated with driving under different scenarios. In your estimation, we would like you to focus on the probability (that is the risk) a CRASH might occur
A crash is any impact between a vehicle and some object, including another vehicle, a pedestrian, an animal, or a fixed object (such as a tree or a road sign).
In this experiment the most likely crashes are:

> **Hitting the vehicle in front of you, if stopped suddenly**
> **Being hit by a car cutting from an adjacent lane,**
> **Running off the road and hitting a tree**

"The scale goes from 1 to 10 with 1 representing very small risk and 10 implying a crash is almost inevitable. Decimals, for example 2.3, are acceptable. Some of the point have been specified, for example 2 is an average road with average risk, to help you assign a value.
"In rating the risk today please be consistent and sensitive to differences. If you rated a previous task with a certain number and you think that the current task is exactly as risky, please try to use the same number. If the current task was slightly more risky or slightly less risky than the previous one, please try to reflect that risk in your ratings. So remember, Consistency, and Sensitivity."

Brad Speaking

- Set the markings in the appropriate spots on the face
- Make sure the spots aren't jumping and the tracking level is high (>70)
- **"Can you please look into the center of camera A on the right and try your best not to blink" -** make the transparent overlay cross hairs
- **"Next, without moving your head can you look into the center of camera B on the left and try your best not to blink"**

"Good, next, will you look into camera A, now B, now just glance around the vehicle."

Practice block

"Before we go out on the route, you should first practice in performing the in-vehicle tasks. All of the tasks will involve a menu that will appear on the touch screen, after you press the start button **press the start button. Also, all of the tasks involve entering data off of cards. Once you are told to begin you can press the start button and one of the 3 types of tasks (radio, phone, navigation) will appear."

Verify volume by playing a beep
ÒCan you hear this well?Ó

For the radio and navigation if you correctly enter the information presented you will hear, * a beep plays**. For the dialing task if you correctly enter the information presented you will hear a phone ringing **** play ringing**. And incorrect for radio tuning and destination entry you will hear the game show sound. **** play buzzer**. For dialing 10-digit number incorrect** **incorrect number dialed tones

Radio

- **"The first type of task is a radio tuning task. To tune to a different station, touch "radio" (go ahead) on the first screen menu, wait for a new menu, and then touch "tuner" (go ahead) from that menu. The radio will appear on the touch screen."**
- **"I am going to hold a card with a station on it and say you may begin. You are free to begin the task whenever you feel it is safe to do so. Once the radio is on the screen the up arrow will move the station up .2, and the down arrow will move the station down .2 like a real radio. When the value on the display (say 91.7) matches the station the experimenter requested, press preset 1. A game show buzzer will sound if the station was incorrect, and if it was correct a beep will play."**
- Walk through the first station from the cards to get the user accustomed to the task.
- **"Try the next station"**: trial 1 – practice block (2-5 more tasks)"

Phone

- **"The second type of task is a phone-dialing task."**
- **To dial a phone number, touch "phone" on the first screen menu and wait for the new menu, and then touch "dial" from that menu. The phone will then appear.**
- **The experimenter will hold a card with a 10-digit phone number to enter. Enter the phone number on the card by touching the numbers on the screen. The digits entered will appear on the screen. To correct an entry, use the delete key. Once the entire phone number is entered, press talk, just like in a real cell phone. If the phone number is correct the phone will ring, otherwise a series of tones will mean the number was not correct."**
- **"Once you are told to begin you can press start whenever you feel it is safe to do so."**
- Walk through the first number from the cards to get the user accustomed to the task.
- **"Try the next number":** trial 2 – practice block (2-5 tasks)"

Navigation

- **"The third type of task is entering a destination, an address, for the navigation system. To enter a destination, touch "navigation" on the first screen menu, wait for a new menu, and then touch "destination" from that menu. The navigation system will appear on the touch screen."**

- **To correct an entry, use the delete key. A game show buzzer will sound if the station was incorrect, and if it was correct a beep will sound."**
- Walk through the first address from the cards to get the user accustomed to the task.

"Try the next address": trial 3 – practice block (2-5 tasks)"

Target

We want to know when drivers can safely look away from the road to complete a 10 to 30 second task, such as tuning a radio, entering a destination, or reading directions. You will be looking back and forth between the touch screen and the road, looking at the screen for as long and often as you feel safe. Do not pretend you are performing a particular touchscreen task, just think about when you should look back at the road. Does these instructions make sense? Your priority is to drive safely." We will let you know when to begin and end.

It may seem a bit odd, but l ets practice this task. So, pretend you are driving, and from time to time over a 10 second period look at the touch screen. Ready? You c an begin whenever you feel it is safe.

Brad – "End Looking Task"

Reminder

In a moment, you will begin the touch screen glance task, this time for (x) seconds. Look back and forth between the touch screen and road, looking at the screen only when it is safe, and for as long as it is safe to do so. Above all else, drive safely. You can begin whenever you feel it is safe.

Brad – "End Looking Task"

Brad Speaking

- **"Before we drive can you please look at the following locations around the vehicle for 5 seconds:**
- **Rearview mirror**
- **Touchscreen**
- **Left side mirror**
- **Right side mirror**

- **"Good, now we will begin the on-road portion of the study."**
- Lock the doors
- Open MenuWorksOR
- Make sure car is in sport mode

IN-VEHICLE: DRIVING PRACTICE

"Now we are going to practice performing the tasks while driving. When we start, we are going to head to Pontiac Trail via Huron Parkway and Nixon. I will give you turn-by-turn instructions as well.
Are you ready to begin?"
"Please drive down to the stop sign and turn right onto Huron Parkway.
Please continue on Huron Parkway across Plymouth Road

Please remember that your first priority is to drive safely. If you do not feel you can drive safely and complete the tasks at the same time, you may choose to defer beginning th e task or not to do

Practice Block 1

Start Radio task
Start Phone task

- Please turn right onto Pontiac Trail at the stop sign
- Please make a left turn onto Joy Road, and another immediate left, we are going to head back down Nixon, the road you were on previously
- Please make a right turn onto Pontiac Trail
- Please make a left onto Nixon

Start Navigation task
Start looking task

Practice Block 2 as necessary

Now we will return to UMTRI to start data collection.

- Please continue down Nixon
- Please turn left on Huron Parkway
- Please continue on Huron Parkway across Plymouth
- Please make a left onto Baxter
- Please make a left into UMTRI
- Please make a right into the lot, follow it around and make a left on the other side
- Please stop in front of the building right here

IN-VEHICLE: DRIVING DATA COLLECTION

US-23 South

Route specific instructions

Forward	Backward
Radio	Navigation
10 sec looking	Phone
Phone	10 sec looking
Navigation	Radio
Curves	Curves
30 sec looking	30 sec looking

In a moment, you will begin the touch screen glance task, this time for x seconds. Look back and forth between the touch screen and road, looking at the screen only when it is safe, and for as long as it is safe to do so. Above all else, drive safely. You can begin whenever you feel it is safe.

Brad – "End Looking Task

Brad Speaking – Car Stopped

"We will be stopping now because the computer needs to save the data. There will be beeps
during this stop while the computer is synchronizing. Also, if you could look at the same places in the car for 5 seconds each – Rearview mirror, touchscreen, left side mirror, right side mirror. Good."

- Hold ESC for 486 computer to stop the data collection and begin the save process
- Hit "Y" when the program asks to save, then wait for the program to save the data
- While 486 is saving – go to Eye Tracking computer stop logging and covert data to text
- When 486 is done saving, reset the test parameters and start data collection again…wait for the 10 seconds to ensure data is collecting properly
- Switch back to Eye Tracking and begin logging data again
- Begin next route

US-23 North

Forward	Backward
Radio	Navigation
10 sec looking	Curves
Curve	Phone
Phone	10 sec looking
Navigation	Radio
30 sec	30 sec

Brad Speaking – Car Stopped

"If you could look at the same places in the car for 5 seconds each – Rearview mirror, touchscreen, left side mirror, right side mirror. Good."

- Hold ESC for 486 computer to stop the data collection and begin the save process
- Hit "Y" when the program asks to save, then wait for the program to save the data
- While 486 is saving – go to Eye Tracking computer stop logging and covert data to text
- When 486 is done saving, reset the test parameters and start data collection again…wait for the 10 seconds to ensure data is collecting properly
- Switch back to Eye Tracking and begin logging data again
- Begin next route

Platt Road South

Forward	Backward
Radio	10 sec looking
Construction	Construction
Traffic Light(M12 and Platt)	Traffic Light(M12 and Platt)
10 Second Looking Task	Navigation
Phone	Stop Light
Stop Light	Phone Dialing
30 sec looking	Stop sign
Stop sign	Radio Tuning
Navigation	30 sec looking
Stony Creek Rd	Stony Creek Rd

In a moment, you will begin the touch screen glance task, this time for x seconds. Look back and forth between the touch screen and road, looking at the screen only when it is safe, and for as long as it is safe to do so. Above all else, <u>drive safely</u>. You can begin whenever you feel it is safe.

Brad – "End Looking Task

Brad Speaking – Car Stopped

"If you could look at the same places in the car for 5 seconds each – Rearview mirror, touchscreen, left side mirror, right side mirror. Good."

- Hold ESC for 486 computer to stop the data collection and begin the save process
- Hit "Y" when the program asks to save, then wait for the program to save the data
- While 486 is saving – go to Eye Tracking computer stop logging and covert data to text
- When 486 is done saving, reset the test parameters and start data collection again…wait for the 10 seconds to ensure data is collecting properly
- Switch back to Eye Tracking and begin logging data again
- Begin next route

PLATT ROAD NORTH

Forward	Backward
Radio	Navigation
10 sec looking	Stop Sign
Stop Sign	Phone
Phone	Stoplight
Stop light	10 sec looking task
Navigation	Radio Tuning
Traffic Light	Traffic light
Construction	Construction
30 second looking	30 sec looking
Ellsworth Traffic light	Ellsworth Traffic light

In a moment, you will begin the touch screen glance task, this time for x seconds. Look back and forth between the touch screen and road, looking at the screen only when it is safe, and for as long as it is safe to do so. Above all else, drive safely. You can begin whenever you feel it is safe.

Brad – "End Looking Task

Brad Speaking – Car Stopped

"**If you could look at the same places in the car for 5 seconds each – Rearview mirror, touchscreen, left side mirror, right side mirror. Good."**

- Hold ESC for 486 computer to stop the data collection and begin the save process
- Hit "Y" when the program asks to save, then wait for the program to save the data
- While 486 is saving – go to Eye Tracking computer stop logging and covert data to text
- When 486 is done saving, reset the test parameters and start data collection again…wait for the 10 seconds to ensure data is collecting properly
- Switch back to Eye Tracking and begin logging data again

SUBJECT WRAP UP

Forms and payment

- Seat subject at rear table
- Complete post-test evaluation form
- Go over the form, ask for clarifications and write them in your words
- Ask for additional comments
- Payment
- Choose payment form according to affiliation
- Pay
- Document

Walk subject to the front door

VEHICLE WRAP UP

After last route, on the way back:

- Exit the secondary task program and shut the computer down
- Turn off tape
- Convert the last eye tracking data to text and shut the computer down
- **"When we come to a stop leave the car running as there is still data collection that needs to take place."**

When the car is stopped, save the data from the last route and exit program on the 486

- Turn off ignition and exit the vehicle with the subject

- While one experimenter helps subject with post test forms, hook up external power
  - Copy data files
  - Eye Tracking:
    - Gather all the text files and zip them to a disk, make sure it all fits on the disk
  - Secondary Task:
    - Gather excel file(s) from desktop and zip them to disk
  - 486:
    - Get data on the Bernoulli disk and obtain the disk
  - Remove tape from Digital video recorder
  - Turn off power strips – power down the digital video recorder, power down strips
  - Turn off power inverter (12-1)
  - Make copy of forms and file them – VX paper port
  - Update the subject data
  - PLUG IN CAR

3.8 APPENDIX C. FORMS

3.8.1 Consent Form

Participant number: _____

On-the-Road Driving Experiment
Primary Investigator: Paul Green (763 3795), Experimenters: Ken Mayer & Brad Zylstra (763-2485)

This experiment examines the distraction of various in-vehicle systems (such as radios, phones & navigation) under actual driving conditions. The results of this study, summarized in a technical report for the sponsor and released to the public, will be used to make future vehicles that you may drive less distracting and thus safer to operate.

First, we will collect some biographical data on you (age, driving experience, etc.) and your driving (e.g., miles drive/year, vehicle most commonly driven, crashes and recent moving violations). Next, in a parked car, you will practice tasks such as dialing a phone and entering navigation destinations until you are comfortable with them. Next you will drive a car on US-23 and a rural road for about an hour. At various times, an experimenter in the car will ask you to complete the same tasks you practiced while parked. After completing each task, rate how risky the task is to do while driving. You can decline to do any task at any time if you do not feel the task is safe to do or for any other reason. For instance, if you asked to dial a phone on a certain segment of road or at a certain time when you do not feel be safe, rate it as 'too risky' and do not do it.

The entire experiment should take about 2 hours and you will be paid $40. You may withdraw from this experiment at any time without penalty.

I understand that I am expected to obey all traffic laws and drive the vehicle in a safe manner. Should an accident occur, I the driver, the test vehicle, as well as any other persons or property involved, would be covered under an insurance policy held by the University of Michigan. However, that does not preclude other insurance coverage from involvement: including my personal injury protection (PIP) insurance - otherwise referred to as no-fault insurance and my health insurance.

I specifically agree to be videotaped in this study and understand that selected segments from the tapes may be used in presentations to explain the results. My name will not be disclosed with the tape. The raw tapes will be erased 10 years after the project is completed.

Sign your name ________________________

Segments from videotapes of my sessions may be used by the media (e.g., on TV) to help explain this research to the public.

[Optional]: Sign your name ________________________

The U.S. Department of Transportation and Delco Delphi Electronics, the project sponsors, may ask for every piece of data collected (driving data, eye fixations, videotape, ratings). I agree to release of that data to them for any purpose. The data will be identified only by a subject number, not by name.

[Optional]: Sign your name ________________________

I HAVE READ AND UNDERSTAND THE INFORMATION PRESENTED ABOVE. MY PARTICIPATION IN THIS STUDY IS ENTIRELY VOLUNTARY.

________________________ ________________________
Print your name Date

________________________ ________________________
Sign your name Witness (experimenter)

Should you have questions regarding your participation in research, please contact Kate Keever:
Human Subjects Projection Office, 1042 Fleming Building, 503 Thompson St., Ann Arbor, MI 48104-1342
Ph: 936-0933, fax: 647 9084, email: IRB-Behavsci-Health@umich.edu, web: http://www.irb.research.umich.edu

3.8.2 Biographical Form

Save-It On-Road Study– Biographical Form

Personal Details

Name ____

Phone: _______________________

Email address __________________ May we email you for future studies? yes no

Born (month / day / yr) ___ / ___ / ___ in (city / state) ______________

Are you a native English speaker? (circle one) Yes No

Occupation: ______________ (if retired: main occupation before retirement)

Education (circle highest level completed and fill in blank)

High-School Some-College College-Degree Graduate-School

Major _____________

Driving

Driver's License # ______________________ Expiration Date: _________

What motor vehicle do you drive most often?

Year: _______________ Make: _____________ Model: _____________

How many miles do you drive per year? ___________

How often do you usually drive? (circle one)

Almost every day A few days a week A few days a month

Have you driven more than 30,000 miles in your lifetime? Yes No

Do you have any special driving licenses (e.g. heavy truck) and if so, what kind?

No Yes: explain -> _______________

In how many accidents have you been involved during the past 5 years? _______

In how many traffic violations have you been involved in the past 5 years? ______

Details: ____

Navigation Systems

Does your current vehicle use a navigation system? Yes No

If yes, how many times per week do you use it? ___________

If yes, do you operate the system while driving? Yes No

Radio

What percentage of stations you choose are preset stations (1 button press)

How do you change stations when not using presets (knob or button press(up/down))

Is the radio in your car a factory or after market system? Factory After Market

Cellular Telephone Use

Do you own a cellular telephone? Yes No

If Yes, how many calls do you make per week? ________________________

Is your cellular phone your primary phone? Yes No

What percentage of your calls are long distance: _______ local: ______

Have you ever used a cellular telephone while driving? Yes No

Where is your phone located normally when your are driving?

Cradle Pocket Seat Purse Other______

How often do you use a cellular telephone while driving?

Once in a while Once a week Once a day Constantly

Touch Screens

Do you use touch screens in the following places?

- Supermarkets (for example Kroger/Meijers) Yes No
- Banks/ATMs Yes No
- Other (for example wedding registry, informational displays) Yes No

Vision Circle what vision correction you use

When driving: no-correction contacts glasses: multifocal, bifocal, reading, far-vision

When reading: no-correction contacts glasses: multifocal, bifocal, reading, far-vision

For the experimenter only 12526616

Far Acuity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	T	R	R	L	T	B	L	R	L	B	R	B	T	R
	20/200	100	70	50	40	35	30	25	22	20	18	17	15	13
80 cm Acuity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	T	R	R	L	T	B	L	R	L	B	R	B	T	R

Subject # ____________ Date: ____________

Risk Ratings for Individual Tasks - Route Specific

	Rural Route (Platt)		**Highway Route (US - 23)**	
Task Type	South	North	South	North
Tuner				
Phone				
Navigation				

3.8.3 Post-Test Evaluation Form

Date: ____________ **Post-test Evaluation Form** Participant number: ________

A. Should in-vehicle functions such as the ones you encountered today be available to the public? (Circle answer)

Never	Most of these functions should not be available in vehicles at all
Only when parked	Most functions should be locked out when the car is not parked
Sometimes	Some functions should be unlocked when driving is easier
Always	The driving public should be allowed to perform such functions while driving

B. What should the government and auto manufacturers do about the tasks you performed while driving? (Circle Answer)

Nothing	Each driver should decide what they can do while driving
Manufact. Limited	Auto Manufacturers should provide devices that limit the functions that are accessible when the demand of driving is high
Some Illegal	Make it illegal to do some of these tasks while driving
All Illegal	Make it illegal to do all such tasks while driving

C. Comments about this study?

D. People feel differently about how safe or dangerous different types of driving behavior are. Please mark down how safe/unsafe you feel it is to...

Use these benchmarks for all scales below.

extremely **safe**	somewhat safe	neither safe nor unsafe	somewhat unsafe	extremely **unsafe**

1. On the drive today: Tune the radio while driving on the highway

2. On the drive today: Dial the phone while driving on the highway

3. On the drive today: Enter an address while driving on the highway

3.9 APPENDIX D. ROADS

A map of the route used for data collection in this study is given in Figure 3.23.

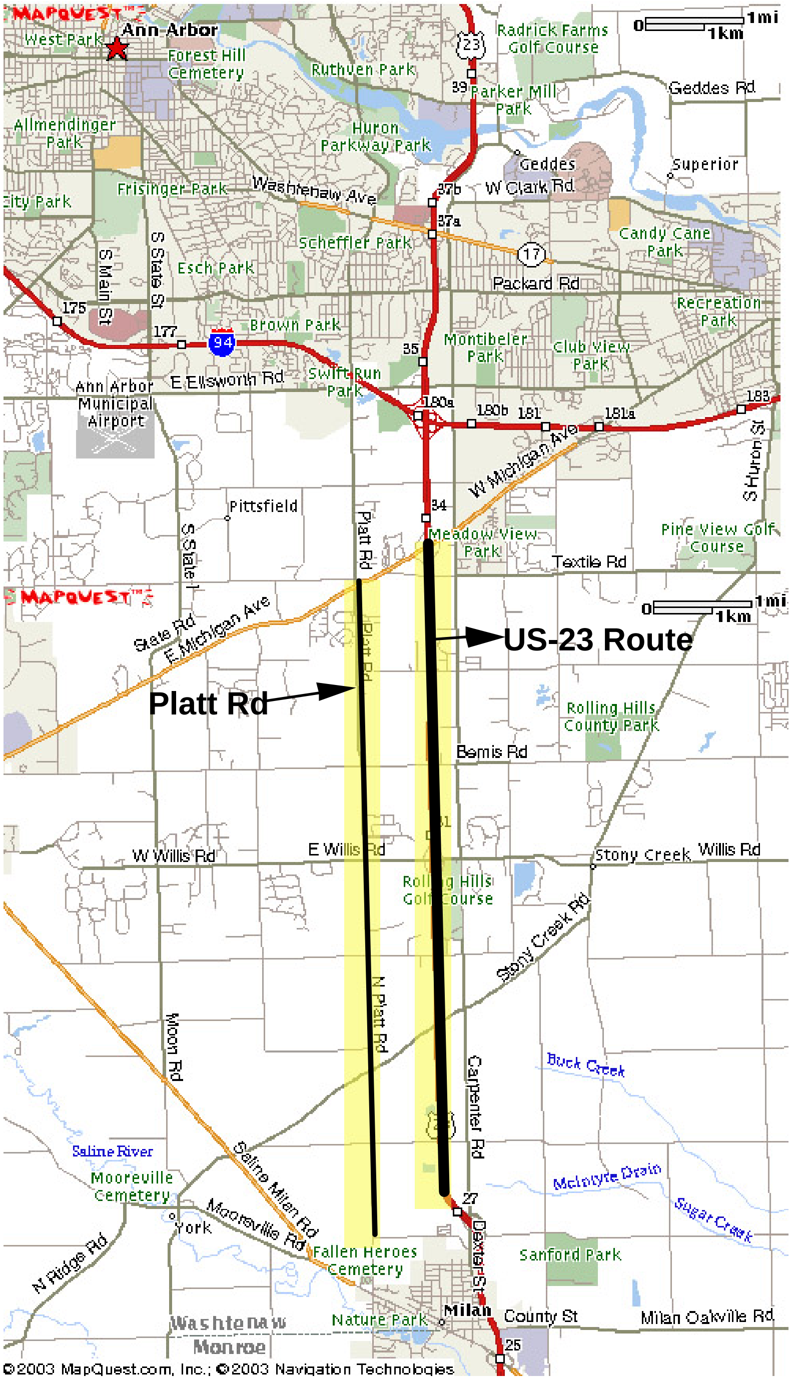


Figure 3.23. Driving route for data collection. US-23 from Michigan Ave to Cone-Azalia Road, and Platt Road from Ellsworth to Stony Creek Road

Figure 3.24. Forward view of US-23

Figure 3.25. Forward view of Platt Road

3.10 APPENDIX E. DRIVER INTERFACE RESEARCH VEHICLE

Connected to the 486 computer is an external hard drive and Bernoulli external removable media drive. Within the 486 are 2 Imagination CX 100-30 frame grabbers connected to a forward-facing Philips 56475 monochrome imaging module with solid state sensor with a Computar MCA-018 mounted in modified side view mirrors. This provides the lane tracking input. Also within the 486 is a D/A converter connected to a signal-conditioning unit designed in-house. The vehicle is also equipped with a forward-looking radar unit, providing headway. The Mitsubishi X4T25471T Laser Radar Unit is connected to the E2Z-561-04 Control Unit, which feeds serially into the 486.

One of the challenges with adding all this equipment to the vehicle was the increased demand on the electrical system. DC to AC inverters are as efficient as straight DC power, and the electronic equipment is sensitive to the quality of the sine wave from the inverter. In creating a power program for the vehicle, a goal was to allow as many devices as possible to use DC current. The car also had work done to upgrade the output of the electrical system. An Ohio Generator 14801-160 160 amp alternator was installed, as was an Optimal Yellow Top deep cycle battery. A Battery Minder automatic trickle charger was also used to keep the charge level topped off.

The power system for the in-vehicle devices uses 3 modes, straight DC, a DC-DC converter, and a DC-AC converter. The system also has a small 12vdc battery to compensate for minor power fluctuations. Additionally, since many more hours are spent setting up and debugging than actually running the system, it allows for house AC and DC (via an AC to DC inverter) to be connected. This was aided by the fact that most devices use a power transformer to go from 110vac to 12vdc. All that was required was wiring that would allow the DC power to connect directly to the device. An AC inverter powered those devices that did not support DC. This was limited to the computers (except the laptop) and the audio mixer.

The instrumentation was installed in an air-conditioned, 1991 Honda Accord LX station wagon with an automatic transmission. (This is a very typical car for Americans to drive. The sedan version of the Accord, quite similar to the station wagon in performance, was the most popular model in the U.S. for five years in a row.) All of the major pieces of research equipment (computers, power conditioners, etc.) were hidden from view in the back seat or in the cargo area, which had its own retractable vinyl cover. From the outside, the instrumented car resembled a normal station wagon.

The vehicle had the following sensors:

<u>Lane tracker</u> - The driver's outside mirror was replaced with a mirror from a late model Ford Taurus. Embedded inside the oversized mirror housing was a black and white CCD camera with an automatic iris lens. Only the tip of the lens barrel housing was visible from the outside. The camera was connected to a frame buffer in an 80486-based computer. Custom computer software was written to detect lane markings and store the lateral deviation, to the nearest tenth of a foot, at a rate of 10 Hz.

Steering wheel position sensor - A string potentiometer was mounted to the steering column under the dashboard. The potentiometer signal was fed through an interface box to the analog board in an 80486 computer. Steering wheel position was recorded to the nearest 0.3 degrees at 30 Hz.

Speed sensor - Built into the left front wheel (for use by the vehicle's engine and transmission controller) was a sensor that pulsed every one-quarter-wheel revolution. Using interpulse interval times, vehicle speeds could be sensed to the nearest 0.1 mi/hr at 10 Hz for speeds in excess of 12 mi/hr.

Accelerator/throttle sensor - An analog signal representing the percentage of declination of the accelerator pedal was obtained from the vehicle's throttle angle sensor. This signal was also monitored by an 80486 computer and recorded at 30 Hz.

Road scene - Mounted in front of the inside mirror and facing forward was a thumb-sized color video camera. The video signal was mixed with the video signal from another camera via a signal splitter and recorded on a VCR.

Driver scene - Mounted on the left A pillar and facing the driver was a second thumb-sized color video camera. This camera captured the driver's head and upper torso (to show eye and head movements, as well as some manual operations). This video signal was mixed with video signal from the road scene camera.

Audio - A microphone was mounted on top of the IP to record comments from the driver, front seat passenger (when present), and the experimenter, as well as sounds from the information systems.

All of the vehicle and driver data was either collected and stored by an 80486 computer or on videotape. The data collection software provided for real-time display of all data streams so they could be checked for accuracy by an experimenter in the back seat. In addition, the software allowed for the entry of time-stamped comments via the keyboard at any time. In this configuration, data could be collected for about half an hour before it needed to be saved to disk.

When choosing components to add functionality to the DIRV, power consumption becomes a major factor. Due to the inherent inefficiencies in DC-AC inverters, 12vdc components where used whenever possible. Also, 12vdc components that were capable of running off an unregulated power supply were preferred.

The arrangement and model numbers of equipment are provided in Figure 3.26. Specifically, a list describing the video equipment is in Table 3.16. Figure 3.27 shows the equipment mounted in the cargo area and Figure 3.28 shows the equipment in the rack where the driver's side rear seat would be. Also shown in Figure 3.29 is the layout of the dash and center console in the vehicle. Note the insets for the risk rating and touch screen detail. The hood over the touch screen was necessary to compete with the glare on the screen. Also note the position of the face cameras over the instrument panel.

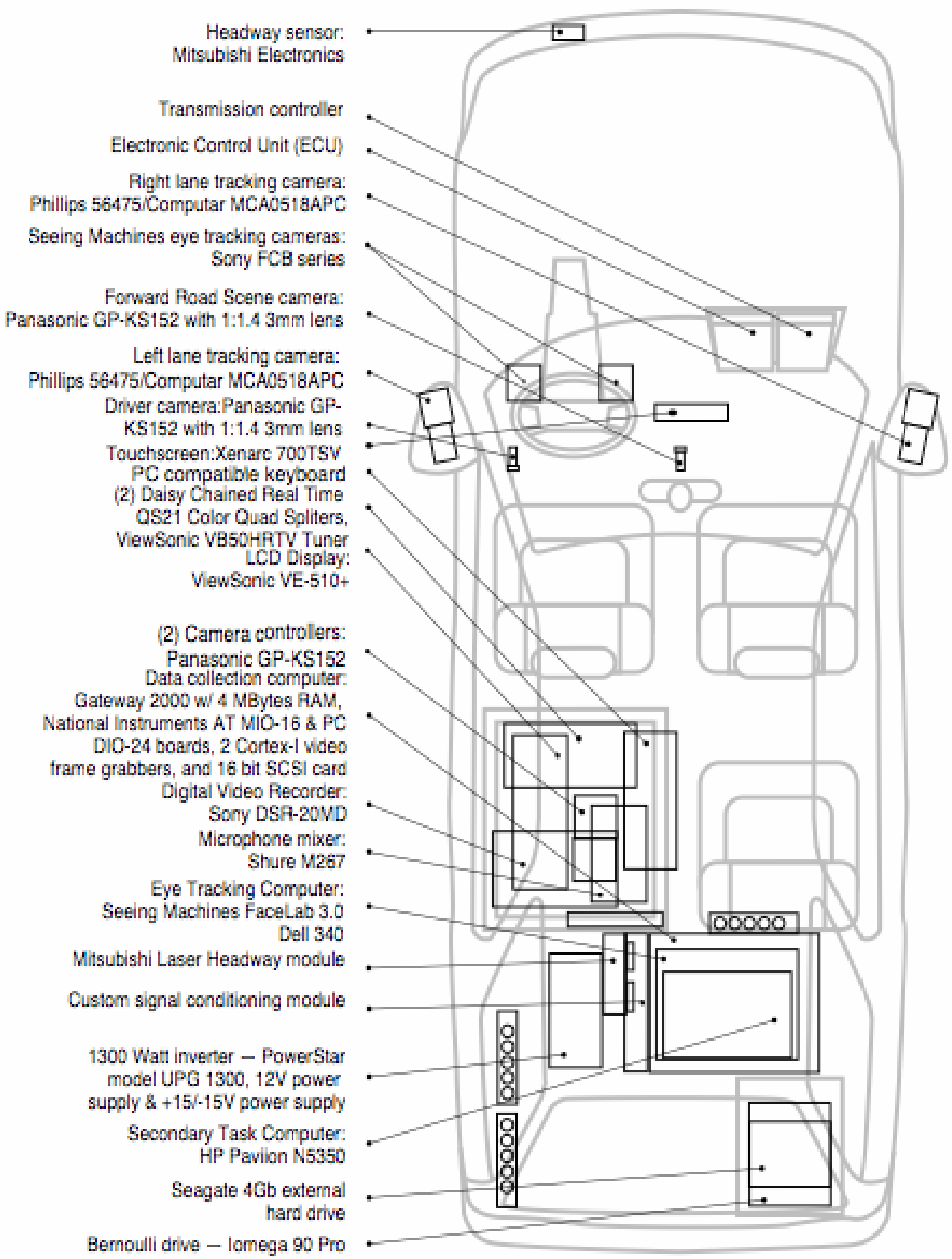


Figure 3.26. Driver Interface Research Vehicle (DIRV) instrumented 1991 Honda Accord wagon

Table 3.16. Video equipment

Equipment	Location	Purpose	Model
Lip Stick Camera	Rearview mirror	Record forward scene	Panasonic WV-KS152
Over the Shoulder	Behind subject	Record touch screen use	Panasonic WV-BP310
Lane Trackers (2)	Side view mirrors	Record lateral position	Philips 56475*
Eye Trackers (2)	Top of IP on eyebrow	Record eye/head data	FCB-EX480A

* Computar MCA0518APC lens and Imagination CX100-30 frame grabber

All of the cameras were connected to 2 daisy-chained Supercircuits QS21 Color Quad Mixers (4x1) and a Sony DSR-20MD Digital Videocassette Recorder.

Figure 3.27. Honda Accord wagon cargo area showing (left to right) custom individually fused/switched power strips, DC/AC and DC/DC inverter, custom signal conditioner, headway sensor signal conditioner, Gateway 486 PC, Dell 310 PC, HP Pavilion laptop, external hard drive and Bernoulli, and blue tool box with road tools

The power requirements resulting from the additional equipment in the vehicle create a spike in demand on the electrical system. This was addressed in several areas. The alternator was upgraded to an Ohio Generator 14801-160 160 amp alternator, and an Optima Yellow Top deep cycle battery was installed. A Battery Minder automatic trickle charger was used to keep the charge level topped off overnight.

The power system for the vehicle uses 3 modes: straight DC, a DC-DC inverter, and a DC-AC inverter. The system has a small 12vdc battery to compensate for minor power fluctuations. Additionally, since many more hours are spent setting up and debugging than actually running the system, it allows for in-house AC and DC (via an AC/DC inverter) to be connected directly.

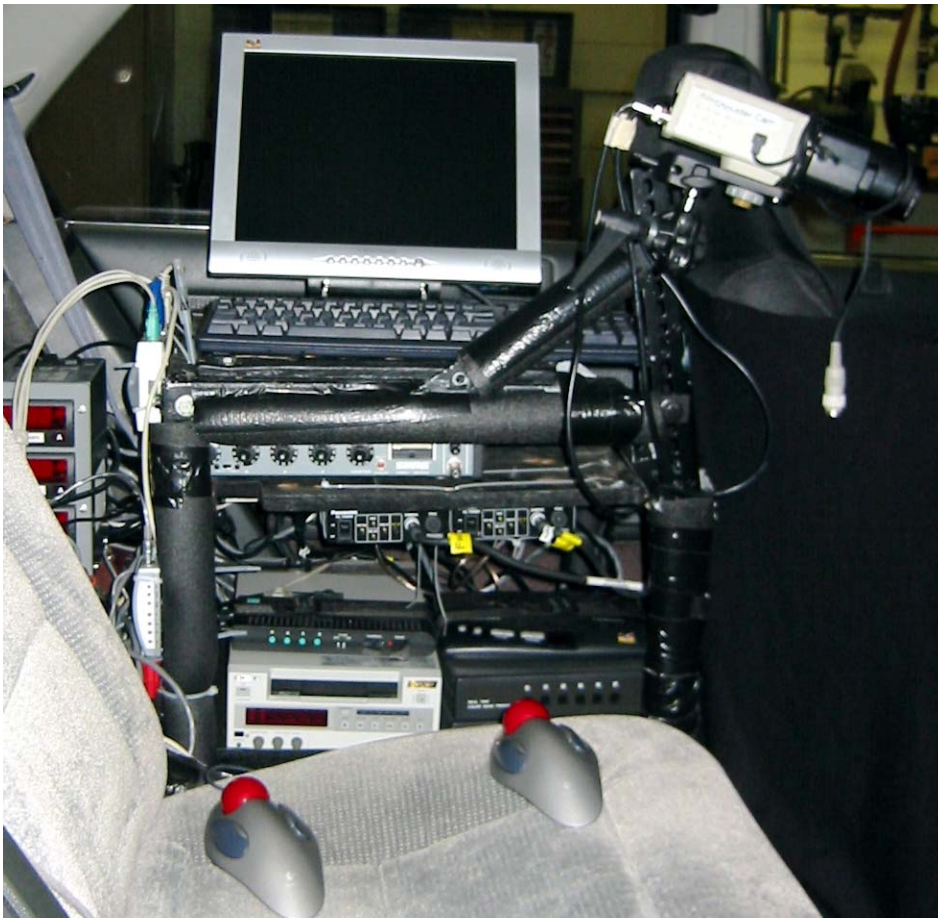


Figure 3.28. Rear seat equipment rack housing (bottom to top, left to right): Sony DSR-20 MD digital video recorder, RealTime QS21 Color Quad Splits, Tview, ViewSonic VB50HR TV tuner, Panasonic GP-KS152 controllers, Shure M267 mic mixer, IOGEAR 4 port KVM, main keyboard, ViewSonic VE510+ monitor, Logitech Marble Mouse (foreground)

Figure 3.29. Dash layout with eye tracking system, risk rating sheet, and touch screen

3.11 APPENDIX F. BIOGRAPHICAL DATA

Table 3.17. Biographical data

#	Sex	Age	Own a Cell ?	Use Cell while Driving?	Vision Correction (Driving)	Vision Correction (Reading)	Far Acuity	Near Acuity
1	F	39	Y	Y - once/day	Glasses(FV)	None	20/18	20/18
2	F	38	Y	Y - once/day	None	None	20/30	20/17
3	F	49	Y	Y - once/week	Contacts	None	20/25	20/18
4	F	51	Y	Y-once in a while	None	Glasses(reading)	20/20	20/20
5	F	68	Y	Never	Glasses(BF)	Glasses(BF)	20/25	20/40
6	F	69	Y	Never	Glasses(FV)	Glasses(reading)	20/50	20/40
7	F	68	N		Glasses(BF)	None	20/30	20/60
8	F	66	Y	Y-once in a while	Glasses(FV)	None	20/20	20/30
9	M	45	N		None	None	20/15	20/22
10	M	38	N		Contacts	Contacts	20/25	20/35
11	M	39	N		Glasses(FV)	Glasses(FV)	20/22	20/20
12	M	39	Y	Y-once in a while	None	Glasses(reading)	20/25	20/22
13	M	65	Y	Never	Glasses(MF)	Glasses(MF)	20/18	20/50
14	M	65	Y	Never	Glasses(BF)	Glasses(BF)	20/20	20/22
15	M	70	N		Glasses(MF)	Glasses(MF)	20/17	20/35
16	M	65	Y	Y-once in a while	Glasses(FV)	None	20/25	20/35

#	Sex	Age	Handedness	Miles Driven/Year	Special Licenses	Accidents (w/in 5 Years)	Moving Violations (w/in 5 Years)
1	F	39	R	28,000	N	0	0
2	F	38	R	8,000	Y-CDL	0	1
3	F	49	R	15,000	N	1	0
4	F	51	R	15,000	Y-Motorcycle	0	0
5	F	68	R	6,000	N	0	0
6	F	69	R	9,000	N	0	0
7	F	68	R	10,000	N	1	0
8	F	66	R	10,000	N	1	0
9	M	45	R	12,000	N	0	0
10	M	38	R	15,000	Y-Class B	0	0
11	M	39	R	5,000	N	0	0
12	M	39	R	15,000	N	0	0
13	M	65	R	15,000	Y-Motorcycle	1	0
14	M	65	R	10,000	N	0	0
15	M	70	R	18,000	N	1	2
16	M	65	R	18,000	N	0	1

Some noteworthy observations are that the subjects were involved in 5 accidents, and that most subjects (13 of 16) did not receive a moving violation within the past 5 years. Most subjects did not use their cell phones frequently while driving, and most (12 subjects) required glasses while driving.

3.12 APPENDIX G. SAE J2365 CALCULATIONS

Keep in mind that total task times depend on the particular sequence used by each person, and that can vary between individuals and within individuals from trial to trial. Determining how tasks are likely to be performed *a priori* requires experience in using this method and usually experience with experimental data for the task of interest. The estimates are just that: estimates, not exact values. However, data collected in experiments are also just estimates based on a sample of subjects.

Menu Task Time Estimate

One could argue the menu task involves 1 mental operation (1.5 s) and 1 keystroke to select the system (radio, phone, navigation), which is similar to selecting a function key, a feature on a drop down menu, and because of confirmation, an entry-like keystroke (1.2 s) for a total time of 4.9 s.

Table 3.18. Estimated total menu task time (s) per J2365

Step	Operator	Time in J2365	Comment
Decide which menu to select	M (mental)	1.5	Since timing starts when the Start key is pressed, there is no reaching to the menu.
Press the desired menu key	F (function)	1.2	Choices are: radio, phone, navigation
Select the menu item	F (function)	1.2	e.g., tune. There could be an additional mental action preceding this key press (M=1.5 s).
Total		4.9	(If mental time is not included, total is 2.4)

Radio Tuning Data Entry Time Estimate

Table 3.19 shows the time for manually tuning a radio. The time depends on the number of button presses to get to the target frequency. The mean is 10.1 s.

Table 3.19. Estimated tuning data entry time (s) per J2365

Step	Operator	Time in J2365	#	Comment
Decide which key to press	M (mental)	1.50	1	Since timing starts when the Start key is pressed, there is no reaching to the device. This task involves determining if the desired frequency is greater or less than the current value.
Press the up or down arrow the first time	C1 (cursor once)	0.80	1	Press the up or down arrow key to start towards the desired station.
Repeatedly press an arrow key	C2 (cursor 2 times or more	0.40	13 or 20	Either 14 or 21 steps to move (total including first). They occur equally often. Since pressing is clearly repeated, C2 time is appropriate
Select the menu item	E (enter)	1.20	1	Press preset .
Total		8.7 or 11.5		Depends if 14 or 21 steps, mean is 10.1

Dialing Data Entry Time Estimate

Table 3.20 shows the data entry time for dialing. The entry time depends on assumptions on whether digits are entered individually or in groups. If the assumption is that grouping is used half of the time, the estimated dialing time is 12.3 s. If there are additional mental times, for example between the local code and the final 4 digits, the estimate would increase by 1.5 s.

Table 3.20. Estimated dialing data entry time (s) per J2365

Step	Operator	Time in J2365	#	Comment
Decide how to enter the sequence, memorize area code	M (mental)	1.50	1	Since timing starts when the Start key is pressed, there is no reaching to the device. The assumed sequence (chunked) is, long distance, area code, fist 2 of last 4 digits, last 2 of 4 digits (1 aaa bbb ccdd).
Press 1	N1 (number once)	0.90	1	Press 1 for long distance.
Press 1st digit of area code	N1 (number once)	0.90	1	Area code
Press digit for rest of area code	N2 (number 2 times or more)	0.45	2	Area code
Read rest of area code	M (mental)	1.50	1	
Press 1st digit of local code	N1 (number once)	0.90	1	Local code
Press digits for rest of local code	N2 (number 2 times or more)	0.45	2	Local code
Press 1st digit of second to last pair	N1 (number once)	0.90	1	Final 4 digits
Press 2nd digit of 2nd to last pair	N2 (number 2 times or more)	0.45	1	Final 4 digits
Press 1st digit of final pair	N1 (number once)	0.90	1	Final 4 digits
Press 2nd digit of final pair	N2 (number 2 times or more)	0.45	1	Final 4 digits
Press send	E (enter)	1.2	1	Send key
Total		11.4 or 13.2		Mean is 12.3. Depends on if multiple keys are hit in succession.

Street Address Entry Time Estimate

Table 3.21 shows the estimated time to enter a street address calculated in 2 ways. The difference is how letters and numbers are entered after the first character in a sequence. When tested statically, people type the first character of a sequence slowly and the remainder more rapidly. However, in the driving sequences examined, each character was a unique entry, so typing each character resembled the first character of a sequence.

Table 3.21. Estimate destination data entry time (s) per J2365
(20 characters = 16 letters + 4 digits)

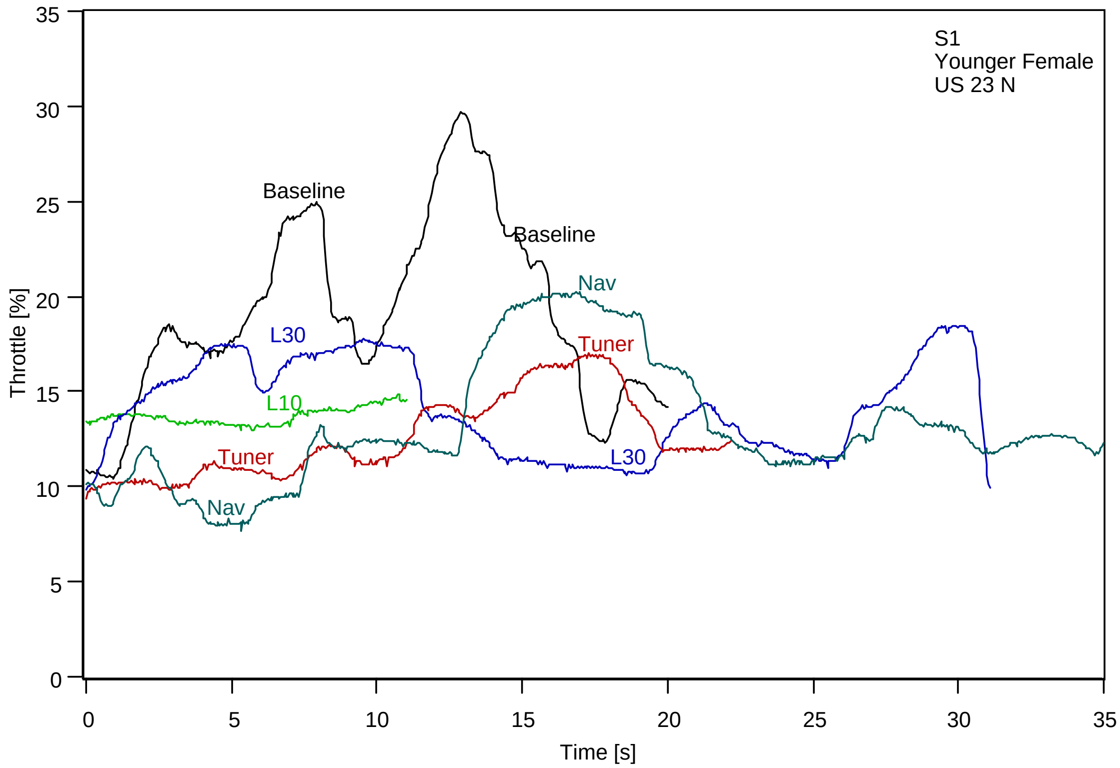
Step	Operator	Time in J2365	#	Comment
Enter city				
Read city	M (mental)	1.50	1	Since timing starts when the Start key is pressed, there is no reaching to the menu.
Type first letter of city name	L1	1.00	1	Assume 8 of 16 letters
Type other letters of city name	L1, L2	1.00, 0.50	7	Remaining 7 letters
Hit return	E	1.20	1	
Enter street name				
Read city	M (mental)	1.50	1	Since timing starts when the Start key is pressed, there is no reaching to the menu.
Type first letter of street name	L1	1.00	1	Assume 8 of 16 letters
Type other letters of street name	L1,L2	1.00, 0.50	7	Remaining 7 letters
Hit return	E	1.20		
Enter Building #				
Read building number	M (mental)	1.50	1	e.g., tune
Type 1st digit	N1	0.90	1	4 digit entry ("house #")
Type remaining 3 digits	N1, N2	0.90, 0.45	3	
Hit return	E	1.20	1	
Total		19.35, 27.70		

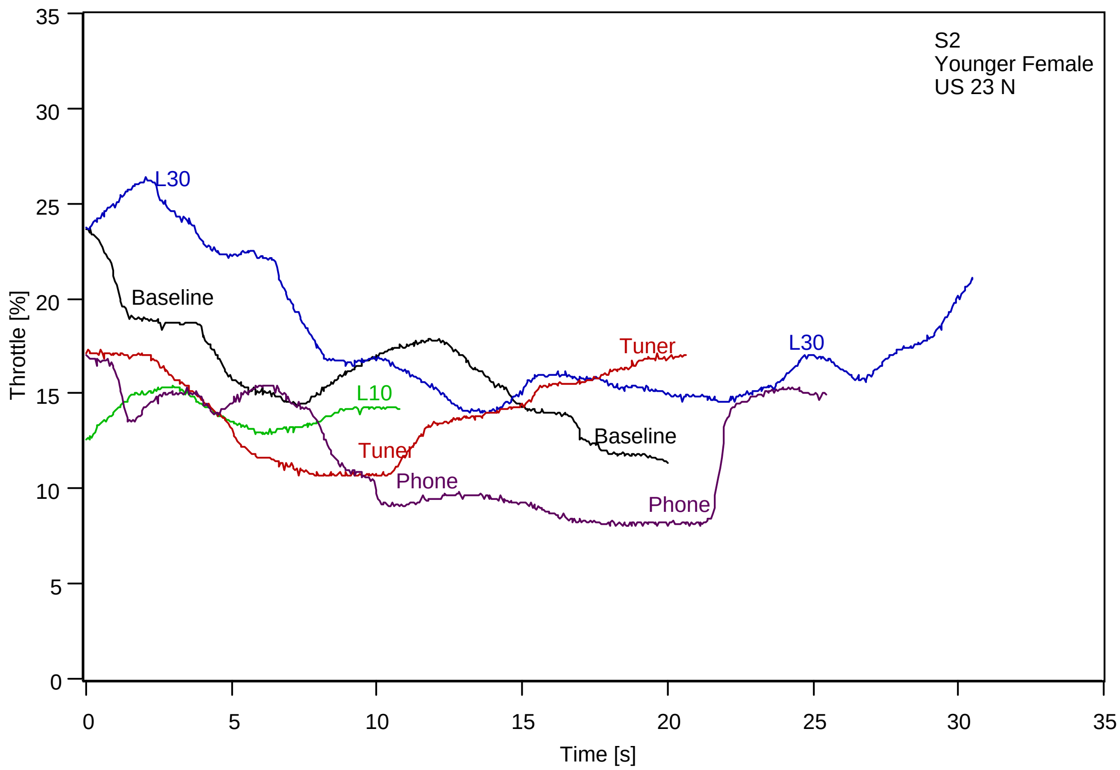
3.13 APPENDIX H: TOTAL NUMBER OF KEYSTROKES

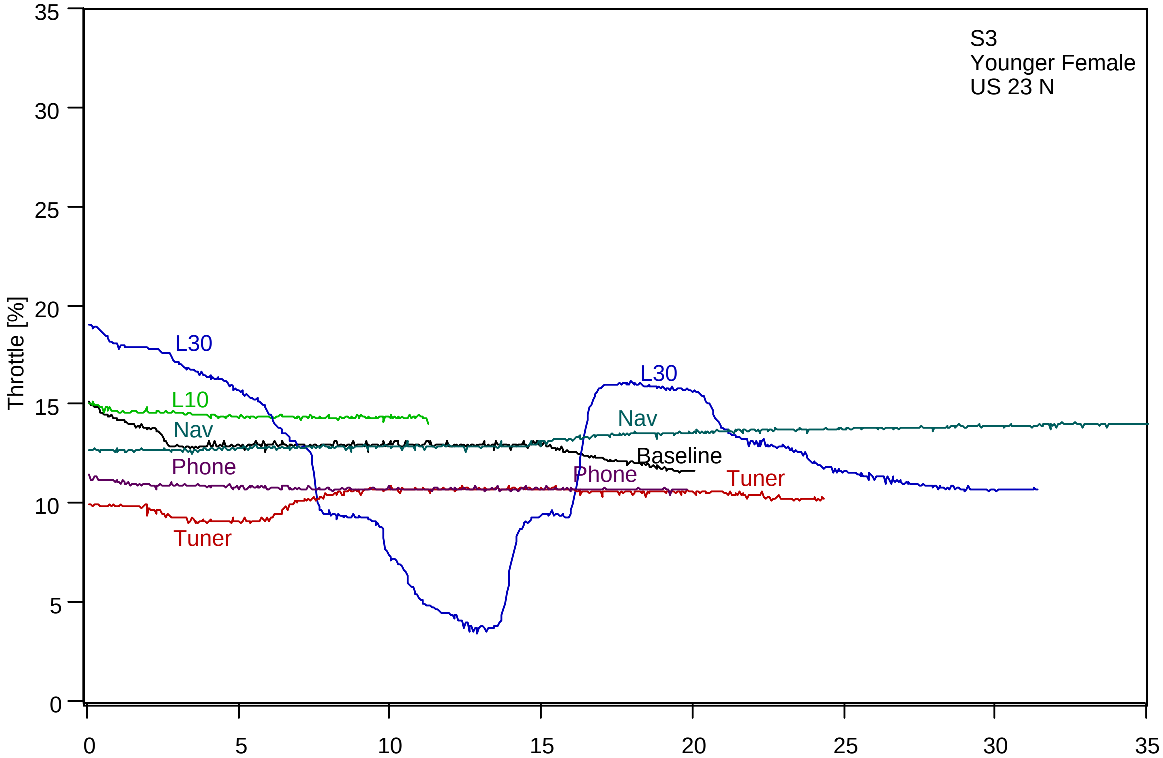
Table 3.22. Frequency distribution for total keystrokes

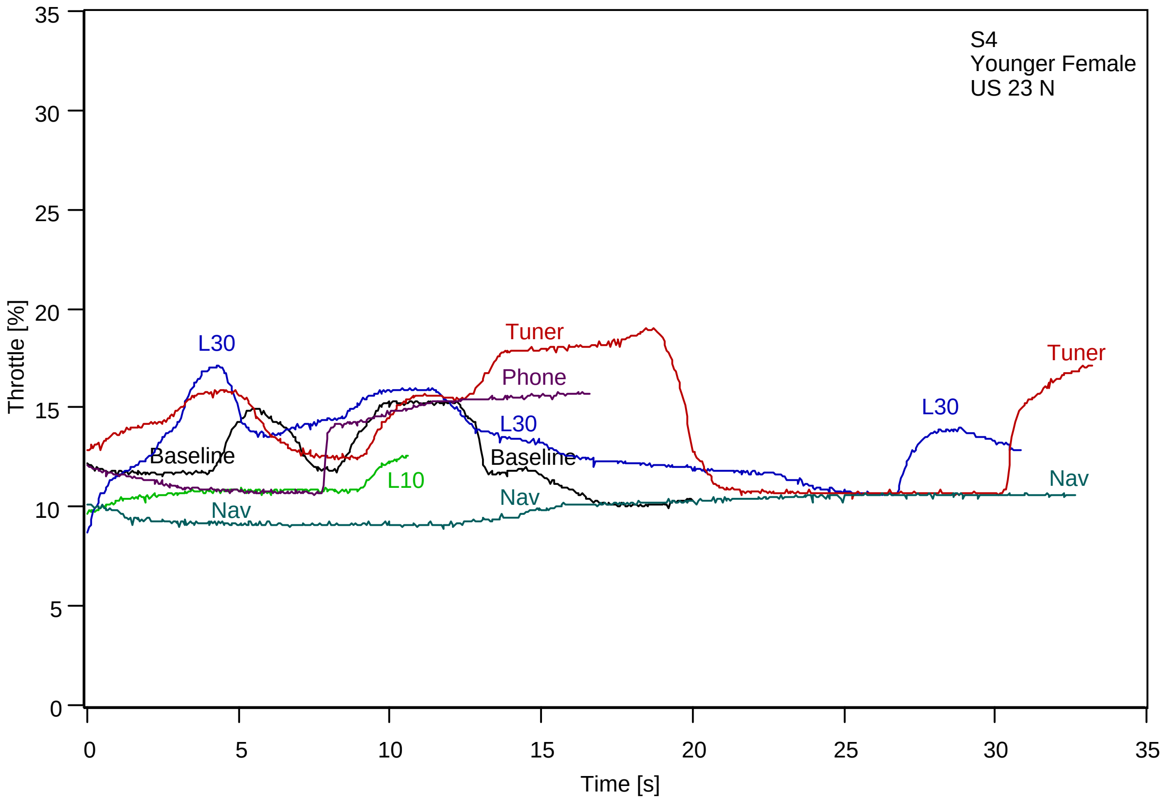
Keystrokes	Tune Count	Dial Count	Enter Addr. Count
6	0	0	1
7	0	0	0
8	1	0	0
9	0	0	1
10	0	0	0
11	0	39	2
12	0	0	1
13	0	11	1
14	0	1	0
15	16	10	0
16	0	0	0
17	5	1	0
18	0	0	0
19	3	1	0
20	0	0	1
21	5	0	19
22	21	0	3
23	1	0	7
24	7	0	3
25	1	0	4
26	2	0	5
27	0	0	3
28	0	0	2
29	0	0	1
30	1	0	0
31	0	0	1
32	0	0	1
33	0	0	1
34	0	0	3
35	0	0	0
36	0	0	2
37	0	0	1
Total	63	63	63

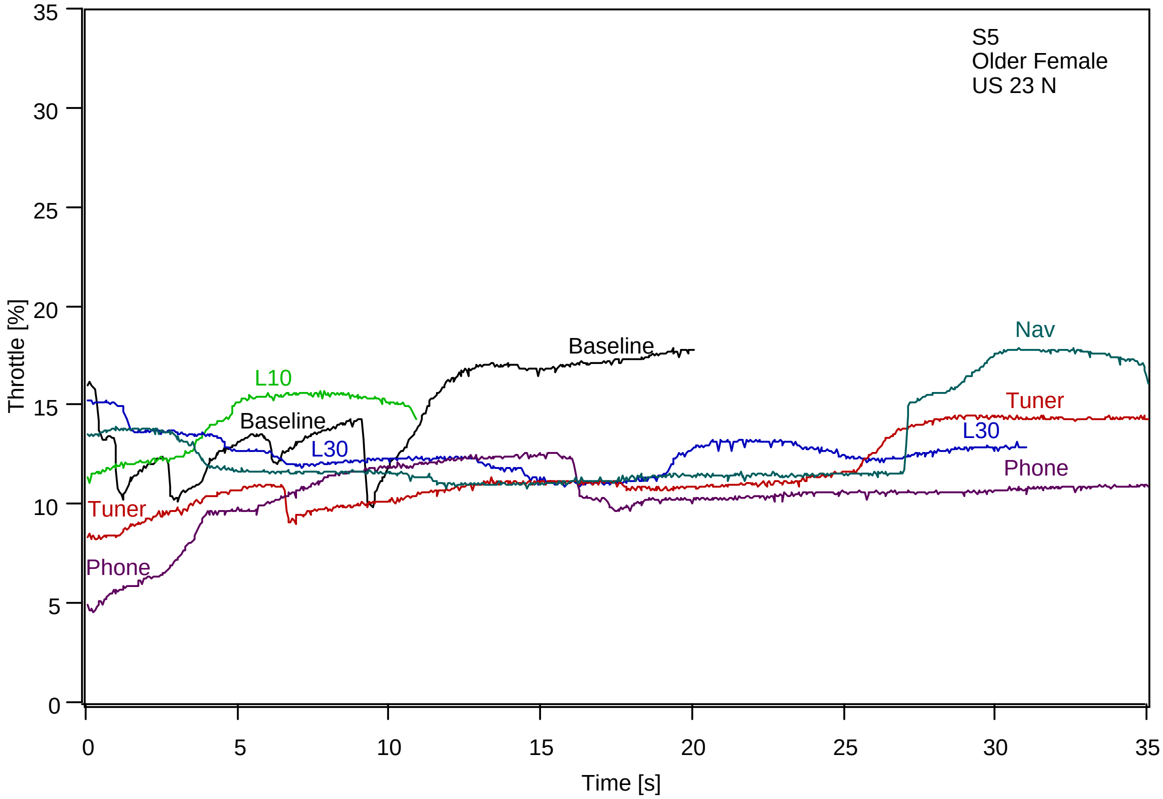
3.14 APPENDIX I. THROTTLE TIMELINES

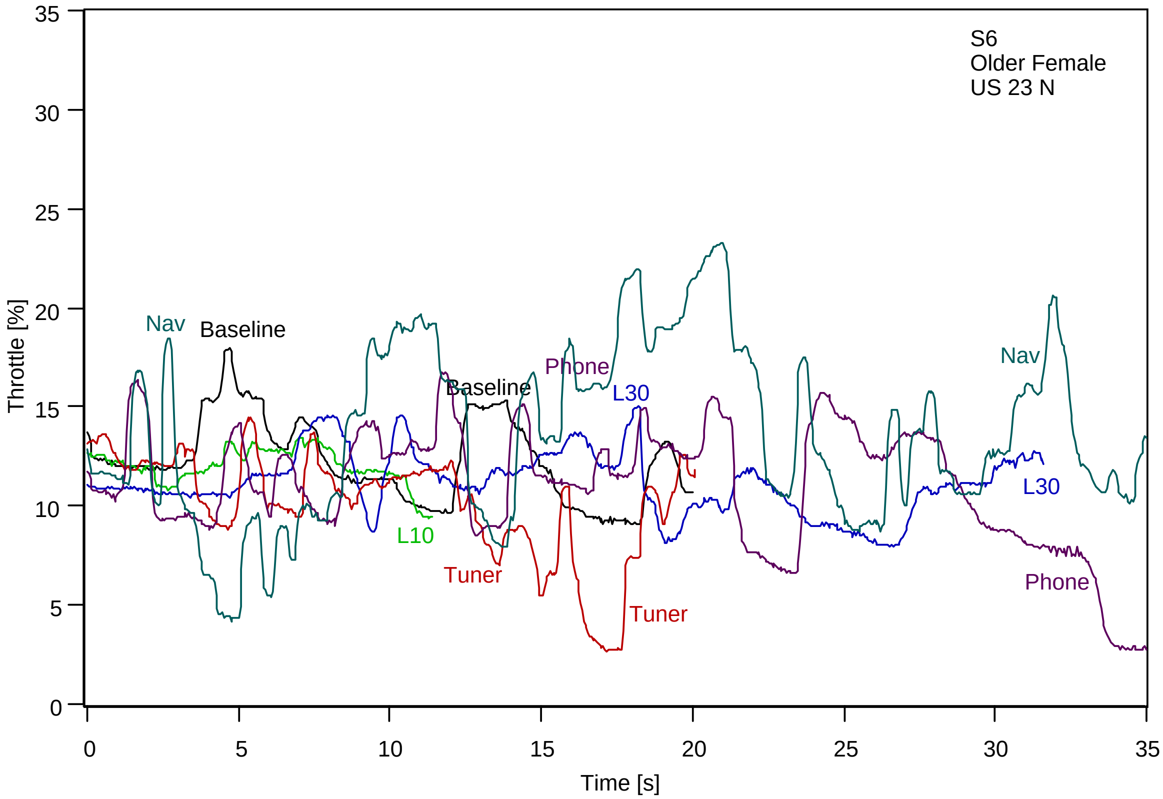


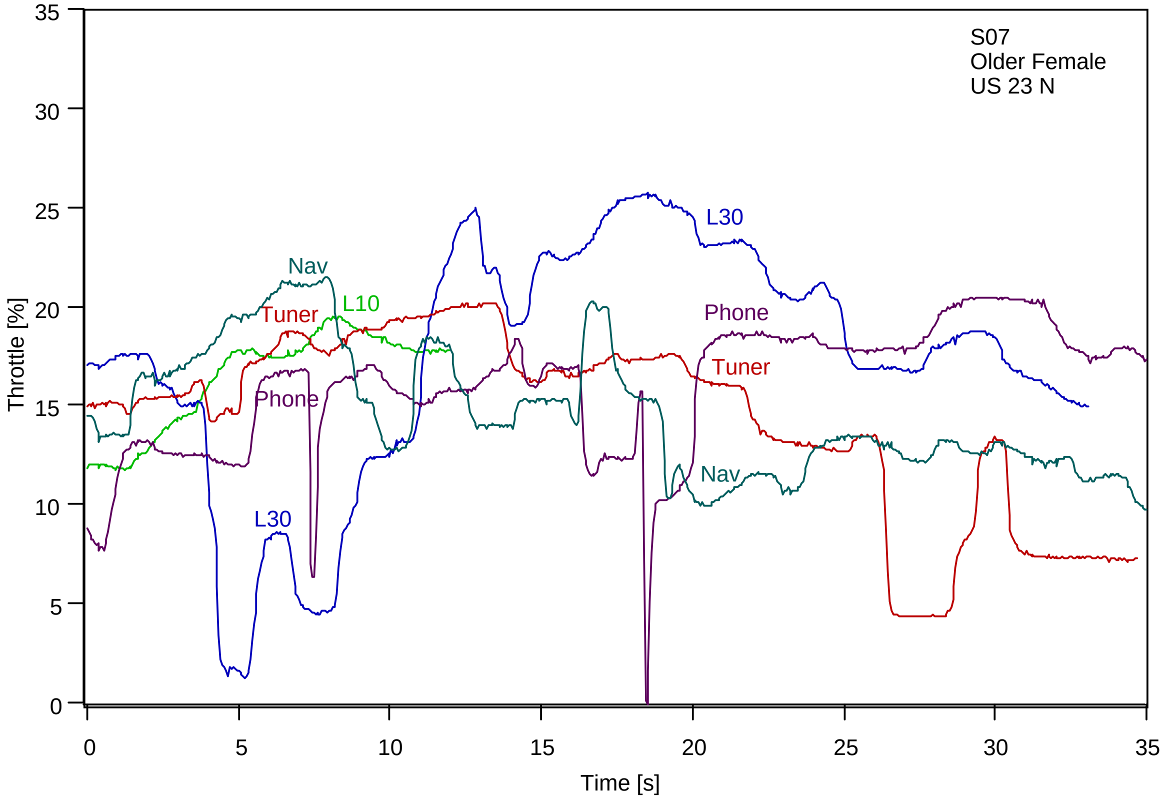


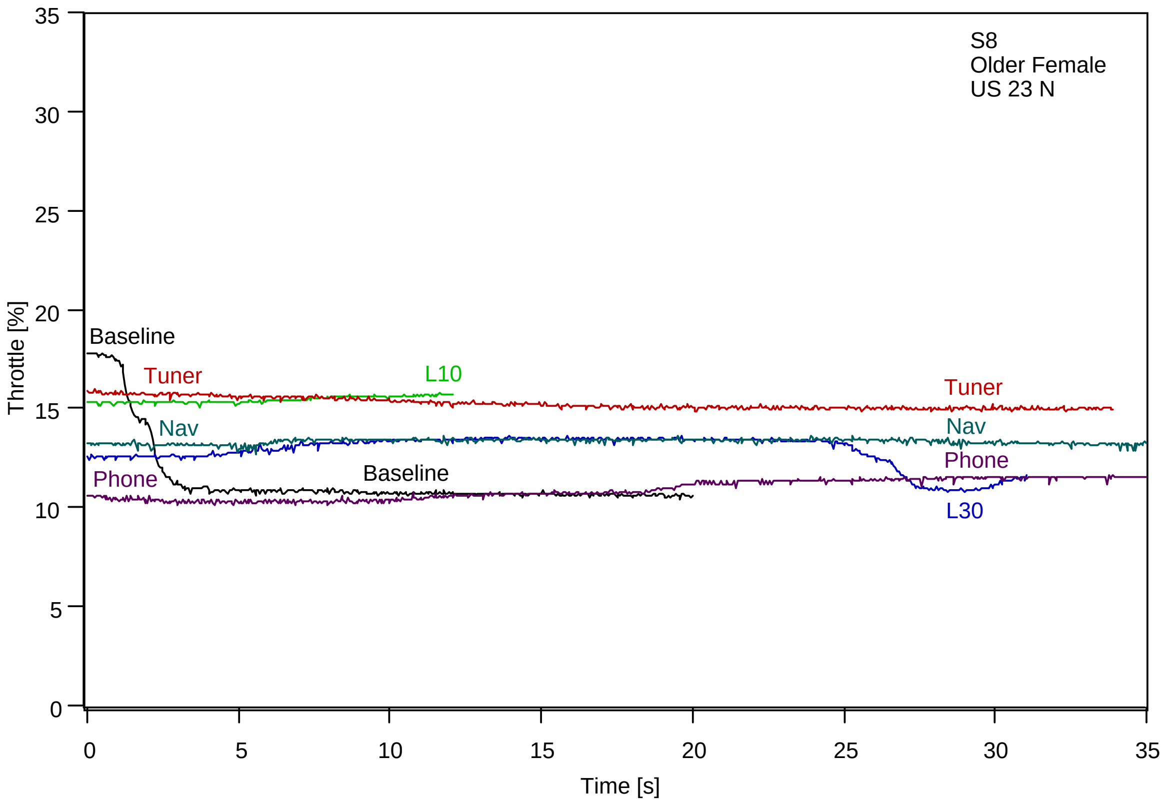

S3
Younger Female
US 23 N
Throttle [%]
L30
L10
Nav
Phone
Baseline
Tuner

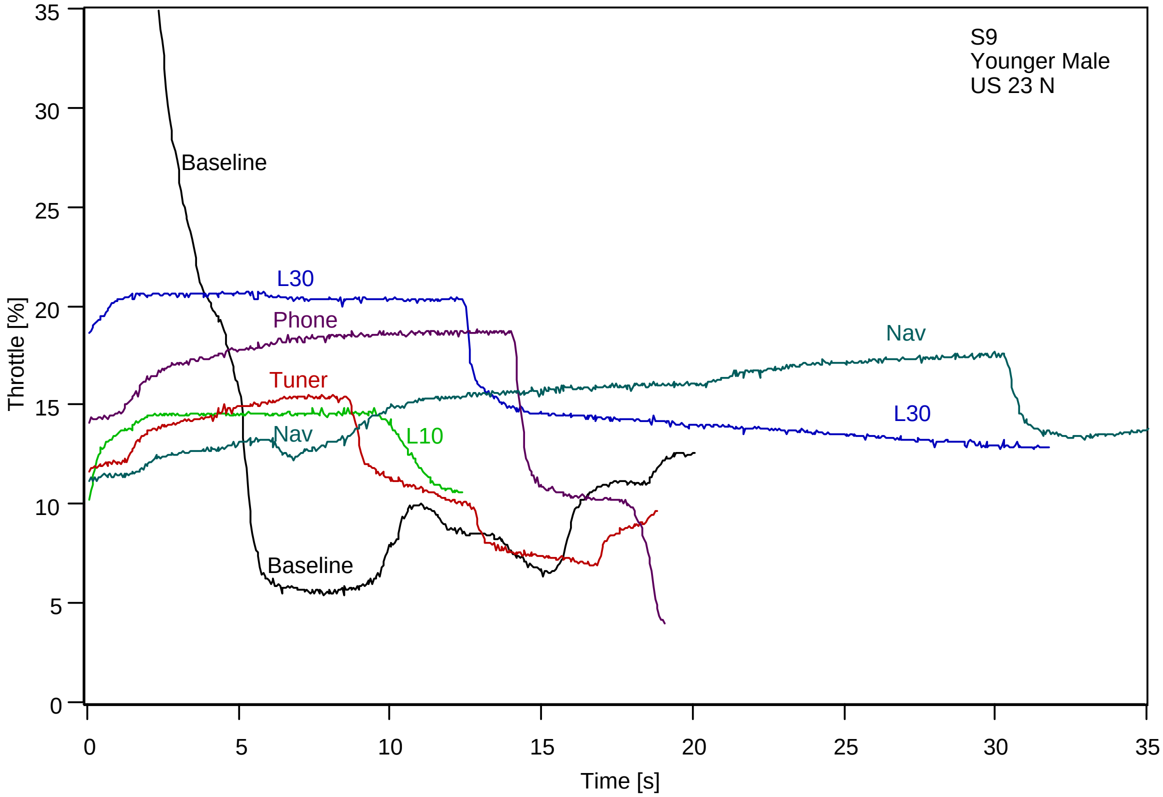

S4
Younger Female
US 23 N
Throttle [%]
Time [s]
L30
Tuner
Phone
Baseline
L10
Nav


S5
Older Female
US 23 N
Throttle [%]
Time [s]
Baseline
L10
L30
Tuner
Phone
Nav
0
5
10
15
20
25
30
35

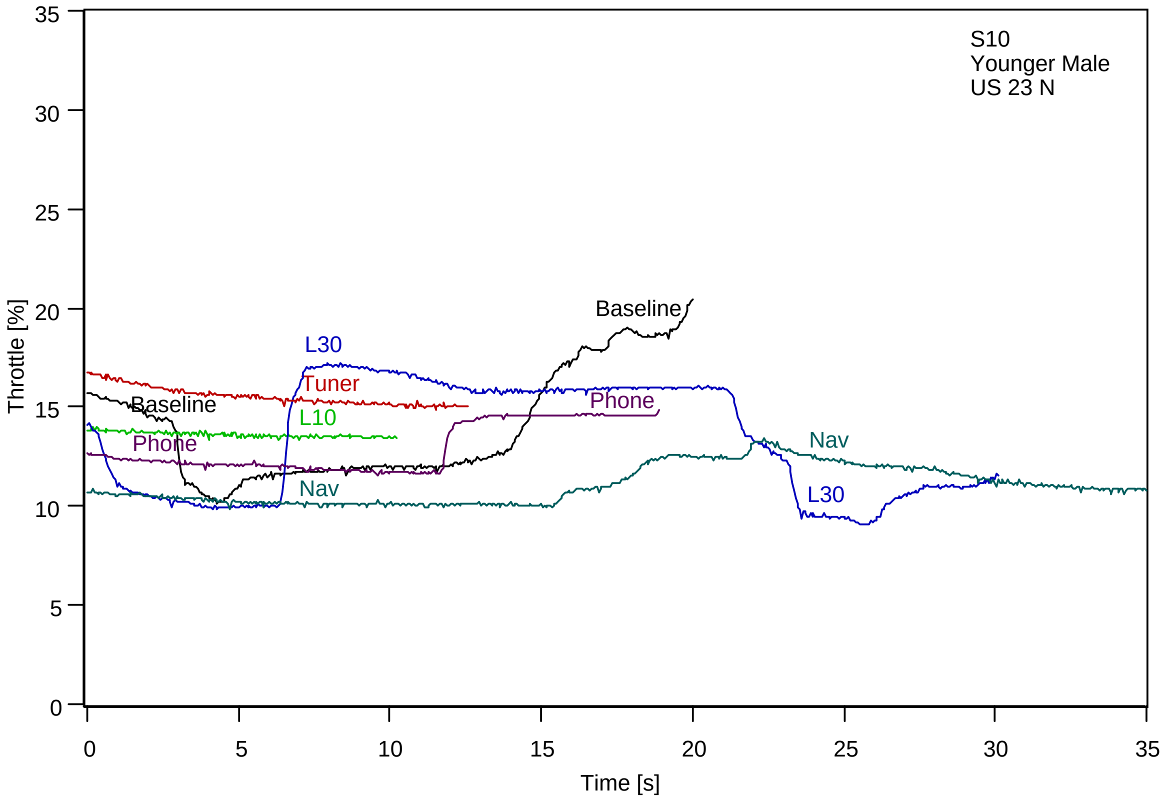

S6
Older Female
US 23 N
Throttle [%]
Time [s]
Nav
Baseline
Phone
L30
L10
Tuner
0
5
10
15
20
25
30
35


S07
Older Female
US 23 N
Throttle [%]
Time [s]
L30
Nav
L10
Tuner
Phone

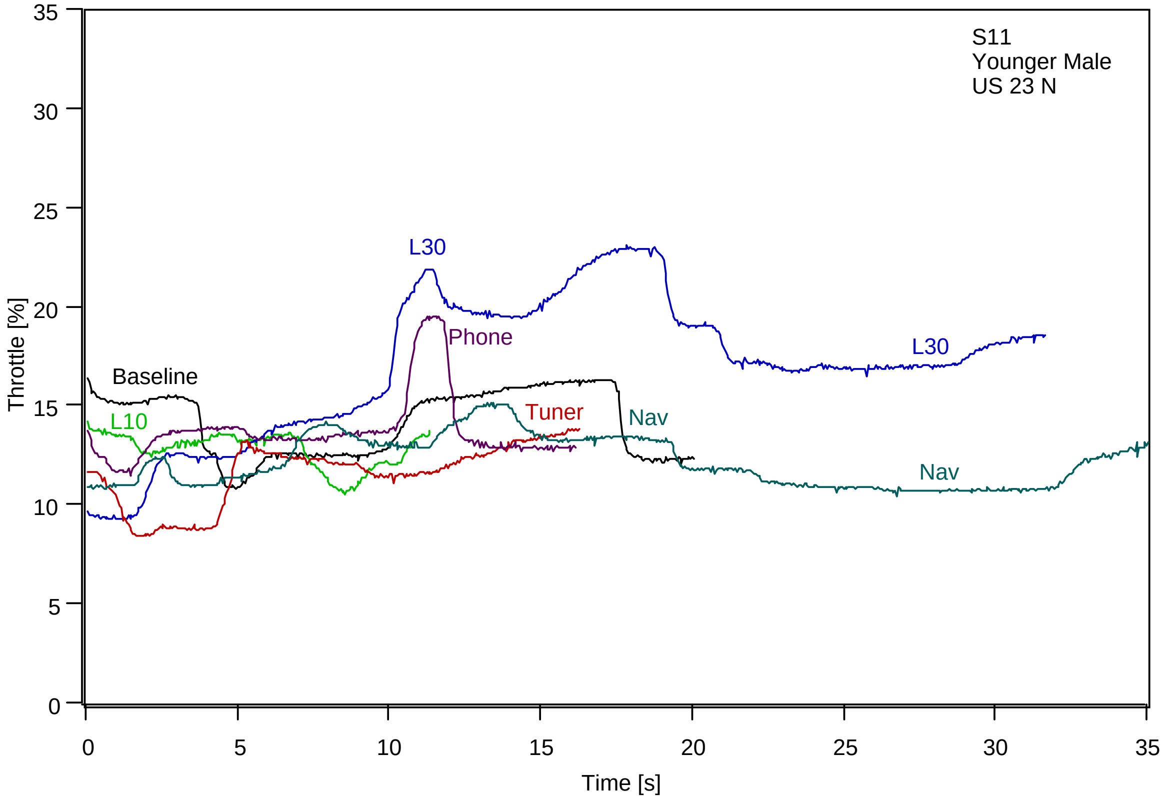

S8
Older Female
US 23 N
Throttle [%]
Time [s]
Baseline
Tuner
L10
Nav
Phone
L30

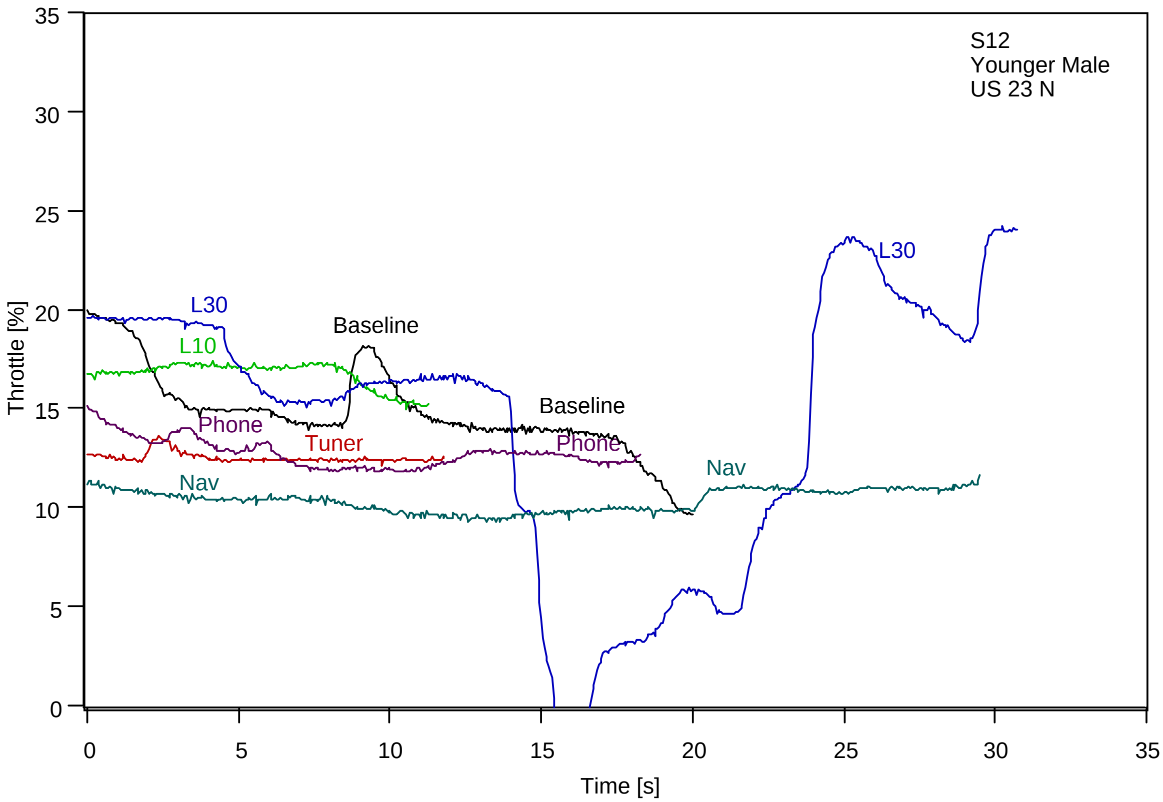


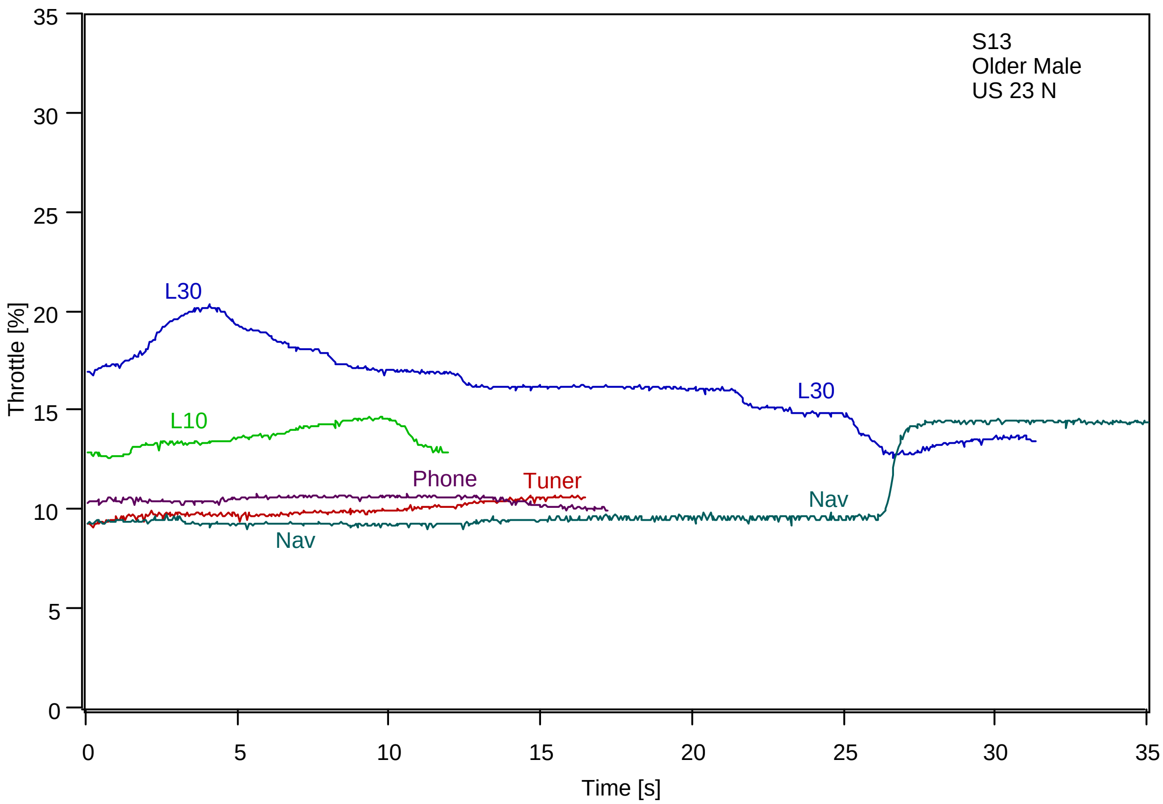
S9
Younger Male
US 23 N
Baseline
L30
Phone
Tuner
Nav
L10
Throttle [%]
Time [s]



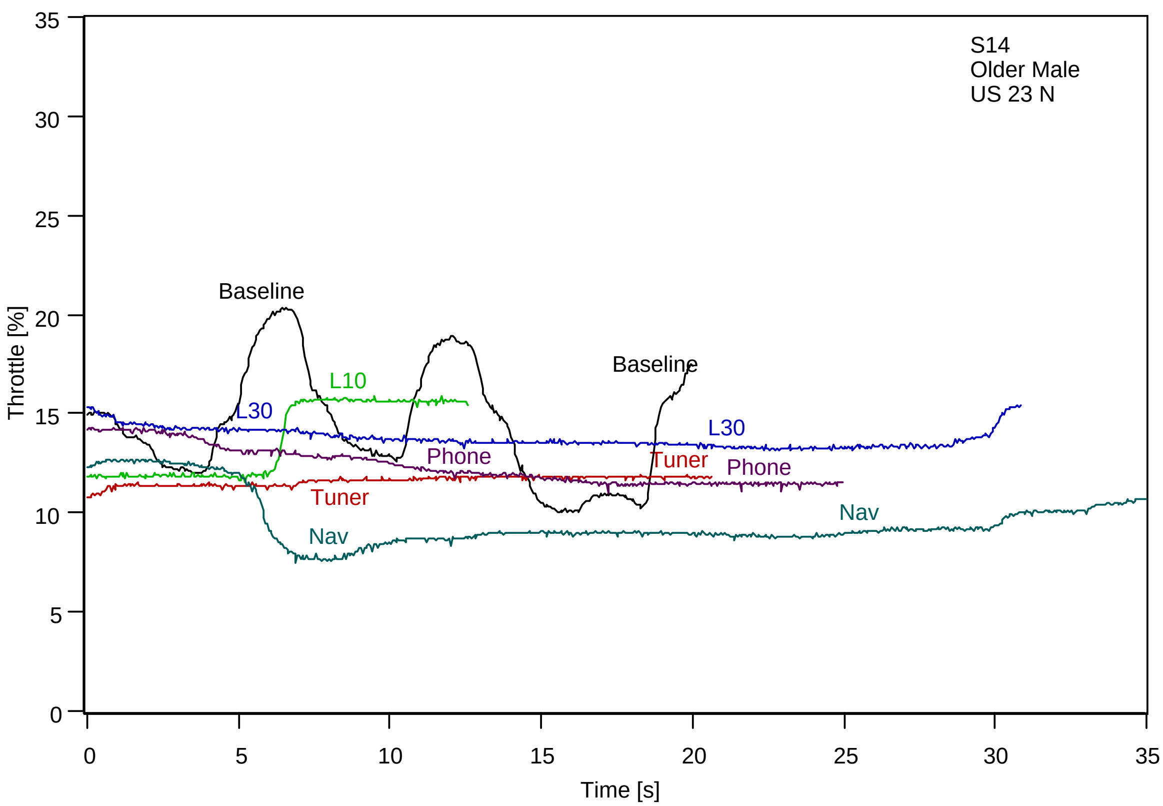
S10
Younger Male
US 23 N
Baseline
L30
Tuner
L10
Phone
Nav
Throttle [%]
Time [s]


S11
Younger Male
US 23 N
L30
Phone
Baseline
L10
Tuner
Nav
L30
Nav
Throttle [%]
Time [s]
0
5
10
15
20
25
30
35

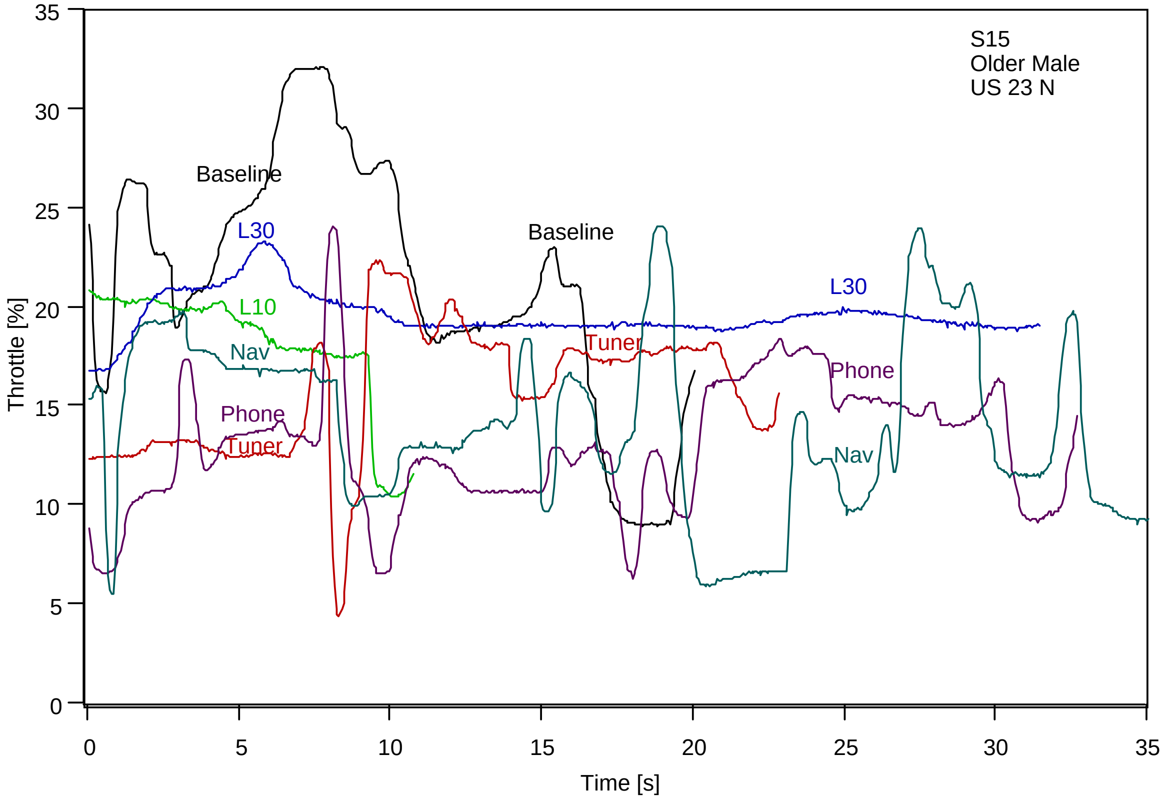

S12
Younger Male
US 23 N
L30
L10
Baseline
Phone
Tuner
Nav
Baseline
Phone
Nav
L30
Throttle [%]
Time [s]
0
5
10
15
20
25
30
35

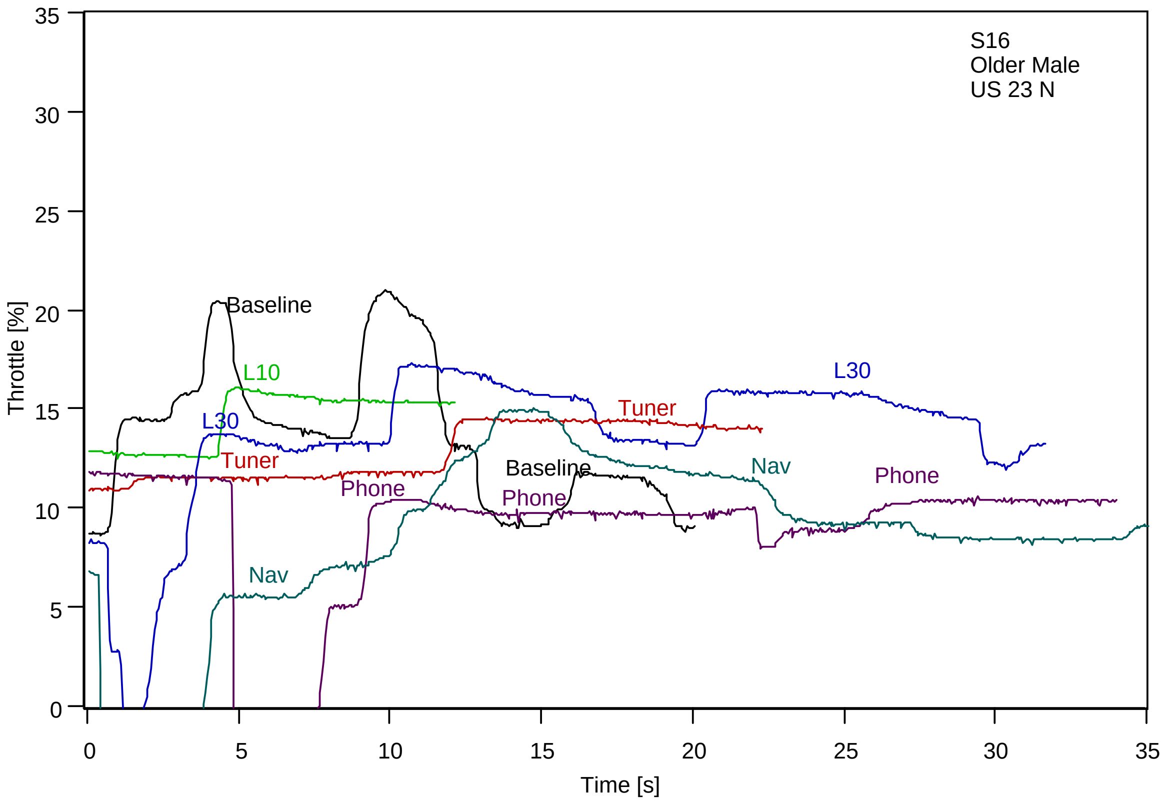


S13
Older Male
US 23 N
L30
L10
Phone
Tuner
Nav
L30
Nav
Throttle [%]
Time [s]
0
5
10
15
20
25
30
35



S14
Older Male
US 23 N
Baseline
L10
L30
Baseline
L30
Phone
Tuner
Phone
Tuner
Nav
Nav
Throttle [%]
Time [s]
0
5
10
15
20
25
30
35


S15
Older Male
US 23 N
Throttle [%]
Time [s]
Baseline
L30
L10
Nav
Phone
Tuner
0
5
10
15
20
25
30
35


S16
Older Male
US 23 N
Throttle [%]
Time [s]
Baseline
L10
L30
Tuner
Phone
Nav
0
5
10
15
20
25
30
35

3.15 APPENDIX J: ANOVAS

Table 3.23. ANOVA menu time

Source	DF	Sum of Squares	F Ratio	P
Task	2	118.00565	4.9102	0.0085
Road	1	0.47299	0.0394	0.8430
Age	1	12.89268	1.0729	0.3018
Sex	1	40.76396	3.3924	0.0673
Run	1	5.02745	0.4184	0.5187
Task*Road	2	0.75632	0.0315	0.9690
Task*Run	2	31.03489	1.2914	0.2777
Task*Age	2	43.47730	1.8091	0.1671
Task*Sex	2	21.68957	0.9025	0.4076
Road*Run	1	11.29360	0.9399	0.3338
Road*Age	1	0.18697	0.0156	0.9009
Road*Sex	1	0.12940	0.0108	0.9175
Run*Age	1	2.45119	0.2040	0.6521
Run*Sex	1	26.20098	2.1805	0.1417
Road*Run*Task	2	1.32849	0.0553	0.9462
Age*Sex	1	461.47302	38.4040	<.0001
Subject[Age,Sex]	4	499.11482	10.3841	<.0001
Error	162	1946.6382	12.0163	

Table 3.24. ANOVA data entry time

Source	DF	Sum of Squares	F Ratio	P
Task	2	54503.513	256.3409	<.0001
Road	1	87.625	0.8242	0.3653
Age	1	0.000	0.0000	0.9987
Sex	1	859.991	8.0894	0.0050
Run	1	7.287	0.0685	0.7938
Task*Road	2	1.414	0.0067	0.9934
Task*Run	2	260.389	1.2247	0.2966
Task*Age	2	3711.005	17.4536	<.0001
Task*Sex	2	509.944	2.3984	0.0941
Road*Run	1	1.138	0.0107	0.9177
Road*Age	1	32.584	0.3065	0.5806
Road*Sex	1	53.724	0.5053	0.4782
Run*Age	1	164.923	1.5513	0.2147
Run*Sex	1	7.065	0.0665	0.7969
Road*Run*Task	2	108.681	0.5111	0.6008
Age*Sex	1	1645.453	15.4778	0.0001
Subject[Age,Sex]	4	2303.508	5.4169	0.0004
Error	162	17222.318	106.31	

Table 3.25. ANOVA risk ratings

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
age	1	66.623	66.623	3.090	.1042	3.090	.354
gender	1	65.918	65.918	3.058	.1059	3.058	.351
age * gender	1	83.345	83.345	3.866	.0728	3.866	.429
Subject(Group)	12	258.698	21.558				
Road	1	4.687E-4	4.687E-4	2.922E-4	.9866	2.922E-4	.050
Road * age	1	.038	.038	.024	.8803	.024	.052
Road * gender	1	26.775	26.775	16.688	.0015	16.688	.973
Road * age * gender	1	.665	.665	.415	.5318	.415	.089
Road * Subject(Group)	12	19.254	1.604				
Direction	1	7.640	7.640	5.262	.0406	5.262	.553
Direction * age	1	6.271	6.271	4.319	.0598	4.319	.471
Direction * gender	1	.359	.359	.247	.6281	.247	.074
Direction * age * gender	1	.038	.038	.026	.8742	.026	.053
Direction * Subject(Group)	12	17.424	1.452				
Task	2	223.295	111.648	32.688	<.0001	65.376	1.000
Task * age	2	25.854	12.927	3.785	.0373	7.569	.629
Task * gender	2	3.815	1.907	.558	.5793	1.117	.129
Task * age * gender	2	3.288	1.644	.481	.6238	.963	.117
Task * Subject(Group)	24	81.973	3.416				
Road * Direction	1	2.975	2.975	5.198	.0417	5.198	.548
Road * Direction * age	1	3.281	3.281	5.733	.0339	5.733	.592
Road * Direction * gender	1	.376	.376	.657	.4333	.657	.113
Road * Direction * age * gender	1	.001	.001	.002	.9627	.002	.050
Road * Direction * Subject(Group)	12	6.869	.572				
Road * Task	2	2.945	1.472	2.166	.1365	4.332	.388
Road * Task * age	2	3.264	1.632	2.400	.1121	4.800	.426
Road * Task * gender	2	5.314	2.657	3.908	.0339	7.816	.645
Road * Task * age * gender	2	4.955	2.478	3.644	.0415	7.289	.611
Road * Task * Subject(Group)	24	16.317	.680				
Direction * Task	2	2.368	1.184	1.952	.1639	3.903	.353
Direction * Task * age	2	.530	.265	.437	.6509	.874	.111
Direction * Task * gender	2	.593	.296	.489	.6194	.977	.118
Direction * Task * age * gender	2	1.145	.572	.944	.4031	1.888	.188
Direction * Task * Subject(Group)	24	14.559	.607				
Road * Direction * Task	2	.108	.054	.080	.9237	.159	.061
Road * Direction * Task * age	2	.702	.351	.518	.6024	1.035	.123
Road * Direction * Task * gender	2	1.813	.906	1.338	.2814	2.675	.252
Road * Direction * Task * age * gender	2	3.738	1.869	2.758	.0835	5.516	.483
Road * Direction * Task * Subject(Group)	24	16.265	.678				

Table 3.26. ANOVA task completion errors

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Age	1	1.838	1.838	14.949	.0031	14.949	.947
Gender	1	1.204	1.204	9.797	.0107	9.797	.815
Age * Gender	1	.704	.704	5.729	.0377	5.729	.576
Subject(Group)	10	1.229	.123				
Road	1	.004	.004	.074	.7910	.074	.057
Road * Age	1	.004	.004	.074	.7910	.074	.057
Road * Gender	1	.104	.104	1.852	.2034	1.852	.224
Road * Age * Gender	1	.004	.004	.074	.7910	.074	.057
Road * Subject(Group)	10	.562	.056				
Road Direction	1	.104	.104	.847	.3789	.847	.128
Road Direction * Age	1	.004	.004	.034	.8576	.034	.053
Road Direction * Gender	1	.004	.004	.034	.8576	.034	.053
Road Direction * Age * Gender	1	.004	.004	.034	.8576	.034	.053
Road Direction * Subject(Group)	10	1.229	.123				
Task	2	4.908	2.454	25.064	<.0001	50.128	1.000
Task * Age	2	1.575	.788	8.043	.0027	16.085	.934
Task * Gender	2	1.458	.729	7.447	.0038	14.894	.913
Task * Age * Gender	2	.558	.279	2.851	.0814	5.702	.487
Task * Subject(Group)	20	1.958	.098				
Road * Road Direction	1	.037	.037	.947	.3533	.947	.138
Road * Road Direction * Age	1	.004	.004	.105	.7523	.105	.060
Road * Road Direction * Gender	1	.004	.004	.105	.7523	.105	.060
Road * Road Direction * Age * Gender	1	.204	.204	5.158	.0465	5.158	.530
Road * Road Direction * Subject(Group)	10	.396	.040				
Road * Task	2	.108	.054	.788	.4684	1.576	.161
Road * Task * Age	2	.108	.054	.788	.4684	1.576	.161
Road * Task * Gender	2	.158	.079	1.152	.3362	2.303	.217
Road * Task * Age * Gender	2	.058	.029	.424	.6600	.848	.108
Road * Task * Subject(Group)	20	1.375	.069				
Road Direction * Task	2	.008	.004	.028	.9723	.056	.054
Road Direction * Task * Age	2	.108	.054	.366	.6979	.732	.099
Road Direction * Task * Gender	2	.058	.029	.197	.8226	.394	.076
Road Direction * Task * Age * Gender	2	.058	.029	.197	.8226	.394	.076
Road Direction * Task * Subject(Group)	20	2.958	.148				
Road * Road Direction * Task	2	.175	.088	1.135	.3412	2.270	.215
Road * Road Direction * Task * Age	2	.008	.004	.054	.9475	.108	.057
Road * Road Direction * Task * Gender	2	.058	.029	.378	.6898	.757	.101
Road * Road Direction * Task * Age * Gend …	2	.058	.029	.378	.6898	.757	.101
Road * Road Direction * Task * Subject(Gr …	20	1.542	.077				

3.16 APPENDIX K: SAMPLE THROTTLE ANALYSIS

Table 3.27. Sample signal detection table

Task	Detect	No Detect		
1	232	0		100%
2	602	21		97%
3	491	171		74%
4	556	44		93%
5	1215	305		80%
0	4535	7588		37%
	HITS	MISSES		
	3096	541		85%
	4535	7588		37%
	FA	CR	d'	1.36

Table 3.27 shows example signal detection for one road type and one direction. For the tasks a 0 is just driving, 1 is a 10-second repeated glance task, 2 is a 30-second repeated glance task, 3 is tuning the radio, 4 is dialing the phone, and 5 is entering a destination. All tasks are detected at least 70% of the time, with some up to 100%.

Table 3.28 shows the sensitivity (d-prime) for each of the subjects for each of the 4 runs they completed. During each run, 5 tasks were completed once. Overall, the females had a mean sensitivity of .81, while the males had a sensitivity of .9. Also, the middle-aged subjects had a sensitivity of .74 and the older subjects had a sensitivity of .96. The minimum and maximum sensitivities were .07 and 2.01 respectively. To put these values in perspective, if "hit" percentage is 50 and "false alarm" percentage is 16, d-prime is close to 1. As was noted earlier, there were 2 instances (subjects 7 and 15) where d-prime was less than 1 (in Figure 3.30), reflecting the statistically variability in the data, a consequence of not all subjects holding the throttle when distracted.

Table 3.28. Sensitivity values for all subjects on all routes

	D-Prime Values					
	Rural Road		Highway			
Subject	South	North	South	North	Age Group	Gender
1	0.58	0.87	1.13	0.07	Middle	Female
2	1.27	0.99	0.88	0.37	Middle	Female
3	0.37	0.46	0.91	0.79	Middle	Female
4	0.70	1.44	0.44	0.20	Middle	Female
5	0.72	1.36	1.63	1.50	Older	Female
6	0.32	0	1.00	0.08	Older	Female
7	0.33	0.46	0.37	- 0.29	Older	Female
8	0.14	1.56	0.96	1.66	Older	Female
9	1.04	1.51	1.20	1.33	Middle	Male
10	0.49	1.48	0.34	0.15	Middle	Male
11	1.20	0.17	0.62	0.43	Middle	Male
12	0.40	0.56	0.67	0.71	Middle	Male
13	0.36	0.67	2.01	1.37	Older	Male
14	1.31	1.33	1.99	1.44	Older	Male
15	0.57	0.70	- 0.41	0.57	Older	Male
16	0.97	0.80	0.53	1.47	Older	Male

These values were used to create the ROC plots for each of the subjects (see Figure 3.30). As can be seen in the figure, the plots are very difficult to interpret due to the lack of data and the need to refine the algorithm. Therefore, it was decided to look at the ROC curve plot based on road route.

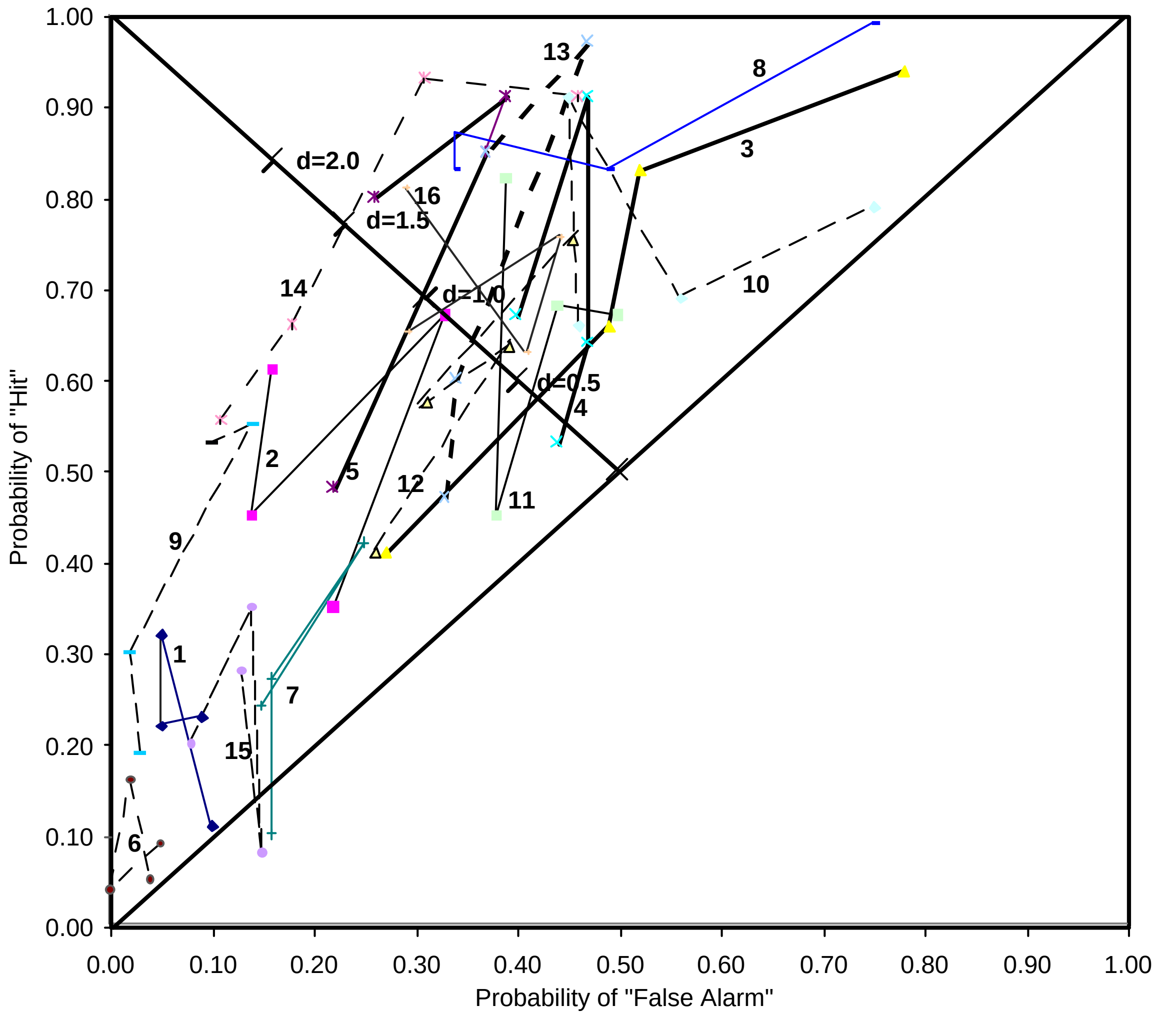


Figure 3.30. ROC plots for all subjects